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Israel's Hydrogen Sector:
An Ecosystem in the Making

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Executive Summary

In the face of the pressing challenges posed by the climate crisis, with 2023 being the hottest year on record, and with the average global temperature exceeding 1.37°C higher than preindustrial levels,[1] nations and leaders are seeking sustainable solutions to mitigate their environmental impact and decarbonize the economy.

The ability to decarbonize rests on the ability to find sustainable power sources that are clean, efficient, scalable, and that reduce emissions in hard-to-abate sectors.[2]

Hydrogen is a pivotal player in the energy transition, with an increasing recognition of its essential role in aligning economics with the targets set forth in the Paris Agreement.[3] These targets aim to limit global temperature increases to "well below" 2°C above pre-industrial levels and making efforts to restrict the increase to 1.5°C above pre-industrial levels, addressing climate change and its negative impacts.[4]

Israel's hydrogen sector is backed by advanced academic research, substantial investments, interest from leading local and foreign investors, and government grants - driving factors that have the potential to position Israel as a frontrunner in hydrogen technologies.

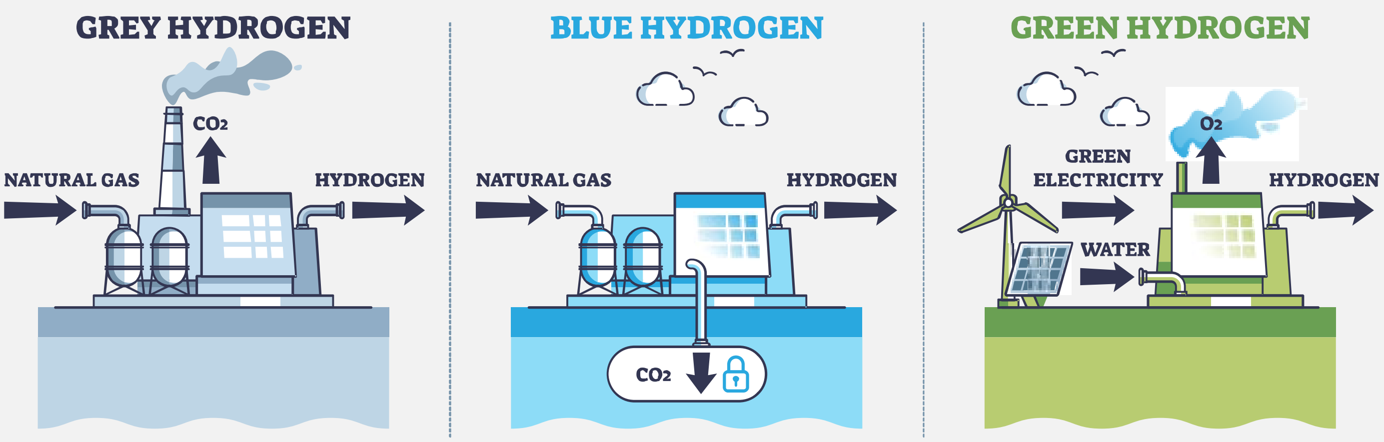
This report focuses on identifying five key applications of hydrogen and its significant environmental and economic potential, highlighting the role of hydrogen in the future energy system. This report also spotlights the blossoming hydrogen ecosystem in Israel and its unique position to impact the global hydrogen ecosystem.

What is Hydrogen?

Hydrogen, the lightest and most abundant element in the universe, is also highly reactive in its nature, tending to bond with various other elements and create fundamental compounds such as water, ammonia, and hydrocarbons.[5] Hydrogen contains a high ratio of energy per weight unit, containing 2.4x the amount of energy carried by the equivalent quantity of natural gas,[6] making it an attractive energy carrier. As a molecule (H_2), hydrogen is a colorless, odorless, non-toxic gas.

Hydrogen is produced by isolating it from the compounds that contain it, requiring usage of energy, typically natural gas (through reformation, also known as "grey hydrogen"), coal (through gasification, also known as "brown hydrogen"), and water (through electrolysis,[7] also known as "green hydrogen"). Once carbon is released during hydrogen production (e.g., brown or grey hydrogen) and is captured and utilized or stored, it is referred to as "blue hydrogen".
Blue hydrogen is regarded as a low carbon production method since most of its emissions are not dispersed into the atmosphere. Both green and blue hydrogen are expected to have a central role in the future hydrogen economy.[8]

Hydrogen can be stored both in gaseous form as well as in liquid and solid forms, enabling hydrogen to be transported via standard transportation methods, including pipelines, Trucks, Planes, and Ships.

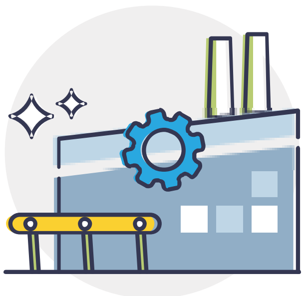


(Photo: VectorMine / Shutterstock)

The Opportunity: Potential Use Cases for Hydrogen

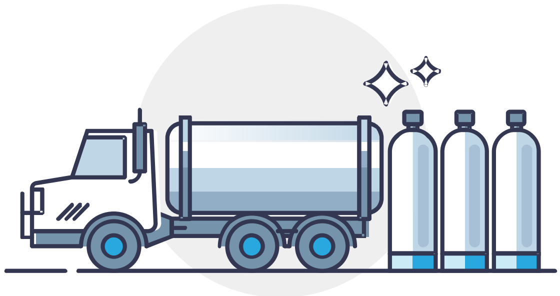
As hydrogen is a molecular-based energy carrier (as opposed to electron-based) it serves as a complementary solution to electrification in areas where it is otherwise limited, potentially serving as the missing link towards achieving Net Zero goals.9

The five main potential end-use applications for hydrogen include:[10]



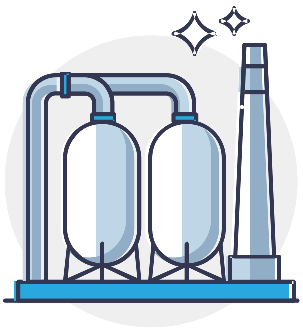
Industry

Hydrogen is mainly utilized today as a feedstock for various chemical processes, such as production of ammonia (used in the manufacturing of fertilizers) and methanol (used in the production of gasoline and other applications). However, the hydrogen currently used as feedstock today is predominantly grey hydrogen, an emission intensive process. Therefore, the most immediate application for green and blue hydrogen (clean hydrogen) will be replacing carbon intensive hydrogen in such industrial processes. Hydrogen can also be utilized in additional industrial applications such as in the production of steel (as a reduction agent instead of carbon monoxide derived from fossil fuels) and in high temperature processes (e.g., gasifying, melting, and drying) needed for manufacturing steel, cement, concrete, and glass.



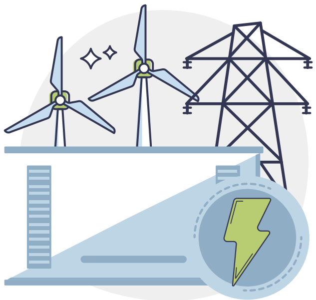
Transport

Hydrogen has the potential to offer solutions to decarbonize "heavy vehicles" (trucks, buses, and trains) because of its superior energy to weight ratio relative to batteries – and enabling the transition from traditional fuel sources to Fuel cell-based electronic vehicles (FCEVs).[11] FCEVs also have shorter refueling times, improving the operational efficiency of logistic fleets.[12] Further, there is exploration into how hydrogen and synthetic hydrocarbon fuels (those produced with hydrogen) can enable the decarbonization of aviation and marine transport.[13]



Long Term/High Volume Storage

Given that hydrogen can be stored in large quantities and for long periods of time compared to other energy carriers (e.g., methanol and gasoline), it can serve as an attractive medium for storing large amounts of energy produced during sunny or windy days. This provides a viable solution for seasonal storage, mainly through storage in salt caverns and large compressed gas containers, which can be positioned closer to demand centers and serve multiple sectors, including transportation and power.[14]



Grid Load Balancing

Hydrogen, may have a key role, together with other storage mediums (e.g., battery and pumped hydroelectricity power), in enabling the integration of renewables to the grid while providing flexibility and mitigating curtailment and congestion.[15]

The increasing penetration of intermittent renewable energy into the grid, which is not continuously available, also requires solutions that allow for balancing electricity supply and demand in real time. Hydrogen (specifically electrolysers) can become part of the solution, providing much-needed flexibility to the grid by absorbing a significant portion of renewable energy and being stored and transported to the most valuable consumption outlets (e.g., for industry and transport sectors), with a portion of hydrogen being reinjected to the grid during peak demands.

Enabling the Commodification of Renewable Energy via Hydrogen

Given that hydrogen can be stored and transited in all forms (i.e., gas, liquid, and solid state) – in contrast to electrons which are limited to transit via electric circuits – it has the potential to transform green energy into a global, tradeable commodity.[16]

Due to hydrogen's various applications and its unique ability to decarbonize hard-to-abate sectors, hydrogen consumption is expected to grow in the upcoming decades from the current ~90 megatons per year.[17] According to Deloitte projections, based on the IEA Net Zero by 2050 scenario, molecule-based energy carriers are expected to provide approximately 30%-35% of total energy consumption by 2050, while hydrogen is likely to constitute approximately 35% of the molecular energy carriers, i.e., around 10% of the total energy consumption in 2050.[18]

Although hydrogen has many potential benefits as an energy carrier, it also has some limitations. First, is that hydrogen needs to be compressed or converted into a liquid or solid to increase its density and make it more practical for storage and transportation. The conversion process is costly and can significantly add to the end price of hydrogen.[19] Another limitation of hydrogen is its ability to penetrate metals due to its small molecular size, causing metals (such as those used in pipelines and gas tanks) to become susceptible to hydrogen embrittlement and weaken over time.[20]

Israel's Hydrogen Sector

The Israeli hydrogen ecosystem is rooted in three main areas: academic research, government support (grant funding), and private sector investment/ commercial activity:

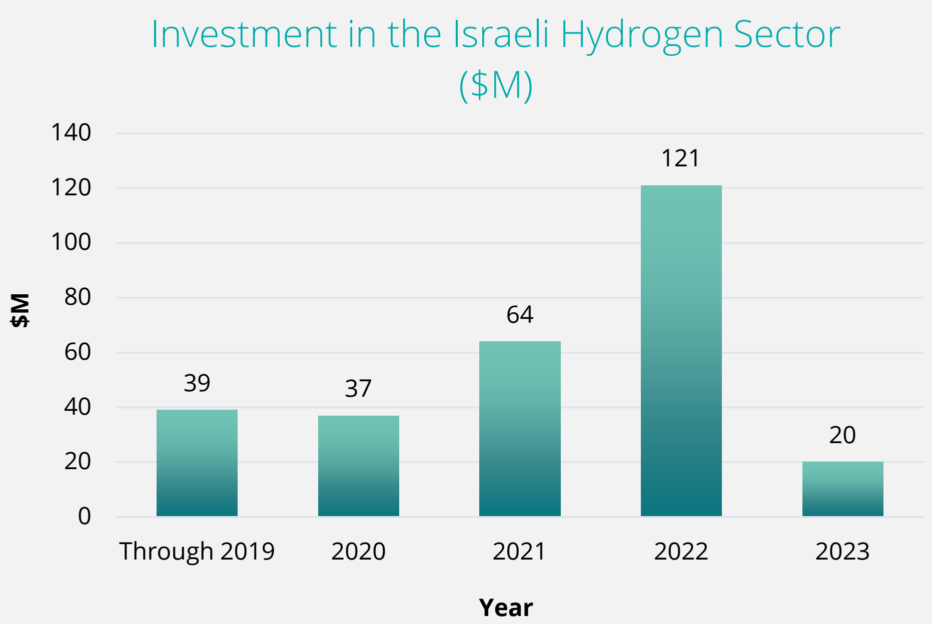
Academic Research

Israel is home to several globally top ranked research institutions and researchers,[21] which, based on our assessment, are responsible for a significant number of hydrogen-related technologies in Israel. This robust scientific foundation supports R&D efforts, fostering innovation within institutions such as Technion, the Weizmann Institute of Science, University of Tel Aviv (TAU), Hebrew University of Jerusalem (HUJI), and Bar Ilan University.

Further, early-stage developments are being rapidly researched including scalable bio-hydrogen production from microalgae (at TAU), on-board and on demand electric power and hydrogen production (two research projects at Technion), and a novel hydrogen storage solution (at the Weizmann Institute of Science).[22] Some major corporate stakeholders in the local energy ecosystem, such as Bazan,[23] and Doral Energy,[24] have formed strategic partnerships and collaboration frameworks to work directly with the leading researchers to develop and commercialize solutions.

Private Sector

With more than 50% of hydrogen-related startups founded after 2019, there has been exponential growth in fundraising with $121M invested in 2022, almost doubling the total amount of capital raised in the sector in 2021 ($64M) and more than tripling the amount of capital raised through 2019 ($37M). Although there was a significant decrease in investments during 2023 due to macroeconomic trends influencing the Israeli tech sector as a whole,[25] the hydrogen sector continues to demonstrate potential, capturing heightened interest from a growing number of both Israeli and foreign investors (including both Venture Capital and Corporate Venture Capital), representing 37.5% of the total Israeli energy investors.[26] Moreover, 50% of the investors in the hydrogen sector are foreign investors.[27]



* Through 2019 - it encompasses investments made before and up to the end of that year.

Several hydrogen projects are currently underway in Israel, featuring collaboration between key players in the Israeli ecosystem, including Bazan, Colmobil and Sonol,[28] leveraging hydrogen-powered trucks with Israel's first hydrogen fuel station opened in May 2023 at Kibbutz Yagur. The trucks, to be imported by Colmobil, will consume hydrogen produced by Bazan through refueling stations that Sonol is installing across Israel. Furthermore, Bazan and Sonol have committed to integrating hydrogen-powered trucks into their commercial fleets, featuring a stack of seven tanks per truck, each capable of carrying 32 kilograms of hydrogen in gaseous form and enabling a 450-kilometer range before requiring a refill, a process that takes only 15 minutes.[29]

Another initiative is a green hydrogen hub being developed in the south of Israel by local players Doral and H2Pro,[30] together with Eilat-Eilot Renewable Energy,[31] and backed by Israel's Ministry of Energy and Infrastructure. The project integrates a 15 MW photovoltaic installation, serving as the energy source, and includes an initial 400 kW capacity for renewable green hydrogen energy production, intended for use in industrial and transportation applications.[32]
One final initiative is the Green Sdom project by Israel Chemical Ltd. (ICL)[33] which aimed to enable the company to achieve energy self-sufficiency through the utilization of clean energy sources. The later stage of the project involves producing green hydrogen and harnessing its diverse properties as a clean fuel, a long-term storage solution, and a raw material for new fertilizers.[34]

These initiatives provide a platform for validation and scaling of local hydrogen innovation.

Public Sector

The Israeli government has continued to provide large amounts of investment dollars (mainly in the form of grants) to kickstart hydrogen-related technology research and development initiatives. Most grants are provided by the Israel Innovation Authority and the Ministry of Energy and Infrastructure, alongside complementary programs such as BIRD Energy[35] and EU Horizon.[36]

Total local government grants to hydrogen-related startups from 2013-2023 has exceeded $20M,[37] providing a more attractive environment for incentivizing private investments.[38] Moreover, the Israeli Ministry of Energy and Infrastructure has published its national strategy plan for developing the domestic hydrogen economy,[39] and it intend to continue to increase research and development investments, facilitate and build essential infrastructure (e.g., fueling stations, identification of suitable hydrogen storage sites, evaluation of the integration of hydrogen into existing natural gas pipelines), strengthen international cooperation around hydrogen initiatives, and develop regulatory policies.[40]

Challenges to Form a Global Hydrogen Market

The global hydrogen sector still faces significant challenges throughout the various components of its value chain, from production to end use applications. To overcome these challenges, a significant amount of investment is being made throughout the value chain,[41] including production, storage, transportation, and end use applications (e.g., fuel cells, hydro-based turbines, and boilers). The Israeli ecosystem offers a range of solutions for core challenges throughout the value chain.

Upstream Challenges – Production

To drive hydrogen demand, there is need for significant cost reduction in producing green and blue hydrogen. Increasing efficiency of both electrolyzers and carbon capture utilization and sequestration (CCUS) technologies, along economies of scale, are key in driving down the unit cost of green and blue hydrogen, respectively.[42]

For green hydrogen production, technology is needed to reduce electrolyzer equipment cost while increasing its efficiency and utilization rate. H2Pro, an academic spin-off based on research conducted in the Technion, that offers a disruptive system for large scale green hydrogen production, aspiring to enable a low price of $1/kg cost for green hydrogen until 2030.

Through their 2-step proprietary E-TAC solution, the company is able to provide over 95% energy efficiency (as opposed to traditional technologies such as Proton Exchange Membrane [PEM] and Alkaline which have roughly 70-75% energy efficiency) while offering a simpler system configuration without a membrane,[43] thus significantly reducing both electrolyzer equipment and operation costs (i.e., CAPEX/OPEX).

Alongside H2Pro, the report identifies academic research in the field of green hydrogen production in various stages of commercialization. Chiral Energies, an early-stage startup, which is commercializing a breakthrough discovery from the Weizmann Institute of Science and HUJI known as the "chiral-induced spin selectivity" (CISS) effect. The discovery indicates that when electrons are transferred through chiral molecules, they possess a certain spin orientation. Based on the CISS effect, the company is now commercializing a unique nano-coating material to apply, on the anode of electrolyzers, fuel cell systems, and batteries. This application leads to superior electrode performance and, therefore, a significant energy efficiency increase of over 30% in the electrolysis process.

Other local startups include QD-Sol, another academic spin-off from the Technion University. The company's technology utilizes sunlight as a direct source of energy to produce green hydrogen using proprietary nanoparticles as a catalyst to split water, thus providing a complementary technology to renewable-based electrolysis, opening new possibilities for hydrogen production. Additional complementary green hydrogen production solutions include Purammon, which offers a technology to generate hydrogen from wastewater at roughly half of the power consumption required for standard electrolysis performed on fresh water, transforming wastewater from an environmental problem into an economically attractive clean energy resource.

For blue hydrogen, the main goal is to significantly reduce capital and operational costs of carbon capture equipment while increasing the efficiency rate. Airovation Technologies, a company in the field of CCUS, achieves this through its mineralization technology captures and utilizes carbon-dioxide emissions at point source at over 90% efficiency, while co-producing high-value chemical byproducts, sulfuric acid and calcium carbonate that can be sold as feedstock to a wide variety of industries such as fertilizers and building materials.

Similarly, we can also find Israeli academic spin-offs that are focused on improving CO2 utilization technologies, such as Carbonade. Carbonade is an early-stage startup, based on novel research from the Weizmann Institute of Science, developing a system that can convert captured CO2 into green fossil-free carbon-based products while consuming low amounts of energy and utilizing a proprietary catalyst based on abundant metals that can maintain performance over long periods of time. Therefore, it offers a solution with relatively low CAPEX and OPEX costs.

Companies such as Airovation and Carbonade offer an important complementary route to carbon storage (once CO2 is captured from the atmosphere, or from a point source, it can be stored in several ways including geological sequestration and mineralization).[44] According to Deloitte research, annual CO2 injection in 2050 will be limited to 1.4 Gt.[45] Thus, the scaling of blue hydrogen can considerably benefit from carbon utilization technologies, in addition to the development of appropriate infrastructure for CO2 storage and transport.

Finally, technological developments around waste-to-hydrogen can also be found in Israel, enabling the utilization of waste and biomass as a source for hydrogen production. One company that is developing such a technology is Boson Energy. The company, whose proprietary Hydrogen Plasma Assisted Gasification technology (HPAG) can currently convert one ton of waste into 100-120 kg of hydrogen per ton, while requiring 8kWh/kg of hydrogen (the required power could be self-generated via fuel cell leaving 60-70 kg/ton to sell or via the grid). One immediate advantage of this technology is enabling local production of hydrogen in areas with no connection to the grid or those lacking cheap or excess of local renewables, providing a cost-competitive hydrogen production alternative to importing green hydrogen. There are additional solutions and developments in the waste-to-hydrogen process, with companies such as Co-Energy and Zohar CleanTech operating in this field.

Midstream Challenges – Storage and Transport

Enabling the storage and transportation of hydrogen over significant distances, while reducing transmission costs, is a key factor for wide-scale hydrogen adoption, so it is likely that initial hydrogen projects will couple production and consumption in proximity, often referred to as hydrogen hubs;[46] a clustered approach to supplying industrial users of hydrogen would reduce requirement for transportation infrastructure.

Storage mediums exist in the form of gas containers and natural salt caverns, as well as storing hydrogen in a liquid or solid-state form. The storage form also defines the method of transportation – whether via pipelines in gaseous or liquid state, or as liquid, solid, or compressed gas through non-pipeline transportation such as truck, rail, ship, or plane.

Pipeline transportation utilizes existing gas infrastructure with certain adaptations while gradually blending larger portions of hydrogen into the system until converting fully into hydrogen in the long run.

However, such a transition would require tools to monitor, detect, and analyze various types and grades of gas blends. One Israeli startup addressing the issue of hydrogen monitoring is Fast Sense. By developing dedicated sensors for effectively monitoring various gas mixtures, the company's solution can provide much needed visibility and provide a potential solution for safety concerns revolving around leakage in storage and transportation of hydrogen due to its colorless and odorless makeup.

Additional Israeli startups in the field of hydrogen monitoring include NanoScent and OptiqGain, which enable real-time monitoring capabilities of both hydrogen purity levels and leakages through their proprietary sensors.

Liquid and solid carriers are likely to provide shorter distance and smaller volume supply as well as enable long distance hydrogen exports between geographies that lack connectivity to mutual gas infrastructure networks. These methods of storage and distribution are usually more expensive than gaseous transmission via pipelines,[47] mainly due to the high rate of energy loss and the required environmental conditions for converting hydrogen from its gaseous state into a liquid or solid form (e.g., temperature and pressure).

In Israel, there are a few solutions and technologies that address the challenge of conversions. One example is Hydro X, that offers a system for storing hydrogen in a non-toxic, non-flammable, and non-explosive water-based liquid that provides improvement in energy efficiency. HydroX offers a solution with the potential to mitigate safety risks, significantly lower hydrogen OPEX and CAPEX storage costs and increase energy efficiency throughout the hydrogen supply chain. The solution, based on a proprietary catalyst and process developed over many years of research at the Hebrew University of Jerusalem, is able to charge and release energy in ambient temperature and with low pressure, requiring only ~2.5kWh to load and discharge 1kg of hydrogen (existing systems usually require around 13kWh/kg). Additionally, the solution allows for the use of water tanks, simple plastic tanks, and affordable water pipelines, while leveraging existing oil infrastructure.

The Israeli ecosystem also offers novel technologies in the field of ammonia, a hydrogen carrier (the most common solid-state storage and transportation carrier for hydrogen). Gencell, a local manufacturer of fuel cell solutions, has developed (in collaboration with TDK Corporation),[48] a novel approach to produce low-cost green ammonia[49] through the utilization of nitrogen and water at low temperature and pressure, reducing the cost of production and boosting the energy efficiency rate of the synthesis process. Another startup operating in the field of green ammonia production is NitroFix, an academic spin-off from the Weizmann Institute of Science.

The company is currently developing an electrochemical cell to allow production of green ammonia via a one-step electrochemical reaction of water and air through a proprietary catalyst at low voltage, enabling distributed production of ammonia.

Another example of a hydrogen storage solution developed in Israel is Electriq Global, that developed a solid carrier in the form of powder (Potassium borohydride [KBH4]). The powder is a non-toxic and non-flammable chemical compound that can efficiently and safely contain hydrogen in ambient conditions, while maintaining high volumetric density. In addition, the solution allows for the elimination of costly infrastructure (e.g., tanks, refrigeration) and enables standard transportation of hydrogen (e.g., box packaging), thus providing an interesting alternative to ammonia, as it requires special handling and logistics due to its toxicity.

Downstream Challenges – End-Use Applications

Fuel systems are key in enabling the use of hydrogen in areas such as transportation and stationary power. One of the most important developments needed is around fuel cell systems that would allow efficiently utilizing chemical energy such as hydrogen, together with oxygen, to produce electricity and heat. Utilizing hydrogen as an energy source requires the development of new systems as well as adaptations to existing assets.

In Israel, there are several examples of advanced fuel cell technologies in development for various use cases. One such company is Gencell (mentioned above). The company has developed novel solutions to incorporate alkaline fuel cell and ammonia cracker technologies, offering simpler configurations. By utilizing abundant metals, the company aims to provide cost-efficient systems for various applications, including hydrogen-based electric vehicle (EV) charging stations and backup and off-grid power, replacing carbon-intensive alternatives such as diesel-based backup power generators.

Another fuel cell developer is Hydrolite, which is developing an anion exchange membrane (AEM) technology for both fuel cells and electrolyzers, with high performance and low costs as a result of the use of low-cost and readily available materials. Hydrolite has recently completed the development of a first-of-a-kind prototype of a stationary backup system containing an AEM stack with a capacity of 8KW, which in its basic configuration can store around 90kWh. In recent months, Hydrolite successfully completed a field test for this system at one of the sites of the Israeli Ministry of Defense. This is one of the first AEM-based fuel cell systems in the world to operate outside the laboratory.

An additional example of innovation in the field of fuel cells is a technology called reversible fuel cells (RFCs), developed in Bar Ilan University, and currently being commercialized through Refhuel.[50] The RFC technology not only allows for electricity production from a proprietary hydrogen-based carrier developed by the company, but also enables the recharging of the fuel cell system through an electrolysis-like process. The process utilizes excess electricity, providing electricity in peak demand while producing and storing hydrogen-based energy from renewables during times of high supply.

Another area of innovation revolves around distributed energy applications based on hydrogen.
An interesting solution in the field of micro turbines is being developed by Turbogen, which offers a cost-efficient and lightweight combined heat, and power as well as cooling (CCHP) system that is able to run on both natural gas and hydrogen (up to 100% hydrogen). The company's micro turbines enable on-site energy production as a prime energy source parallel to the grid supporting the energy demands during peak consumption, ensuring continuous power.
Another distributed hydrogen-based solution is offered by Fonto Power. The company developed a solid-oxide fuel cell (SOFC) system that can support various blends of natural gas and hydrogen (up to 100% hydrogen) to generate heat and electricity. In addition, the company is developing an AI-based energy generation management solution to optimize energy consumption from the various energy sources. For example, it determines when to consume electricity directly from the grid and when to self-generate power from the SOFC system. The company has recently been bought by SolarEdge, an Israeli global leader in renewable energy.

Summary

Hydrogen is a promising energy path for reaching Net Zero goals.[51] The journey towards becoming a substantial element in the future global energy system is full of challenges. Overcoming these challenges requires several technological breakthroughs. Israel's fast-growing hydrogen ecosystem shows significant promise in its ability to solve crucial obstacles throughout the value chain and serve as a key innovative contributor in the emerging global hydrogen economy.

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Israeli Hydrogen Ecosystem

Startups

Upstream Production

- Boson Energy
- Chiral energies
- CO-ENERGY
- H2 Energy Now
- airovation technologies
- H2PRO
- Purammon
- QD-SOL
- ZCT
- StandardCarbon

Downstream Applications

- CARBONADE
- AQUARIUS
- FontoPower
- NitroFix
- GenCell
- HydroLite
- Luminescent
- maygia
- TURBOGEN CHP
- HEVEN DRONES

Midstream Storage & Transportation

- nugen
- REFHUEL
- Electriq Global
- FrostSense
- nanoscent
- HydroX
- optiGain

Investors

- BAZAN GROUP
- Breakthrough Energy
- CAPITAL NATURE
- DORAL Tech Ventures
- HYUNDAI
- ESIL
- extantia
- GROVE VENTURES
- Elbit Systems
- OTHER SOURCES ENERGY GROUP
- TEMASEK
- TDK VENTURES
- YARA
- Contrarian Ventures
- IN
- OurCrowd
- NGV NEXTGEAR VENTURES
- TPY CAPITAL
- ArcelorMittal
- E44 VENTURES
- NetZero Technology Ventures
- qFund

Academia

- BGN
- BIRAD
- RAMOT TEL AVIV UNIVERSITY
- TECHNION TECHNOLOGY TRANSFER
- YEDA
- YISSUM

Ecosystem Contributors

- ICL
- COLMOBIL CORP.
- חברת החשמל
- DOR
- רשות החדשנות Israel Innovation Authority
- EnergyCom.IL
- Sonol
- IGNITE THE SPARK
- BIRD Israel-U.S. Binational Industrial Research and Development Foundation
- Ministry of Energy and Infrastructure
- CLIMATE FIRST
- START-UP NATION CENTRAL
- נתיבי הגז הטבעי לישראל ISRAEL NATURAL GAS LINES
- Taavura
- quantum
- EILAT EILOT Renewable Energy

For Further Reading

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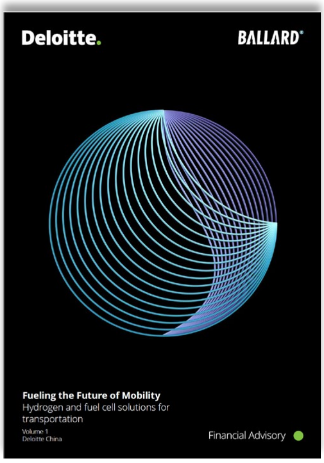

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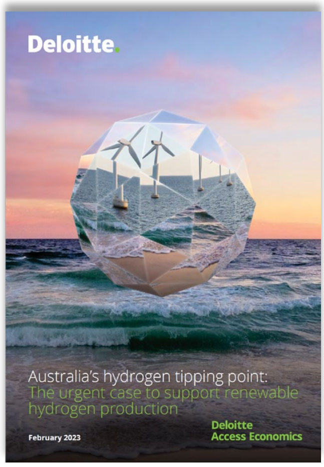

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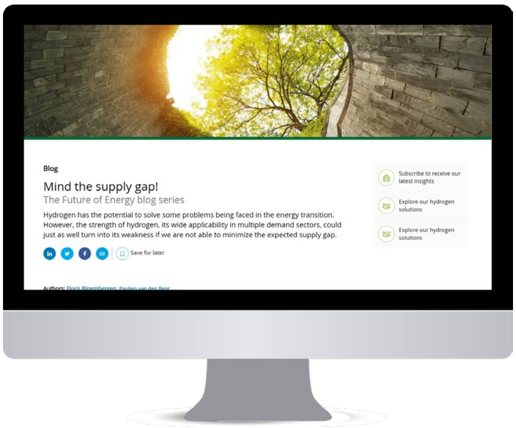

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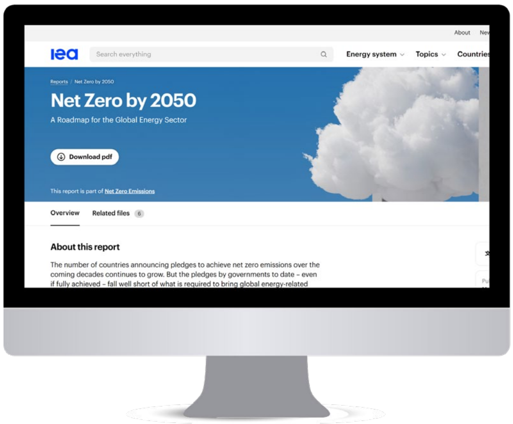

IEA. Net Zero by 2050. IEA, Paris. May 2021.

Technion, Israel Institute of Technology - TTO, T3

Research Institution Name
Technion, Israel Institute of Technology - TTO, T3

Short Description
Hydrogen and electric energy production on-demand

Description
Hydrogen storage and transportation is both in efficient and hazardous. Hydrogen production by reaction of water and chemically treated aluminum can be done on demand and on the location where the hydrogen will be used. Weight of hydrogen produced is 11% of weight of Al used for the reaction. The reaction doesn't need energy and is exothermic. The basis of the invention is a novel, thermo chemical process for activation of powdered aluminum. Water needed for the reaction can be of low grade such as sea water or even wastewater.

Researcher
Prof. Alon Gany

Potential Use Cases
On-board hydrogen production

Website
Hydrogen and electric energy production on-demand - T3 (technion.ac.il)

Research Institution Name
Technion, Israel Institute of Technology - TTO, T3

Short Description
Harvesting electrical current from live macroalgae

Description
Producing renewable energy might still pollute – producing photovoltaic cells uses hazardous materials such as cadmium, hydrogen production requires electricity etc. In addition, producing and installing PV cells, wind turbines and other equipment requires transportation, energy and materials.
Bio-photoelectrochemical cells produce photocurrent from photosynthetic systems. Using real natural sources – plants and more specifically algae have huge benefit: in addition to producing energy they use CO2 and produce oxygen. They are already grown for different uses such as food, cosmetics and even for the pharmaceutical industry. However, typically, BPEC technologies utilize a potential bias on the anode to improve the current production. Such a process entails an extra investment of energy, which in some cases is higher than the energy produced by the BPEC itself.
Ulva and other macroalgae produce current along side hydrogen with no need for external energy invested. At the same time they utilize CO2 and produces oxygen to build biomass very quickly.

Researcher
Prof Noam Adir and Prof. Gadi Schuster

Potential Use Cases
Energy production at algae aquaculture sites

Website
Harvesting electrical current from live macroalgae - T3 (technion.ac.il)

Technion, Israel Institute of Technology - TTO, T3

Research Institution Name
Technion - TTO, T3

Short Description
H2 Production by electrocatalysis assisted by Peptoid complex

Description
Water splitting is an important process towards the generation of H2 as a renewable and sustainable energy source; however, the high overpotential and slow kinetics limit its applicability.
Most current photo- and electro-catalysts are expensive to make, not environmentally friendly and the processes consume a lot of energy. Some are not stable kinetically or require extreme conditions such as high pH.
Designing biomimetic, ligands that can stabilize water oxidation catalysts intermediates, which also include proton acceptor groups, within stabilizing catalytic systems (appropriate buffer conditions) enables the stabilization of the catalysts during the entire catalytic cycle lowering overpotential and increasing efficiency.
It was demonstrated that a peptoid ligand can be assembled in the presence Cu(II) ions to form a di-nuclear copper complex, and that the latter is a highly active electrocatalyst for water oxidation in borate buffer at mild pH and low over-potential. At these conditions faradaic efficiency was >90% at an overpotential of about 600 mV, and with about 45 kV/h required to produce 1 Kg, which is 10% lower than what is used in industry today.

Researcher
Prof. Galia Maayan

Potential Use Cases
Efficient hydrogen production by electrocatalysis

Website
H2 production by electrocatalysis assisted by Peptoid complex - T3 (technion.ac.il)

Research Institution Name
Technion - TTO, T3

Short Description
Carbon-based Electrodes for Fuel Cells+

Description
Hydrogen fuel cells are a key enabling technology towards supplant CO2-emitting fuels with hydrogen. Proton Exchange Membrane (PEM-FC) technology is the dominant incumbent for automotive applications. However, PEM-FCs suffer from a strong drawback in the cost of the fuel cell stack, which is deeply embedded in the core technology. Alkaline Exchange Membranes (AEM-FCs) retain the benefits of PEM, while the alkaline environment allows for significantly lower-cost materials. A key AEM-FC benefit is a facile oxygen reduction reaction (ORR), which in PEM is only achievable with a significant loading of high-cost platinum catalysts.

The technology offers a range of novel carbon materials, with a broad range of surface chemistries (for catalysis), controlled and tunable pore structures (for ionic conductivities), and graphitization (for electronic conductivity)- for alkaline ORR

Researcher
Dr. David Eisenberg

Potential Use Cases
Electrodes for fuel cells and for other electrocatalytic processes, Supports for electrocatalysts and heterogeneous catalysts

Website
Carbon-based electrodes for fuel cells - T3 (technion.ac.il)

Technion, Israel Institute of Technology - TTO, T3

Research Institution Name
Technion - TTO, T3

Short Description
Highly Active Nanostructured Electrodes

Description
Nano-engineered electrodes were shown to dramatically increase catalytic activity versus electrodes made of the same materials prepared by standard methodologies. Current preparation methods, such as ALD, are expensive, slow, and generally non-scalable. Such electrodes can be used e.g., for several applications in the field of renewable energy storage and CO2 capture.
In a world powered by intermittent renewable energy, electrolyzers will play a central role in converting electrical energy into chemical energy, thereby decoupling the production of transport fuels and chemicals from today's fossil resources and decreasing the reliance on bioenergy. Solid oxide electrolysis cells (SOECs) offer two major advantages over alternative electrolysis technologies. First, their high operating temperatures result in favorable thermodynamics and reaction kinetics, enabling unrivaled conversion efficiencies. Second, SOECs can be thermally integrated with downstream chemical syntheses. In addition, SOECs are capable of working in high pressure and don't require expensive, scarce materials such as platinum.
The nano-engineered SOECs electrodes increase the SOEC current density by up to 2 orders of magnitude.

Researcher
Prof. Charlotte Vogt

Potential Use Cases
Electrolyzers, Fuel Cells, Carbon Capture

Website
[Highly active nanostructured electrodes - T3 (technion.ac.il)]

Research Institution Name
Technion - TTO, T3

Short Description
Catalytic Reformer for Energy Recycling

Description
Internal combustion engines (ICE) will remain main propulsion technology for various applications for many years.
The known challenges of using internal combustion engines are security of energy supply, climate change issues and air pollution. The aim of this technology is to deal with all those issues by reduction of energy consumption, pollution mitigation and use of renewable energy sources. The new technology is an add-on to an existing ICE and will allow use of renewable non-fossil fuels of low carbon intensity. Such is the on-board high-pressure thermochemical recuperation (TCR) of alcohols (ethanol, methanol etc.) utilizing thermal energy of the engine exhaust gas to sustain endothermic reactions of fuel reforming to a gaseous hydrogen-rich reformate.

Researcher
Prof. Leonid Tartakovsky & Prof. Moshe Sheintuch

Potential Use Cases
Internal combustion engines, Hybrid systems combining fuel cell and internal combustion engine

Website
[Catalytic reformer for energy recycling - T3 (technion.ac.il)]

Technion, Israel Institute of Technology - TTO, T3

Research Institution Name
Technion - TTO, T3

Short Description
Highly Stable Membranes for Alkaline Fuel Cells and Electrolyzers

Description
Alkaline fuel cells and electrolyzers offer many advantages over their acidic counterparts, the main one being the possibility to replace precious metals in electrodes with other, low cost and abundant metals. However, the alkaline environment leads to substantial electrolyte decomposition – an anion exchange membrane (AEM) – limiting the operating hours of the devices. Moving away from classical chemistries, new polymers with protected cations leads to AEMs with unparalleled alkaline stability.

Researcher
Prof. Charles Eliezer Diesendruck & Prof. Dario R. Dekel

Potential Use Cases
Electrolyzers, Fuel cells, Flow batteries, Metal-air batteries

Website
Highly stable membranes for alkaline fuel cells and electrolyzers - T3 (technion.ac.il)

Tel Aviv University - TTO, Ramot

Research Institution Name
Tel Aviv University - TTO, Ramot

Short Description
Scalable Bio-Hydrogen Production

Description
A novel Chlamydomonas reinhardtii green algal strain carrying two mutated genes, produces high scale H2 (up to 3.2 mg. H2 per hour per liter culture) under ambient growth conditions, requires no nutrient deficiency, centrifugation or other steps that disrupt the process continuity. The mutated algal strain characteristics address the current production challenges and allows fast, efficient and long term (about 7-10 days without any media changes) H2 production. Furthermore, the new strain is robust and performs well in relatively high temperatures (up to 36 degrees) and high light exposure (300μE). In 1 square meter, using bioreactors at height of 3 meters with LED lamps powered by solar panels you can have 3000 liters culture, which translates to up to 84 Kg H2 per square meter per year.

Researcher
Prof. Yacoby Iftach

Potential Use Cases
Hydrogen Production

Website
Scalable Bio-Hydrogen Production; a Novel Green Energy Technology (ramot.org)

Research Institution Name
Technion - TTO, T3

Short Description
Gas sensors with enhanced selectivity based on integrated magnetic and conductometric measurements

Description
a new type of gas sensor that solves the problem of cross-sensitivity by monitoring two independent parameters sensitive to the target gases: resistance and magnetization. The sensor concept is based on the so-called Extraordinary Hall effect (EHE) by which magnetization of ferromagnetic films can be detected by a simple electronic transport measurement. The procedure is technically similar to the four-probe measurement of resistance, with two modifications: 1) Hall voltage is measured in the direction perpendicular to electric current flow, and 2) the measurement is generally done under a bias magnetic field. Thus, two independent gas-sensitive parameters are measured in the same magnetotransport setup. In the test-case of hydrogen detection, the EHE sensitivity of CoPd sensors in the ppm H2 concentration range is two orders of magnitude higher than the conductometric on.

Researcher
Prof. Alexander Gerber

Potential Use Cases
Hydrogen Monitoring

Website
Novel gas sensors with enhanced selectivity based on integrated magnetic and conductometric measurements (ramot.org)

Tel Aviv University - TTO, Ramot

Research Institution Name
Tel Aviv University - TTO, Ramot

Short Description
Structure dependence of fuel cell catalysts for oxygen reduction reaction (ORR) and hydrogen oxidation reaction (HOR)

Description
utilizes pulse electrodeposition (PED) and reverse pulse electrodeposition as a technique for the evaluation of crystallographic orientation on ORR catalytic activity in polycrystalline systems. The film thickness, morphology, and microstructure can be controlled electrochemically by 4 degrees of freedom (peak height, reverse peak height, duty cycle, and pulse period) giving a high order of control to the deposition process. These parameters can be tuned to generate a continuous range of film geometries ranging from planar to nano-particulate to dendritic. These films can be an excellent system for evaluating the effect of orientation and microstructure on ORR activity because PED can generate novel compositions, morphologies, and phases unattainable through other synthesis methods. Improvement of ORR catalysts is a leading goal for improving the overall efficiency of PEM (and similar) fuel cell devices

Researcher
Dr. Brian Rosen

Potential Use Cases
Fuel Cells

Website
Dr. Rosen Brian Ashley (ramot.org)

Weizmann Institute - TTO, YEDA

Research Institution Name
Weizmann Institute - TTO, Yeda

Short Description
Hydrogen storage system

Description
Efficient, solvent-free, liquid to liquid hydrogen storage systems based on reversible dehydrogenation and hydrogenation using a single heterogeneous supported Pd catalyst

Researcher
Prof. David Milstein

Potential Use Cases
Storage

Website
Weizmann Institute | Prof. David Milstein | Publications

Research Institution Name
Weizman Institute - TTO, Yeda

Short Description
Recycling of precious metals via an efficient process with no toxic byproduct

Description
Platinum group metals (PGM) are well-known precious metals that play an important role in many industrial applications as catalysts. Current methods for their recycling are not efficient, require extreme conditions, and involve toxic reagents or byproducts. Prof. Igor Lubomirsky and his team developed a method for efficient and environmentally benign recovery of precious materials that are currently discarded in large quantities from spent catalysts (automotive and industrial) from industrial processes (particularly in the electronic industry). The process is based on volatilization for selective extraction of precious and rare metals using benign metal salts rather than dangerous chlorine gas as a chlorinating agent. The new process requires relatively low temperatures and is free from hazardous waste, among its additional advantages over conventional methods.

Researcher
Prof. Igor Lubomirsky

Potential Use Cases
Metal Recycling

Website
Recycling of Precious Metals via an Efficient Process with no Toxic Byproduct | YEDA Technology Transfer (yedarnd.com)

The Hebrew University of Jerusalem - TTO, Yissum

Research Institution Name
The Hebrew University of Jerusalem - TTO, Yissum

Short Description
Quantum Nano Materials for Photo-Catalytic Applications

Description
Developed a novel platform technology based on photocatalytic colloidal quantum nano-materials. The novel catalysts for light-induced REDOX reactions and reactive species formation enable significant advantages such as:
efficient photocatalytic activity, superior single and two-photon light sensitivity, high solubility in various solvents including water, high stability allowing prolonged use and multi-functionality, wide and tunable absorption spectra suitable for excitation in the near UV-VIS range. The nano-materials can efficiently and continuously produce reactive species on demand by near UV-VIS light excitation in both organic and aqueous solvents, allowing the replacement of the traditional polymerization processes currently done in organic solvents and/or with deep UV light sources.

Researcher
Prof. Uri Banin, Prof. Hermona Soreq and Prof Shlomo Magdassi

Potential Use Cases
Green Hydrogen Production

Website
Quantum Nano Materials for Photo-Catalytic Applications - Yissum

Research Institution Name
The Hebrew University of Jerusalem - TTO, Yissum

Short Description
Lightweight polymer-based tanks for hydrogen storage

Description
Development of a metallic coating, i.e., liner, of the inner part of lightweight polymeric tanks that will be used for storing hydrogen at very high pressures. The metallic coating will prevent the diffusion of hydrogen across the polymer and is made by electroless and electrochemical deposition.

Researcher
Prof. Daniel Mandler

Potential Use Cases
Hydrogen Storage

Website
Research activities – Daniel Mandler | Prof. Daniel Mandler (huji.ac.il)

The Hebrew University of Jerusalem - TTO, Yissum

Research Institution Name
The Hebrew University of Jerusalem - TTO, Yissum

Short Description
Salt bricks made from Compressed Salt (NaCl) for hydorgen storage

Description
One of the current technologies to store large volumes of hydrogen is through salt caverns. Yet, such salt caverns are limited in number. Therefore, the research is aimed to utilize the strength and density of compressed salt bricks to build artificial salt caverns in the form of large underground storage bunkers for storing hydrogen. The technology is based on utilizing millions of tons of Halite that accumulate as a byproduct of industrial processes, for example, at "Dead Sea Works", a producer of Potash products which generate 20 Millions tons of Halite each year as a by-product. Importantly, the salt is formulated to stabilize against water & humidity, compressed to form very strong blocks and boards.
The Building blocks & boards are produced by compression of formulated Halite (NaCl), used to build interior walls, providing beneficial properties. Compatible with other building materials (gypsum, cement and more). Low energy & cost of production, utilizing huge industrial waste streams, fully recyclable at end of life.

Researcher
Prof. Daniel Mandler

Potential Use Cases
Hydrogen Storage

Website
Strong, Environmentally-friendly Construction Materials made from Compressed Salt (NaCI) - Yissum

The Bar Ilan University - TTO, BIRAD

Research Institution Name
The Bar Ilan University - TTO, BIRAD

Short Description
Hydrogen Sensor from Organometallic Precursor

Description
Novel nanoscale sensors with ultra-low power consumption.

Researcher
Prof. David Zitoun

Potential Use Cases
Monitoring

Website
Hydrogen Sensor from Organometallic Precursor – BIRAD – Research and Development Co. Ltd

Research Institution Name
The Bar Ilan University - TTO, BIRAD

Short Description
Technology for electrochemical production of hydrogen, that can significantly cut down the energy demand for hydrogen evolution and the total costs of the cells' components and their maintenance

Description
In contrast to the conventional electrolyzers, in which water are discharged simultaneously into hydrogen and oxygen by electro-catalytic reactions, and the products (hydrogen and oxygen) are separated by an ion exchange membrane (or a diaphragm), oxygen is not evolved within the cells, and membrane is not an essential part in the electrolyzer, neither expensive oxygen evolution catalysts are required.
During the catalytic hydrogen evolution reaction over the cathode, electronic charge is counter-balanced on the anode, by specific interactions that do not involve any oxygen evolution, in a way that the potential (and hence, the overall voltage) on the anode is low.
Thanks to specific design of the anode and the system, charge is not accumulated on the anode, and total voltage is kept steadily along the hydrogen evolution reaction.

Researcher
Dr. Eran Avraham and Dr. Izaak Cohen (from Prof. Doron Aurbach's group)

Potential Use Cases
Green Hydrogen Production

Website
BIRAD – Research and Development Co. Ltd – BIRAD – Research and Development Co. Ltd

The Bar Ilan University - TTO, BIRAD

Research Institution Name
The Bar Ilan University - TTO, BIRAD

Short Description
A Bimetallic Catalyst and Fuel for Use in a Direct Dimethyl Ether Fuel Cell

Description
Solution that replaces the use of hydrogen with Dimethyl Ether (DME). DME can be liquefied under low pressure and produce relatively high energy density.
DME-based fuel cells may become one of the most promising alternative energy technologies due its high energy density, low cost, and physical properties which make it very easy to handle.

Researcher
Dr. Lior Elbaz

Potential Use Cases
Fuel Cells

Website
A Bimetallic Catalyst and Fuel for Use in a Direct Dimethyl Ether Fuel Cell – BIRAD – Research and Development Co. Ltd

Endnotes

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2. Deloitte, Getting from hard-to-abate to a low-carbon future, 2021.
3. United Nations, "The Paris Agreement" accessed April 3, 2023.
4. Ibid.
5. Deloitte, Green Hydrogen: Energizing the Path to Net Zero, 2023.
6. Deloitte, Australian and Global Hydrogen Demand Growth Scenario Analysis, 2020.
7. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called electrolyzer.
8. Deloitte, "A hydrogen rainbow is emerging, but which colors lead to the pot of gold?", The Future of Energy blog series. For further details on the types of hydrogen see source 8. In Israel, we identified additional complementary methods of producing clean hydrogen. Two interesting methods currently being developed and commercialized are production from waste, as well as through photosynthetic microbes (e.g., technology developed in the labs of Tel Aviv University for cost-efficiently producing at scale hydrogen from algae).
9. United Nations Climate Change, Key Aspects of Paris Agreement.
10. Deloitte, Green Hydrogen: Energizing the Path to Net Zero, 2023.
11. Deloitte, Will hydrogen be the surprise of this decade?, 2023.
12. A logistics fleet can include Trucks, vans, ships, airplanes, or any other vehicles necessary for supply chain operation.
13. Deloitte, "Creating a Viable Hydrogen Economy: A Future of Energy Point of View", 2021.
14. Deloitte, Investing in Hydrogen: Ready, set, net zero, 2020.
15. Curtailment and Congestion - Curtailment involves intentionally reducing electricity generation, typically from renewable sources, due to oversupply, while congestion refers to limitations in the energy grid's transmission capacity, hindering the efficient flow of electricity.
16. IRENA - International Renewable Energy Agency, Energy Transition - Hydrogen.
17. IEA, Global Hydrogen Review, 2022. Hydrogen demand reached 94 million tonnes in 2021, equivalent to 0.393 exajoule.
18. Deloitte, Hydrogen: Making it Happen, 2023.
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20. Deloitte, Transmission of Hydrogen for Commercial Consumption in the US, 2021.
21. See the academic research appendix for a full list of applicable research.
22. Ibid.
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24. Doral Energy - a global company in the field of renewable energy, with aggregate projects of over 15.2GW (DC) and 12.3 GWh Storage capacity globally.
25. Ctech, Private equity investment in Israel plummets by 33% in 2023, 2023.
26. Startup Nation Central, energy investors.
27. Startup Nation Central, IVC and Pitchbook
28. Sonol - one of the largest fuel companies in Israel, while Colmobil is a vehicle importer, including that of Hyundai Motor.
29. The Times of Israel, "Israel's first hydrogen refilling station for vehicles opens in north" 2023.
30. H2Pro - an Israeli startup within the green hydrogen production segment. The company's technology is described in the report.

Endnotes

31. Eilat-Eilot Renewable Energy - a public benefit company, owned by the kibbutzim of the Arava, JNF, and local industrial, developmental, and academic entities in Israel. The company strives to make the southern Arava region an international center for research, development, and commercialization of renewable energy technologies.

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33. ICL - a global specialty minerals company that creates impactful solutions for humanity's sustainability challenges in the global food, agriculture, and industrial markets.

34. "The Green Sdom Initiative: Beating Climate Change with Green Energy in Factories", ICL Blog, June 2023.

35. "BIRD - an Israeli-U.S. R&D program providing grants to U.S.-Israel cooperation on a range of clean energy technologies, including renewable energy, energy efficiency, natural gas, hydrogen, and energy-water technologies. Israeli companies that received funding through this program are: Gencell, Hydrolite and Rafael.

36. EU Horizon - a European research and innovation program providing grant funding to a range of clean energy technologies, such as Airovation, OptiqGain and Electriq Global in the Hydrogen field.

37. Based on aggregated public data from Startup Nation Central and IVC.

38. BIRD Energy Approved Projects. Supporting energy tech companies shows strong growth; for instance, the BIRD Energy program approved 10 projects from 2022-2021, while the BIRD HLS program approved only 4. This indicates greater activity in the energy sector.

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41. Deloitte, Green Hydrogen: Energizing the Path to Net Zero, 2023.

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46. Breakthrough Energy Ventures, "How to Transport and Store Hydrogen", April 2023.

47. For a more elaborate analysis on the importance and costs of conversion, storage and transportation of hydrogen see Sources 5 and 14.

48. TDK Corporation - a Japanese multinational electronics corporation that manufactures electronic components and recording and data-storage media.

49. Green Ammonia - Ammonia is a pungent gas that is widely used to make agricultural fertilisers. Green ammonia production is where the process of making ammonia is 100% renewable and carbon-free.

50. Refhuel – is a subsidiary of Decama Capital LTD. Refhuel is developing a revesible fuel-cell technology, based on a proprietary liquid hydrogen carrier, that will enable the efficient production and storage of clean energy.

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Disclaimer:

The companies in this report were selected through a meticulous process, supported by data from IVC Research Center, Startup Nation Finder, and PitchBook databases, based on discussions held with Israeli academic institutions. Additionally, a compilation of articles pertaining to the subject matter has been included for reference. It is imperative to emphasize that the chosen companies align with the report's publication date, acknowledging the inherent dynamism of the industry and the potential for frequent changes.

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