ENERGY TRANSITION REPORT

DECEMBER 2020

RYSTAD ENERGY

ENERGY SOCIETIES IN 2050

RYSTAD ENERGY TRANSITION TRENDS

Contents

Can solar, wind and battery storage replace base load power generation? Photo:Petmal

Picking a winner in the decarbonization race – CCS, hydrogen or batteries?

2020 could go down in history as the single most turbulent and eventful year ever for the global energy system. Not only have we seen the largest single-year drop in global oil demand (-10%), gas demand (-2%) and electricity consumption (-2%), but we have also witnessed a cascade of structural changes in behavioral patterns, with direct implications on energy demand. This includes a double digit drop in global car sales combined with a record rise in electric vehicle market share, the further acceleration of decarbonization initiatives, several new technology breakthroughs, and a recent green tailwind in American politics along with more than 30 new net-zero targets announced by major countries and energy consuming corporations.

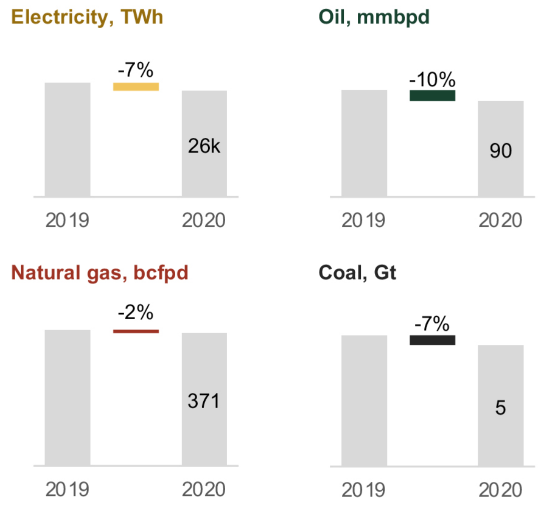
Our data expertise gives us a unique vantage point to explore this development, and in the following pages we will offer three tableaus depicting what our global society may look like after the Energy Transition. The main objective of this report is to introduce these net-zero scenarios and to set the stage for what is to come in 2021. Being the first in a series of reports, it will explore the many facets of the energy transition, from the decarbonization of the power sector, industrial carbon capture and green hydrogen, to the electrification of the transportation sector. Some decarbonization technologies are on the verge of becoming self-supporting, such as renewable power generation and electric vehicles, while others have yet to prove their role in a carbon-free energy system. And although there are many in the latter category, three technologies are currently competing to become the dominant platform on the pathway to net-zero – carbon capture and storage (CCS), hydrogen and batteries.

In our CCS Society, we weigh the economic advantages of deploying carbon capture and storage technologies against the cost of emitting, a poignant discussion as only 23% of global emissions are currently part of a carbon pricing initiative. Our Hydrogen Society considers the value chain underpinning the current hydrogen market, and new areas where H2 may have direct application. And in our Battery Society, we highlight that the capital cost of large-scale grid storage has plummeted by 80% in the last eight years, potentially offering huge gains as the energy system electrifies.

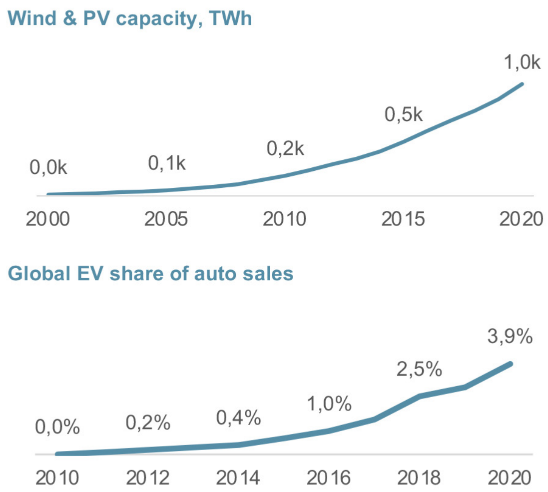
Of course, there is no crystal ball to tell us what the future may hold. But in exploring these societies, we endeavor to do what Rystad Energy does best: utilize our data to paint a picture of tomorrow.

Welcome to the Rystad Energy Transition Trends Report.

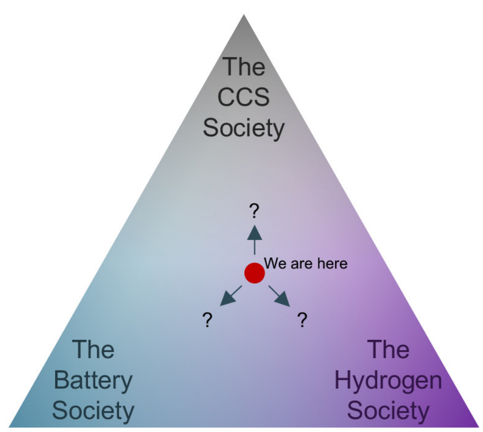
Covid-19 impact on energy consumption



Self-supporting decarbonization trends



Future decarbonization pathways



Source: Rystad Energy research and analysis, RenewablesCube

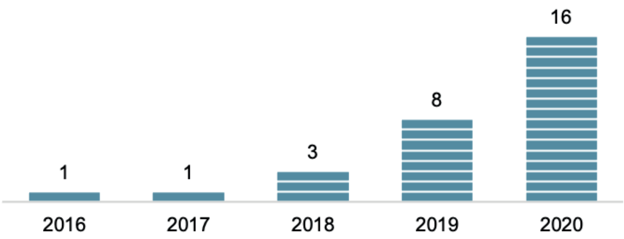
Photo: Alessandro Bosi

Net-zero commitments were doubled in 2020

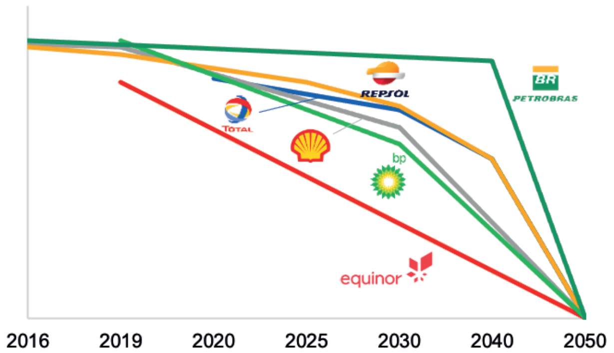
The year draws to a close amidst a flurry of new net-zero announcements from heavy hitting countries and companies alike. In late September, China announced its ambition to reach carbon neutrality by 2060, with peak emissions before 2030. Just two months later the United States followed suit, electing Joe Biden to the presidency, and with him, a renewed commitment to reach net zero by 2050. The two countries join 27 others who have announced net zero targets, and which together account for 27 billion tonnes of CO_2 equivalent ($GtCO_2e$) greenhouse gas (GHG) emissions, corresponding to over 50% of global emissions.

The efficacy of these targets will of course hinge on corporate action. Upstream player Repsol closed out the year by announcing its intention to reach net zero by 2050, while peers such as Shell and Total announced similar goals earlier this year.

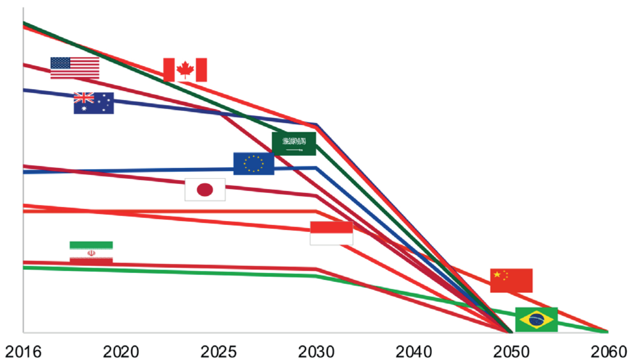
Number of countries to announce net zero targets
Count, split by year of announcement



Carbon intensity of top upstream companies
Tonnes of CO_2 per terajoule, (tCO_2 per TJ); Scope 1, 2 and 3



Top emitting countries
Green house gas emissions per capita ($MtCO_2e$)*



Source: Rystad Energy research and analysis; ClimateWatch; *Net Greenhouse Gas (GHG) emissions per capita

Photo: Albert Pego

Being one of the largest CO_2 emitters, the cement industry is also one of the hardest to abate.

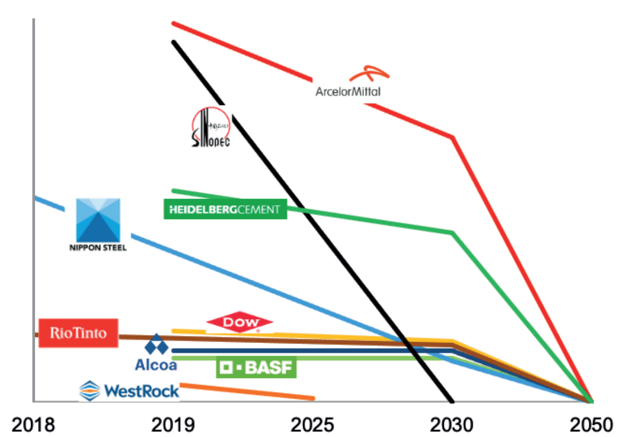
Industry looks to new technologies while Big Tech doubles down on targets

The industrial sector has struggled to set ambitious goals on reducing emissions, as manufacturers face a variety of fundamental operational constraints that vary by industry – obstacles that must be addressed with new technologies. Building material manufacturer HeidelbergCement became the first cement maker to commit to net zero, aiming for CO_2 neutral concrete production by 2050. Japanese steel manufacturer Nippon Steel launched a new phase of existing R&D initiatives under its Super Course50 campaign, exploring new refining techniques to decarbonize the steelmaking process by implementing a reduction method centered on hydrogen, rather than carbon. Altogether, nine industrial leaders have thus far announced net zero targets for 2050.

Technology companies doubled down on carbon reduction measures with some of the most ambitious corporate targets. The Big Five tech firms have all announced net zero targets by or before 2040, potentially reducing emissions by more than 108.3 $MtCO_2e$. However, Microsoft took this a step further, announcing its intention to be carbon negative by 2030 and accounting for all historical emissions by 2050. The tech giant will start this process with a $1 billion investment into its own Climate Innovation Fund, aimed at investing in new technologies across the energy system that are ready to scale.

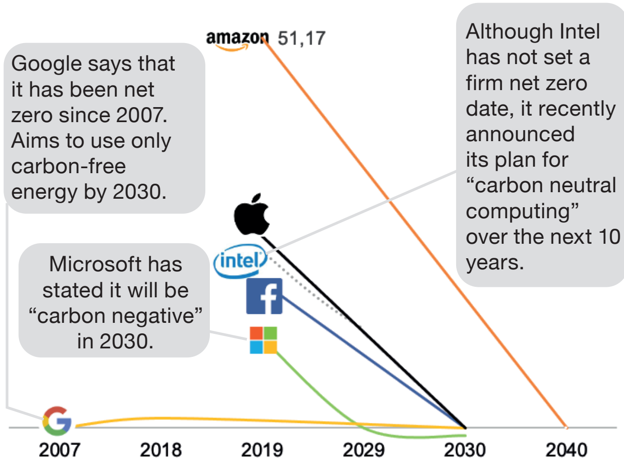
Emissions from top industrial companies

Million tonnes CO_2 equivalent*



Emissions from technology

Million tonnes CO_2 equivalent*



*Scope 1, 2 and 3

Source: Rystad Energy research and analysis; company reporting

Introduction to the Global Energy System

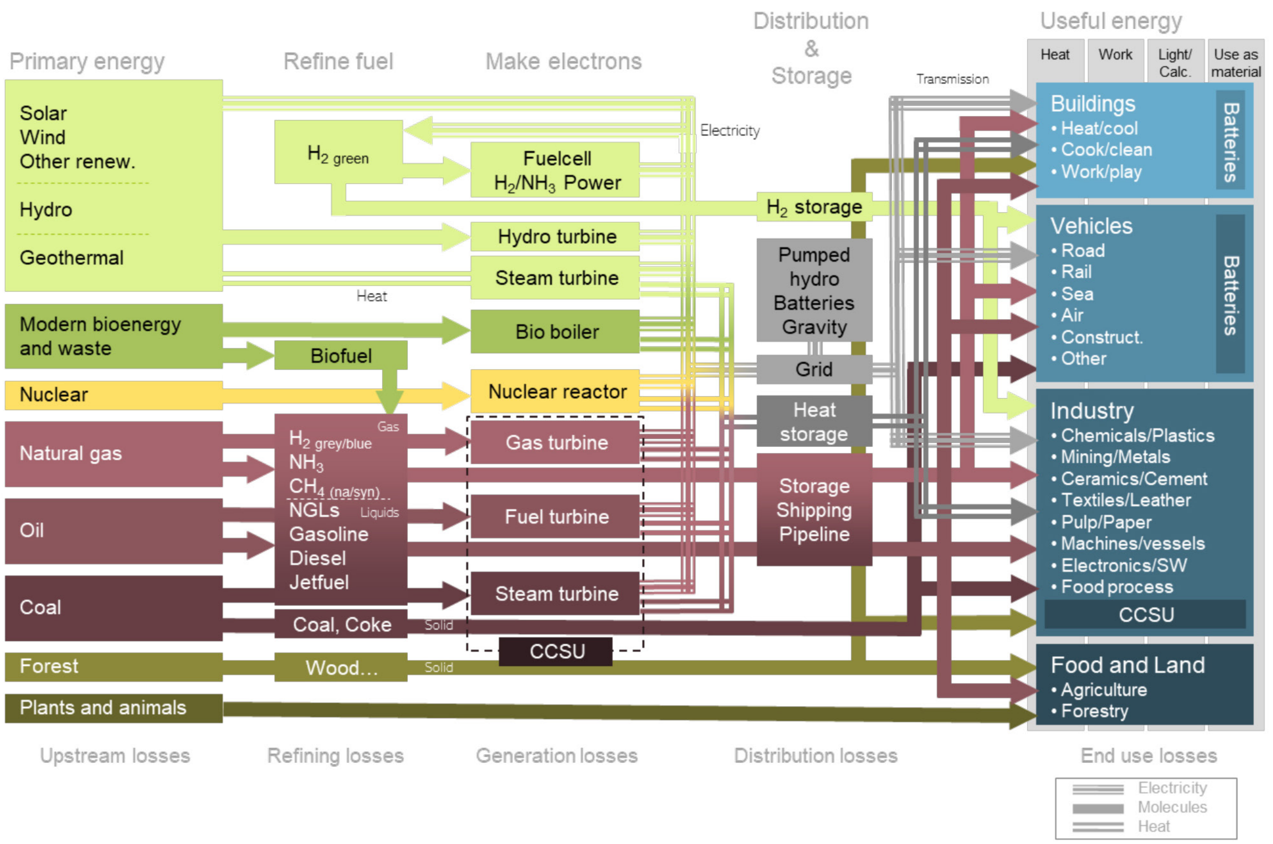
The Energy Transition has just begun, but to understand the implications of the transition we need to understand the energy system. This figure illustrates how Rystad Energy envisions the near-future energy system that will take us through the transition, including the key decarbonization technologies – renewable power, hydrogen, batteries and CCS.

At the leftmost part of the energy system is the supply of various primary energy sources, split into modern renewable sources, nuclear, fossil fuels and traditional bio. Fossil fuels are still by far the dominant energy source, making up approximately 80% of the world's energy needs. The primary uses of fossil fuels are combustion for power generation, fuel in the transportation sector, combustion for process heat in industrial applications, and feedstock to industrial/chemical processes. The steps to convert primary fossil fuels into useful end-products are separated into the refining of fuels and the making of electrons (i.e. power generation). Additionally, a byproduct of power generation is waste heat, which can be used for district heating.

Modern renewable sources produce electricity directly, in addition to heat for some sources (solar thermal, geothermal). Most modern renewable energy sources are also what we call non-dispatchable, meaning they don't necessarily produce electricity when it is needed, but rather when nature tells it to (solar, wind, run-of-river hydro). This creates the need for storage, both in the short and long-term.

Bioenergy is similar to fossil fuels in the sense that it is mostly used in combustion processes, either in power generation or as biofuel for transport. Biofuel may, at least partly, contribute to the decarbonization of the aviation, trucking and maritime sectors, and be used as feedstock in the petrochemical industry. Nuclear, as with fossil fuel combustion, produces electricity and heat, and although facing negative sentiment in recent years it is still a carbon-free and efficient energy source once constructed.

Moving further to the right in the energy system, past refining and power generation, we see the distribution and storage of energy. This is where the transition to renewable energy is beginning to be seen within the system. ▶



Source: Rystad Energy research and analysis

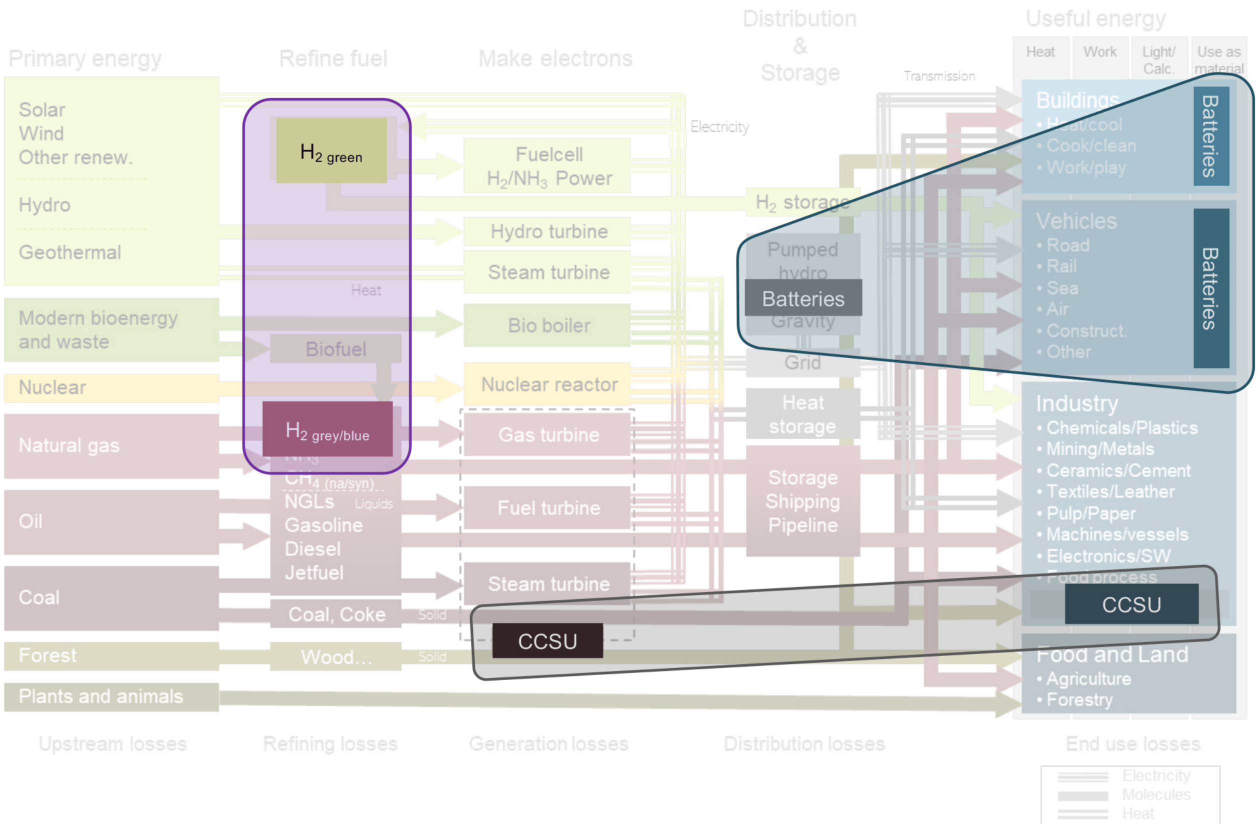
- Non-dispatchable power generation creates a mismatch between electricity supply and demand. This can be solved either by storing the electrons in batteries for future use, or by converting the energy into another form to be utilized at a later point in time. This alternative form can either be through mechanical energy – such as pumped hydro, gravity-based storage, compressed air or other up-and-coming technologies – or it can be through the synthesis of molecules for use as fuel, such as green hydrogen in a fuel cell to re-generate electricity. A third option is to convert the hydrogen into another fuel (Power-to-X) or use it as feedstock in chemical or industrial processes. However, this does not solve the problem of missing supply in the absence of wind and solar generation.

Three metrics determine the optimal storage solution. The first is the cost of the system, the second is the capacity utilization, and the third is the energy efficiency of the system (i.e. the amount of output electricity divided by the amount of input electricity during one full cycle). A grid battery that is charged and discharged several times a day is more valuable than a battery that sits idle for two weeks to provide backup energy for one windless day. At the same time, a battery that sits idle for two weeks, but has an energy efficiency of 90%, might be more valuable than a hydrogen storage system with an energy efficiency of 35%. It all comes down to the technology development cost and electricity prices.

Batteries and hydrogen are also competing to become the energy carriers of tomorrow's transportation sector. They both have benefits and shortcomings, which make them more or less attractive for various applications.

An alternative option, partly circumventing the entire storage problem, is carbon capture and storage (CCS) on fossil power plants, allowing for the continued operation of dispatchable fossil-fueled power generation.

At different places in the energy system we nominate each of these three technologies to complement renewables, as a competitive force on the path to net zero. They will all play a role, but uncertainty remains around the size of market share each will hold in the future.



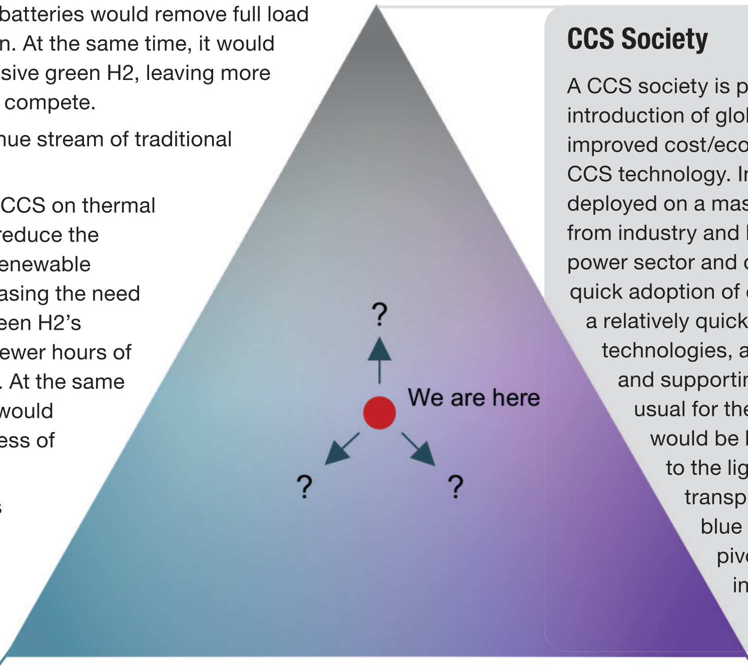
Source: Rystad Energy research and analysis

The Rystad Energy Societies

The three Rystad Energy Societies are conceptual futures in which each of the three key technologies become the dominant path to decarbonization in its own society. Each society will contain elements of all three, but with varying degrees of technological penetration. Through the first quarter of 2021, we will elaborate on the status quo of each technology, the direction each is heading, and the pace of deployment. Regardless of where we end up as a global society, the forces behind each technology are already vying to expand their market share.

Some examples of key dynamics:

- A high penetration of grid batteries would remove full load hours from green hydrogen. At the same time, it would lower the volume of expensive green H2, leaving more room for blue hydrogen to compete.
- Batteries eat into the revenue stream of traditional power generation.
- Carbon taxes would drive CCS on thermal power plants. This would reduce the intermittency problem of renewable generation, thereby decreasing the need for batteries, as well as green H2's competitive edge (due to fewer hours of very low electricity prices). At the same time, cheaper CCS costs would increase the competitiveness of blue hydrogen.
- Battery supply constraints and/or a flattening of the battery cost curve would limit battery integration and leave more room for other technologies.



CCS Society

A CCS society is predicated on the introduction of global carbon taxes and improved cost/economies of scale for CCS technology. In this scenario, CCS is deployed on a massive scale in everything from industry and blue hydrogen to the power sector and direct air capture. The quick adoption of carbon taxes ensures a relatively quick adoption rate for CCS technologies, alleviating carbon budgets and supporting prolonged business as usual for the fossil industry. Batteries would be largely constrained to the lighter segments of the transportation sector, and blue hydrogen would play a pivotal role in decarbonizing industry and hard-to-abate transport.

Battery Society

Within a Battery Society, battery costs continue to plummet, allowing for cheap grid storage which can deal with intraday intermittency, as well as supplying electricity for days. In this scenario there are no substantial supply side bottlenecks. Cheap batteries also support the rapid electrification of transportation and would (in combination with cheap solar, wind, and a strengthened power grid) deal a lethal blow to the fossil fuel industry. CCS and hydrogen would become niche technologies within industry and transportation.

Hydrogen Society

In a Hydrogen Society, the overcapacity in renewable generation and cost reduction in electrolyzers would result in competitive green hydrogen. The establishment of a widespread hydrogen economy would increase demand for blue hydrogen in addition to green. This demand increase, coupled with the mainstreaming of hydrogen pipeline grids, would support everything from transportation to power and heating.

Source: Rystad Energy research and analysis

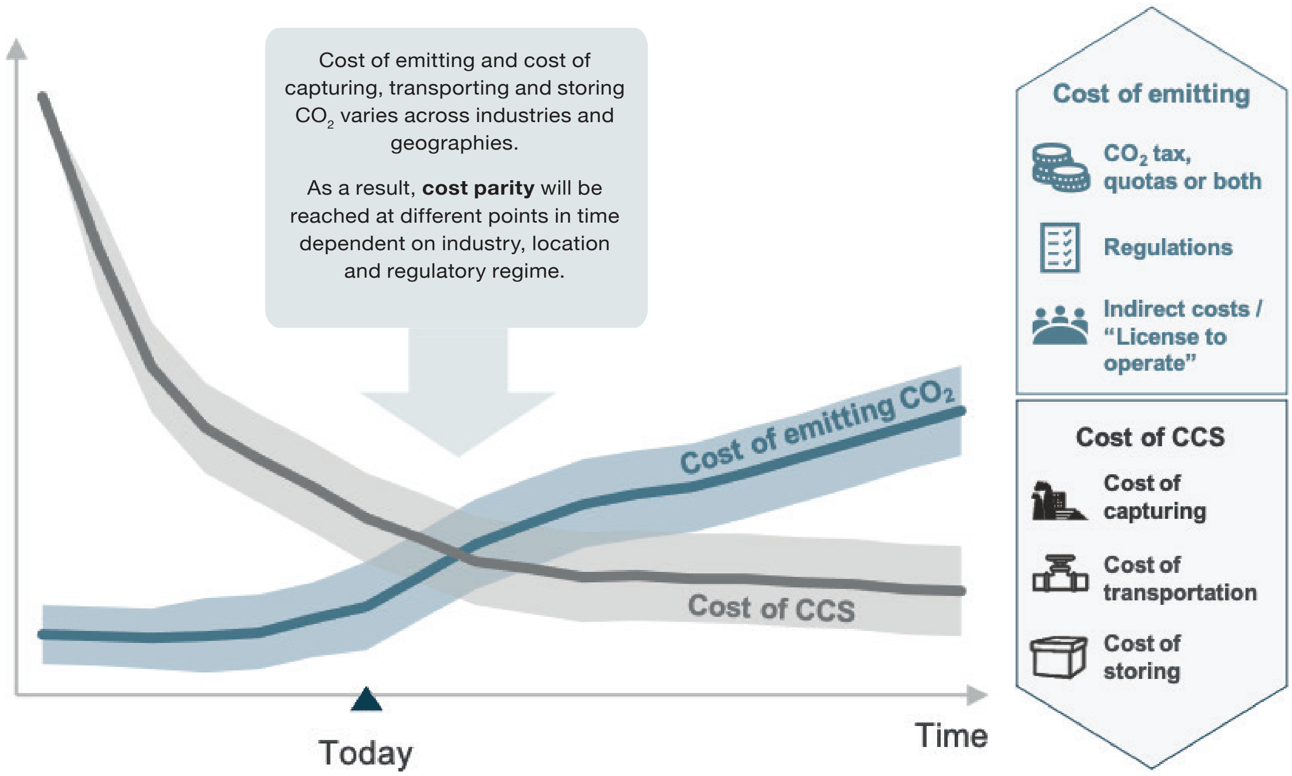
Cost of emitting and switchability as key drivers

To make carbon capture and storage economically feasible, it must become more costly to emit CO_2 than to capture it.

Today, only 23% of global CO_2 emissions are part of a carbon pricing initiative, and pricing is generally far from sufficient to justify CCS project economics for most applications. At the same time, the trend is moving towards higher carbon pricing and a wider adoption of carbon pricing. China has recently reinforced its national emissions trading scheme, and with a new government in the US, the probability of a US carbon tax has increased significantly. Perhaps just as importantly, the probability of a joint EU–US push for international carbon pricing seems much more tangible.

Carbon pricing is not the only mechanism pushing companies towards carbon capture solutions; their social license to operate is also being challenged to a much greater degree. Customers are focusing more on sustainability, and investors are increasingly shying away from "dirty" investments, putting pressure on both fossil fuel producers and industrial emitters. Carbon capture is just one solution, but for many applications there are alternatives such as electrification or altering parts of industrial processes.

Cost of emitting CO_2 vs cost of capturing, illustration
Relative costs



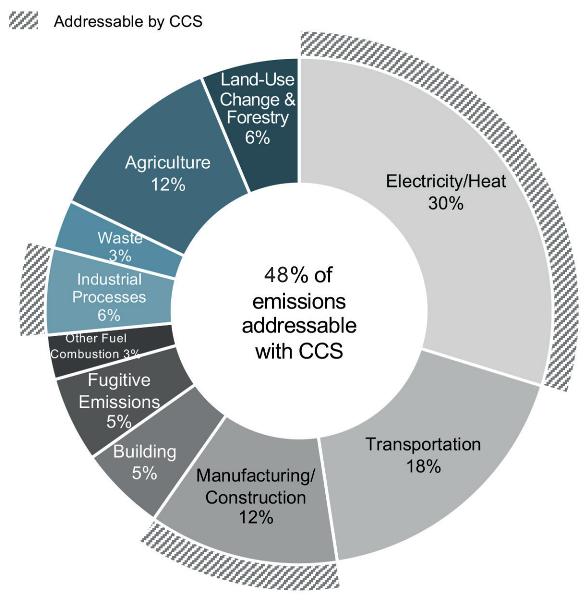
Source: Rystad Energy Research and analysis

▶ The steel industry is one such example where hydrogen could replace coke as a reactant in iron ore smelting. Contrary to the steel industry, cement industry producers (also major emitters) have limited options apart from CCS to fully decarbonize.

An alternative to directly address man-made emissions through traditional CCS is to use technologies that capture CO_2 in the ambient air through Direct Air Capture (DAC) or Bio Energy CCS (BECCS). Both are rather new technologies, but with the potential to contribute to emission reductions in the giga-tonne scale.

CCS' ability to address greenhouse gas emissions

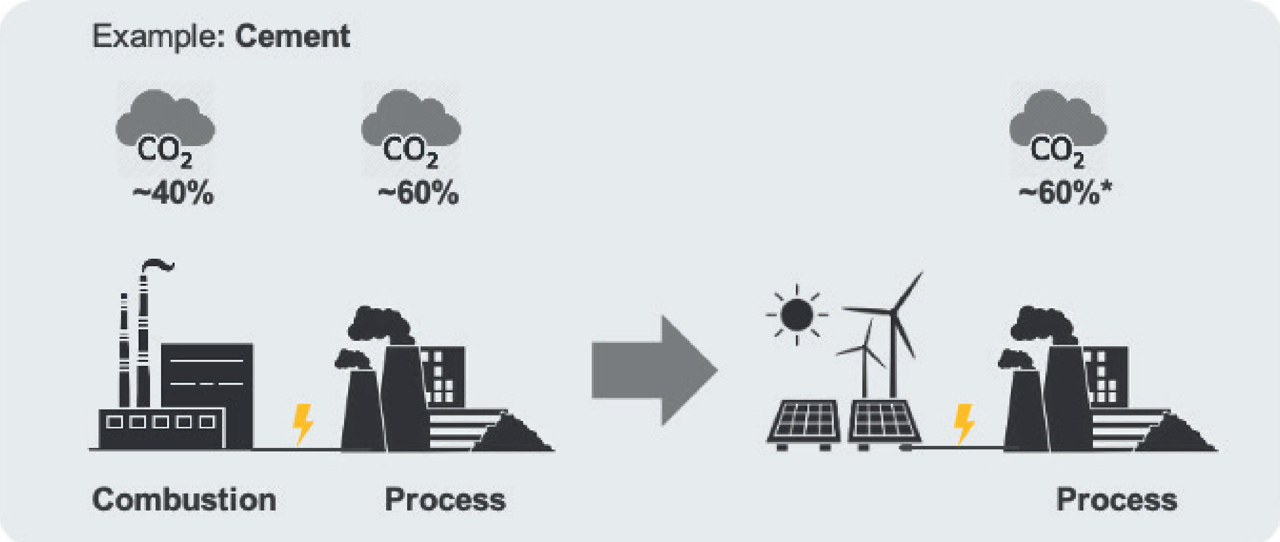
GHG emissions by sector



Source: Rystad Energy research and analysis; Climate Watch

"Non-switchable" end uses / end processes

Energy consumption or industry processes where the process itself prohibits new energy carriers from being part of the abatement solution from a technical standpoint.

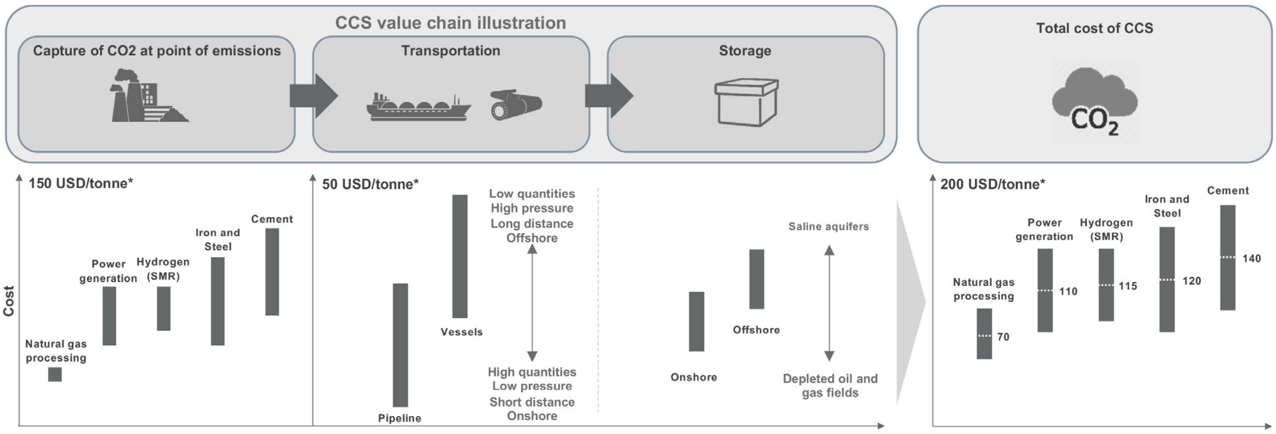


Source: Rystad Energy Research and analysis

It all comes down to the application

The CO_2 capture cost varies significantly between applications based on factors such as CO_2 concentration, capture rates, capture volume, location, energy source and steam supply. The cost can range from $20 per tonne for gas processing, to above $100 per tonne for cement, but several factors drive costs down. The carbon capture industry has seen rapid technology development in recent years in terms of modular design, standardization and economies of scale, thanks to increased competition and innovation from new entrants. CO_2 storage providers commonly offer transport services as well, through operated or leased infrastructure or vessels. Customers typically pay for the initial transportation to the main grid or port, while a fixed fee covers remaining transportation, as well as storage. The introduction of hubs is a key factor behind reduced transportation costs. This leads to significant economies of scale as customers can share the same infrastructure. Reduced unit costs for the operator will trickle down into reduced fees for the emitter.

As with transportation, increased volumes and resulting economies of scale will be the primary factors in driving costs down for offshore storage, resulting in savings for the operator. Further cost reductions can be gained by utilizing existing infrastructure, monitoring plan optimization, or use of drones. Considering the many factors influencing total project costs, it is difficult to indicate an explicit cost of CCS, but the chart to the far-right gives an indication of the cost range that can be expected for the various applications.



*Illustrative. Several cost components associated with CCS are decreasing due to economies of scale, technology improvements, increased competition and standardization
Source: Rystad Energy research and analysis; IEA; CCSNorway; DNV GL

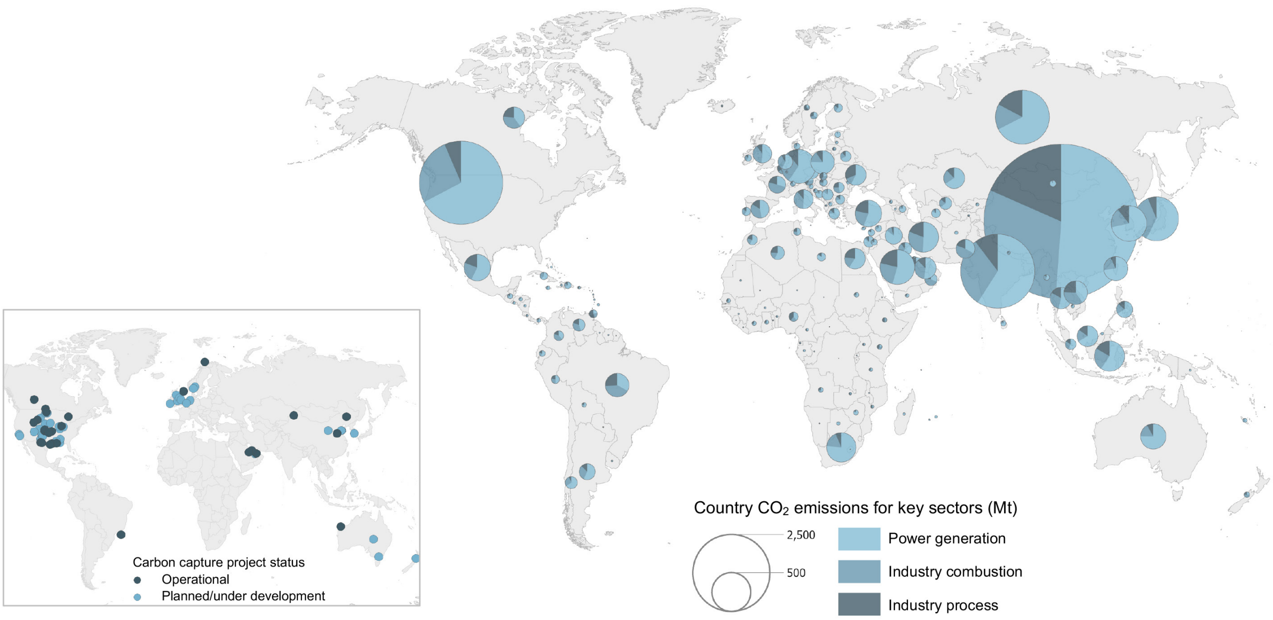
Carbon capture technology at work, using filters to remove GHG CO_2. Photo: IGphotography

Global potential in CCS – the current portfolio is focused on gas processing

The core applications for CCS, as illustrated on the previous page, are within natural gas processing, power generation, hydrogen production (steam methane reforming or SMR), and industrial processes. Today, the vast majority is related to natural gas processing and hydrogen production for use in refining and fertilizer production.

The large map illustrates the CO_2 emissions from power generation, industry combustion, and industry processes, and highlights potential key areas for CCS. Not surprisingly, we find the largest potential in China, India and the US, where power and combustion outweigh process emissions. The power sector, although significant, is less likely to utilize CCS than industry, as renewable energy – given the fast decline in costs – outcompetes some CCS projects in the power sector. The small map illustrates the global status of carbon capture projects. A majority of existing projects stem from onshore natural gas processing and/or gas derived production in the US, where the captured CO_2 is used for enhanced oil recovery, with questionable climate impact.

Regardless, it highlights the point that emission costs have not been high enough to justify projects with a meaningful climate impact. It also underscores the fact that the current portfolio of operational projects is, to a very large degree, based on the second-hand value of CO_2 itself. However, this is not the case for the new project pipeline, wherein a large portion of CCS projects are in the power utility sector.



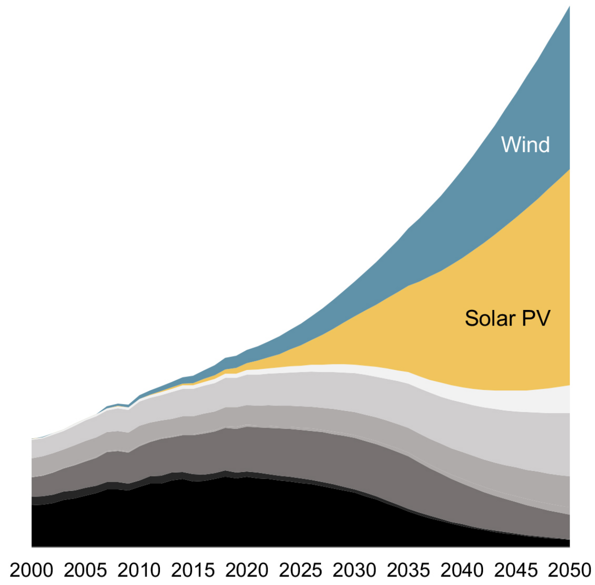
Source: Rystad Energy research and analysis

Hydrogen has the potential to scale and is intrinsically tied to renewable capacity

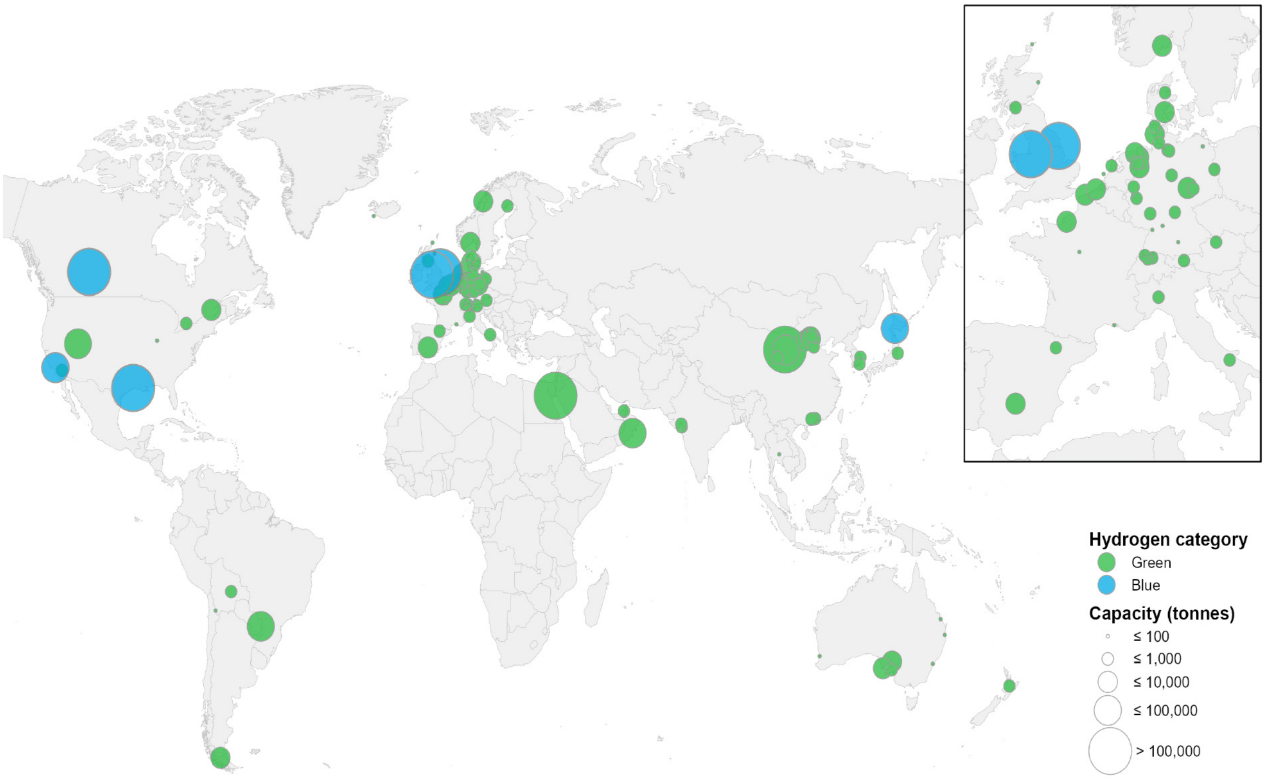
The establishment of a worldwide hydrogen economy is predicated on a massive increase in the global generative capacity of solar PV and wind. Our research indicates this is not only feasible, but likely. Towards 2050, global power generation will surge to meet sharply increasing demand. Company communication from top solar and wind manufactures suggests manufacturing capacity will keep pace and, as renewable costs continue to decline, these new sources will gradually displace power generation from traditional sources.

Yet, in order for a green hydrogen society to become economical, wind and solar generation must exceed most forecasts in the industry, outpacing normal electricity demand as we understand it today. In this scenario, the high intermittent renewable power generation would provide sufficient low priced load hours for competitive green hydrogen production at a large scale. This may at first appear oversupplied relative to the mechanisms of the power market today, but it would not be oversupplied when considering the energy system as a whole, taking systems cost into account.

Global electricity generation in the Hydrogen Society
Terawatt hours (TWh)



Clean or low emission hydrogen projects
2020



Source: Rystad Energy research and analysis

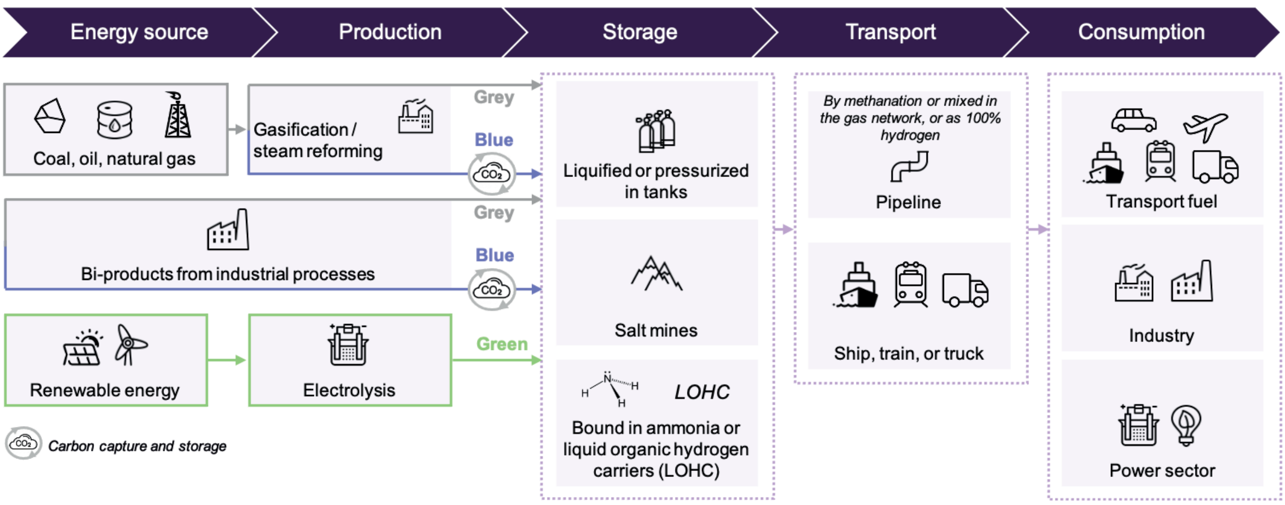
Compressed hydrogen storage tanks.

Hydrogen project pipeline at 80 GW under existing value chain

Cheap electricity from an "oversupplied" power market would then drive green hydrogen prices down and fuel a global ramp in both green hydrogen capacity and hydrogen value chain technology such as fuel cells and H2-transportation. This would likely also be positive for blue hydrogen as the hydrogen market as a whole reaches scale, benefitting the end users with cheap, competitive hydrogen technologies – for example, offering a rival to the electric vehicle.

Today, 80 GW of green hydrogen projects exist at various stages of development, 50 GW of which was proposed in 2020. The existing value chain for green, blue and grey hydrogen is determined by a variety of economic factors. Blue and grey hydrogen are sourced from coal, oil, natural gas, or bi-products from industrial processes, albeit the vast majority is today from natural gas. These sources undergo gasification or steam reforming, whereas green hydrogen is sourced from renewable energy through electrolysis.

Once processed, the hydrogen can be stored in one of three ways; as liquified or pressurized in tanks, via salt mines, or bound in ammonia or liquid organic hydrogen carriers. Hydrogen may then be transported via pipeline or shipment to be used as transportation fuel, in industry, or in the power sector.



Source: Rystad Energy research and analysis

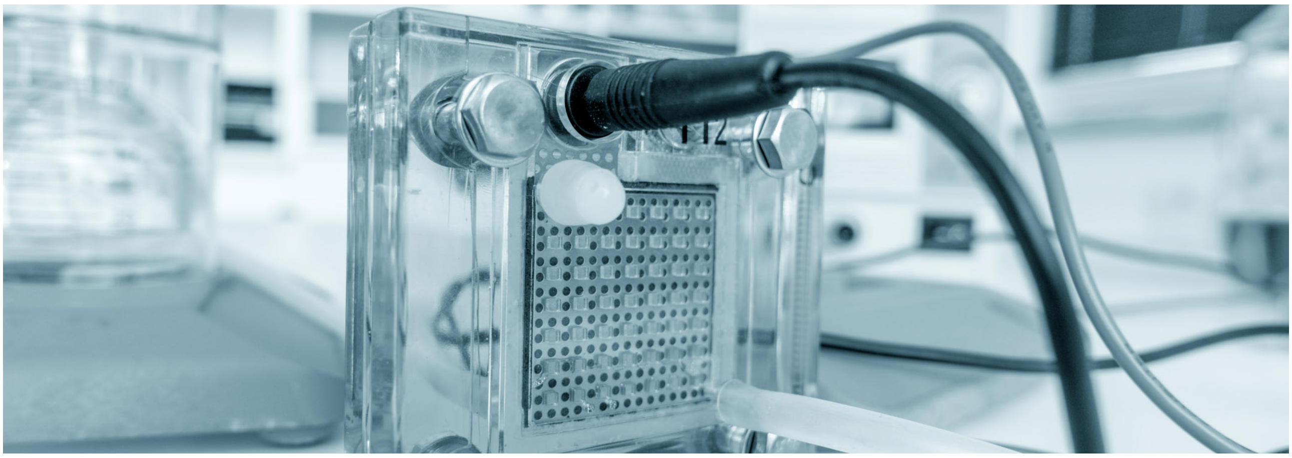


Photo: Luchschen

Proton-exchange membrane fuel cell (PEM FC) used in transport and stationary fuel cell applications.

Hydrogen meeting fierce competition from batteries and electrification

Hydrogen is applicable across a large number of markets, but competitiveness and adoptability vary across sectors. In transport and power generation, hydrogen technology is already directly applicable and in use. However, hydrogen will face stiff competition in these sectors from batteries, a technology which has already entered both markets commercially. Hydrogen use in industrial processes is still in the pilot phase but shows promise, especially in the chemical industry. Meanwhile, hydrogen has limited potential as a heating fuel, as the amount of hydrogen required to heat a building is five to six times that of electric heat pumps.

Sector	Application	Competitive assessment	Main competition
Transport	*Road transport*	The envelope of hydrogen application in road transport is shrinking for every incremental improvement in battery technology.	• Battery electric
	Aviation	Battery electric aviation has come furthest in terms of proof of concept but will likely be limited to short haul. Technologies for long haul flights are still unproven.	• Battery electric • Synthetic fuels • Biofuels
	Shipping	Short sea shipping could to a large extent be based on battery electric in the future but is not a viable solution for deep sea shipping. Methanol and ammonia are currently the best candidates.	• Methanol • Battery electric • Biofuels
Industry	*Steel production*	Still in pilot phase with promising technologies being developed for both hydrogen and purely electric solutions.	• Iron ore electrolysis + electric arc furnaces • CCS
	Chemical industry	It is expected that recycling will take a larger share of the future petrochemical market, but additional feedstock will still to be needed and hydrogen could prove an important pathway to decarbonize the chemical industry, both plastics and other	• Bioplastics • Recycling
	Other industry	Mostly used for process heat in industrial boilers. Competition with efficient electric boilers, but low power prices during intermittency might benefit green hydrogen	• Electricity
Power	*Power generation*	The battle will likely come down to how much of the storage market can be economically viable covered by batteries.	• Battery storage • Gravity based
Buildings	*Heating*	The energy needed to heat buildings with hydrogen is 5-6x that of electric heat pumps, with the implications that hydrogen will have limited potential in building heating. This market will likely be close to 100% electrified	• Electricity

Source: Rystad Energy research and analysis

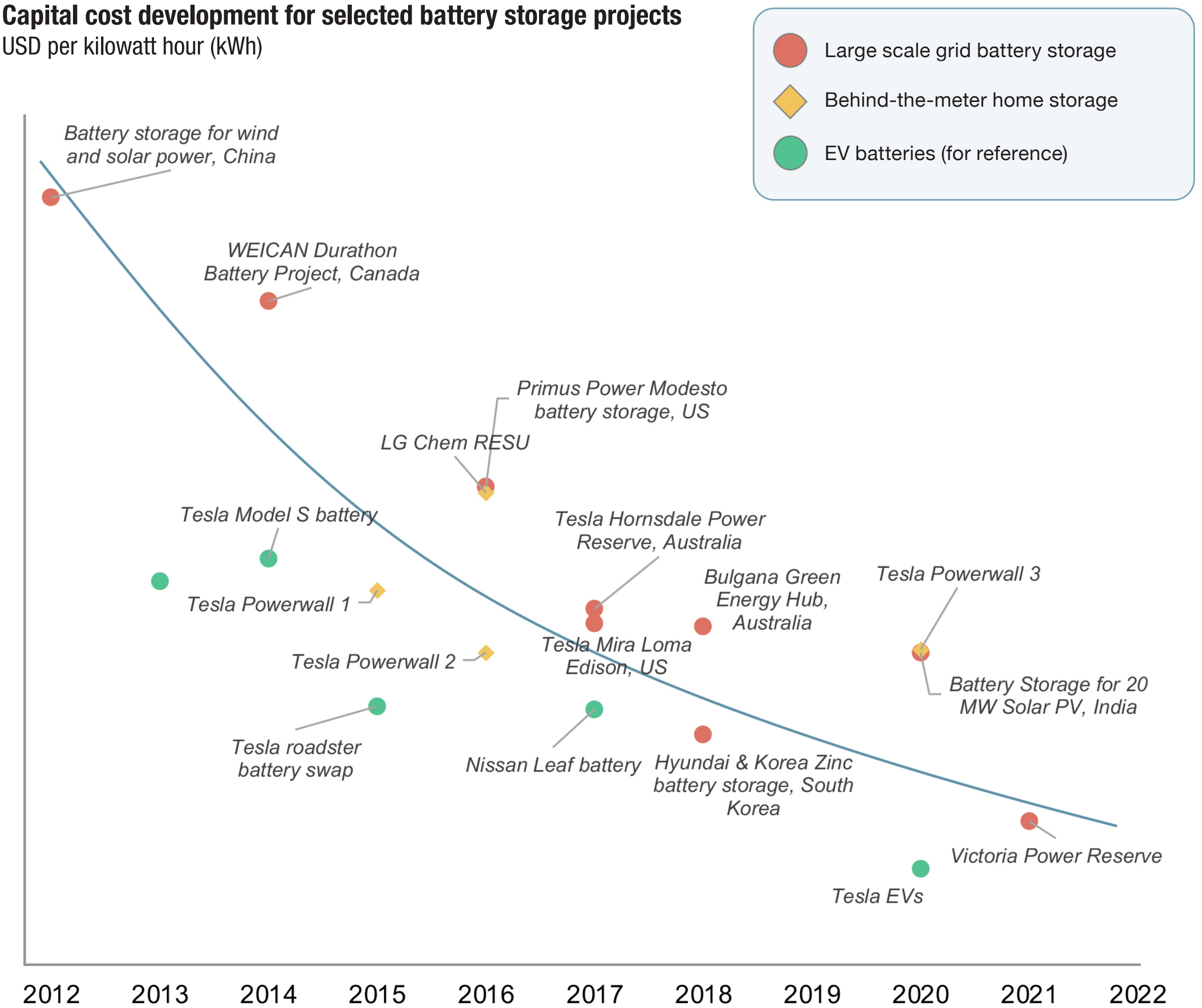
The capital cost of large-scale grid storage projects has plummeted by 80% since 2012

The cost of grid storage has plummeted over the past decade and with each incremental drop in cost comes an incremental increase in the total addressable market for batteries. Batteries entered the power sector as an ancillary service, stabilizing the grid by providing a short burst of electricity, but they have proven to be more than just a back-up. In recent years, grid batteries have begun to disrupt the frequency control markets, eating into the market for peaker plants and, most recently, base load capacity in combination with solar and wind.

If battery costs continue to decline at current rates, they will comprise an increasing share of the power market and can, together with cheap renewables, potentially displace a significant portion of the current fossil fuel baseload generation. This development will also provide cheap batteries for other parts of the energy system, including distributed and behind-the-meter batteries in buildings, while also supporting the rapid electrification of the transportation sector.

An important advantage for this society is that battery manufacturers only need to rely on technological developments within their own sector in order to increase their addressable market and make the Battery Society a reality. The CCS and Hydrogen Societies, on the other hand, are dependent on policy changes and cost developments in other parts of the value chain. In order to succeed, they essentially need batteries to fail.

Capital cost development for selected battery storage projects
USD per kilowatt hour (kWh)



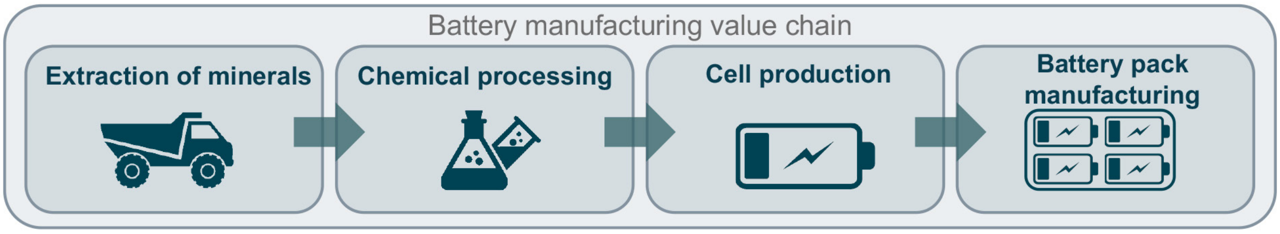
Source: Rystad Energy research and analysis

Breaking down the cost of a battery – still a lot of room for improvement

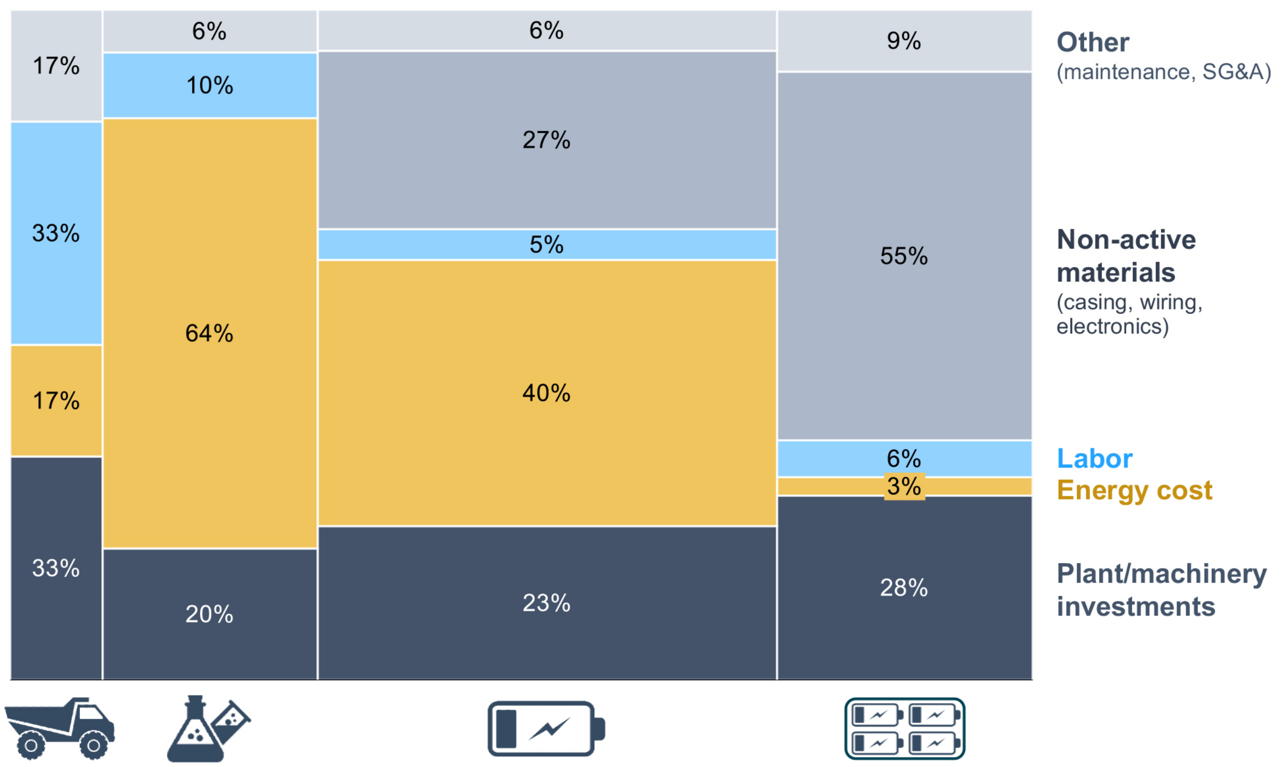
Given the trajectory of battery prices over the past decade, it would be easy to assume that this decline will eventually flatten out. This is further substantiated by the fact that the cost of raw materials represents an increasing share of the total cost for battery cell manufacturers, and currently stands at 50-60% of the cost of goods sold (depending on chemistry and form factor). One might think this leaves limited room to further improve economics. But if we expand the analysis to look at the various cost components of the entire value chain for batteries, we might arrive at a different conclusion.

For example, looking across the entire value chain, we see that 34% of the cost of battery production is tied to energy consumption. And most of this involves electricity used for drying operations in the chemical processing and cell production phases. With new and improved techniques, these costs could be vastly reduced – a potential that will likely soon be realized in cell manufacturing. Additionally, we see a shift towards more vertical integration in the battery industry, with battery producers moving upstream in order to better optimize the mining and processing part of the value chain.

As both battery cell and battery pack designs become more specialized and optimized for their intended applications, there is also the potential to reduce expenses related to non-active materials, to cut labor costs through automated manufacturing processes, and to reduce up-front investments through enhanced production facility design.



Buildup of battery cost, illustration



Source: Rystad Energy research and analysis

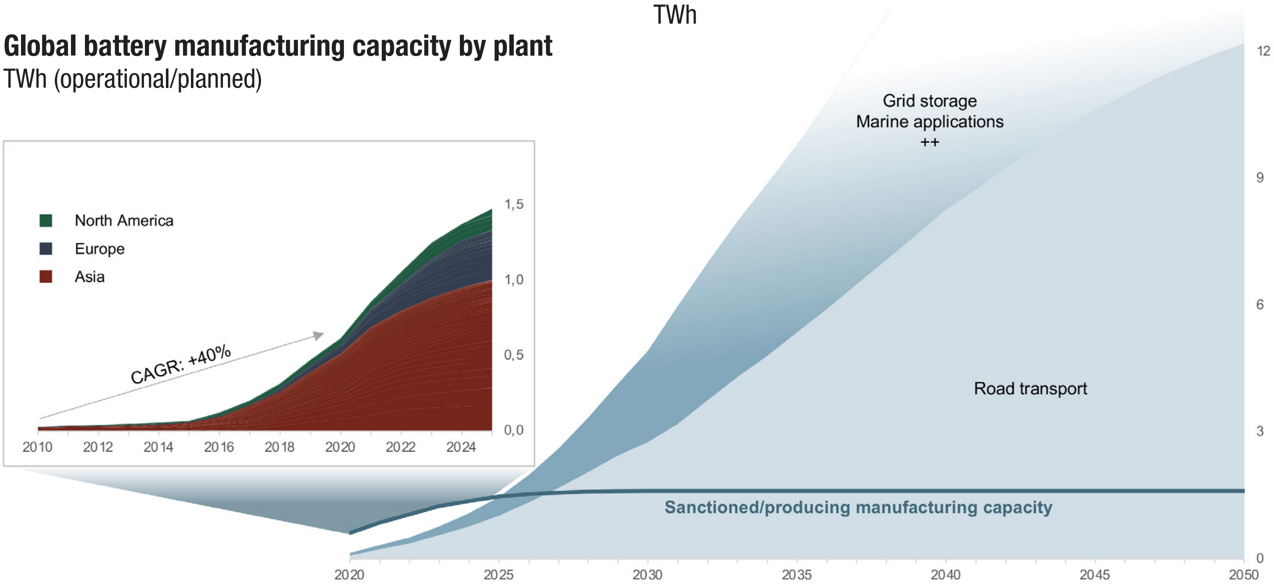
The battery market will surge, driven by growth in EV battery demand

Battery manufacturing capacity has surged in recent years, with an average annual growth rate of 40% over the past decade. This is expected to continue into 2021, beyond which communicated plans are more limited. This has allowed battery supply to keep up with demand, as electric vehicles and grid batteries have begun to enter the market. However, this development is marginal compared to the task ahead.

We expect annual demand growth for batteries to remain above 40% over the next decade to support the rise of EVs and grid batteries, as well as other applications such as residential storage, commercial freight, shipping and aviation.
The repurposing of old EV batteries into grid storage will alleviate this growth spurt, as capacity requirements for grid batteries are much less demanding than for EVs.

Global battery manufacturing capacity by plant
TWh (operational/planned)

Global battery demand
TWh



Source: Rystad Energy research and analysis

EV charging. Photo: Baona

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The Rystad Energy Societies in-depth reports slated for 1Q 2021

Launch schedule

January 2021 report
In-depth view on the CCS Society

February 2021 report
In-depth view on the Hydrogen Society

March 2021 report
In-depth view on the Battery Society

RYSTAD ENERGY

Rystad Energy is an independent energy consulting services and business intelligence data firm offering global databases, strategy advisory and research products for energy companies and suppliers, investors, investment banks, organizations, and governments. Rystad Energy's headquarters are located in Oslo, Norway.

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