



RystadEnergy

Global Energy Scenarios 2023

Tipping points

An accelerated transition is emerging

Executive summary

Energy Transition Analytics
November 2023

The changing global energy system: cleaner and leaner

There are two common beliefs on the future of energy. One is that primary energy will continue to grow at pace with the global economy, and the second is that it will be simply too expensive to replace fossil fuels with renewables. Both beliefs are widespread but behind the times, concluding erroneously that fossil fuels will continue to dominate for decades, and that global warming cannot be limited to 1.5 or even 2.0 degrees.

In this report we will document that these beliefs have no support in recent data on the development of the energy system. On the contrary, our observations shows that new disruptive technologies are already being implemented at a pace that will outcompete fossil fuels sufficiently fast to limit CO₂ emissions to between 650 gigatonnes (Gt) to 1,200 Gt which correspond to 1.6- to 1.9-degree scenarios, respectively, of global warming according to IPCC's carbon budgets. In addition, new technologies for methane emission reduction are coming, representing an upside of up to 0.2 degree of avoided global warming. Thus, the 1.5-degree target is within reach.

Let me first explain why *primary energy* will soon peak at around 630 EJ and then decline. When molecules are combusted to make electricity or motion, only 30-50% of the chemical energy is converted to useful energy. The rest represents heat-losses to the environment. With renewable energy like solar or wind, 70-90% of the primary energy is available for the end user, even including storage and distribution.

Increased use of heat pumps in industry and buildings also enables much more efficient heat generation than traditional electric radiators. Thus, a transition from fossil fuels to renewables means a revolution in energy efficiency. Of the 500 EJ of primary energy from fossil fuels today, only 250 EJ is used by the end user, while about 440 EJ would be made available if the 500 EJ of primary energy came from solar, wind or hydro.

Moreover, energy efficiency improvements in buildings, appliances and machines have been one percent per year over the last decades led by better materials and design. This trend is now accelerating. End users are getting ever more energy services per megajoule consumed. Thus, under the assumption that more than half of the energy mix is renewables, a global population of 10 billion people in 2055 will have access to more energy services per capita than today – even if the primary energy production is down by around 10%.

But can we believe in the assumption that such a large share of primary energy consumption will be renewable? This will not only require current electricity generation of around 29 000 TWh is replaced by renewables, but also that electricity has grown sufficiently to electrify relevant end user segments like buildings, road transportation and industrial heat and machines.

The answer can be found by carefully tracking the pace of the deployment of technologies that can outcompete current fossil fuel-based technologies and mitigate about 38 Gt of CO₂ emissions. In Rystad Energy we have built an organization geared to do just that. We have identified 12 core technologies that could do the job, representing the difference between 2.5-degree global warming and 1.5-degree global warming.

Even if a combination of technologies is needed – suggesting no technology could go at it alone – we can in a simplified manner list the contribution necessary to avoided global warming for each of the 12 technologies.

Solar PV heads the list, contributing 0.25 degrees of avoided global warming. Solar need to grow from 250 GW new installations in 2023 to 1,300 GW per year in the mid-2030s.

This sounds aggressive, however 1,200 GW of named manufacturing capacity is already under construction. After solar, three other technologies are needed, each contributing to 0.12 degrees of avoided global warming. This includes batteries, electric vehicles and chemical absorption CCUS. Wind power, the hydrogen chain and geothermal/heat pumps each have the potential to reduce global warming by 0.08 degrees, while biofuels, high temperature heat storage, circular economy measures and agricultural process changes are collectively poised to deliver the remaining 0.15 degrees of avoided global warming, including reductions to methane emissions. This must all happen by the 2050s if global warming is to be limited to 1.5 degrees.

In this report we will show which pace each of these technologies must track to reach the target, and what pace can actually be observed today. We see no major showstoppers like material shortages, but policy support initiatives such as carbon pricing and subsidies are essential to reach the lower end of the range.

Finally, another feature with a renewable energy system based on electrons, not molecules, is that 15 billion tonnes of logistics related to fossil fuels can be avoided, corresponding to 45% of tonne mileage in shipping. Moreover, electrical machines have five times more horsepower per kg; this effect will also scale to lighter and leaner foundations and buildings. Thus, the future energy system will not only be cleaner, but also leaner

**Jarand
Rystad**
CEO



Primary energy peaks by 2030 in the 1.6 DG scenario, useful energy grows

Primary energy supply is currently about 600 EJ, including all fossil fuels and renewables. Primary energy supply has grown by a factor of four since 1965, driven by strong population growth and economic development.

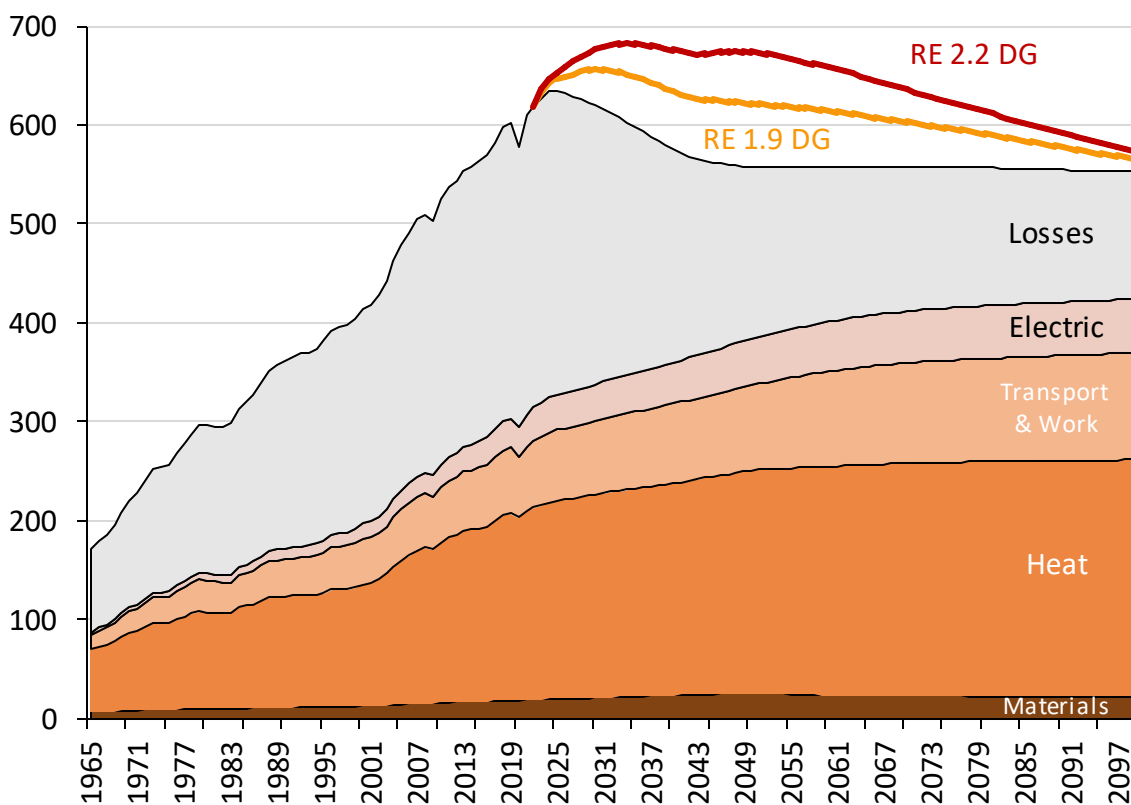
However, primary energy supply is likely to peak soon around 630 EJ and then decline.

Combusting molecules to make electricity or motion only convert 30% to 50% of the chemical energy to useful energy. The rest represent heat losses to the environment.

With renewable energy like solar or wind, 70% to 90% of the primary energy is available for the end user including storage and distribution. For heat generation, the difference is less, but renewables are also more efficient for heat. This means that a transition from fossil fuel to renewables means a revolution in energy efficiency. Of the 500 EJ of primary energy from fossil fuels today, only half is used by the end user. However, if this 500 EJ of primary energy came from solar, wind or hydro, then about 440 EJ would be available to end users.

Primary energy production in 1.6 DG scenario, by energy service

Exajoules (EJ)



Source: Rystad Energy, Energy Scenario Cube

Electrification of road transport will cut losses in half

The ongoing rapid transition towards electric vehicles (EV) in the road transport sector is a critical stride towards curtailing energy wastage. This evolution is primarily characterized by a reduction in the total energy demand per unit of transportation.

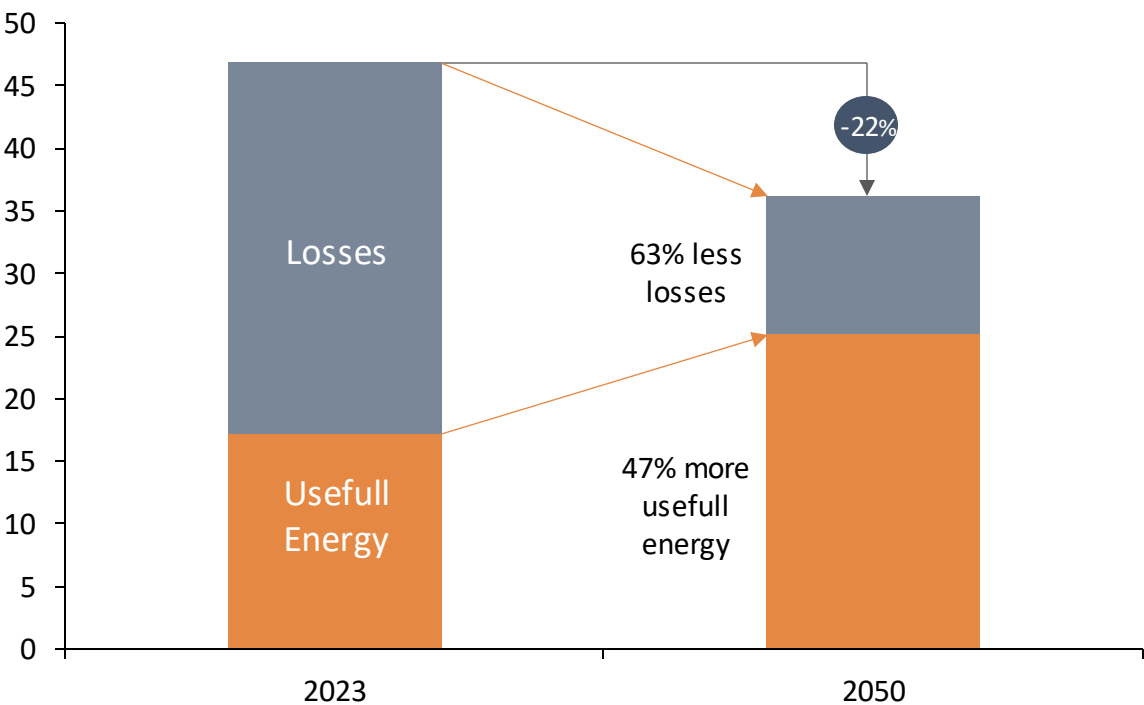
In the absence of such advancements, we would see an inevitable rise in energy requirements in this sector, far higher than otherwise expected.

Electrification brings more energy-efficient vehicles to the forefront. EVs, despite their dependence on raw materials, mark a significant improvement over their internal combustion engine (ICE) counterparts. The efficiency here transcends mere reduction in energy consumption; it's about a smarter and more effective utilization of energy.

A notable benefit of this shift is the substantial decrease in emissions. The lowered lifecycle emissions of EVs, compared to ICE vehicles, play a crucial role in this aspect. Furthermore, the inherent efficiency of EVs in converting energy into motion means they require less energy to cover distances, leading to a decrease in overall fuel usage, and a considerable decrease in emissions. In the transportation sector, the combustion of fossil fuels to produce motion result in severe heat losses. By electrifying cars according to a 1.6-degree scenario, losses in road transportation can be reduced by a staggering 63% by 2050, lowering total energy demand by 22% over the same period. At the same time, the expected increase in useful energy is 47%, indicating a substantial spike in the total mileage.

Road transport energy demand by energy use, RE 1.6 DG

Exajoules (EJ)



Source: Rystad Energy research and analysis, Energy Scenario Cube

Historical energy efficiency improvements align with 1.6 DG

Energy efficiency improvements are essential to reach the low-degree scenarios. Historically, we have seen impressive improvements to technology, combined with heavy reductions in losses due to electrification.

The industrial sector has historically been dominated by the use of fossil fuels due to the need for high temperatures in, for example, calcination and melting processes. Lately, however, other alternatives have become more relevant, and electricity and hydrogen have become viable options. In cement production there has been a vast improvement in energy efficiency of more than 50% since 1990. The efficiency improvement is largely due to switching the kilns to more effective technologies, along with the pre-heating and drying of the cement prior to the calcination process.

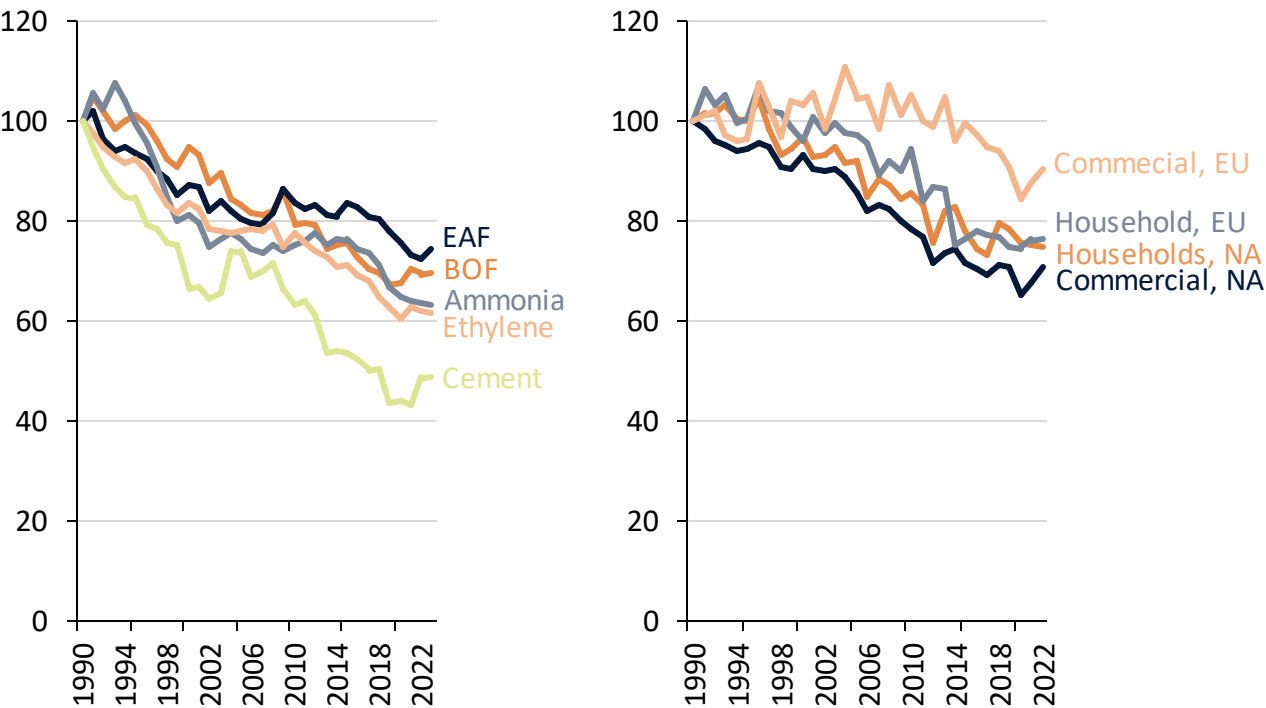
Similarly, several other industrial processes have seen a major energy efficiency improvement.

Ethylene, ammonia, and iron & steel have seen improvements of between 20-40% over the last 30 years.

Also, impressive improvements have been made to the energy efficiency of in the building sector. Fueled by improvements to technology, electrification, and insulation efforts, the energy intensity in the North American commercial & public building sector has improved by ~35% since 1990. Households in the US and Europe have seen similar improvements, although commercial buildings in the European Union have been lagging.

Continued energy efficiency improvements are needed to reach a 1.6-degree scenario, but with critical regulatory efforts for energy efficiency improvements in buildings, such as the revised Energy Performance of Buildings Directive in the EU and the Inflation Reduction Act in the US, a 1.6-degree scenario is within reach.

Energy intensity improvements, by industry sector and buildings type
Index (1990=100)



Source: Rystad Energy, Energy Scenario Cube

45% of global tonne-mileage to be avoided as fossil fuels decline

Tonne miles go down with the uptake of cleantech – less mass needed to sustain the system – while there is a high focus on critical raw material demand increase, the quantity of raw materials will be significantly smaller compared to what has been the status quo in the fossil fuel era. Also, as cleantech disrupts oil and gas demand, transport of oil and gas will also go down. Fuel oil demand will decline, with the downtrend of fuel transportation. Moreover, the shift towards renewable energy sources such as wind, solar and hydroelectric power entails a fundamental change in the nature and structure of the energy supply chain.

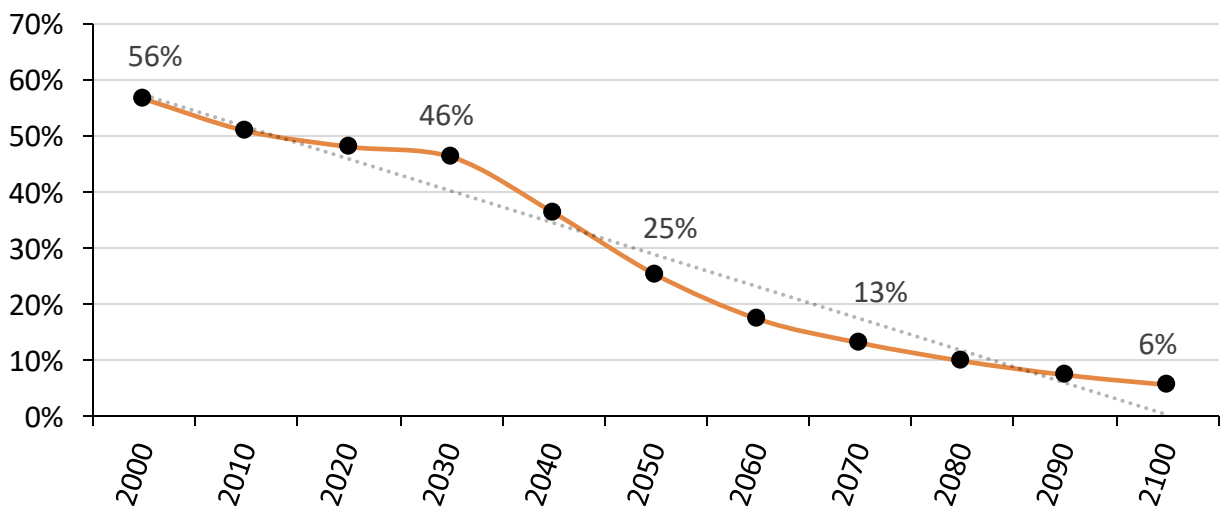
These energy sources are more decentralized and often require a one-time transportation of equipment such as wind turbines or solar panels, as opposed to the continuous shipment of fossil fuels. This change implies a reduction in the frequency and volume of shipments, leading to a leaner logistics demand. The adoption of EVs and the gradual phasing out of internal combustion engine vehicles will further impact global logistics. The manufacturing and distribution of EVs involve different supply chain dynamics compared to traditional vehicles. The reduced need for

components such as engines and transmissions, which are heavy and often transported over long distances, will decrease the logistics footprint. Additionally, the distribution of electricity, as opposed to liquid fuels, simplifies the supply chain, since electricity is predominantly transmitted through power grids rather than requiring physical transportation.

However, the demand for critical raw materials such as lithium, cobalt and rare earth elements for batteries and other clean technologies will surge. This will require the establishment of new supply chains, potentially leading to an initial increase in logistics demand, particularly in regions where these materials are mined and processed.

The overall lifetime logistics requirement for these materials is, however, lower compared to the continuous extraction and transportation needs of fossil fuels. Also, innovation in logistics and supply chain management to support the cleantech sector are likely. The use of digital technologies such as blockchain for traceability, AI for optimizing routes and loads, and electrification of transport fleets can both reduce the environmental impact of logistics and enhance efficiency.

Global tonne-mileage from primary extracted fossil material, 1.6 degree scenario
Share of global tonna-miles



Note: Primary extracted fossil material includes crude, coal, gas as well as petroleum products
Source: Rystad Energy research and analysis

Global emissions to peak this decade

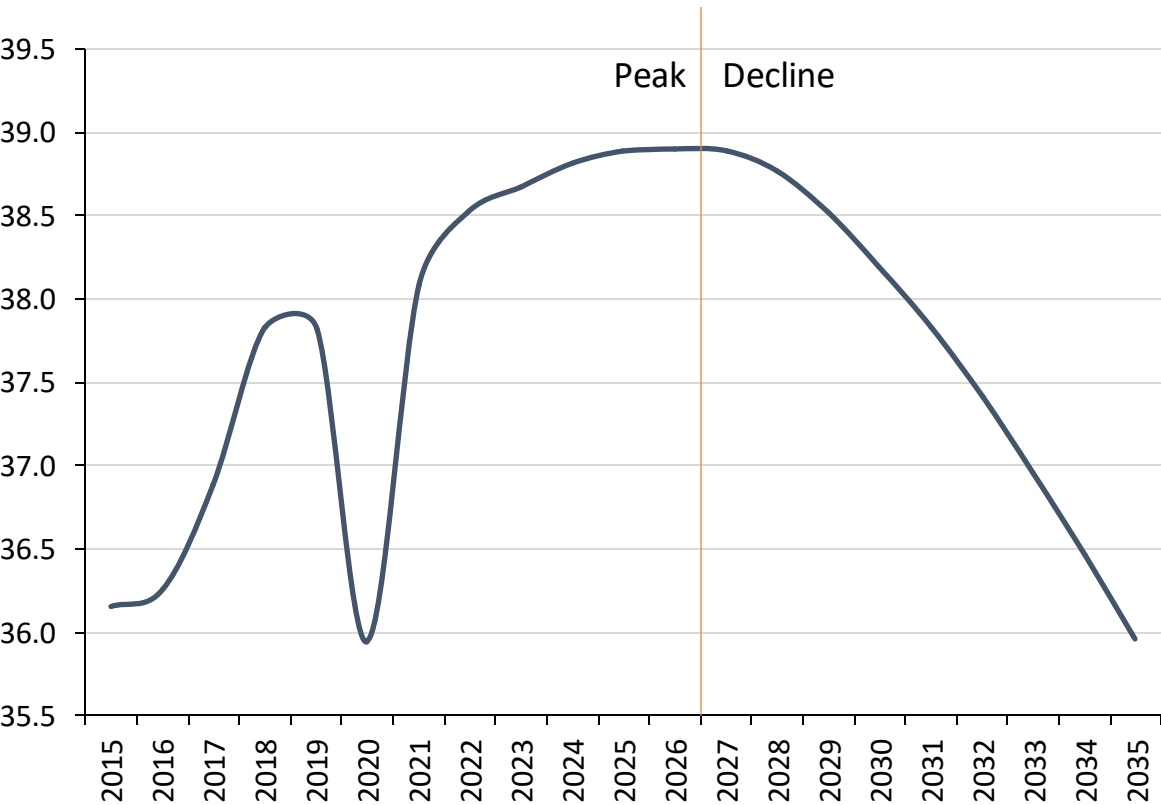
A peak in global CO₂ emissions around 2027 is a significant marker in the ongoing energy transition. This trend reflects the growing impact of renewable energy sources and transition to cleaner fuels across all sectors. Historically, emissions reductions in the power sector has been the strongest contributor to declining total emissions in the United States and in the European Union. This has been largely incentivized by competitive natural gas prices, which motivated coal-to-gas switching, and declining costs of renewable energy, like wind and solar PV.

For global emissions to peak we need to see a transformative change in Chinese emissions, which contributed to about 70% of the net increase in

global CO₂ emissions since the year 2000. We are now witnessing substantial growth in solar and wind in China, contributing to lower the carbon footprint of the Chinese power sector. We should also expect China to reduce production of cement and steel in the coming decades, as the economy transitions to more service-based sectors and the population growth peaks.

We expect emissions in India and other developing countries to continue growing as these countries experience economic growth. However, by 2027 we see stronger forces pushing for lower emissions, tilting the needle in favour of net emission reduction.

Global CO₂ emissions from fossil fuels – current pathway
Gigatonnes (Gt)



Source: Rystad Energy research and analysis

Low-carbon energy investments to surpass oil and gas by 2025

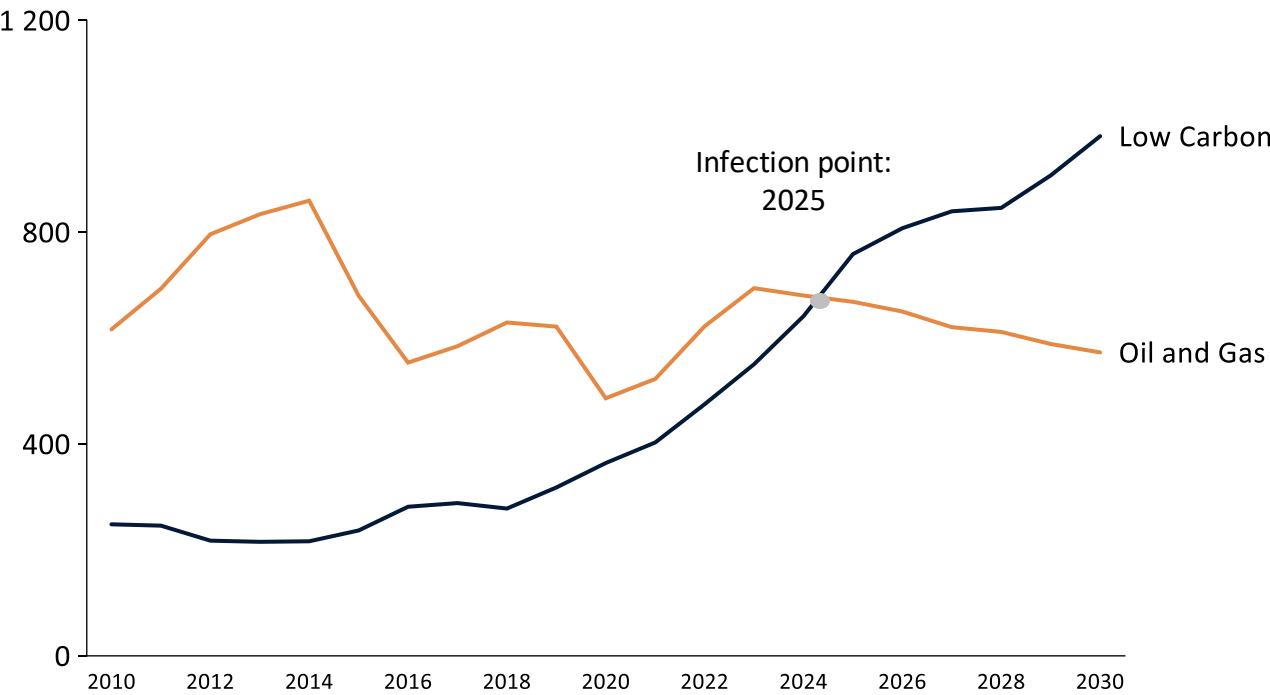
The energy investment horizon is tilting toward renewables and cleantech. Sanctioning activity in the fossil fuel domain, once dominant, is now part of a broader narrative that includes substantial strides toward clean energy alternatives.

By 2025, investments in low-carbon energy solutions such as solar and wind are predicted to eclipse those in oil and gas, marking a pivotal shift. This transition is not limited to established sectors; geothermal and CCUS technologies are gaining traction and are expected to contribute to this investment surge.

Suppliers are responding to this change, strategically expanding their portfolios to incorporate renewable technologies. This expansion is strategic, allowing suppliers to maintain their footing in the fossil fuel sector, while embracing the burgeoning demand for renewable solutions.

In essence, the energy sector is recalibrating, balancing the act of fuelling today's needs with the imperative of fostering a sustainable tomorrow.

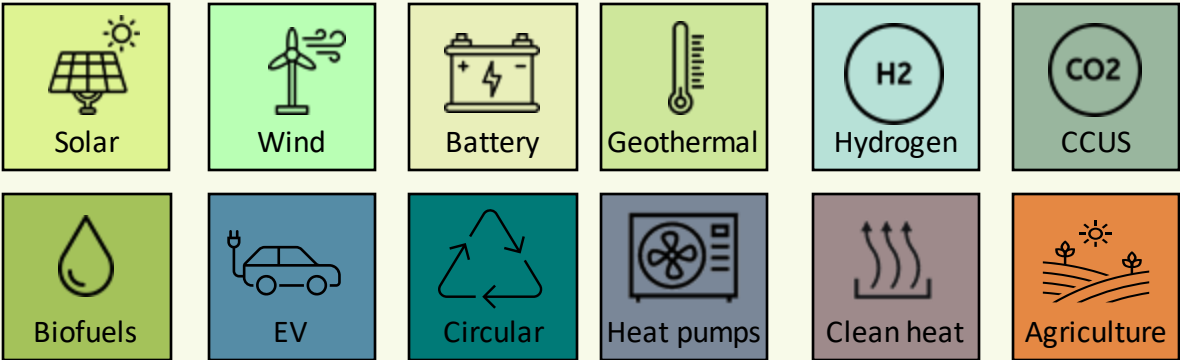
Energy investments – oil and gas vs low carbon
Billion USD (Nominal)



Note: low-carbon includes solar, wind, CCUS, hydrogen, geothermal, nuclear and hydropower. Oil and gas encompasses upstream, midstream and downstream
Source: Rystad Energy ServiceCube

Toolbox ready for net-zero emissions

12 technologies and mitigation strategies for net-zero emissions



Rystad Energy has identified 12 core technologies and mitigation strategies with a potential to shift the emissions trajectory to 1.5 degrees of global warming.

Solar power has the highest potential to achieve emissions reduction as it can deliver at scale and at low costs.

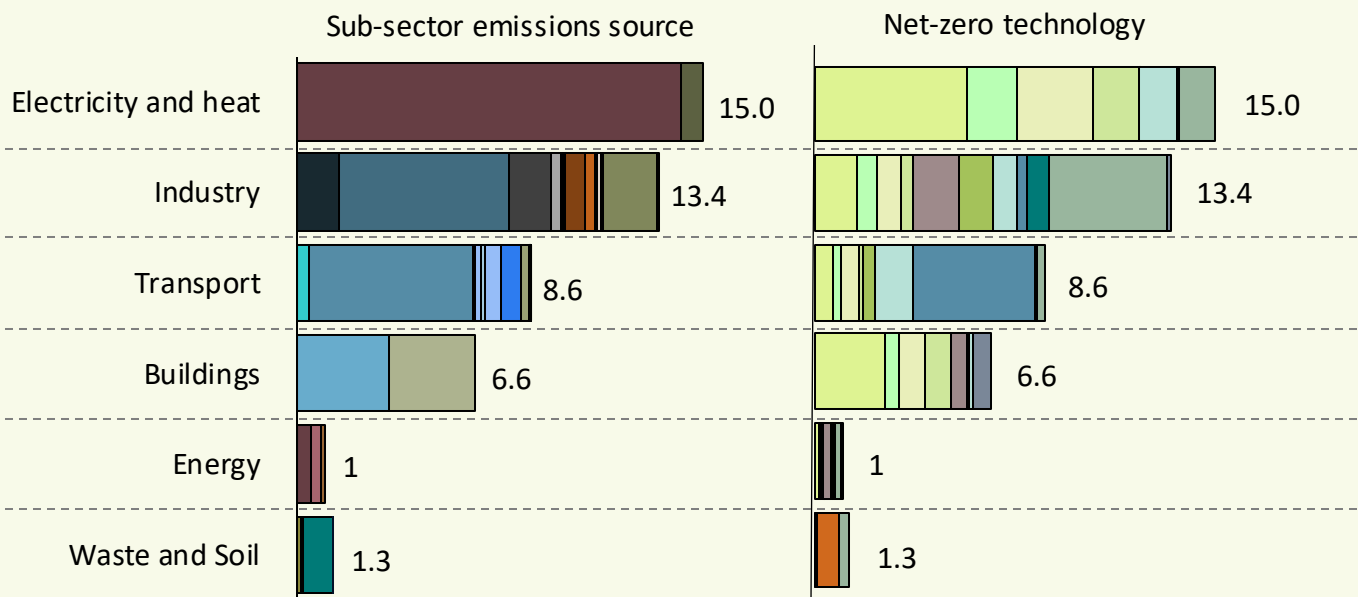
Wind is a good supplement to solar in many regions and together with batteries, geothermal

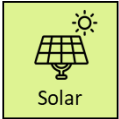
and heat pumps it can deliver on a cost-efficient decarbonization pathway for the power sector.

Electric vehicles and hydrogen will be needed in the transportation sector, and clean heat and circular economy measures will be crucial to decarbonize the industrial sector.

Finally, agriculture management can help lower emissions from the food production.

Global 2023 fossil and biogenic CO₂ emissions (Gt CO₂)





Solar manufacturing capacity spikes since 2022, ahead of 1.6 DG

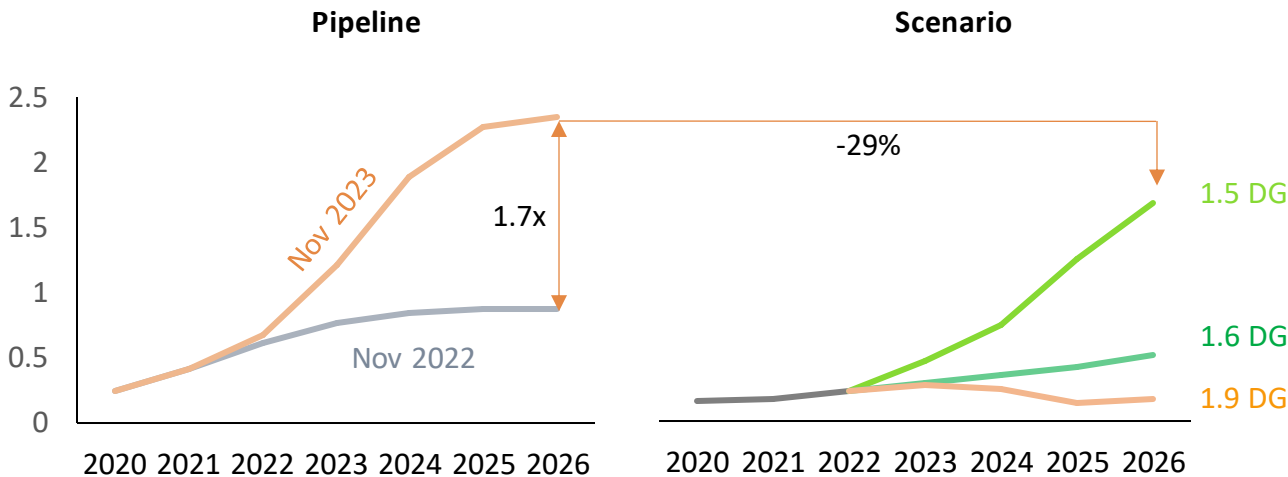
The current landscape of solar energy, hailed the cheapest form of energy in history, is a testament to the remarkable strides made in cost reduction and efficiency. With manufacturing capacity surging 1.7x year on year, now standing at over 1,200 gigawatt, the sector is already 29% ahead of the tall order set under the 1.5 degrees Celsius scenario.

This growth is characterized by an exponential increase in production capacity, with the cost per unit continuing to decrease as capacity doubles – a pattern that not only underscores

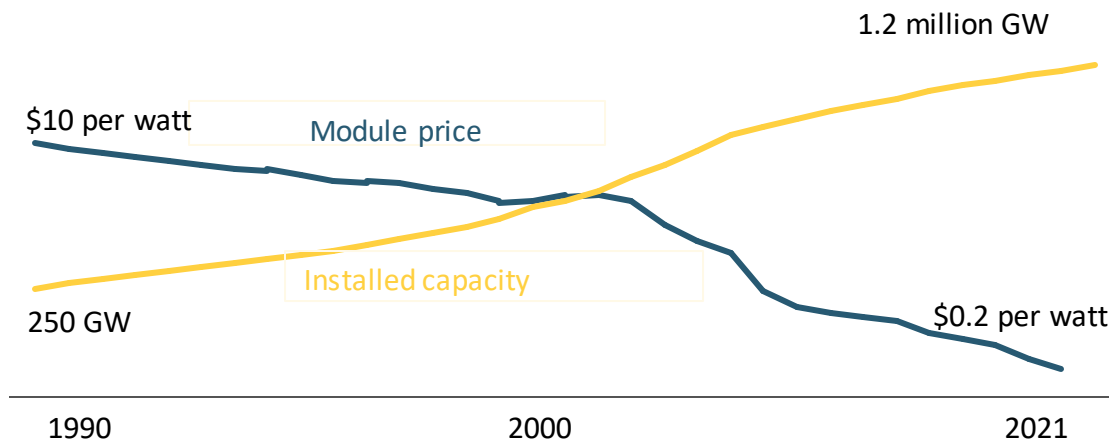
the scalability of solar energy solutions but also its increasing affordability and role in global energy transition.

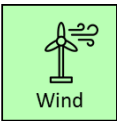
And as solar capacity growth supports the technology becoming cheaper, projects increase in size, and costs continue to plummet. This is exemplified by notable projects like Al Dahfra, a 2 GW development, offering energy at a groundbreaking \$13 per MWh, and the Mohammed bin Rashid Al Maktoum Solar Park, pricing its 1.8 GW (6th phase) development at \$16 per MWh.

Active and announced cell manufacturing capacity demand Terawatts (TWdc)



Solar PV learning rate – price goes down with capacity growth





Wind facing towards 1.6 despite navigating inflation

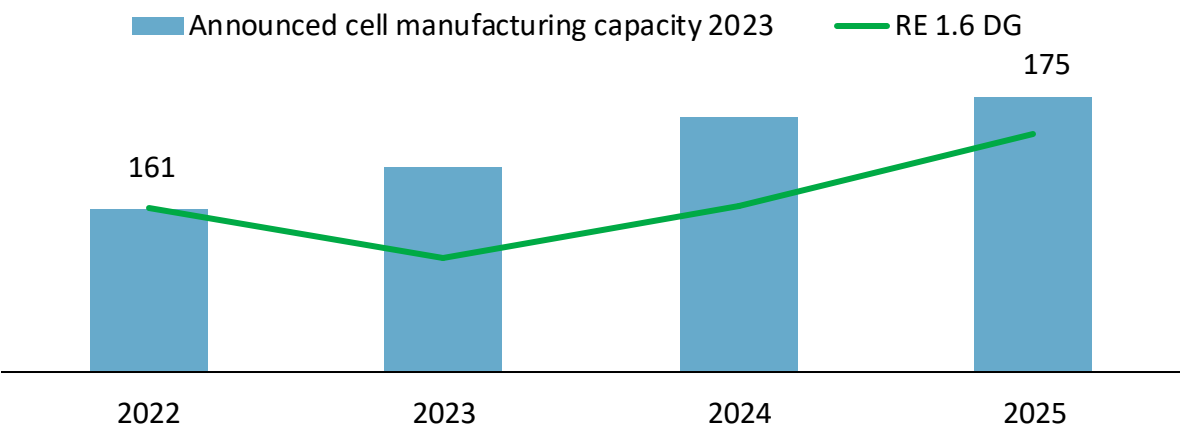
Wind energy, while not experiencing cost reductions as rapidly as solar, is nonetheless on its way to becoming increasingly cost-effective. This trend is propelled by an aggressive learning rate and economies of scale as projects grow in size and number.

However, the sector has recently encountered challenges due to heavy price inflation, impacting development costs and timelines. Failure rates and quality concerns are emerging

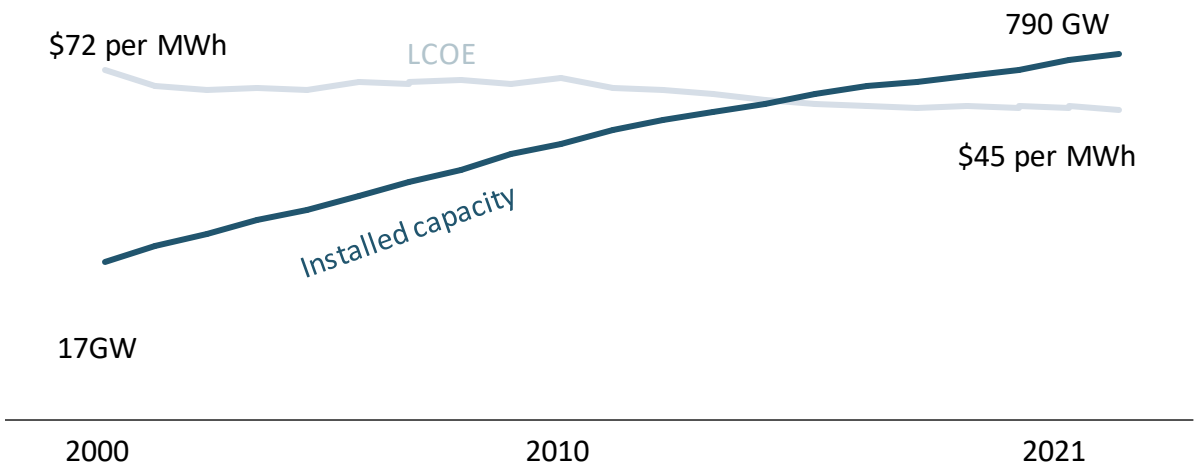
as key factors questioning the financial wellbeing of projects as unexpected repair costs (related to faulty components) could overshadow the margin recovery recently witnessed by many Western OEMs.

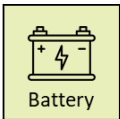
Partly, this recovery is due to the adoption of longer blades and larger turbines, bringing additional technical and operational requirements for OEMs.

Wind energy demand vs turbine manufacturing capacity
Gigawatts (GW)



Levelized cost of onshore wind vs. installed onshore wind capacity





As costs plunge, battery supply is set to surpass demand

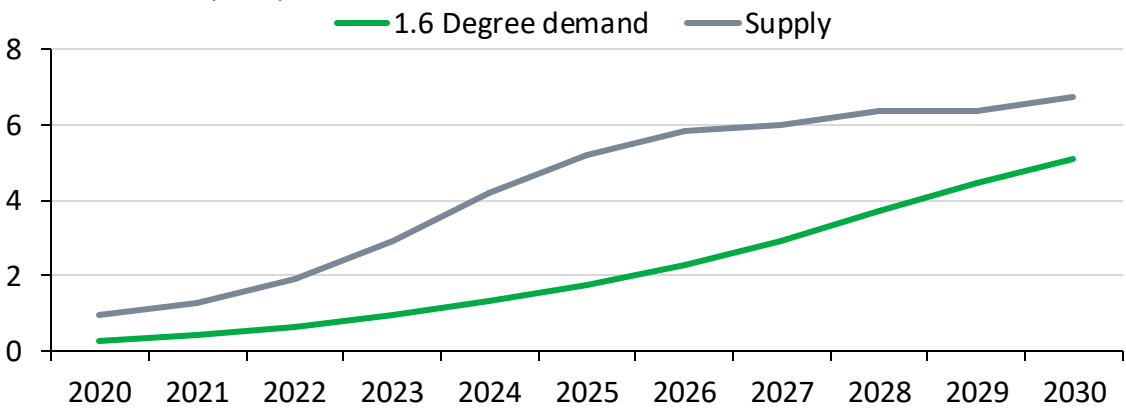
The plummeting costs of batteries are reshaping renewable energy and electric vehicle (EV) markets, positioning them as a linchpin in the decarbonization effort. As a crucial element in managing intermittent renewable energy systems, batteries are increasingly becoming indispensable.

Their role in stabilizing power grids and enabling the widespread adoption of EVs underscores their significance in the journey toward a low-carbon future. Remarkably, the supply pipeline for batteries is advancing faster than demand, a testament to the rapid scale-up of cell manufacturing. This acceleration is buoyed by historical cost declines, driven by impressive

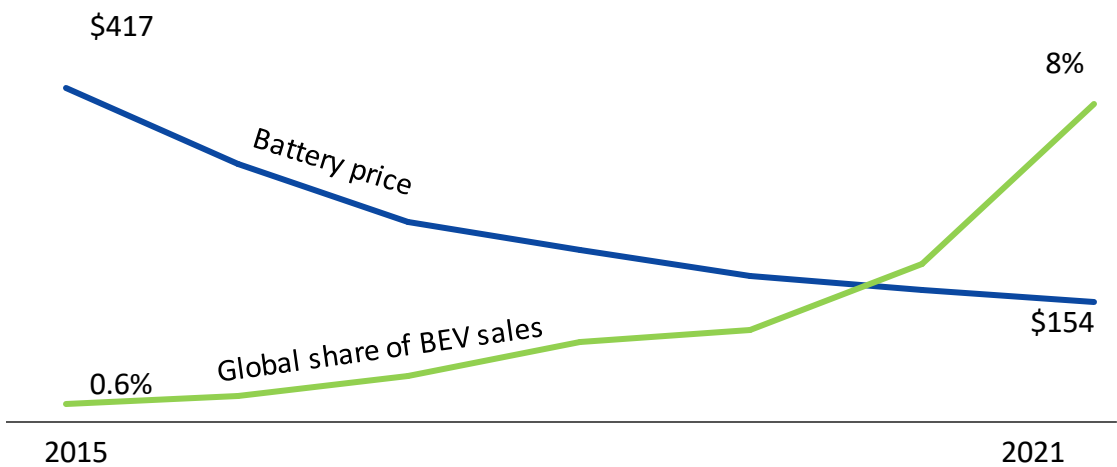
learning rates. As the uptake of EV escalates, the demand for batteries has surged, contributing to a consistent yearly drop in prices. This synergy between rising demand and falling costs highlights batteries' crucial role in the energy transition, making them a vital piece of the decarbonization puzzle.

Their expanding production and affordability are key factors propelling the shift to a more sustainable and electrified future. However, regional disparity of cell supply with high concentration in a few countries calls into question the true ability of production to cater demand.

Battery demand v cell supply capacity
Terawatt-hour (TWh)



Battery price v global share of battery electric vehicles





Electric vehicle sales to overtake internal combustion within four years

The burgeoning rise of electric vehicles (EVs), expected to account for 22% of all global vehicle sales in 2023, signals a profound shift in the automotive landscape. This surge reflects both rapid technological advancement as well as a broader societal and economic pivot towards electrified transportation.

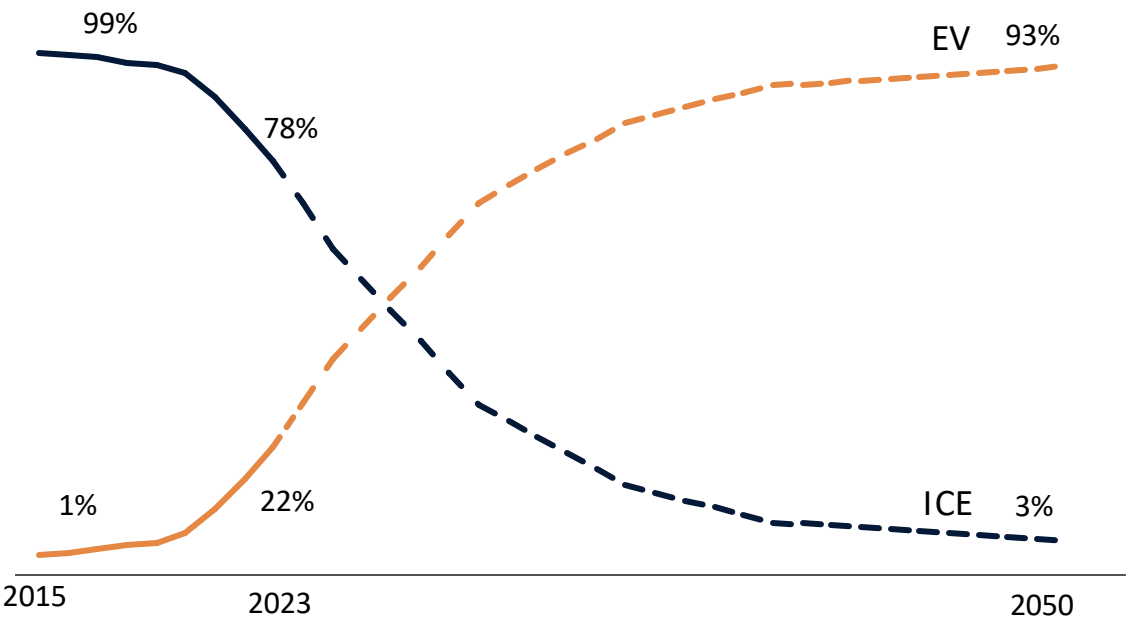
The increasing preference for EVs over traditional internal combustion engine (ICE) vehicles is a clear manifestation of the world's commitment to mitigating climate change and embracing cleaner energy solutions, and a testament to the growing market competitiveness of EVs.

This transition has passed the tipping point and is set for a structural shift.

In the context of our 1.6-degree scenario, the trajectory of EV sales is not linear but exponential. By 2025, EVs are projected to hit a crucial inflection point, surpassing the market size of their ICE counterparts. And as EVs take the lead, they bring with them the promise of a cleaner and more efficient global transport fleet and setting a new course for the automotive industry.

This shift to EVs will also bring with it significant energy savings as losses decrease due to energy efficiency enhancements from electrification. It is key to reducing global carbon emissions and signals a decisive move away from fossil-fuel dependency in transportation.

Global vehicle sales, 1.6 degree scenario
Percentage of all vehicles sold



Announced hydrogen projects 19% shy of 1.6 DG by 2030

In a 1.6-degree scenario, the amount of hydrogen in the energy mix needs to reach 17 EJ, up from 12 EJ today. As the amount of grey hydrogen is expected to decline, the introduction of blue and green hydrogen must grow rapidly to close the gap. If we consider only the announced projects, the added capacity for net-zero emission hydrogen is going to be 5 EJ by 2030. By adding the new capacity on top of the projected grey hydrogen capacity, we reach a total hydrogen production capacity of 14 EJ. This represents a disparity of ~19% compared to what is required in a 1.6-degree scenario. Thus, indicating that the required hydrogen capacity can be met by the end of the decade.

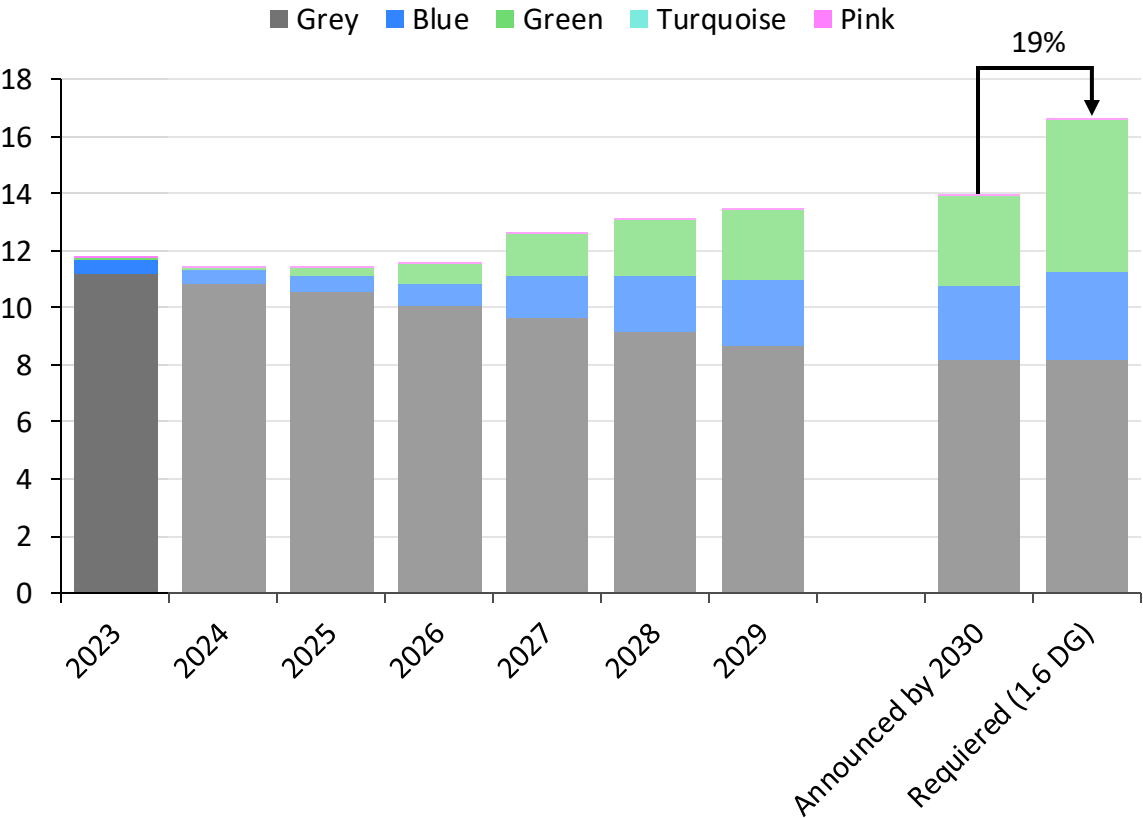
In 2023, new projects contributing to a production capacity of over 6 million tonnes of clean hydrogen

have been announced. If we see the same frequency of announcements going towards 2030, the gap between 1.6-degree scenario and the announced capacity will decrease from 31.6 Mt of hydrogen to 7.5 Mt.

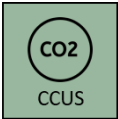
However, if the pace of announcements picks up amid a supportive regulatory frameworks, such as the European Green Deal and the US Inflation Reduction Act, it could help close the gap between the actual outlook and the required demand in a 1.6-degree scenario.

On the contrary, there is downside risks since 80% of the projects are currently on the concept stage. There are also risks to future project announcements, delays or cancellations, which can make it challenging to meet what is needed to reach our 1.6 DG scenario.

Hydrogen production pipeline vs demand
Exajoule (EJ)



Source: Rystad Energy, Energy Scenario Cube, Hydrogen Solution



CCUS pipeline ready for 1.6 DG

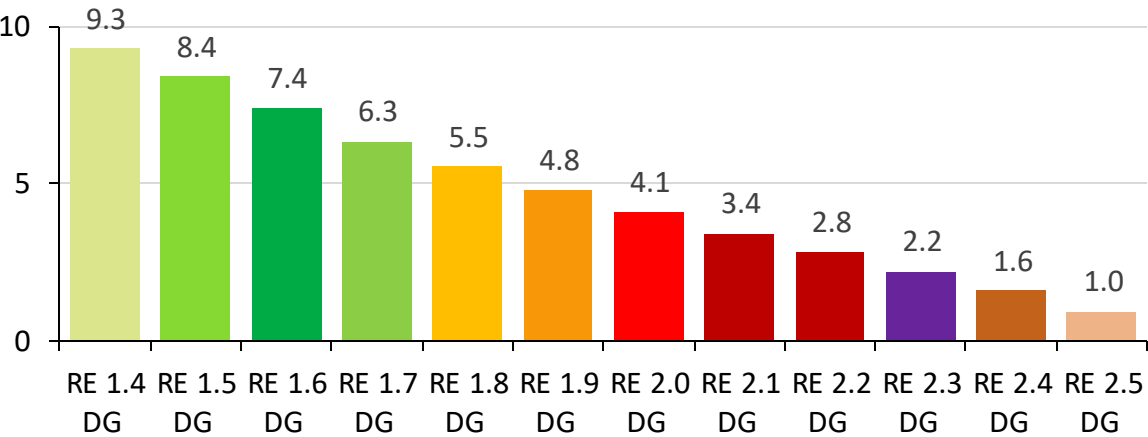
The carbon capture, utilization and storage (CCUS) project pipeline has seen unprecedented growth over the past few years as governments have stepped up climate action and announced more incentives to reduce emissions.

We estimate the current CCUS pipeline unrisked will be able to deliver 600 million tonnes of capture capacity by 2030, which is aligned with the required to achieve the 1.6 DG scenario. However, based on experience, some projects will experience delays or cancellation due to multiple reasons. Solving

permitting bottlenecks and financing will be crucial to make sure that these projects are able to deliver as planned. To achieve the climate reduction targets of the Paris Agreement, CCUS capture capacity needs to reach at least 4.1 Gt by 2050. This includes CCUS used by industry, particularly cement, iron and steel, and the chemical industry, as well as to decarbonize base power, and other parts of the energy sector. In addition, it also includes direct air capture (DACC), which will be needed to achieve the most ambitious climate scenarios.

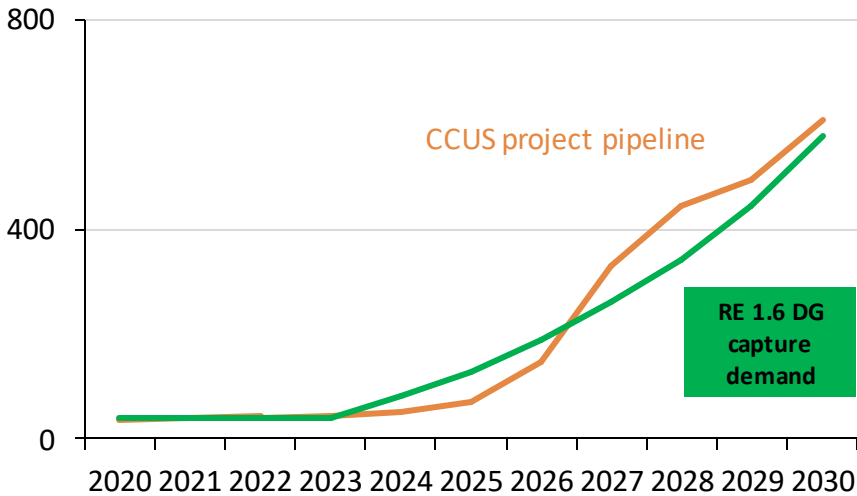
CCUS capturing capacity in 2050, by scenario

Gigatonnes of CO2 captured (Gt)



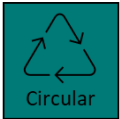
CCUS project pipeline compared to the 1.6 DG scenario

Million tonnes of CO2 captured (Mt)



600
million tonnes
of CO2 capture
pipeline
on track to reach
1.6 DG

Source: Rystad Energy, Energy Scenario Cube, CCUS Solutions



Growing recycling rates lower emissions, energy use, and costs

Circular economy must be a part of a cost-efficient decarbonization strategy. Across all materials, recycled products have substantially lower energy intensity and carbon footprint.

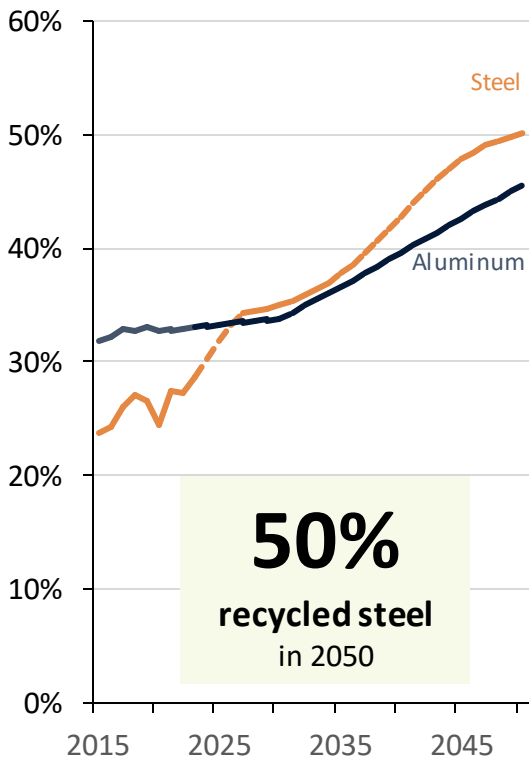
Primary steel today is produced using large amounts of coal creating 2.3 tonnes of CO₂ emissions for every tonne of steel that is being produced. However, recycled steel can be produced by emitting 680 kg CO₂ per tonnes. This implies that a 70% emissions reduction is possible if recycled steel is available for the steel producer.

Recycled materials are growing as materials reach their end of life, product design improves, and more

governments are putting in place the right incentives for reducing waste and recycle materials. According to our forecast, the share of secondary steel production is expected to reach 50% of total steel production in 2050, almost double what it is today. This will bring substantially lower energy intensity and emissions in the iron and steel sector and one of the most cost-effective mitigation measures for the industry.

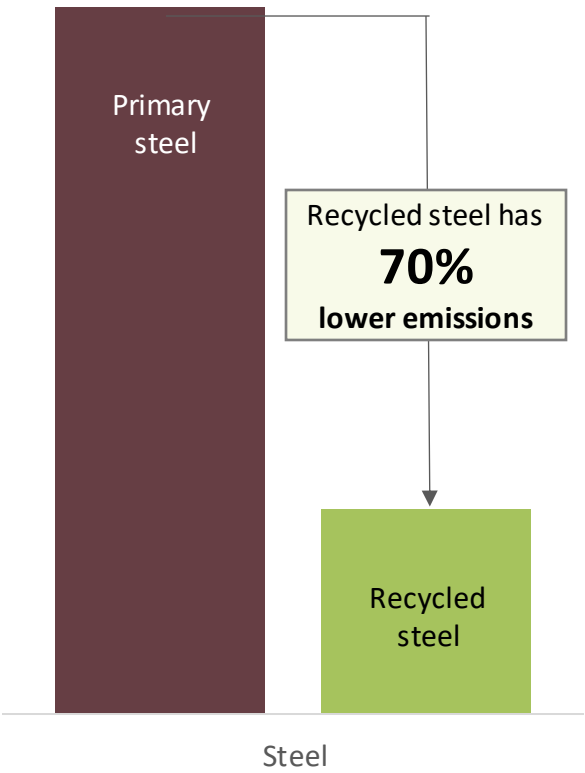
Aluminum also has substantial emissions reduction potential from recycling, in the 80-90% reduction range. According to our estimates the share of secondary aluminum is likely to reach 46% in 2050.

Recycled steel share of total steel production
Share (%)



Source: Rystad Energy, Energy Scenario Cube

Emission intensity for steel by type
tCO₂ per tonne of steel



Industry is the largest global energy consumer

The industrial sector is the single largest energy consuming sector, making up 39% of total final energy demand or 173 EJ. Over the past 20 years, final energy consumption in the industrial sector has grown by more than 50%, outpacing both the transportation and buildings sector.

The industrial sector consists of a heterogeneous group of industries, from metal production, to fertilizer, textiles, and mining. However, all sub-sectors have in common the fact that energy is used for either heat, work, electric services, or in materials. We call this the *energy service* provided by final energy demand. Across all industries, heat makes up 54% of final energy demand, as many industries, such as iron and steel, and the cement industry, require high heat to process raw materials into more useful products. Of the other energy services used in the industrial sector, work makes up 9%, materials 7% and electric services 2%. Losses are responsible for 28% of final energy

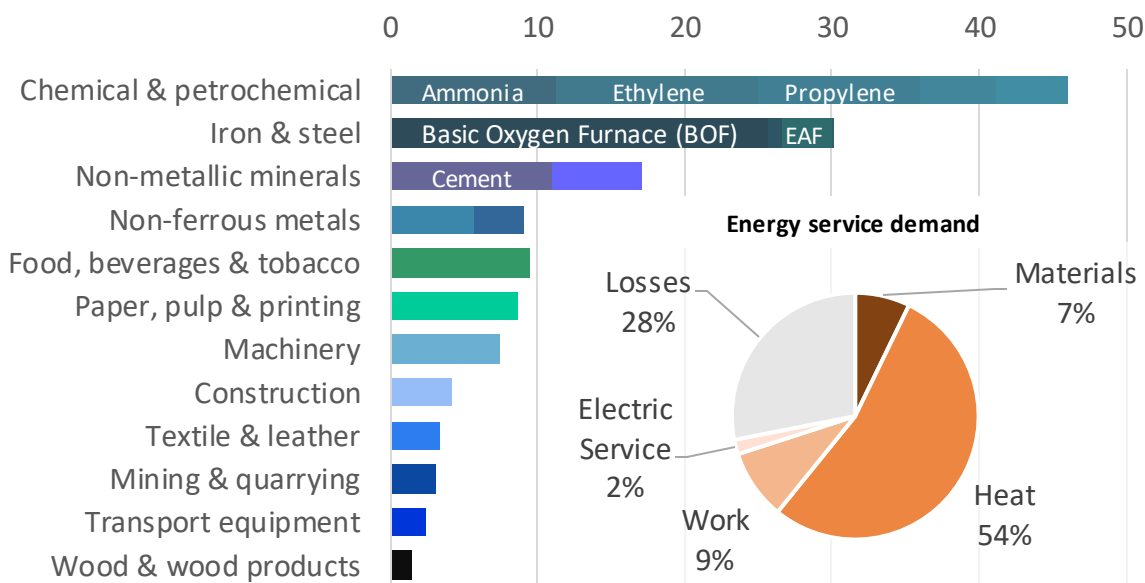
demand, which speaks to the potential for energy efficiency improvements in all scenarios.

The largest industrial sector is the chemical & petrochemical sector with 46 EJ, of which 53% is used for feedstock in products such as plastics and fertilizer.

Iron and steel is the second largest, due to its high consumption of steel globally and the high heat needed to turn iron ore into finished steel products. For 2023, we estimate that the global steel industry will consume 29 EJ, which is close to India's current final energy demand.

Of the non-metallic industries, cement is by far the largest, with annual final energy demand of 11 EJ. Final energy demand in the cement sector is expected to increase to 18 EJ by 2050 in our 1.6 DG scenario, due to the significant energy needed to capture CO2 from the cement production process.

Final energy demand industry by sub-sector, 2023
Exajoules (EJ)



Source: Rystad Energy, Energy Scenario Cube

Hard-to-abate industries reduce 6.3 Gt of emissions to achieve 1.6 DG

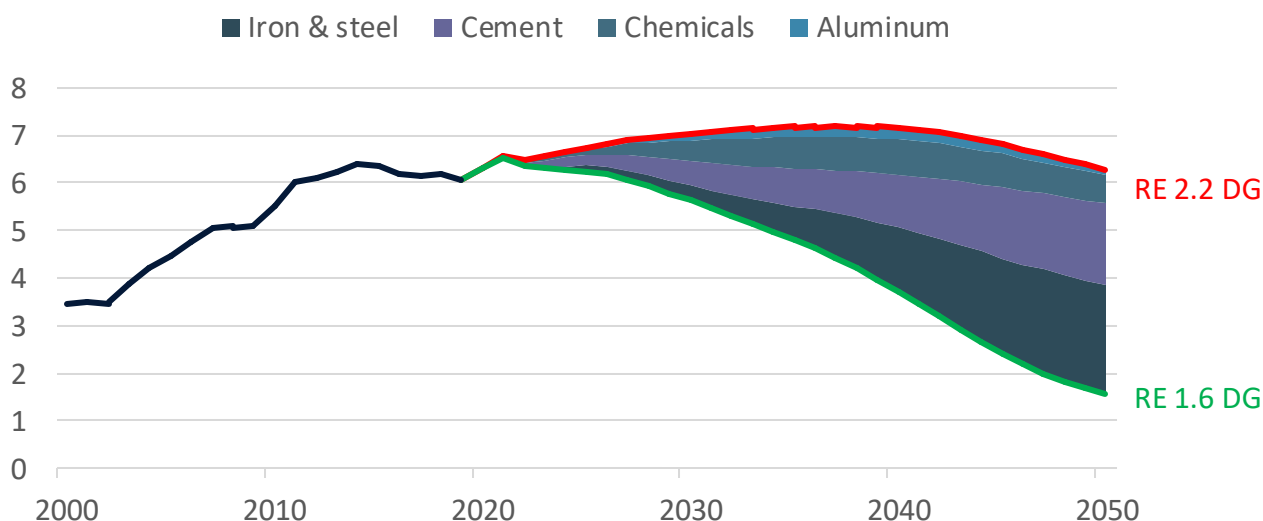
The industrial sector is emitting close to 10 Gt of direct CO₂ every year, about 60% of which comes from iron & steel, chemicals, cement and aluminum – often referred to as hard-to-abate industries. Addressing emissions in these four sectors will be critical in reaching targets set out in the Paris Agreement.

According to Rystad Energy's modelling of the global energy system, there is a 75 Gt cumulative emissions gap between 1.6 DG and 2.2 DG for hard-to-abate industries. About 50% of the emission gap can be closed by addressing emissions in the global iron & steel industry. This will require a transformative shift away from unabated blast furnaces to steel produced using carbon capture, utilization and storage (CCUS), hydrogen, or a directly electrified steel-making process, which is currently being developed. A cost-efficient decarbonization pathway for steel depends on the higher use of recycled steel in the steel-making process. In our 1.6 DG scenario, we estimate that more than half of all steel in 2050 will be produced using scrap.

More than one third of the emission gap is in the cement sector, which depends on successful deployment of CCUS to address CO₂ emissions from the calcination process. In the 1.6 DG scenario, CCUS capacity reaches 1.1 Gt CO₂ by 2050, which implies that 70% of global cement process emissions are captured by mid-century. This will require significant amounts of electricity, as capturing carbon is energy intensive. The cement sector also needs to find alternatives to fossil fuels in creating the high heat needed for the cement-making process. Biomass and alternative fuels will play an important role here, depending on local availability.

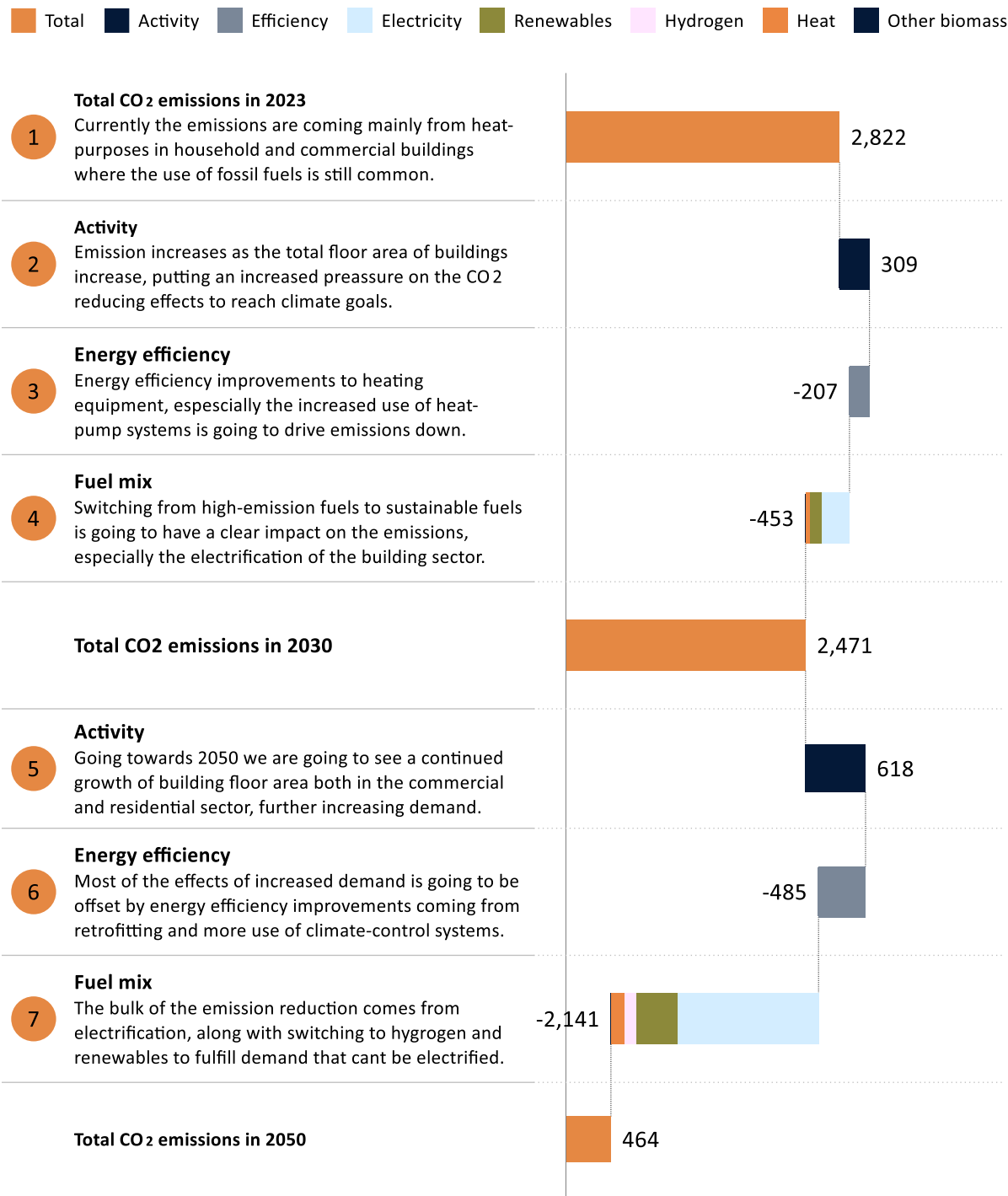
The final 15% of the emissions gap will be addressed in the chemical & petrochemical sectors, as well as the aluminum industry. In the latter, most emissions are indirect and relate to the source of electricity. In the chemical industry, enhanced energy efficiency, green hydrogen, higher electrification and deployment of CCUS will be needed to reduce emissions to fit the 1.6 DG carbon budget.

Hard-to-abate industries direct CO₂ emissions reduction between 1.6 DG and 2.2 DG Gigan tonnes (Gt)



Source: Rystad Energy, Energy Scenario Cube

CO₂ emission pathway to 1.6-degrees in the building sector



Source: Rystad Energy research and analysis, Energy Scenario Cube

US to contribute the most to global transport decarbonization in 1.6 DG

Emission reductions in the transportation sector are heavily reliant on the US achieving a climate-neutral transportation sector by 2057. If the world is to reach the 1.6 DG scenario, the US alone will need to reduce CO₂ emissions by a staggering 1.8 Gt by 2050 compared to today. To achieve this, fossil fuel-related emissions from cars in the US will need to be limited to just 0.02 Gt, compared to 0.81 Gt today, representing a 97.6% reduction in CO₂-related emissions.

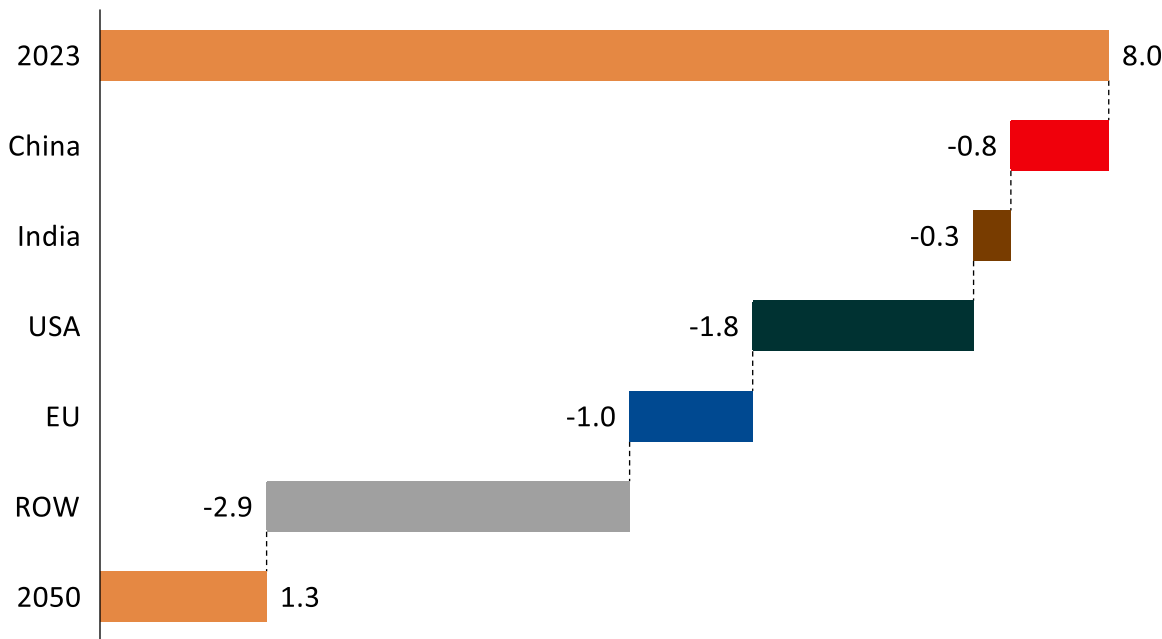
Similarly, the EU would need to reduce emissions by around 1 Gt from today by 2050 under a 1.6-DG scenario. The largest impact would also need to be seen in the cars sector, which would have to reduce CO₂ emissions by 0.45 Gt (96.1%). Countries within the EU that will need to reduce the most CO₂ emissions from transport are Germany (95% or 0.17 Gt), France (93% or 0.14 Gt), Spain (88% or 0.12 Gt), and Italy (91% or 0.12 Gt).

Furthermore, contributions to global emission

reductions in the transportation sector will have to come from Asia, namely from China and India. China will need to reduce CO₂ emissions in the transportation sector by 0.8 Gt with India cutting them by 0.3 Gt. The combined efforts of the two countries are distributed, with 0.89 Gt coming from emission reductions in the road transport sector, 0.11 Gt from aviation, 0.08 Gt from shipping, and 0.02 Gt from rail.

The final largest group is the rest of the world which will have to reduce CO₂ emissions by a combined 2.9 Gt by 2050 under a 1.6-degree scenario. Within this broad group of countries, the ones that must reduce transportation CO₂ emissions the most are Japan (0.22 Gt), Russia (0.19 Gt), Indonesia (0.13 Gt), Canada (0.17 Gt), and Singapore (0.12 Gt).

Direct transport CO₂ emissions reduction in 1.6 DG, by country
Gigatonnes (Gt)



Source: Rystad Energy, Energy Scenario Cube

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