From resource scarcity to energy abundance and infinite supply

The paradigm shift being wrought by the energy transition

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[1] The opinions expressed in this publication are those of the individual authors and do not necessarily represent the opinions, position, or policy of BRG or its other employees and affiliates. This paper was supported by contributions from Tom Choi, Jack Tunstall and Matthew Drews.

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QUANTIFYING THE LOW-CARBON JOURNEY

For more than two-hundred years, energy economics have been defined by society's increasing hunger for the depletable resources of coal, oil and natural gas. These fuels have been used to enable the Industrial Revolution, the progressive electrification of society, and the ever-greater transportation and mobility of people, goods, services and information. Since the beginning of the Industrial Revolution, we have seen a formidable increase in global energy consumption, starting from 19,289tn Btu in 1800 and increasing over thirty-fold to 591,460tn Btu in 2019 (on a substituted energy basis, Oxford[2]). Over that period, the growth of energy supply from depletable fossil fuels has provided the underlying foundation for the improvement of virtually every measure of human progress, socioeconomic welfare and economic growth.

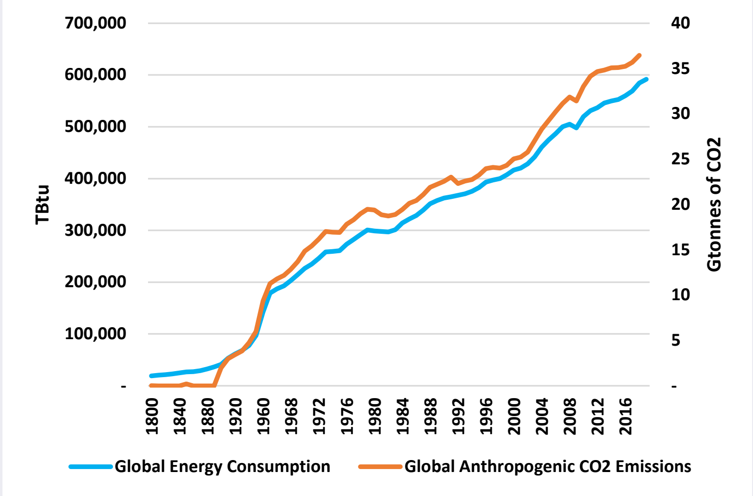
The energy in everything

The world's most advanced economies are also the biggest energy consumers, with high-income countries using 14 times more energy per capita than low-income countries[3]. Throughout both advanced and emerging economies, energy content exists in virtually everything we use. We use energy directly to fuel our vehicles (or charge their batteries), light our homes and offices, and run our appliances, computers and smart devices—but also indirectly to manufacture cement, metal, glass and wood products for construction; the wood and fabrics in our furniture; the glass, ceramic, plastic and paper products in food packaging and storage; the medicines and healthcare products we require; and so forth.

Although energy supply has become the bedrock of socioeconomic progress, our vast consumption, combustion and also waste of fossil fuels increasingly presents an existential threat to the earth's climate and natural environment. This has been made abundantly clear by the increasingly demonstrable and devastating consequences of anthropogenic climate change in the form of extreme weather, floods, fires and disease. In the US alone, large events such as hurricanes, wildfires, and other disasters related to climate change caused $95bn in overall damage in 2020 (NOAA).

While the scientific evidence of climate change is clear and widely accepted, our ability and best options to master this challenge have stirred intense debate, disinformation and dilemma. With a growing global population that almost universally aspires to an energy-intensive modern way of life, how indeed can humanity continue to multiply, modernise and prosper without continued massive consumption of fossil fuels and vast emission of greenhouse gases such as CO2, shown in the figure below?

Fig. 1: Global energy consumption and anthropogenic CO2 emissions[4]



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[2] The data originally was reported in TWh; BRG converted to gigajoules. The substituted energy basis considers inefficiencies in fossil fuel production and converts non-fossil energy to their "input equivalents". This method is also adopted by BP when publishing its energy statistics when all data is compared in exajoules.

[3] This estimate is based on the World Bank's energy use per capita data and classification by income category for 2014, the most recent and complete year in the database.

[4] The data includes emissions from coal, oil, natural gas, cement and flaring, from Global Carbon Project.

So here we stand at the dilemma of a crossroads between sustained population and economic growth and environmental stewardship:

- On the one hand, we face idealistic net-zero[5] targets for GHG emissions built upon rebuilding the vast majority of the world's energy supply infrastructure without agreed strategic plans, implementation steps, operational programmes or financial budgets. We are confronted further with global energy transition costs estimated at $73tn (Stanford), which are needed to rapidly remake the energy foundations of modern society without socioeconomic interruption or failure.
- On the other hand, we must contend with the practical realities of centuries of developed energy and industrial resources, infrastructure, and methods, and the entrenched interests promoting their continued use as the only way to maintain, and improve upon, our current way of life.

As with many dilemmas, the underlying dichotomy may well be false. In this case, it is built upon centuries of intellectual practice, or habit, of understanding energy resources as depletable, supply finite and production constrained. However, the intellectual tools of the past are of little use to mastering the climate imperative. We need to "think outside the box" and redefine the problem. ☐

From scarcity to abundance: The shale revolution sparks the energy transition

The energy transition requires a new intellectual framework built around access to increasingly abundant, and ultimately infinite, energy supply. In that regard, a first stage of this paradigm shift has already been in progress for at least a decade due to the technological advances of the shale revolution, which introduced a new abundant, increasingly low-cost and relatively clean (as compared with coal and oil) source of energy to US and global markets.
In the early 2000s, just before the shale revolution took off in the 2010s, energy economists widely debated the notion of "peak" oil and gas supply. The US EIA anticipated that global oil production would peak by 2040, but others (including the Association for the Study of Peak Oil and Gas) forecast a peak as early as 2010 or sooner. Such economists speculated that a future economic production constraint for hydrocarbon resources eventually would shift production toward more difficult-to-access resources (e.g. deepwater, Arctic, remote) that eventually would increase the cost of oil and gas supply relative to previously more-expensive renewable energy resources. Thus, economic limitations on hydrocarbon supply, and the increasing costliness of this supply, eventually would foster the energy transition toward relatively cheaper and cleaner energy sources.

Over the last dozen years, however, the shale revolution destroyed the notion of a near-term constraint in low-cost hydrocarbon supplies by unlocking abundant new sources of hydrocarbon production from shale resources far below conventional deposits at economically competitive prices. The shale revolution is a story of technological breakthroughs, industrial ingenuity and learning, and economies of scale in relation to the combination of hydraulic fracturing and horizontal drilling for the production of gas and oil from shale rock.

The abundant shale gas production unleashed during the shale revolution led to a climate-friendly cascade of events. The abundant US gas production yielded highly competitive US natural gas prices, mounting US LNG exports and reduced natural gas prices worldwide. As a result, US and global gas-fired power generation economics became competitively superior to coal and began to accelerate the retirement of ageing and inefficient coal-generation units. This economic shift also benefited the environment because, as compared with gas-fired generation, coal generation typically emits twice the GHGs per MWh generated. A significant consequence of the shale revolution was therefore to bring electricity generation economics into closer alignment with environmental and climate imperatives to rapidly reduce GHG emissions.

Another effect of the shale revolution was to raise the competitive economic hurdle for renewable energy sources in competitive power generation markets. Over the last decade, wind and solar power have risen to that challenge to achieve economic "grid parity". As these technologies were deployed at ever-greater scale, they too became more efficient and economically competitive as needed to compete with low-cost power generation from economic shale gas. ☐

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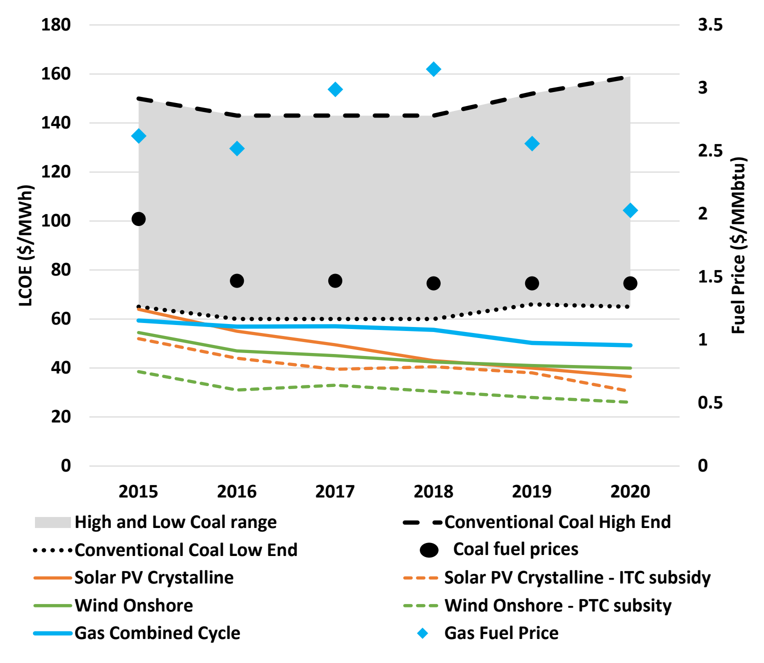
[5] "Net-zero" refers to achieving zero additional greenhouse gas emissions released into the atmosphere by both reducing and absorbing emissions (such as through carbon capture & storage and carbon offsets).

From abundance to infinite: Low renewable generation costs will deepen the transition

While the shale revolution's technological advances launched a first stage of the paradigm shift to abundant, low-cost energy, the competition from this resource and technological advances in renewable energy generation have sparked a second stage based on something far more potent: the infinite supply of renewable energy that is free of both commodity supply cost and GHG content and emissions. With clean energy supply available from the sun, wind and water, the only constraint is on our ability to develop, install, and maintain the physical infrastructure needed to convert this energy into useful forms—such as electricity and/or clean fuels (e.g. hydrogen)—and to store and reliably deliver it when needed. Over the long term, renewable energy will usher in an era of cheap electricity with the use of infinite and low-cost renewable energy resources.

In the US, the cost of clean energy has declined to the point where utility-scale solar and onshore wind-generation facilities now produce electricity for prices that beat even the lowest-cost coal-fired generation (see **Fig. 2**). In fact, in some US regions, such as Texas, low-cost onshore wind and utility-scale solar have beaten out conventional power for at least the last half-decade.

Fig. 2: US Levellised cost of electricity (LCOE) generation (Lazard)[6]



Lazard's 2020 LCOE analysis indicates that coal is the most expensive generation source, at $65 to $159 per MWh, whereas renewables and gas combined cycle—even without subsidies—are the cheapest generation sources per MWh. Wind and solar are even cheaper after accounting for US federal tax subsidies like the production tax credit (PTC) and the investment tax credit (ITC).

Other reputable institutions have reached conclusions similar to Lazard's that renewable economics are increasingly favourable toward driving the energy transition. The EIA, National Renewable Energy Laboratory (NREL), Bloomberg New Energy Finance (BNEF) and IEA have all documented declining solar and wind unit capital costs over the last decade and anticipate that this trend will continue well into the future. For instance, NREL's latest analysis forecasts that renewable capital expenditures per kW will decline by around 50pc from 2020 to 2050.[7]

[6] Unless specified otherwise in the legend, the graph relies upon the average of Lazard's high and low unsubsidised LCOE estimates. Lazard's natural gas LCOE analysis is presented on an unsubsidised basis and relies upon a US fuel cost assumption of $3.45/MMBtu. We updated the fuel cost assumption to reflect actual historical Henry Hub price for each year of analysis, using that annual average for that year. These prices ranged from $2.03/MMBtu in 2020 to $3.15/MMBtu in 2018. Lazard's wind and solar LCOE analysis is presented with and without federal tax subsidies (ITC and PTC, respectively). For coal, we depict the range between the high and low LCOE. The low coal LCOE is based on advanced supercritical pulverized coal technology, and the high coal LCOE assumes 90pc carbon capture and compression (but not storage).

[7] Average calculation of utility wind, utility solar and four-hour battery capital expenditures from 2020-ATB.

The cost of generating electricity with fossil fuels tends to be higher in Europe than in the US, because natural gas supplies are largely imported and therefore are more expensive due to additional import costs for long-haul pipelines and LNG liquefaction, shipping and regasification. As a result, offshore wind particularly has been competitive in some European markets. For instance, the 2017 offshore wind auctions in the UK were competitive with newbuild gas-fired power plants; and, more recently, the 2019 offshore wind auctions at around £40/MWh will be competitive with existing gas-fired plants by 2023 (Carbon Brief).

Renewables are now on a course to outcompete fossil generation on their own merits and the economic shift toward low-cost clean energy already is redefining the energy generation landscape in the US and Europe, despite recent economic and political headwinds.

The US added 23GW of new wind capacity and 12.8GW of new utility-scale solar capacity in 2020 alone, helping boost renewable generation from wind and solar by 14pc from 2019. Despite federal policy headwinds under the Trump administration, corporations and states are increasingly an important driver of renewable growth through direct power-purchase agreements with wind and solar farms and higher policy targets, respectively. Conversely, US natural gas generation grew by only 2pc and coal generation declined by 20pc in 2020, compared with 2019 (EIA). In the EU, power production from wind and solar overtook coal for the first time in 2019, and the EU added a total of 26GW of renewable capacity in 2020, despite the economic duress of the pandemic. In China, also, the pandemic did not deter renewable growth, with a record 85GW of renewable capacity added in 2020, a 30pc increase from 2019 (IEA).

Looking forward, large-scale deployment of renewables, without fossil fuel backup, will require developing a vast amount of storage needed to balance the intermittency of renewable power. Currently, battery storage remains relatively expensive; nonetheless, its deployment outlook is promising and proving increasingly competitive with gas peakers[8] on a unit $/kW basis in many markets (IEEFA). We expect that, over the coming years, electricity storage—as well as other expensive clean energy sources, like offshore wind in the US, green hydrogen-fuelled turbines and geothermal power—will follow onshore wind and utility-scale solar to become increasingly competitive on the market.

In fact, utility-scale battery unit capital costs have already declined substantially with continued technological breakthroughs. NREL estimates that the price of lithium-ion batteries has fallen by 80pc since 2015 (NREL). Even under our current economic duress due to the Covid-19 pandemic, US utility-scale battery deployment broke all-time records in 2020, with the annual market for grid batteries exceeding both the $1bn mark and the 1-gigawatt threshold for the first time (GreenTech Media).

Technological and economic improvements in emerging renewable generation, electricity storage and clean fuels continue to advance rapidly as the challenge of developing the lowest-cost, GHG-free energy supplies has stimulated fierce competition between renewable energy companies, technological conglomerates, and oil and gas majors. Worldwide, public and private R&D funding is being poured into improving renewables energy and new clean-fuel technologies.

For instance, recent wind power breakthroughs include the development of GE's Haliade-X 12MW wind turbine in 2018 and Siemens Gamesa 15MW wind turbine in 2020—two of the world's largest. One of the most recent solar energy improvements was from Oxford PV, a solar technology firm that is poised to produce in 2021 the world's most efficient solar panels by using perovskite coating, which generates nearly one-third more electricity than traditional solar panels. ☐

[8] A gas-fired peaking power plant runs only when there is peak demand for electricity, and as such, tends to command a higher unit electricity price than baseload power.

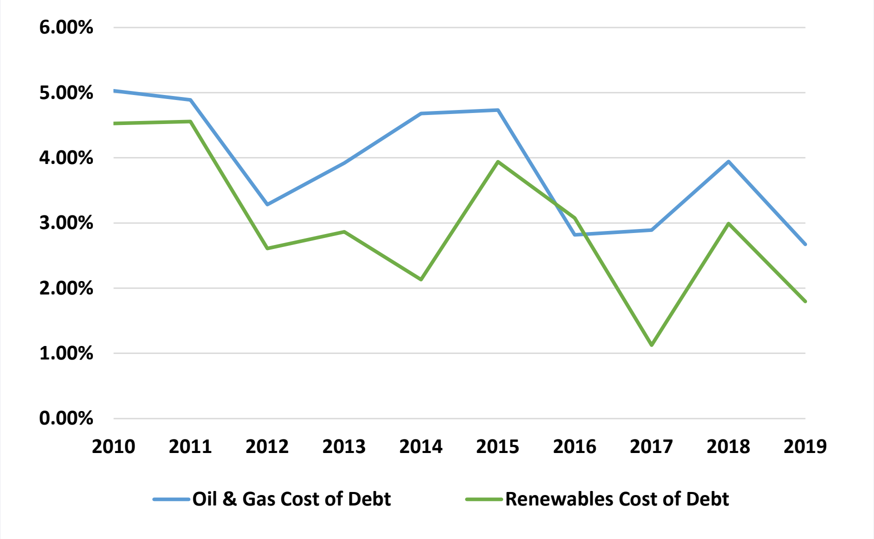
Renewable energy also is also benefiting disproportionately from declining cost of capital

In its economic competition with fossil fuel power generation, renewable energy generation has benefited from not only the elimination of fuel costs and improved technological efficiency, but also relatively greater reductions in the cost of capital.

As compared with fossil fuel generation, which includes a large component of variable operating costs for fuel commodity inputs, renewable energy generation costs are composed primarily of fixed capital and operating costs. As such, financing costs represent a greater share of renewable energy generation costs relative to fossil fuel generation costs. This has been quite important over the last decade because (a) renewable generation has benefited disproportionately from the overall trend of low interest rates and flat equity risk premiums (Damodaran) and (b) the cost of money for renewable energy companies has declined relatively more than the cost of money for fossil fuel companies, which increasingly struggle to attract capital.

We analysed this trend by comparing the cost of debt for portfolios of renewable energy and oil and gas companies (see **Fig. 3**). As shown below, the cost of debt has become cheaper for all technologies due to falling interest rates, but this has disproportionately benefited relatively more capital-intensive renewables compared with fossil fuels. □

Fig. 3: Weighted Average Cost of Debt for Oil and Gas and Renewable Energy[9]



More interestingly, oil and gas bonds have a significant and increasing yield premium over renewable bonds that is unexplainable by the risk-free rate and the default spread[10]. This suggests a significant and growing carbon premium for oil and gas bonds and a carbon discount for renewables. This also aligns with trends seen in financial markets, where demand for green bonds is high, and they are routinely oversubscribed as result (S&P Global), thereby supporting higher bond prices (and lower bond yields).

These analytical results align broadly with empirical evidence suggesting that fossil fuel companies are increasingly disadvantaged with respect to renewables. Indeed, fossil fuel firms have struggled to prove to investors that they can maintain profits in the new post-scarcity energy landscape,[11] and the cheap money they attracted in the last decade has become ever harder to access. For example, five of the six largest US banks have stopped financing fossil fuel drilling (WSJ), and the European Investment Bank has announced it will cease funding

[9] Calculated as risk-free rate + average default spread + empirical calculation of corporate bond yields for a portfolio of firms in each sector controlling for broader interest rates, default spread and duration.

[10] We netted the risk-free rate and the default spread for corporate bonds in each sector, taking into account bond duration, to determine whether the remaining yield differed between renewable bonds and fossil fuel bonds.

[11] Free cash flow per bl was negative for many independent oil and gas companies throughout the 2010s.

fossil fuel projects by year-end 2021 (Reuters). Meanwhile, those fossil fuel producers that survived last year's wave of bankruptcies continue to face an uphill battle. Even with recent oil prices exceeding $50/bl, US shale producers are aiming to strengthen their balance sheets by exercising financial restraint and not jumping back into production immediately (MRT). Finally, intensifying investor demands for ESG efforts and the looming threats of climate change, regulation and declining renewable technology costs have led investors to look more warily on fossil fuel investments while pouring large amounts of capital into renewables (Bloomberg), lowering the relative cost of capital for these technologies and accelerating the growth of renewable infrastructure.

Whereas Lazard's LCOE bases its estimates on a fixed 7.7pc weighted average cost of capital (WACC) throughout the years (see **Fig. 2**), falling interest rates and the emergence of a climate risk premium suggest that renewables may be even cheaper than a traditional LCOE analysis suggests when declining capital cost trends are taken into account, which may reduce the WACC by 1.0pc to 1.5pc (depending on capital structure and tax assumptions). In Lazard's LCOE analysis, a 1.2pc decline in WACC reduces the LCOE for wind by about 5pc and for solar by about 10pc. In other words, the availability of cheaper capital has the potential to reinforce declining renewable and storage investment costs through more rapid investment, which could stimulate economies of scale and technology cost reductions.

Other institutions support this financial trend, with, for instance, NREL's WACC projections anticipating a cost of money premium for fossil fuel investments over renewables of 0.6pc starting 2025, further enabling the growth of renewable assets. ☐

In 2020, renewables trounced fossil fuels despite Covid-19's energy demand destruction

At the beginning of the Covid-19 pandemic, many initially expected that the multiple distractions of economic catastrophe, energy demand destruction and public health imperatives would present a substantial setback for climate change policy and renewable energy—but, in fact, the opposite has occurred.

As we predicted in Q2 2020, the energy demand destruction caused by Covid-19 policy responses actually has accelerated the phasing out of uneconomic forms of energy production to the benefit of renewable energy and clean fuels (Petroleum Economist). The reduced mobility and mandatory lockdowns have hit fossil fuel demand and prices the hardest and unleashed a wave of corporate bankruptcy and restructuring activity. Milder reductions in power demand (due to the shift from commercial to residential electricity consumption) and electricity prices are forcing out some of the least economic forms of fossil fuel generation, particularly coal.

However, renewable energy generation and new installations actually enjoyed a bumper year, gaining a competitive advantage over fossil fuels during the near-term decline in power prices on account of their very low LCOEs and financing costs, often outcompeting natural gas. Compared with other fossil fuels, natural gas demand proved resilient, given its use in residential heating, and the abundance of US shale gas resources ensured gas remained a competitive source of generation supply. As such, with renewables and storage increasingly ramping up to replace fossil fuels, cost-competitive natural gas and LNG will provide necessary grid reliability in the wake of coal-fired plant retirements.

Fig. 4: 2020 Predictions [12] and outcomes

Topic	2020 prediction	2020 outcome
Energy industry	Accelerated energy transition with reduced fuel demand and intensified demand for high-efficiency, low-cost energy	Acceleration of the energy transition with 34pc reduction of oil and gas capex investments (BCG) and with 90pc of new electricity investments being renewable (IEA)
Oil	Sustained global market decline with a slow and partial recovery	Global supply decline of 10pc, with some forecasts implying that year 2019 reached peak oil demand (BP)
Natural gas	Global moderate decline, with a more rapid recovery than oil	Global supply decline of 3pc, but proved resilient compared with oil
LNG	One- to two-year delay in new LNG infrastructure project FIDs due to short-term lower demand, but with a faster recovery outlook than oil industry	LNG demand recovery as nations seek reliable and cleaner alternative to coal, especially driven by Asian demand; 2020 LNG demand roughly equal to previous year (Bloomberg)
Coal	Sustained market decline	Continued market decline, with 7pc global supply reduction
Renewables	Bullish global market growth that accelerates the transition	Global supply growth of 1pc, despite 5pc energy demand reduction
Green stimulus and climate change policy	Implementation of green stimulus and climate change policies to achieve dual ends of economic recovery and climate change mitigation	Green stimulus packages passed in the EU and some parts of Asia; moderate green stimulus in the US, where more aggressive policies, like carbon taxes, are gaining traction, but still pending definition and implementation by the new administration and Congress.

In line with our predictions, the pandemic accelerated the penetration of economically efficient and must-run generation such as wind and solar, as per the following (IEA):

1. The US shale industry survived in a low oil-price environment, and natural gas and power demand proved resilient. Yet, renewable energy was the biggest winner with 1pc global growth in 2020, despite energy demand declining by 5pc.
2. Dirty fossil fuels proved to be the biggest losers in 2020. Oil continued its long and steady decline, plummeting by approximately 10pc. The continued bankruptcies of upstream producers and the reduced capital expenditures of the oil and gas majors even suggest that oil demand may have peaked in 2019. Moreover, coal energy supply declined by 7pc in 2020 due to its inflexible and expensive characteristics, further foreshadowing its increasingly upward battle in the wake of the economic paradigm shift driven by renewables and natural gas competitiveness.
3. Finally, and as predicted, we witnessed an increase in green stimulus deals to support the dual goals of fostering economic growth and meeting climate change targets. These post-pandemic stimulus measures have added further urgency to the broader discussion regarding climate change and energy transition policies around the world.

The climate effect of the economic paradigm shift and the pandemic have helped reduce global carbon dioxide from fossil fuels and industry by 7pc in 2020, with the US leading the pack with a 12pc reduction (Carbon Brief). This reduction should not, however, be attributed solely to increased gains in fossil fuel carbon efficiency, but rather to the economic and behavioural changes wrought during the pandemic. While these are promising strides, concerted global policy efforts are urgent and necessary to ensure that pandemic-induced emissions reductions—which, on their own, translate to only a 0.01 °C reduction in global warming by 2050 (UNEP)—lead to lasting and structural changes in our climate change policy, energy infrastructure and electricity generation mix. ☐

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[12] We published a five-part web series in Petroleum Economist online in May and June 2020 that predicted the near- and long-term effects of the Covid-19 pandemic on global energy markets, the energy transition and climate change policy.

In the coming years, policy imperatives will accelerate and massify the energy transition

The recent, ongoing economic momentum away from fossil fuels and toward clean energy sources will be accelerated and massified by a growing array of global policy initiatives. The overwhelming consensus on the anthropogenic nature of climate change, with 97pc of climate scientists in agreement (NASA), stresses the urgency to drastically cut GHG emissions. This urgency has been amplified by the need for pandemic rebound stimulus investments (such as the EU's new Green Deal and Biden's "build back better" proposals). These factors signal a rapid escalation of national and multinational policies that aim to achieve net-zero economies within the coming few decades.

As summarised in **Fig. 5**, we broadly expect the US and EU will make substantial strides in completing the transition from coal to natural gas and renewables this decade, as a result of renewed national commitment to climate change mitigation under the Biden administration in the US and aggressive economic recovery efforts combined with green policy in the EU. Highly coal-dependent countries in Asia are likely to need more natural gas for a longer transition period than the US and EU, as needed to stabilise supply as Asia retires its massive base of coal-fired generation (1,436GW of operating capacity as of 2019). For all regions, the policy targets summarised in **Fig. 5** are formidable, and success in these endeavours will be subject to an array of operational, logistical, financial and political challenges.

Fig. 5: Global power-sector transition policy initiatives

Topic	US	EU	East Asia	China & India
Economy-wide net-zero goals	Carbon neutrality by 2050	Carbon neutrality by 2050	Carbon neutrality by 2050 for Japan and South Korea	Carbon neutrality by 2060 for China No carbon neutrality goal yet for India
Known policy tactics	Net-zero emissions power sector by 2035 Tax credits for clean energy Renewable portfolio standards Carbon tax and carbon border tax (CBT) [13] expected under Biden administration	55pc reduction of carbon emissions below 1990 levels by 2030 European carbon trading scheme Green Deal stimulus Renewable energy directive and feed-in-tariffs CBT is expected	Retirement of inefficient coal plants and replacement of some with natural gas plants Increase clean energy fuel, including hydrogen and ammonia Feed-in-tariffs	Renewable electricity quota Reduction of carbon intensity across sectors
Expected role of gas and coal	Transition role for gas this decade Phase-out of coal this decade	Transition role for gas this decade Phase-out of coal this decade	Transition role for gas this decade and next Phase-out of coal next decade	Transition role for gas this decade and next Phase-out of coal next decade

[13] A carbon border tax represents a tax on the carbon emissions content embedded in imported goods. Typically, this tax is aimed at energy-intensive imports—such as metals, cement, glass, or petrochemicals—that have a high carbon footprint. The idea of a CBT is to tax imports at a similar rate to a domestic carbon tax to level the playing field and avoid a situation of "carbon leakage" via switching domestic manufacture of high-carbon goods that are taxed with imports off those goods that are not taxed.

In the US, Biden's policy goals foretell renewed federal transition efforts on the horizon

In the US, the last decade has already seen substantial progress on the phase-out of coal generation and reduced GHG emissions due to the wave of abundant gas supply after the shale revolution and low cost of combined-cycle gas generation (see Fig. 2). Between 2010 and 2019, the US in fact reduced its power CO2 emissions by close to 30pc, despite the headwinds from the Trump administration's withdrawal from the Paris Agreement and rollback of numerous US climate change and GHG emissions regulations. This has occurred largely because of numerous state-level initiatives to drive the energy transition forward. For example, California (the nation's second-highest energy consumer) plans to derive 50pc of its electricity from renewables by 2026, 60pc by 2030, and 100pc by 2045. Even hydrocarbon-rich Texas has more than 10,000 wind turbines with 21,450 MW of installed capacity, making it the sixth-largest wind-energy producer in the world (IEEE).

Recent green stimulus measures passed by Congress signal a growing bipartisan appetite for more aggressive federal climate policy. The $1.4tn omnibus package and $900bn in Covid-19 relief funds passed by Congress last month contained significant clean energy and climate change provisions, and carbon taxes and carbon border tariffs are gaining bipartisan support. For instance, the Energy Innovation and Carbon Dividend Act has gained traction from Democrats and Republicans alike.

Looking forward, we expect that renewed federal commitment to decarbonisation policy under the Biden administration, and the new democratic-controlled Congress, will accelerate these trends and the transition toward net-zero CO2 emissions in the power sector by 2035. Biden has rejoined the Paris Agreement and has pledged to achieve net-zero power sector emissions by 2035 and reach a 100pc carbon-free economy by 2050. We expect support from Congress on these decarbonisation efforts given the Democratic party's control of the House and its election victories on 6 January that gave it control of the Senate, in which Vice President Kamala Harris will act as a vote tiebreaker in instances of partisan disagreement.

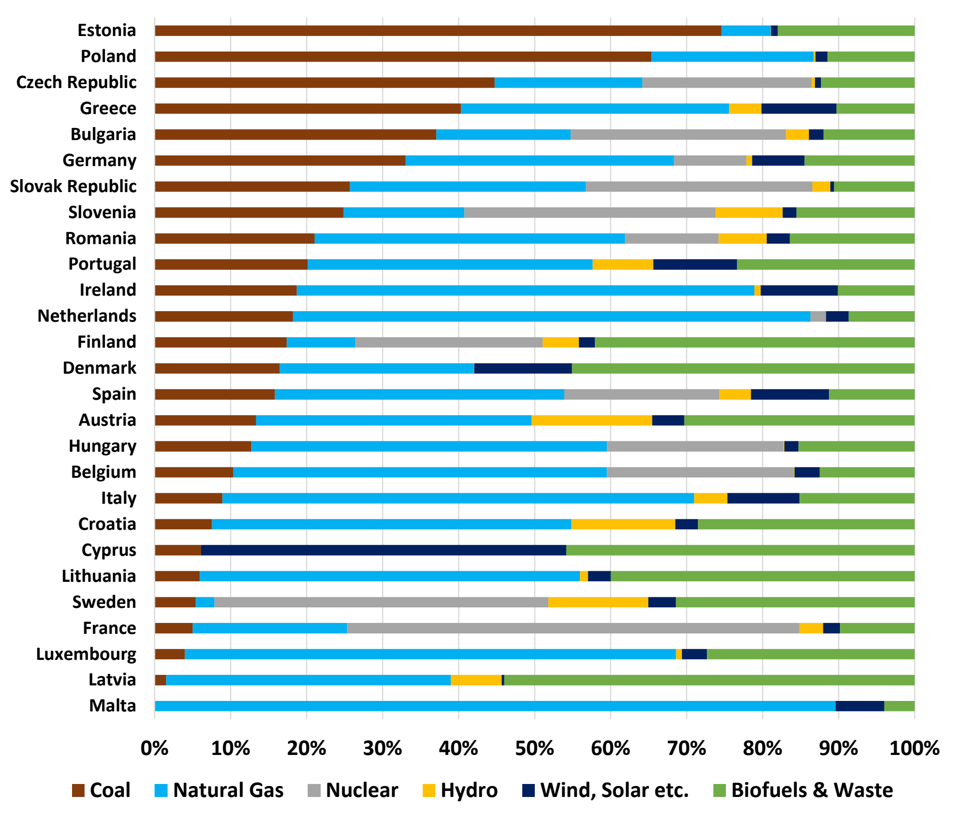
To reach Biden's target of net-zero power section emissions by 2035, the US first will need to phase out approximately 240GW of utility- and independent generator-owned coal-fired generation with speed (probably before 2030, in our view), and replace it with gas-fired generation and/or renewable energy. While gas-fired generation also would need to be phased out of the US generation mix by 2035, natural gas will continue to play a major role through the end of the decade in order to give wind, solar, batteries and other emerging technologies, such as green hydrogen, enough time to scale up.

The EU leads the way in global energy transition policy

Europe has been the most ambitious region in advancing net-zero policies. Recently, the EU27 has redoubled its energy transition leadership by tethering its efforts on climate change mitigation to post-pandemic economic recovery. Most significantly, the EU27's Green Deal stimulus programme, agreed last month, aims to reduce carbon emissions to 55pc below 1990 levels by 2030 on the way to achieving full decarbonisation of the economy by 2050. The landmark deal allowed for the 2030 target to be achieved collectively as a compromise solution to assuage the concerns of heavily coal-reliant countries (such as Poland, which uses coal for 80pc of generation). Nevertheless, this means policymakers will continue to vigorously negotiate the speed of each member country's decarbonisation efforts and the apportionment of shared emissions cuts between member states.

Many EU27 member countries have already heavily reduced their reliance on coal in favour of renewables, nuclear and/or natural gas (see **Fig. 6**). In 2000, coal accounted for 30pc of power generation in the EU27, but this declined to only 20pc in 2018 (Eurostat); as a percentage of the overall energy supply, coal declined from 19pc to 15pc from 2000 to 2019 (IEA).

Fig. 6: EU member state energy supply mix in 2018 (pc) [14]



As in the US, natural gas will be necessary to supplant the EU27's coal-fired generation until renewable energy, electricity storage, and clean fuels such as green hydrogen and biogas can support substantial green energy electrification. For now, natural gas remains a cornerstone of the EU27's power generation mix and overall energy landscape (comprising 17pc of the EU27's power generation (Eurostat) and 23pc of the EU's overall energy supply (IEA) in 2018 and 2019, respectively), but EU governments are increasingly eschewing the expansion of natural gas infrastructure in favour of renewables and clean fuels. For instance, the Just Transition Mechanism, which provides funds to communities to alleviate the socioeconomic impact of the transition, will not be permitted to finance natural gas projects, and last month, the European Commission proposed new "TEN-E" rules that restrict funding for natural gas projects in favour of low-carbon technologies such as hydrogen pipelines, offshore power grids and smart gas grids (Reuters).

To achieve the EU27's 2030 goal, the proportion of renewable sources in power generation needs to rise to about 66pc, and fossil fuel sources will need to diminish to under 20pc. Renewables' share of total energy supply will need to rise to about 32pc by 2030, including adding 40GW of green hydrogen electrolysis and targeting 60GW of offshore wind. These energy goals will require substantial energy overhauls for some countries (including Poland and Estonia, which massively rely upon coal for their energy supply), but will be easier for other countries (such as France and Sweden, which rely upon mainly nuclear and renewable energy).

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[14] This graph does not include energy supply from oil, which means it mainly illustrates energy supply for the power, industrial and residential sectors. Data is from the IEA.

East Asia will need natural gas to achieve targeted reduction of coal-fired generation

While the replacement of coal-fired generation with renewable energy and natural gas is already well underway in the US and EU, Asian countries are further behind in the energy transition. They face the daunting task of retiring or converting a massive base of low-cost coal-fired generation, which has supported substantial economic growth over the last two decades. In 2019, Asia relied on coal for 58pc of its generated power, up from 51pc in 2000. Replacing Asia's massive installed base of coal-fired generation will require substantial growth of both renewable energy and natural gas generation (potentially in addition to a measure of co-firing coal generation with ammonia to reduce GHG emissions).

In East Asia, there has been a recent wave of announcements regarding renewed commitment to climate change mitigation. Japan and South Korea have each pledged to reach carbon neutrality by 2050 and, as an interim goal, have targeted a significant reduction of inefficient coal-fired generation by 2030 and 2034, respectively, to be replaced with renewables and natural gas. Both countries also have begun to limit their finance of coal-fired generation overseas, which is significant because South Korea, Japan, and China (discussed below) account for over 69GW of new coal power under development internationally. Japan and South Korea have also instituted the following policies:

- Japan's power sector contributes to approximately half of the country's CO2 emissions and depends on fossil fuels for over 70pc of its supply. In its recently released "green growth strategy", Japan aims by 2050 to derive 50pc to 60pc of its power from renewables, 30pc to 40pc from nuclear plants and/or thermal generation plants with carbon capture, and 10pc from hydrogen and ammonia (Nikkei). As the world's largest importer of LNG, Japan has signalled it will decarbonise the entire LNG value chain, such as by producing hydrogen and ammonia from LNG in tandem with carbon capture (S&P Global), as well as importing ammonia itself (Ammonia Energy Association).
- South Korea's recently released long-term energy transition plan substantially reduces coal-fired and nuclear generation, specifically calling for the closure of 30 coal power plants by 2034, 24 of which will be converted to natural gas fuelling. As a result, coal will fall to 15pc of South Korea's power generation mix by 2034 from 28pc in 2020. Despite these large increases in natural gas-fired capacity, natural gas will fall slightly from 32.3pc of the country's power generation mix in 2022 to 30.6pc by 2034, due to increasing power supply and steep growth in renewables (S&P Global).

China and India's decarbonisation efforts remain limited

While heavily coal-reliant China and India have pledged to reduce GHG emissions and add renewable power generation, these plans are premised on a longer transition timeline than the decarbonisation policies being implemented, or planned, in the US and EU. Intensified climate action from both would require substantial reliance on natural gas to phase-out coal over the next decade due to the scale of coal-generation retirements required (1,234GW of operating capacity in China and India alone).

- China, with a massive coal-base, has targeted the goal of carbon neutrality by 2060. President Xi Jinping has indicated China will reduce its carbon intensity by over 65pc by 2030, but the government has released few details to date on how it would meet these targets. In our view, the limited nature of its current climate change commitments appears to provide the government with the economic flexibility to stimulate a post-pandemic economic rebound and the strategic flexibility to adjust course based on EU and US decarbonisation policy developments and global climate negotiation conditions.
- India's climate change commitments are weaker than China's, with a commitment to cut its carbon footprint by increasing the share of non-fossil fuel power generation to 40pc by 2030. It also has instituted renewable energy targets of 450GW by 2030 (or 60pc of its power generation capacity).

Ultimately, a key challenge in these countries will be in funding the massive energy transition costs associated with the retirement or conversion of inefficient fossil fuel infrastructure, R&D, and new clean energy infrastructure. In China alone, the cost of transitioning all energy sectors is estimated at $16.6tn (Stanford). The other major challenge will be in curbing carbon emissions without stymieing economic growth or its export competitiveness, which relies upon cheap factors of production, such as low-cost labour and energy inputs.

This issue is critically important throughout the heavily coal-dependent regions of South and Southeast Asia. In those regions, the leading coal-consuming countries have been particularly reticent to change course from their heavy usage of coal and oil to support their economic growth (WRI). Additional progress here is likely to require regional leadership from China and India as well as the economic pressure of CBTs from the US and EU. ◻

Net-zero policy: Natural gas needed to fuel the next stage of energy transition

Based on the above policies, the question arises: how do we get from here to net-zero? Natural gas has long been viewed as a bridge fuel to facilitate the transition toward a cleaner energy future, not only for the fact that it produces far less CO2 emissions than heavier fuels but also because it may be deployed in place of coal on the way to full grid decarbonisation while renewables and battery storage improve in efficiency, scale and reliability (Public Utilities Fortnightly). As net-zero policies—which, by definition, must ultimately phase out gas-fired generation—gain momentum around the world, we can posit at least two scenarios for the scale of the energy transition that portend the role of natural gas (see **Table 1**):

Table 1: Energy transition scenarios

BRG Energy transition scenarios	Description
EU Net-Zero	A business-as-usual scenario that includes current regional or national decarbonisation policies only; namely, the EU's European Climate Law (European Commission) that targets a net-zero emission economy by 2050.
Global Net-Zero	A more ambitious global decarbonisation scenario that implements stated net-zero emissions goals for the US and JKT, [15] as well as ambitious decarbonisation policies for Other Asia.[16] The US targets net-zero power sector emissions by 2035 and joins the EU in an aggressive climate-forward posture. Both regions place additional diplomatic and economic pressure on Asian countries to accelerate decarbonisation.

The Global Net-Zero scenario is the most challenging but shows promise because of the new climate initiatives from the Biden administration and the potential for renewed Atlantic climate cooperation between the EU and the US. This in turn would escalate a snowball effect of accelerating the energy transition worldwide, as the US and EU together place increasing pressure on Asian export economies to accelerate and intensify their decarbonisation efforts, including especially implementing a coordinated approach to CBTs. The challenges of implementing such aggressive policies will sustain significant, but uncertain and potentially volatile, demand for natural gas as the critical bridge fuel, and even more so for LNG as the world's marginal or "swing" source of natural gas supply (Public Utilities Fortnightly).

Although we expect a solid decade of global gas demand growth under the Global Net-Zero scenario, regional disparities will intensify due to vast differences in the starting supply mix and speed at which each region is actually able to decarbonise. In the 2030s, as the deadline for net-zero emissions approaches and countries begin to wean themselves off of gas in favour of renewable energy, electrification and cleaner fuels, natural gas and gas infrastructure may pave the road toward completing decarbonising of the power sector and switching to cleaner industrial and transportation fuels through production of "blue hydrogen", blending of "green hydrogen", and/or repurposing natural gas infrastructure to transport and store hydrogen, ammonia and other clean fuels.

Global gas demand keeps growing, but with stark regional differences

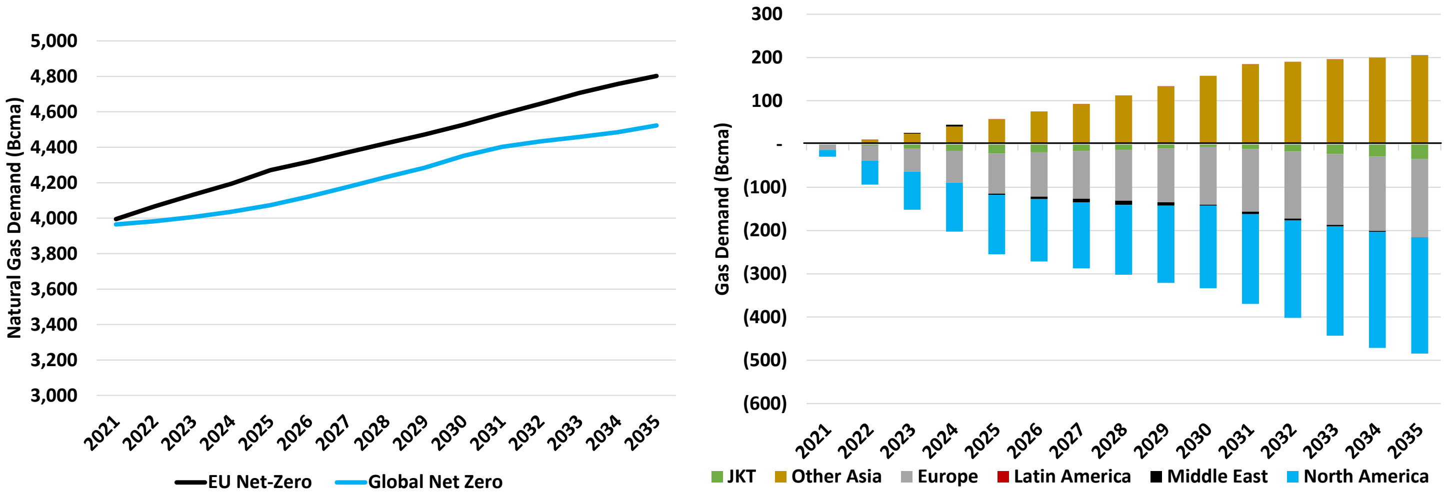
Under a Global Net-Zero scenario, worldwide demand for natural gas as a transition fuel will continue to grow throughout the coming decade as the US and Europe work to retire coal and ramp up renewables and clean fuels, and as China and India require increased volumes of natural gas to supplant coal-fired generation in their energy mixes.

Even with the implementation of aggressive global decarbonisation policies under an EU Net-Zero case, natural gas will remain a critical transition fuel that continues to grow into the next decade. We project that global natural gas demand will grow by over 807bn m3 by 2035 (a CAGR of 1.3pc). By comparison, under the Global Net-Zero scenario, global gas demand grows by around 558bn m3 at a CAGR of 0.9pc through 2035. This reflects the combined effect of a decade-long decline in gas consumption in the EU and US, offset by increased demand growth in Other Asia, followed by reduced demand growth after 2031 as the Other Asia demand plateaus (see **Fig. 7**).

[15] "JKT" includes Japan, South Korea and Taiwan.

[16] "Other Asia" includes all Asian countries except for the highly developed economies of JKT. The Global Net-Zero scenario assumes that the Other Asia countries implement substantial decarbonisation efforts resulting in a decline in 2013 CO2 emissions of at least 56pc by 2050 (APEC Energy Demand and Supply Outlook, 7th Ed., 2019). Specifically, the low carbon scenario from APEC assumes total gas demand for South and Southeast Asian countries increases by 90.5pc from 2020 to 2040. We adopt this gas demand projection for all of "Other Asia" in our analysis.

Fig. 7: Global gas demand (left) and global net-zero impact [17] on gas demand (right) [18]



As indicated in **Fig. 7**, a Global Net-Zero scenario would produce vast regional disparities in gas demand over the coming decades due to current regional differences in the composition of electricity generation and the realistic speed at which decarbonisation policies can be implemented. We expect that, if global net-zero policies are implemented prior to the early 2030s, then natural gas demand will decline in developed regions, such as North America, Europe, and East Asia (JKT), but increase in the developing markets of Other Asia.

This is because the Asia-Pacific markets are still reliant on coal for 58pc of their total power generation (as of 2019) and, as a first step toward achieving decarbonisation, will need to replace coal with gas and LNG. We forecast that total gas demand in Asia will grow at an average rate of 3.6pc per annum from 2021 to 2035 under the Global Net-Zero scenario and will not begin to plateau until 2031.[19] But within Asia, there are also clear fault lines between the most developed economies of JKT—which have recently pledged similar carbon emissions reductions as Western nations—and the developing economies of China and India. Global Net-Zero causes JKT gas demand to decline by 17pc from 2021 to 2035, as compared with 100pc growth for Other Asia (which includes China and India) over the same time period.

There is comparatively less remaining market space in Europe for natural gas due to its diminishing importance as a transitional fuel in the continent's major economies. As such, we project that natural gas demand in Europe will decline by 32pc under the Global Net-Zero scenario.

US net-zero power generation will liberate natural gas for LNG exports

Under the Global Net-Zero scenario, aggressive implementation of power decarbonisation policies in the US would reduce domestic demand for natural gas, following the retirement of coal and the replacement of gas-fired generation with renewable energy, storage and cleaner fuels. We project that, between 2021 and 2035, annual North American gas demand would fall by over 142bn m3, or 14pc.

As the US implements Biden's target of net-zero power section emissions by 2035, a growing surfeit of domestically produced natural gas would weigh on US gas prices. We expect that Henry Hub prices would fall by $0.54/mn Btu between 2021 and 2035, making US natural gas and LNG exports increasingly competitive relative to other sources of supply.

Given the enhanced competitiveness of North America LNG supplies on the market, we expect that, under the Global Net-Zero scenario from 2021 to 2035, the net total 78bn m3 of LNG export growth would reflect 109bn m3 of increased exports from North America, offset by 31bn m3 of reduced exports from other West of Suez (WOS) and East of Suez (EOS) exporters. These trends are presented in **Fig. 8**.

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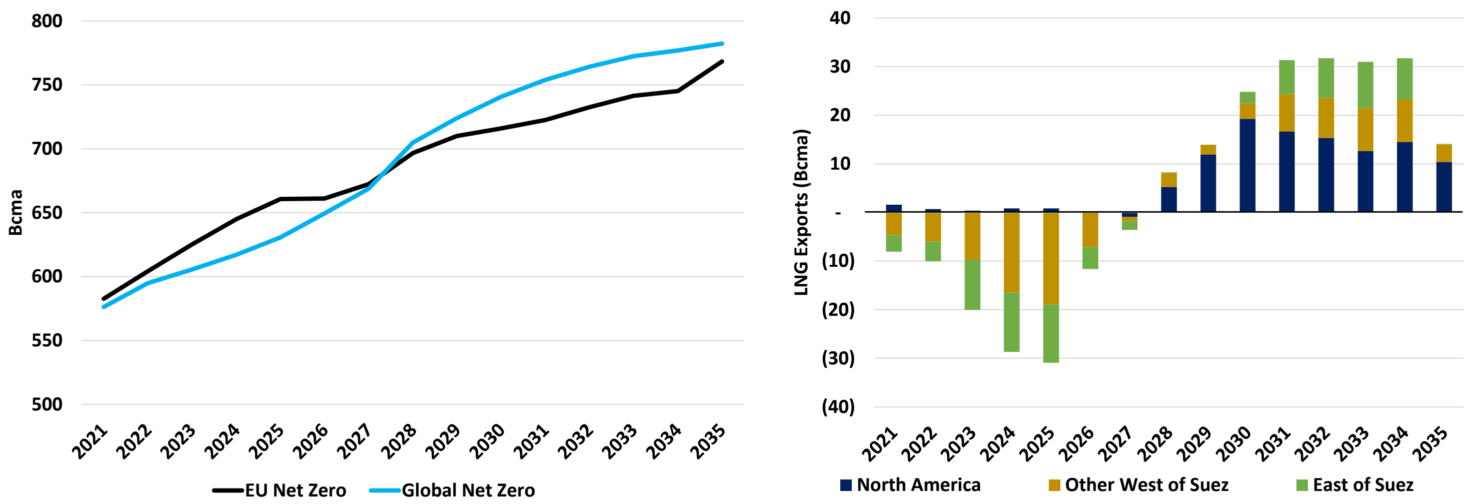
[17] In our analysis, we refer to the "impact" of the Global Net-Zero scenario as compared to the EU Net-Zero scenario.

[18] In this graph, JKT means Japan, South Korea and Taiwan, and FSU means Former Soviet Union.

[19] China is included in the "Other Asia" category shown in **Fig. 7**.

Fig. 8: Global LNG exports (top) and impact of Global Net-Zero on LNG exports (bottom)

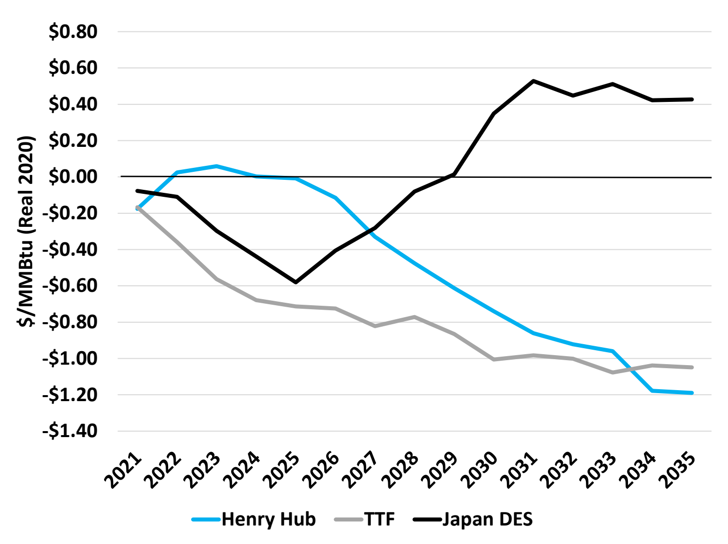


If East Asia, China, India and other developing economies in the Asia-Pacific region also pursue aggressive decarbonisation targets, we expect that North American LNG exports would increasingly flow to EOS markets to assist supplanting Asia's coal generation.

Under Global net-Zero, both natural gas and LNG prices will come under pressure

The magnitude of the regional natural gas price impacts of global net-zero policies is dependent upon the relative natural gas demand and supply in each region. As compared with the EU Net-Zero scenario, the Global Net-Zero scenario on prices by 2035 would reopen the "Asia premium" for LNG prices by reducing US Henry Hub and European TTF prices by $1.19/mn Btu and $1.05/mn Btu, respectively, and increasing JKM prices by $0.43/mn Btu, primarily due to increasing natural gas and LNG demand in China and India (see **Fig. 9**).

Fig. 9: Impact of Global Net-Zero on Hub Prices



Severe winter LNG supply crunch of 2020-21 likely to be brief

As a short-term observation at the time of publication, we note that in December 2020 and January 2021, a perfect storm of unusual planned and unplanned winter LNG supply outages, a shortage of available vessels, congestion at the Panama Canal and extremely cold weather in major LNG consuming markets (Japan, Korea, China, and Spain above all) have caused critical LNG supply and deliverability shortages. This has yielded record-setting Asian spot prices reported in excess of $30/mn Btu, up from only $5 to $7/mn Btu a few months prior.

From late September onward, a series of three unplanned technical outages, plus one longer-than-anticipated planned maintenance, reduced total supply from these facilities by more than 3mn t during mid-November through the first two weeks of January.[20] Globally, total LNG production fell by 1pc year-on-year, to 66mn t from over 67mn t. Further, recent news suggests two additional LNG facilities will also undergo January maintenance,[21] which will likely extend through the end of the month, likely shutting in at least 0.5mn t of production capacity and reducing February supply. Such a large volume of winter LNG supply outages is unusual.[22]

Shipping delays and inefficiencies, due to congestion at the Panama Canal and a scarcity of available tankers, have amplified the deliverability impact of this supply deficit. These supply and deliverability issues coincided with surging winter LNG demand in Northeast Asia as a result of colder-than-average weather. EOS buyers imported approximately 50mn t of LNG, an 8pc year-on-year increase in demand that led US exporters to operate at close to maximum capacity to serve Asian demand, including redirection of cargoes destined for Europe. This produced a surge in demand of 2.2mn t while having a supply decrease of 2.8mn t compared with the 2019–20 winter.

It appears the winter supply crunch will be short-lived once temperatures climb, LNG terminals return to service, the vast LNG tanker orderbook begins to yield new vessel deliveries and Panama Canal constraints are resolved. Notably, JKM futures prices are in steep backwardation, with prices for February, March and April delivery at approximately $19/mn Btu, $9 to $10/mn Btu, and $7/mn Btu, respectively, at the time of publication. □

Getting from here to there: The economic costs of energy transition

Rapidly developing and deploying renewable energy and clean-fuel technologies will require massive investment in new infrastructure, management of stranded asset costs and decommissioning or conversion of old infrastructure. Recent research estimates that the total global cost of the transition for all economic sectors will reach $73tn by 2050 (Stanford), which implies investing almost one year of global GDP over a 30-year time period. One way or another, energy consumers and taxpayers will need to pay for these investments.

In the US, we estimate that Biden's plan to achieve net-zero power generation by 2035 will require $2.3tn in cumulative, levellised capital and operational costs to replace all fossil fuel power assets with renewable energy infrastructure, transmission and batteries.[23] However, this is only part of the economic picture. The retirement of fossil fuel power generation also would eliminate substantial fuel supply costs, which for US power generation in 2019 amounted to $57bn (EIA, Tables A2 & A3). Through 2035, we estimate that the cumulative savings on avoided fossil fuel investments, feedstock fuel and operational costs will reach $1.3tn (levellised). This implies that the US transition to net-zero power generation by 2035 will cost a net amount of $1.0tn (i.e. $2.3tn in costs less $1.3tn in savings). This $1.0tn net cost would increase the levellised wholesale cost of electricity generation by $22/MWh on average over the period from 2021 to 2035, representing an increase of 21pc above the average 2019 US retail electricity price.[24]

In the US and worldwide, over the coming decades of energy transition, the capital costs of new investments will be offset only partially by fossil fuel cost savings. But over the longer term, as the energy transition investment period is completed, fossil fuel cost savings will grow to far exceed the energy transition investments.

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[20] Unplanned technical outages include Ras Laffan (Qatar), Snohvit (Norway), and Bintulu (Malaysia), while the longer-than-expected maintenance took place at Gorgon (Australia).

[21] In early January, the Ichthys project in Australia announced an unplanned outage with no clear end date at the time of publication, and the Bontang project in Indonesia is undergoing planned maintenance that will last until the end of the month.

[22] For liquefaction plants, extended shutdowns for maintenance are rare from mid-November through January, when demand in Northeast Asia and Europe reaches its annual seasonal peak. For example, the only shutdown that took place in 2019 appears to have affected two trains at the North West Shelf facility in Australia, but the plant was able to maintain production.

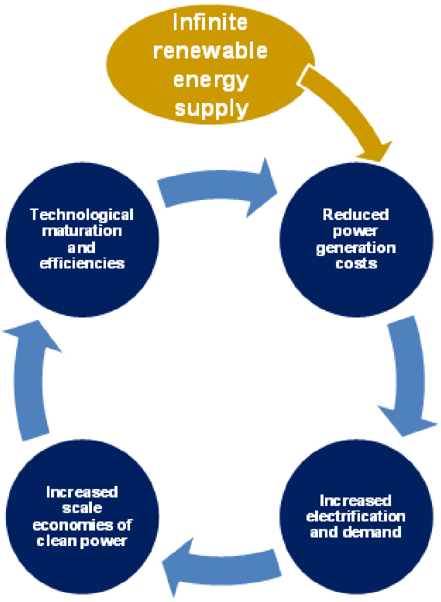
[23] The cumulative annualised costs do not include capital expenditure still being amortised after 2035.

[24] The average 2019 wholesale prices comprise ERCOT, Indiana, Mid C, Nepool, NP15, Palo Verde, PJM, and SP15 (EIA). The average 2019 retail prices comprise the residential, commercial, industrial, and transportation sectors (EIA).

Once the energy transition investments are borne, absorbed, and amortised, average power generation costs will begin to decline toward the future LCOE of renewable energy and storage replacement capex and O&M. Over the long term, electricity supply costs may be reduced further by improvements in wind and solar technical efficiency and battery costs, discharge capabilities, and useful life duration. For this to occur, it will be necessary to tackle substantial R&D, technological maturation, and scale deployment challenges to support the large-scale deployment of renewable energy with stable grid operations at economically competitive costs.

Finally, the decline in electricity costs wrought by the energy transition has the potential to spark a self-reinforcing "virtuous cycle" of sustained cost reductions and demand growth. As infinite and low-cost renewable energy yields increasingly low-cost electricity supply, demand for electricity will increase. Low-cost power from renewable energy will also stimulate the profitable development of clean fuels such as green hydrogen, which requires low-cost electricity for electrolysis. As the scale of electrification grows, this will yield scale economies and promote technology maturation, and thereby further reduce power supply costs that are liberated from the volatility of fossil fuels (see **Fig. 10**). ☐

Fig. 10: Virtuous cycle of renewable energy supply, reduced costs and increased scale



From abundant to infinite: The paradigm shift being wrought by the energy transition

Over the last decade, the technological breakthroughs of the shale revolution brought abundance to global energy markets in a fashion that challenged prior notions of peak oil, obviated resource scarcity, facilitated a massive shift from coal-fired generation to natural gas and reduced GHG emissions substantially. Harnessing ever-greater amounts of the infinite renewable energy supply will require a new paradigm for energy economics and pricing that is built on renewable energy abundance instead of hydrocarbon resource scarcity. After energy transition investments are borne and amortised over the coming decade(s), long-term electricity generation costs will decline in a virtuous cycle of increasing scale and declining costs toward the low, stable fixed costs of renewable energy operations and maintenance. The commercial, economic and geopolitical implications of this paradigm shift are potentially significant and far reaching:

- Commercial: Energy stakeholders that forecast energy transition requirements and economics accurately and invest accordingly will be ideally positioned to profit and thrive during and after the energy transition. Already, fossil fuel companies are repositioning their enterprises to achieve market growth in a net-zero environment by forging new paths in carbon management; carbon capture, utilisation and storage (CCUS); and clean-fuel logistics, storage, and transportation. For example, numerous oil and gas companies already are pursuing net-zero emissions targets and investing massively in renewable power and carbon capture technologies, all while reducing their involvement in oil and gas upstream activities (S&P Global). For example, Chevron invested in Blue Planet Carbon Capture technologies (Reuters), and Occidental Petroleum eventually will use its infrastructure toward carbon emission management (NGI). Meanwhile, European gas utilities are adjusting their current infrastructure to support the energy transition, such as blending hydrogen with natural gas in pipeline networks (GreenTech Media).

- Economic: The countries that champion the replacement of resource-constrained, price-volatile fossil fuels with low-cost and price-stable renewable energy supply also will be the first to enjoy the socioeconomic and foreign trade benefits. The impacts on industrial production of energy-intensive export products and international trade may be substantial. Just as access to vast, low-cost fossil fuel supplies drove the Industrial Revolution and rise of mercantile powers of the last two centuries, the basis of competitive advantage for international trade in this century will be defined by access to infinite, low-cost energy supply from renewable energy.
- Geopolitical: The countries and societies that can marshal or attract the capital and technology needed to master the energy transition will be the first to erase the economic and political power of supply cartels and petrostates. With access to infinite energy supply from nature, energy independence will be available to all, the notion of a supply driven energy crisis would become obsolete, and there would be little incentive for military conflicts regarding fossil fuel supply and/or prices.

In addition to the altruistic objective of averting catastrophic climate change, important strategic and economic objectives and benefits are available to the companies and countries that champion the next stage of energy transition. This is important because achieving the long-term benefits of the energy transition will be technically challenging and operationally costly over the coming decade(s), and therefore the energy transition leaders will require sustained long-term vision and economic fortitude to stay the course. ☐

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