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The "Energy Transition": myth or reality?

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Summary. — Rapid technological advances across a variety of industries are enabling society's quest for sustainability. The resulting "Energy Transition" is causing an unprecedented shift in how the world's population consumes energy and natural resources, driven by a range of factors including decarbonisation, economics, access to energy, societal expectations around environment and climate, energy efficiency, political and regulatory forces and emerging technologies. The "Energy Transition" will occur at different speeds and shapes in different geographies, depending on local economic and societal pressures. World energy demand is continuing to rise, mainly in the emerging economies of India, China and Africa, driven by population growth and economic development. Many countries are trying to do the "right thing" for their population and their economy and are not necessarily driven by a desire to "save the planet". Maximising income to fund important social and education programmes is often higher in the priorities of some governments than reducing carbon emissions. The energy transition is not as simple as doing what is right for the planet. Governments, businesses and people in fossil fuel producing regions have shown that they will protect their economies despite the threat of environmental harm. The fossil fuel era will not be over soon. Despite the rapid growth in the use of renewable energy resources, in all reasonable scenarios there will still be a need for oil, gas and coal for the foreseeable future —if we are to meet the social and economic expectations of the world's growing population. The energy mix will certainly change as we try to reduce carbon emissions, but the speed and magnitude of that change will depend heavily on national economic priorities, political will and public opinion. How fast can we realistically move towards a low carbon future and still meet the world's growing demand for energy? What are the key constraints on the rate of change? —and what role will geoscientist play in driving and delivering the new energy solutions? The "Energy Transition" is a huge responsibility, but also a huge opportunity, one in which we all have our part to play.

1. – Introduction

Many people see the "Energy Transition" in rather simplistic terms as the "*switch from carbon-based to non-carbon-based fuels*", but there is much more debate about the time scale over which this switch can and, indeed, should occur. Expectations of the general public in this regard vary significantly, ranging from "today", to a few years to a few decades.

One widely accepted definition of "The Energy Transition" is *"a pathway towards transformation of the global energy sector from fossil-fuel–based to zero-carbon by the second half of this century*" (IRENA —International Renewable Energy Agency).

Transition implies change, radical change in this case, and radical change cannot happen overnight or it will leave economic disparities and insecurity. Transitioning from our current energy system, with more than 80% of total energy supply coming from fossil fuels, to a more diverse mix of resources dominated by renewables in just a few decades will require unprecedented effort. Many people do not understand just how difficult it will be, and how it will impact them personally [1]. Our fossil-fuel–based energy system is much more fragile than many realize and any significant disruption of this delicately balanced system will inevitably lead to energy and commodity demand/supply imbalances, market volatility and, unless demand is moderated faster than supply, will result in associated price spikes and, ultimately, increased cost to consumers. The global energy market is currently fragmented, vulnerable and precarious.

The global energy scene is already in a state of flux due to both economic and societal drivers. Large-scale shifts in the global energy system are occurring thanks to rapid deployment of, and rapid reduction in the cost of, major renewable energy technologies and a growing shift towards electricity in energy use across the globe. Many countries are trying to do the "right thing" for their economy and populations, but they are not necessarily driven by a desire "to save the planet". Maximising income to fund important social and education programmes is often higher in the priorities of some governments than reducing carbon emissions. At least 25 countries around the world are dependent on their national oil companies for at least 20% of their total government income, with several relying on oil revenues for as much as 90% [2].

Energy transition is happening —and will continue to happen— but it will take different speeds and shapes in different geographies, given various local economic and societal pressures. In all scenarios, there is still a need for oil and gas for the foreseeable future, and the demand for certain earth metals will increase materially —estimates vary, but a 200% increase in demand for aluminium, iron, lead and nickel and a 1000% increase in demand for cobalt, lithium and manganese have been suggested. It is important to remember that renewable energy and other "cleaner" sources of energy also have environmental impacts. It is not the fuel that is the issue, but the environmental impacts.

2. – Historical energy transitions

The current energy transition is not the first to affect humanity. Until the 18th century, the energy supply for industry was dominated by water-powered mills and the use of wood charcoal. Wood charcoal was used for both iron smelting and glassmaking. In the 16th and 17th centuries water-powered hammers began to be used in the production of iron and brass and water supplied the power for the manufacture of gunpowder and paper, and for saw-milling and knife grinding. In the 18th century, the use of charcoal for iron smelting was gradually replaced by coke, first introduced by Abraham Darby at Coalbrookdale in Shropshire, England, in the 1720s. Patents for the production of coke by heating coal in the absence of air, were granted as early as 1590 and, as a fuel, it was critical to the Industrial Revolution in Britain. There simply was not enough wood to power Britain's demand for iron and steel —coke made British blast furnaces more competitive, reducing the price of steel.

By the late 16th century and early 17th century so much woodland in the Weald area of southern England was being cut down to make charcoal for glass and iron production that it pushed up the price of wood for building and domestic heating, leading to social unrest. Queen Elizabeth I introduced laws in 1559 and 1584 restricting the felling of trees in the Weald to make charcoal for iron production and in 1615 King James I prohibited the use of charcoal in glass making. The switch from charcoal and water to coke and coal represents the first great "Energy Transition" in the industrialised world.

The industrial use of coal began in Scotland in 1575 when a pit was sunk under the Firth of Forth by Sir George Bruce of Carnock of Culross using an artificial island with ships drawing up directly alongside to be loaded with coal. Coal, in turn, led to the development of steam power, first introduced by Thomas Savery and Thomas Newcomen nearly simultaneously in around 1712. It provided the technology for Britain to switch to coal power and for 200 years, steam became the power source of industry and transport worldwide.

The first oil wells were dug in China as early as 347 B.C., but the modern oil industry began in 1847 in Derbyshire when a Scottish Chemist called James Young distilled oil seeping into a local coal mine into a thin lamp oil and a thicker oil for lubricating engines. Twelve years later, in 1859, the world's first commercial oil well was drilled in Titusville, Pennsylvania, ushering in the second great global Energy Transition and the beginning of the "Oil Age", leading, in turn to the development of the internal combustion engine and all the energy consuming technologies of modern times. Drake's discovery came at an opportune time as it coincided with the decline in Whale Oil supplies, due to over-hunting. Whale Oil had previously both stimulated and supplied a growing market for lubricants and as a fuel for lighting, heating and cooking.

What can we learn from these historical energy transitions?

1) Transition certainly is not "instantaneous" —charcoal continued to be used for iron making for at least another 100 years and coal continued to be used for power also for at least a century.

2) Transition was generally not the result of running out of a particular source of energy —it just became economically and/or socially more attractive to use something else because of the environmental impact and/or concerns about sustainability.

3) Often government intervention was required to drive the transition.

4) Ultimately, the transition resulted in huge —and often unexpected— social and commercial changes including the growth of new industrial centres and the collapse of industries based on the older energy source.

3. – The benefits of abundant and affordable energy

Since the early 1900s abundant and affordable energy has fuelled huge improvements in the quality of life of billions of people around the world (fig. 1). Abundant and affordable energy helps speed and simplify basic tasks allowing people (usually women) to have more time for other productive work while lighting homes helps improve education by allowing people to read in their homes after dark. Other benefits include better medical care, refrigeration and the use of air conditioning to reduce heat-related deaths in the "heat islands" of over-crowded inner-city areas. Sustainable Development Goal 7 (SDG7) —one of the 17 goals set out by the United Nations General Assembly in 2015— set the ambition of achieving universal access to affordable, reliable, sustainable and modern energy by 2030.

Today 2.5 billion people still have little or no access to affordable energy and rely on cooking and heating homes by burning wood, coal or dung, fuels that fill their homes and lungs with particulates. In 2012, nearly 25% of the population of 105 developing countries (including 57% of the population of Africa) had no access to electricity, leaving a total of some 930 million people in the world "living in the dark". Access to electricity in sub-Saharan Africa is the worst in the world. According to "Tracking SDG7: The Energy Progress Report", produced by a consortium of organisations including the World Bank, the International Energy Agency and the World Health Organisation, 759 million

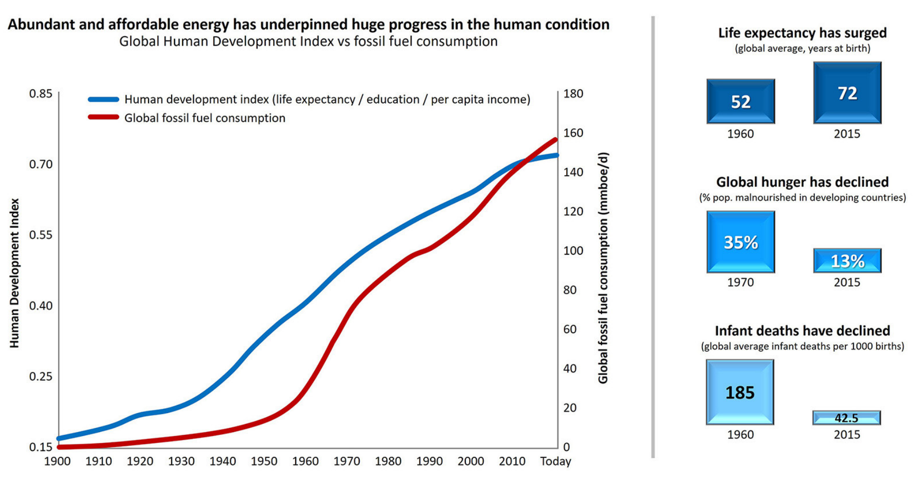


Fig. 1. – Left: energy consumption and quality of life. Right: abundant and affordable energy from fossil fuels has underpinned huge improvements in the quality of life for billions of people around the world for more than a century.

people were without electricity in 2019 and three-quarters of them were in sub-Saharan Africa [3]. More than 70% of health facilities in sub-Saharan Africa have no access to reliable electricity. The limitations that result from a shortage of reliable electrical power range from teachers struggling to conduct lessons in the dark to midwives forced to work with only the weak light from a mobile phone —providing they can find someone with a generator to recharge the phone [3]. Progress in other areas of the world has been much better. By 2019, 94% and 95% of the population in Western Asia and North Africa, respectively, had access to electricity.

Access to energy and energy consumption varies dramatically between different countries (fig. 2). About 3 billion people in the world subsist on the energy equivalent of 2 litres of gasoline a day. People in Europe consume between 7 and 12 litres of gasoline per person per day while, in the U.S. the per capital consumption is 20 litres per day. 90% of households in the United States had air conditioning in 2022 [4]. In India, the annual per capita income (2022) is about 91 000 rupees and the average cost of an air conditioner is about 22 000 rupees or about 25% of total annual income.

Annual per-capita electricity consumption varies from between 4000 and 16000 KWh in much of Europe, and in Australia, the U.S. and Canada to a few 10s of KWh in much of sub-Saharan Africa. A normal domestic fridge consumes 9 times more energy in a year than someone living in Ethiopia!

For the last 200 years, half of humanity has been burning fossil fuels to generate more abundant and affordable energy, and their appetite for energy is still increasing. Meanwhile, the other 3.5 billion people struggle to survive because they do not have access to sufficient or reliable energy, and they aspire to one day enjoy the additional benefits and comforts that energy abundance provides.

Energy poverty is not just a problem in the "developing world". Even in Europe the majority of EU countries have "moderately high" to "extreme" levels of energy poverty

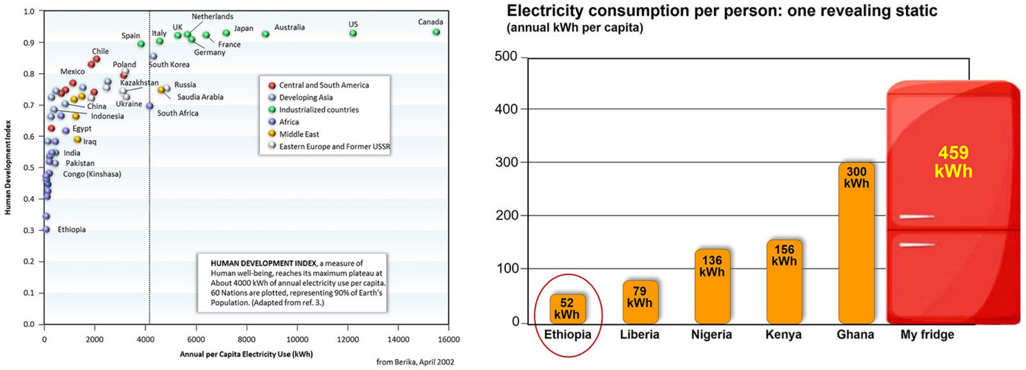


Fig. 2. – Left: human development index *vs.* annual per capita electricity use for 60 nations, representing 90% of the world's population. Right: energy consumption per person (annual kWh per capita) in selected African countries compared with the annual energy consumption of a domestic fridge.

among low-income households (OpenExp, 2019). In some European countries in 2019 up to 22% of households were returning to heating systems based on firewood (20.4%) or coal (1.6%) because of the high cost of other forms of energy, while in one European country 400000 households, primarily in rural areas, were not yet connected to the electricity grid.

Renewable energy sources (particularly off-grid solar power) can make a considerably contribution to alleviating energy poverty in many areas of the world but, in the meantime, the number of coal-fired power stations in Southeast Asia and China continues to grow at an alarming rate as countries in these regions try to keep pace with surging energy demand from their growing populations. Those who live in extreme energy poverty have little capacity to embrace renewable energy sources and for them, at least, decarbonisation is not a priority.

It is estimated that some 2 billion people will still live in energy poverty in 2040 —perhaps 25% of the world's population at that time. How do we lift 2 billion people out of energy poverty while, at the same time minimizing the environmental impacts?

4. – Climate change and greenhouse gas emissions

Humans have emitted about 2500 tons of CO_2 ($GtCO_2$) into the atmosphere since 1850, leaving less than 500 $GtCO_2$ of the remaining carbon budget if we are to keep global warming below 1.5 °C. In other words, the world has collectively burned through 86% of its carbon budget [5]. The U.S. has released more than 509 $GtCO_2$ since 1850 and is responsible for the largest share of historical emissions, about 20% of the global total. China is second with 11%, followed by Russia (7%), Brazil (5%) and a tie between Indonesia, Germany and the U.K. (4% each).

Despite having known about the detrimental effects of climate change since at least the 1980s, nothing much has changed in the last 40 years. Most of us still use fossil fuels to heat our homes and power our cars, we take regular cheap flights and are addicted to energy-consuming technology of mobile phones, wifi and endless TV and radio streaming. Internet use currently accounts for 10% of the world's electricity use and is projected to consume most of the equivalent of the world's entire renewable wind and solar energy production capacity for the next few decades. Air conditioning accounts for another 10% of the world's total electricity demand and is expected to triple by 2050, requiring more new electricity than that already used by the US, EU and Japan combined [6]. Greenhouse gas concentrations in the atmosphere, global sea levels and ocean heat all set record highs in 2021. A pronounced dip in carbon emissions during 2020 during to Covid pandemic was only temporary. Carbon-equivalent emissions from energy, including methane, industrial processes and flaring increased by 5.7% in 2021 [7]. A transition to a cleaner energy is imperative, but global energy demand has quadrupled in just 50 years (fig. 3) and today fossil fuels still supply about 83% of global primary energy demand.

It is important to understand the painful truth that climate change cannot be addressed just with renewable energy —we simply cannot scale solar and wind fast enough to impact emissions at the scale and in the time frame that climate models suggest is necessary without significant technological advances. There are no easy solutions that bal-

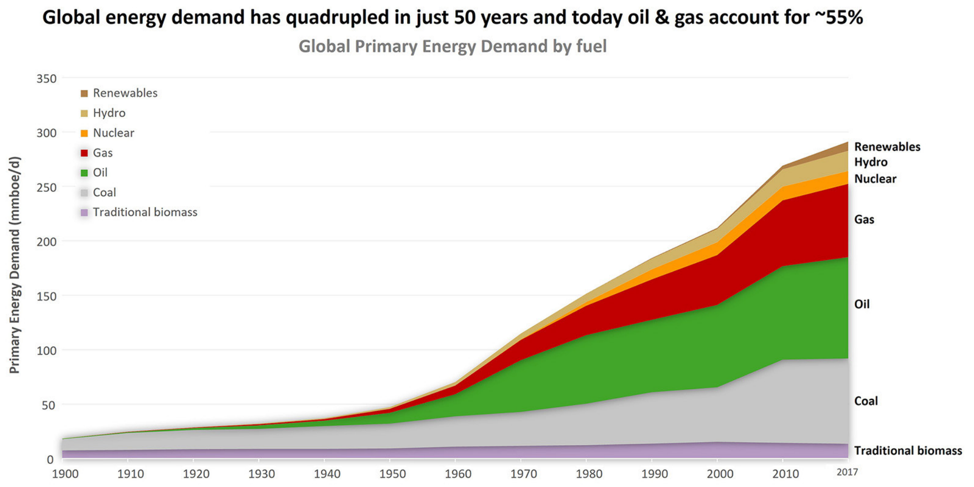


Fig. 3. – Global Primary Energy Demand by fuel type in mmboe/d between 1900 and 2017 (Source: Eni S.p.A.).

ance the growing need for energy with the need to dramatically reduce carbon emissions.

It is clear from almost all analysis that the Accelerated Energy Transition now needed to maintain the global temperature rise to below 1.5 °C will require multiple decarbonisation solutions to be deployed across all sectors of the global economy —power, buildings, industry, transport, plus carbon capture and, potentially, direct air capture of CO_2 (fig. 4). It is also clear that with the currently stated policies the world will not meet

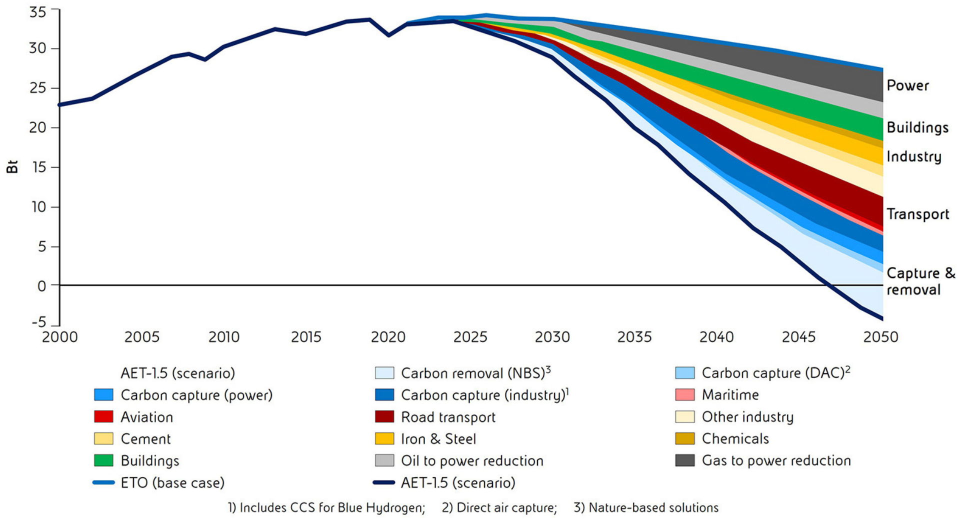


Fig. 4. – We need to deploy multiple solutions to achieve net zero emissions (Source: Wood Mackenzie, 2022 [8].)

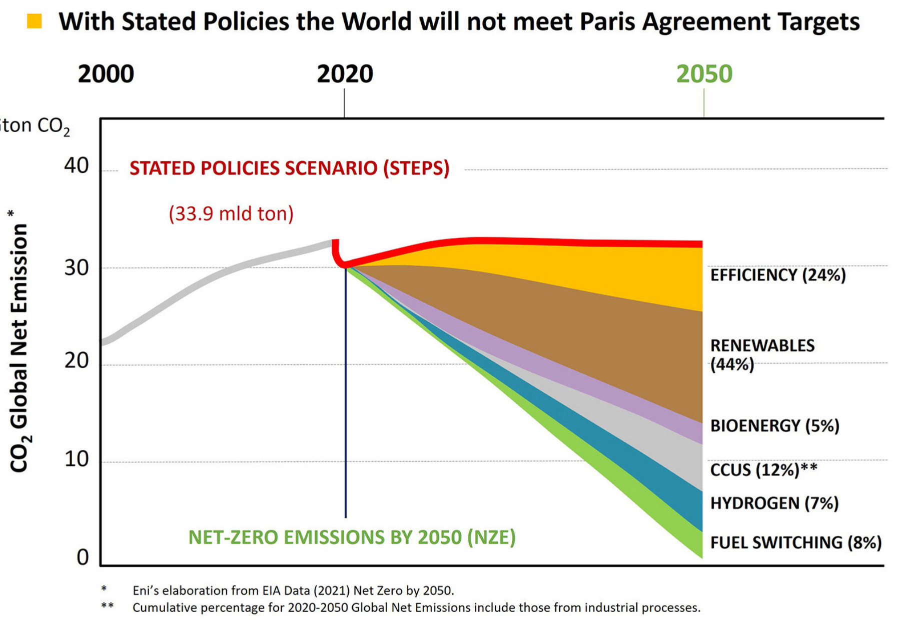


Fig. 5. – Greenhouse Gas Emissions —The Climate Change Challenge (Source: Eni/EIA, 2021).

the Paris Agreement targets. Reaching net zero by 2050 will require further massive reductions through increased efficiency, the use of renewables, bioenergy, CCS, hydrogen and fuel switching (fig. 5).

Different types of oil and gas have different levels of "greenhouse" gas (GHG) emissions (figs. 6, 7). Total lifecycle GHG emissions from gas are ca. 25% lower than GHG emissions

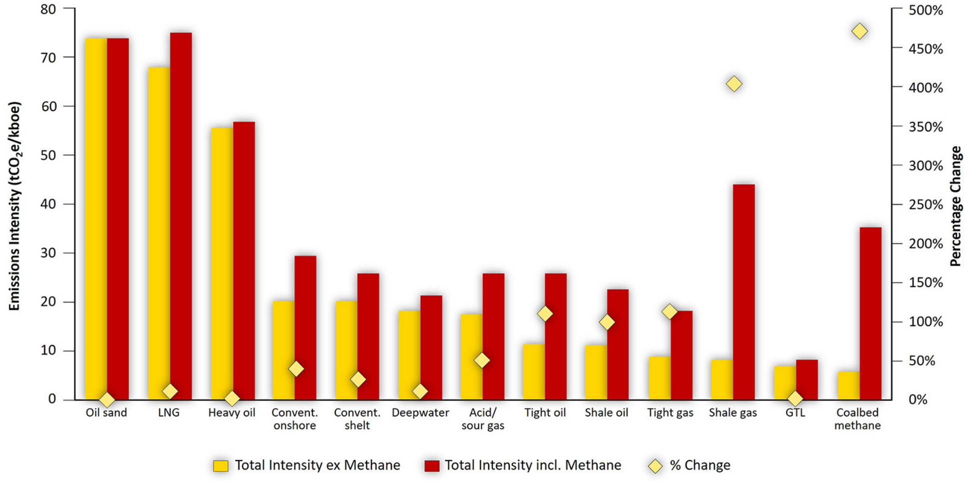


Fig. 6. – Average upstream emissions intensity for different types of oil and gas resource (Source: Wood Mackenzie, 2019).

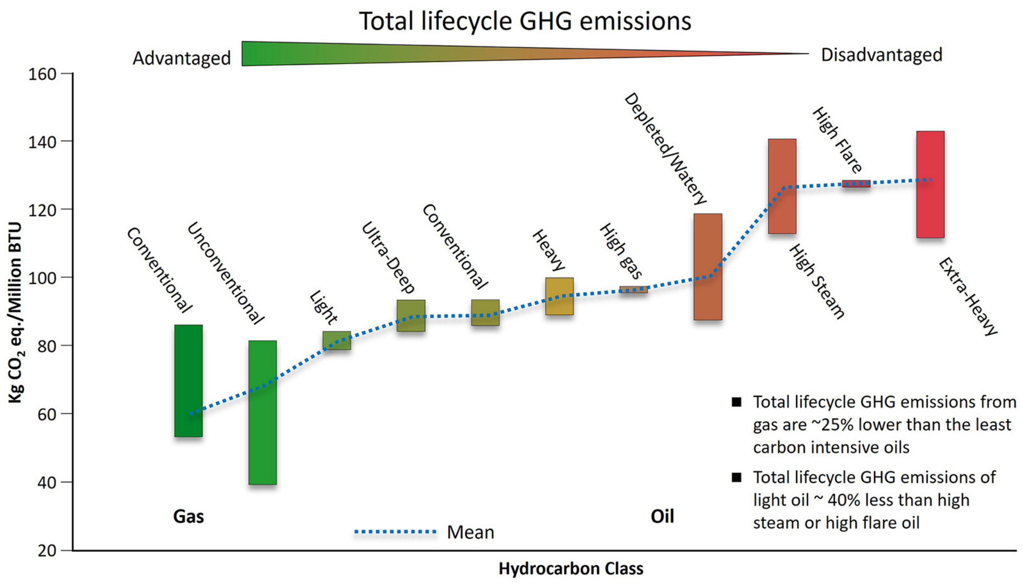


Fig. 7. – Total lifetime GHG emissions for different types of oil and gas resource (Source: Davies and Simmons, 2021 [9]).

from the least carbon intensive oils, while total lifecycle GHG emissions of light oil are at least 40% less than those from oil sands and heavy oils. Liquified Natural Gas (LNG) has high emissions intensity (fig. 6) because of the heavy power requirement for liquefaction, transportation and regasification. In the future we will have to use renewable energy for the liquefaction and degasification and some of the LNG cargo to power the tankers which transport LNG around the world.

Low-cost, low carbon-intensive oil and gas resources (so-called "advantaged" hydrocarbons; fig. 7) will be needed to replace high-cost, high carbon-emission production.

5. – Global energy demand: history and prediction

World energy consumption is continuing to rise, mainly in new emerging economies, where accelerating energy demand is driven by population growth (fig. 8) and economic development. The latest estimates from the United Nations, released in July 2022, are that world population will continue to grow until 2086, peaking at just over 10.4 billion people, somewhat lower than earlier estimates of 13 billion by 2100. The growth is partly the result of declining levels of mortality, particularly in children, and an increase in life expectancy. With rising population, but moderating energy intensities, overall global energy demand will slow. It is expected to increase from 13 Btoe in 2018 to 16 Btoe in 2040 —a growth rate of just 1%, half the rate of the past decade. The global energy mix is changing only gradually and, if this does not change, the world is likely to rely heavily on fossil fuels for decades to come. Most current forecasts suggest that coal, gas and

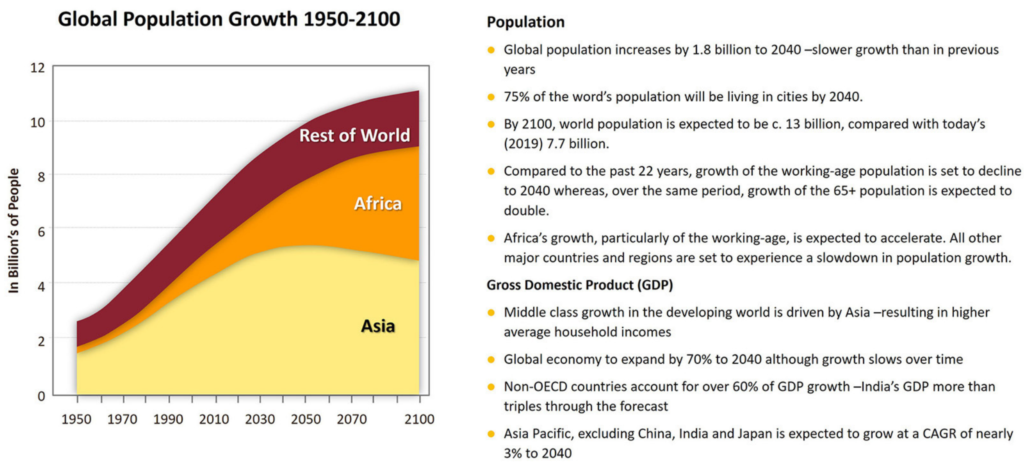


Fig. 8. – Global population growth, 1950–2100 and population and Gross Domestic Product (GDP) trends to 2040.

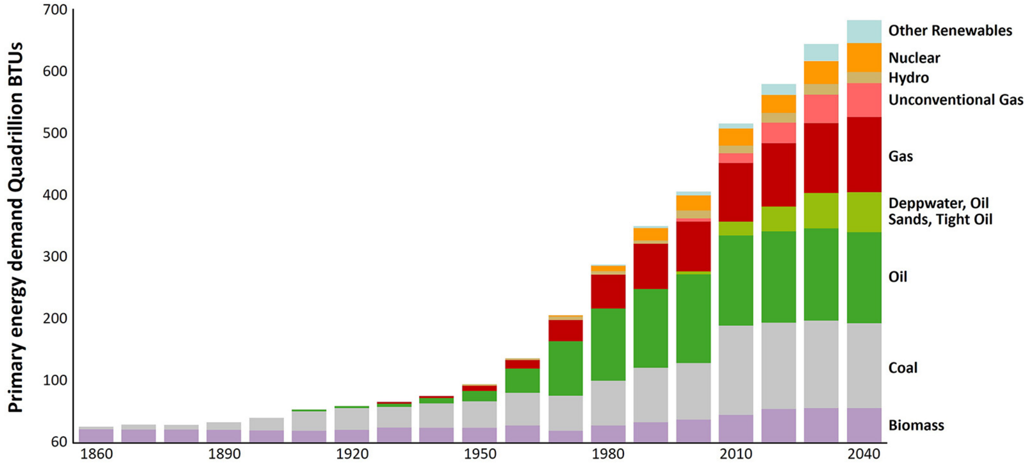


Fig. 9. – Evolution of global energy demand, 1860–2040. Primary energy demand in quadrillion British Thermal Units (BTUs).

oil will still contribute around 85% of primary energy supply by 2040, much the same as today (fig. 9). Availability of resource, infrastructure and cost competitiveness (lack of a realistic carbon price) keeps fossil fuels resilient. Overall, global energy demand is expected to increase by about 25% between 2010 and 2040, due primarily to population growth in emerging economies. Cutting-edge technologies must be employed to meet that demand while simultaneously decreasing greenhouse gas emissions to slow climate change.

Wind and solar will contribute about 25% of global power supply by 2040 compared with about 7% today, but zero-carbon energy (nuclear, hydro, wind and solar) will remain a relatively small part of the overall energy mix. In rural areas, small-scale or off-grid renewable energy systems (mostly solar) are expected to play an increasingly important role, but the infrastructure requires a lot of maintenance. Renewables, excluding hydroelectric, continue to increase their share of global power generation with strong expansion in solar and wind energy. In 2020, approximately 10% of global electricity generation was from renewable sources, but this was at least in part due to lower demand from large coal, oil and gas-fired power stations during "lockdowns" because of the Covid pandemic. Renewables share in global power generation reached almost 13% in 2021, considerably higher than nuclear energy at 9.8% [7].

In 2021, wind energy already formed a significant proportion of total electricity generation in some European countries – Denmark (48%), Ireland (33%), Portugal (27%), Luxembourg (25%), Spain (23%), United Kingdom (21%), Germany (20%) and Greece (20%) [10]. In the United States, wind energy provided 9% of total electricity supply in 2021, with an average levelised cost of $32/MWh, about the same cost as to produce energy from any other source [4]. In the United Kingdom, the cost of electricity generated by offshore wind farms reached an all-time low of £37.35/MWh (c. $44.25/MWh) in 2021.

About 22% of electricity in the United States was generated from renewable sources (hydropower, wind, solar) in 2022 and this is expected to reach 24% in 2023. In 2022, the United Kingdom (29%), China (28%) and Germany (22%) accounted for more than 75% of global installed offshore wind power capacity. The 1.2 GW Hornsea Project One in the UK was the world's largest offshore wind farm in 2022. One full rotation of a wind turbine will power a typical home in the west for one full day.

In major OECD markets, wind and solar's share of power output will range from 35% to 50% by 2040, but globally, wind, solar, geothermal and hydro will still only contribute about 10% to global power demand by 2040, largely because we will continually trying to keep up with the rising global energy demand. To achieve net zero by 2050 probably requires that wind and solar energy scale rapidly to account for 61% of a significantly larger power market in which electricity dominates, providing 48% of the world's energy consumption [8]. At present there are significant technological limitations —particularly around long-duration storage— in reaching a fuel mix comprised of 50% or greater share for solar and wind. Longer duration and cheaper storage are the key to high renewables penetration.

How do we meet our future energy needs while, at the same time, reducing carbon emissions from fossil fuels?

6. – World energy growth by region 2015–2035

India and China will lead energy demand growth over the period 2015–50, while China peaks and OECD (Organisation for Economic Cooperation & Development, 36 member states) markets decline. Since 2010, the growth rate in energy demand in the Asia Pacific region has been ca. 35%, while it has been nearly flat in North America and Europe. By 2040, energy demand in the Asia Pacific region will be 3× larger than North America's

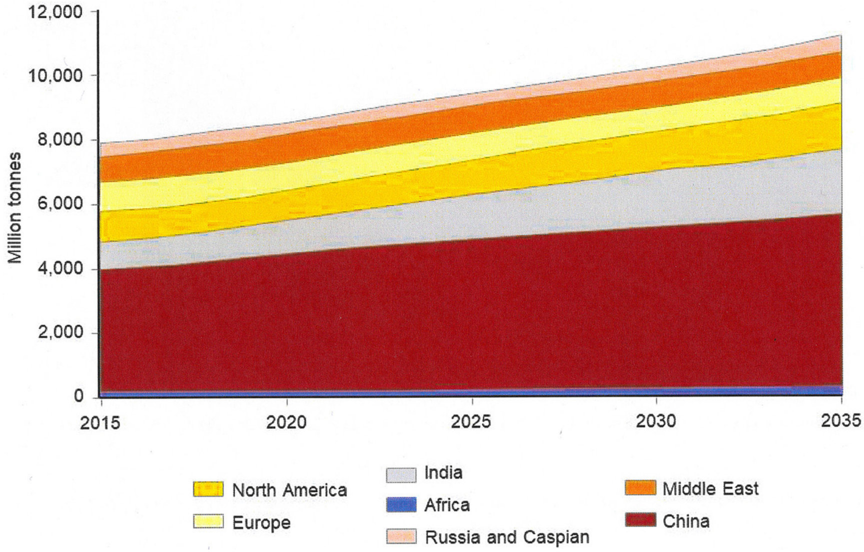


Fig. 10. – World primary energy demand by region, 2015–2035 (Source: Wood Mackenzie, October 2015).

total energy market. About 70% of world energy demand growth to 2040 will be in Asia, driven by China and India (fig. 10).

Four regions of the world —United States, Middle East/North Africa, Russia and China— account for the majority of global hydrocarbon production. Monthly crude oil production in the United States exceeded 10 mbpd in 2019, the highest since 1970. Currently, crude oil, natural gas, and other petroleum products represent 92% of primary energy resources in the United States (EIA, August 2020). The same sources produce 39% of the electricity used in the United States and 91% of the transportation fuel used in the United States is petroleum-derived (EIA, 2019).

In Wood Mackenzie's 1.5 °C "accelerated energy transition scenario" (AET-1.5), oil demand falls from ca. 100 million b/d today to 70 million b/d in 2035 and 35 million b/d in 2050 [8]. Even in this "1.5-degree scenario" world, investment in oil and gas is required as supply from onstream fields declines by about 40 mb/d between now and 2040 —ca. 2 million barrels per year— and low-cost, low carbon-intensive oil and gas resources (so-called "advantaged" hydrocarbons) will be needed to replace high-cost, high carbon-emission production.

The hydrocarbon era will not be over soon. According to a recent McKinsey study, fossil fuel use might flatten from 2035, with oil and coal in decline, but gas use will continue to increase. The great benefit of oil is its portability and its high energy intensity per unit volume. If we could use crude oil without the emissions we certainly would because it is one of the most energy dense forms of energy we have. One barrel of oil contains 5.7 Million BTU of energy —the equivalent of a human working 8 hours a day, 5 days a week for 10 years! (fig. 11).

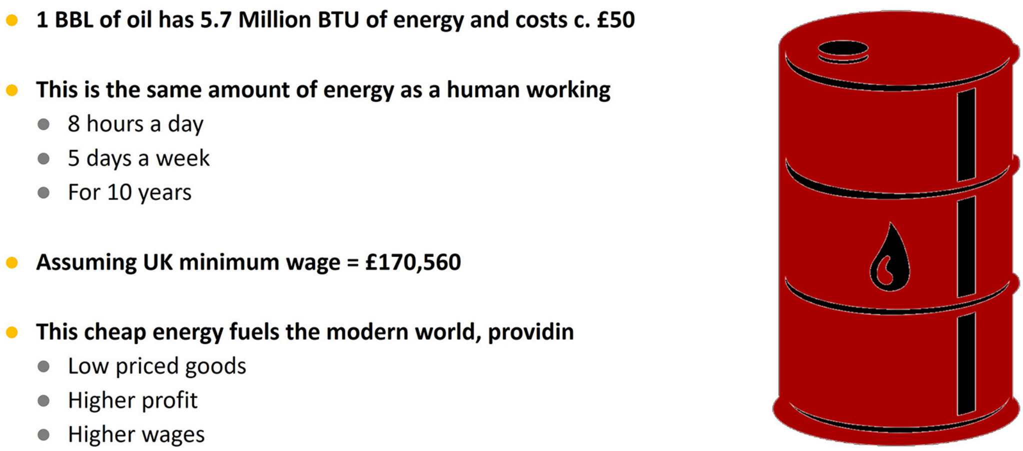


Fig. 11. – The real value of a barrel of oil (Courtesy of Mike Simmons, Haliburton Landmark).

In the next decade, liquids demand growth will be fuelled by chemicals and transport. Today, the world consumes about 100 million barrels of oil per day —the equivalent of about 2 litres of oil for every man, woman and child on the planet every day. We have a serious addiction to oil!

The accelerated energy transition requires more low-carbon energy, sooner and faster. In the early stages we will have to rely heavily on commercially proven technologies — mainly wind, solar and electric vehicles, but hydrogen/ammonia, CCUS, long-duration battery storage, nuclear (Small Modular Reactors), geothermal and bioenergy will all have a role to play. The world cannot just switch off fossil fuels —we have to wait until the low-carbon alternatives and innovation can deliver at scale. Modern society must create a new energy system in which both generation and sustainability are compatible.

Global coal demand is expected to peak in the next decade (some analysts consider it peaked in 2014), largely due to the rapid and intentional displacement of coal with gas as the power sector goes low carbon. In the United States and the United Kingdom, for example, electricity generation is moving away, or has moved away, from coal-fired plants with natural gas and renewable energy sources predicted to meet future demand. However, governments elsewhere must be convinced that gas is a viable and profitable alternative to coal.

While coal use for power generation will fall to zero in some Western European markets, in some other economies, like India, large populations will be connected to the electricity grid using a coal-heavy fuel mix. In 2021 coal-fired power generation reached an all-time record (10 244 terawatt-hours). In early 2022 new coal-fired power plants were under construction in China, India, Indonesia, Turkey, Mongolia, Vietnam, Singapore, Zimbabwe, South Africa, Greece, Bosnia and Hertzegovina, Serbia, Poland, Kazakhstan, Colombia, Brazil and Mexico. Vietnam's energy policy calls for doubling its power production from coal. China, India and Indonesia were the top 3 countries in 2022 in terms of the percentage of their electricity generation that comes from coal-fired power stations [11]. China and India between them accounted for more than 70% of the increase in coal-fired power generation between 2021 and 2022. Currently, about 70% of India's power is coal-based. India's coal-fired power plants are so inefficient that it has been suggested that the government could feasibly shut down 20–30% of them without major disruptions to the country's energy supply. India has introduced a moratorium on all new coal projects from 2027, with solar currently being cheaper than coal in India. At COP26 in November 2021, Indian Prime Minister Narendra Modi pledged to cut India's carbon emissions by one billion tonnes and reduce the carbon intensity of the economy by 45% by 2030 by installing 500 GW of renewable-energy capacity. India remains decades behind the renewable capacity of other economic powerhouses, such as China. India, with a current population of 1.4 billion people, is set to surpass China as the world's most populous country in 2023.

China is investing heavily in renewables, but it will still be almost 50% dependent on coal for power in 2040. The energy mix in China is changing fast —China will invest 343 billion euros between 2017 and 2020 in wind, nuclear, hydro and solar to replace their coal-fired electricity generation. China's ambition is to create 13 million jobs in renewable energy and provide their population with cleaner air. China has also said that it will not build new coal-fired power stations abroad and that it will increase support for green energy projects in developing countries. China is a major producer and importer of coal, but in 2022 Russia discounted its coal prices so much that China began importing Russian coal and stockpiling its own. Before Russia discounted its price, the lowest price coal in the region was $210/ton shipped from the Port of Newcastle in Australia. Russia discounted its price to $150/ton. Indonesia responded to the price war by discounting its coal prices below Russia's [12].

Coal's share in world electricity output reached 41% in 2014 but will decline to 25% by 2040. However, currently strong growth in coal demand in India and other developing markets is partially offsetting declining demand in OECD countries and in China. In the United States CO_2 emissions have gone down due to a surge in shale gas production, which replaces coal. Cheap US coal exported to Asia and Europe is increasing emissions there. U.S. coal exports increased by 61% in 2017 as exports to Asia more than doubled. Meanwhile, the coal industry in the U.S. continues to grow, especially for metallurgical coal used by the steel industry.

Global primary energy production increased by almost 6% in 2021, reflecting the world's post-pandemic recovery. The increase in primary energy production between 2019 and 2021 was almost entirely driven by renewable energy sources. The level of fossil fuel consumption remained largely unchanged between 2019 and 2021, with lower oil demand offset by higher natural gas and coal consumption [7].

7. – Future global oil and gas demand

Global oil demand is expected to peak in the next two decades (ca. 2035) at around 112 million b/d of liquids with a slow decline by 2040 (fig. 12). Technological and

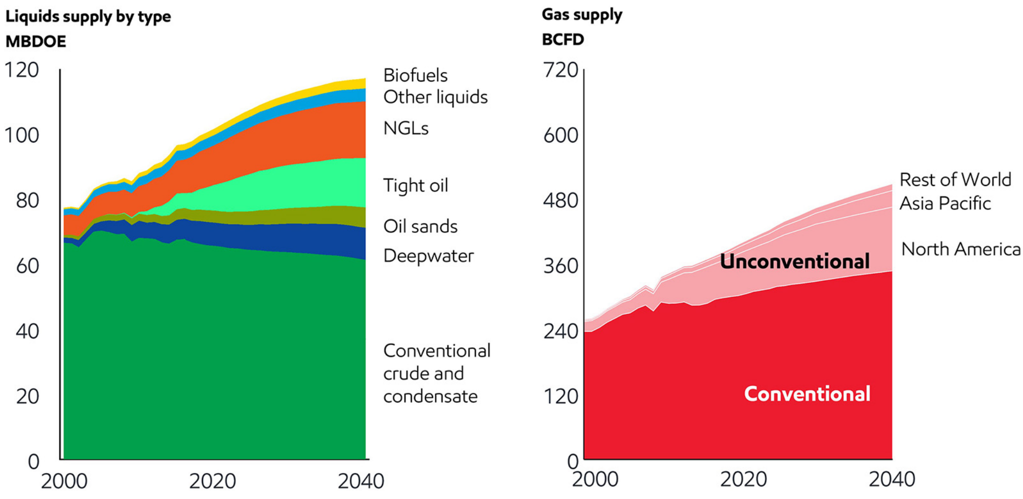


Fig. 12. – Global liquids supply by type in million barrels per day oil equivalent and gas supply by type and region in billion cubic feet per day, 2000–2040 (Source: ExxonMobil, 2017).

economic competition for oil is coming with a shift from oil-based transport to electricity-based transport. The question is "when" rather than "if". Oil's resilience depends on continued petrochemicals demand (the largest proportion of oil demand growth in next two decades) despite moves to address single plastics use. Oil demand is expected to fall in Europe and North America due to fuel efficiency and energy transition (fig. 13), but the International Energy Agency expects global demand for oil to increase from 96.5 MMbopd in 2021 to 104.1 MMbopd in 2026.

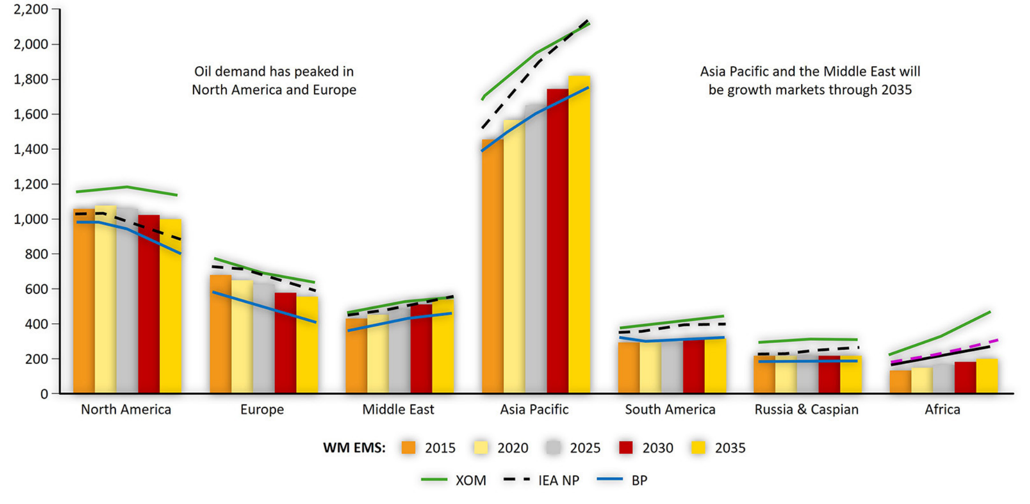


Fig. 13. – World oil demand by region, 2015–2035 (Source: Wood Mackenzie, 2017).

Global gas demand is expected to continue to grow until at least 2040 (fig. 12) with the pace determined by affordability of gas relative to other fuels and technologies — and the policies that governments put in place to tackle climate change. Demand for gas is expected to expand by 30% from 2020–2040. Gas is a foundation fuel for the energy transition —not a bridge— meeting low carbon goals in heating, and a flexible source of power generation. About 35% of the UK's electricity is currently produced by gas-fired power stations, but about 50% of all the gas consumed in the U.K. (including both electricity generation and domestic consumption) is imported. This heavy reliance on gas imports, primarily from Russia and Qatar, raises serious concerns about security of supply, concerns which are amplified by the fact that the UK has little or no gas storage capacity. Following the Russian invasion of Ukraine in 2022, Europe is looking to cease imports of Russian gas completely and is looking to alternative sources of piped gas and LNG. In May 2022, the price of natural gas averaged $8.14 MMBtu (million British thermal units); exactly one year earlier, it was $2.91/MMBtu. In June 2022, total European Union LNG imports from the US exceeded imports of gas by pipeline from Russia for the first time [13]. Global LNG demand will grow strongly as indigenous production in major consuming markets either declines or struggles to increase.

Why gas?
When burned cleanly, gas releases about half as much carbon as coal. Cleaner electricity generation means economies can grow and produce lower emissions if they replace coal-generation with gas-generation. In the U.S. gas is now so abundant that producers cannot find enough domestic demand, so they are rushing to export.

But. . . .
Excess gas from oil wells is sometimes burned off by "flaring", releasing carbon dioxide. Gas leaking from pipelines and processing plants adds methane to the atmosphere —methane is 84 times more efficient at trapping heat in the atmosphere than carbon dioxide over a 20-year period. This is currently the "Achilles heel" of the gas industry.

8. – Climate change and the future energy mix

The global energy system needs to move sharply towards a global warming pathway limited to 2 °C or lower, but despite great efforts to reduce costs in renewables, electricity, zero-carbon technologies and advanced transportation —not to mention burgeoning support in governmental polices worldwide— we are still way off track! The global backdrop has become more challenging and more polarized —with less collaboration. Polices being promoted by the EU and smaller economies are helpful, but larger, energy-dense countries and energy-rich segments generally lack any serious progress. The Russian invasion of Ukraine in 2022 has heightened concerns about energy security. Many countries that rely heavily on fossil fuel imports will want to diversify their supply of gas, coal and oil away from Russia to other sources and will place increased effort on developing low-carbon energy sources —more renewables, nuclear and hydrogen— to bolster energy security.

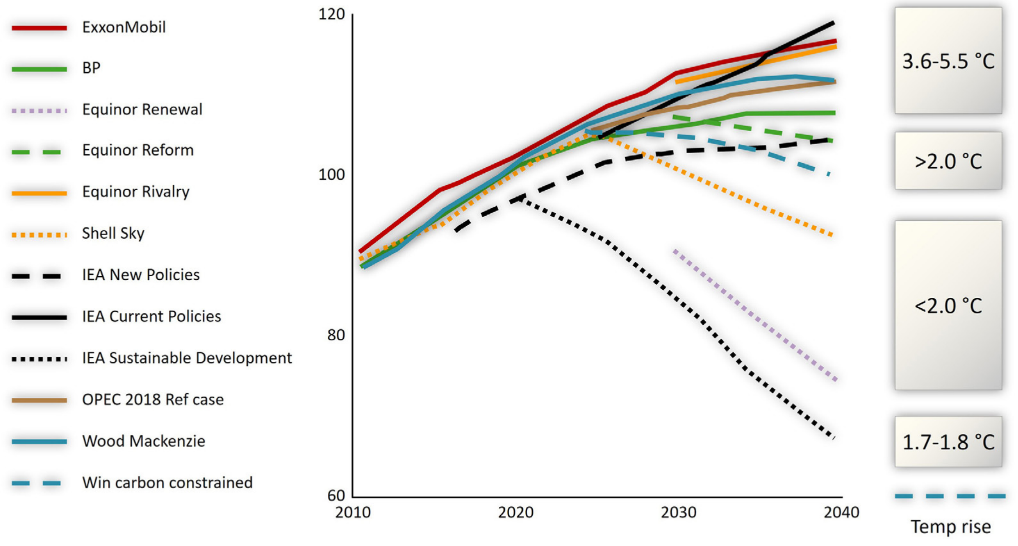


Fig. 14. – Global oil demand predictions in millions of barrels per day, 2010–2040 and the associated projected rise in global average temperature by 2100 (Source: Wood Mackenzie, April 2019).

Most predictions indicate that oil demand is set to rise to 110 million b/d or more by 2040 (fig. 14), but if these demand projections are realised, without equivalent carbon offsets elsewhere, climate science is telling us that the result will be a rise in global temperatures of somewhere between 3.5 and 5.5 °C —which would be catastrophic. Scenarios that work back from a 2 °C limit (IEA Sustainable Development, Shell SKY, Equinor renewable, for example) all infer a peak in oil demand in the 2020s followed by a drop to 70–90 million b/d by 2040 or 65–70 million b/d to achieve a 1.5 °C limit (fig. 14). To reach the International Energy Agency's zero-carbon target requires EV sales, efficiency gains and nuclear capacity at 2–3× most reasonable forecasts and carbon prices in excess of \$100/t and probably reaching a global average of \$175/t by 2050 [8]. At the peak of the Covid pandemic in 2020, with few planes flying and few vehicles on the roads, the world was still consuming about 80 million barrels of oil per day.

To accelerate the shift to a 2-degree world, governments need to incentivise development of low carbon technologies —decarbonisation of the industrial sector, the rise of hydrogen fuel and CCS are essential technologies to accelerate the energy transition.

Data from the International Energy Agency allows us to envisage two different scenarios for the future of world energy supply (fig. 15):

- A Stated Polices Scenario, based on existing commitments (but with an assumption that not all of these will be met) with a post-Covid recovery followed by increasing supply, with coal, oil and gas essentially unchanged through 2025 to 2040.

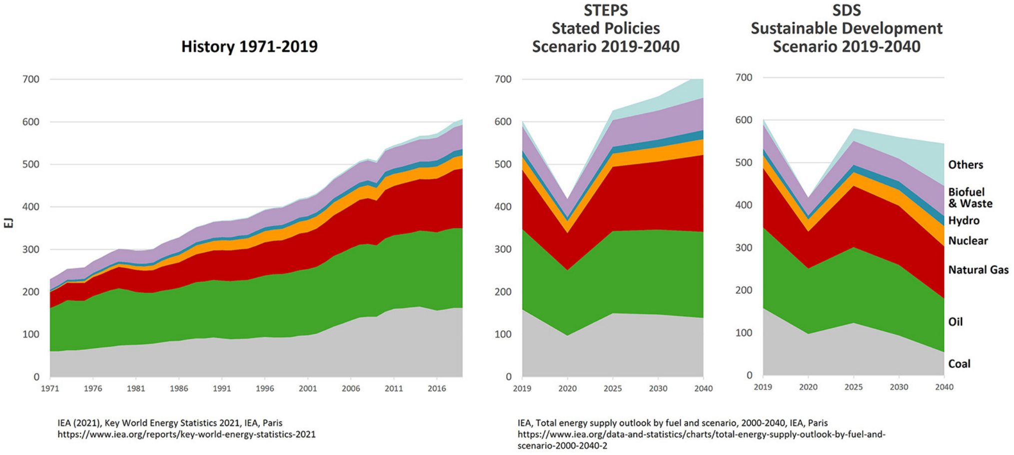


Fig. 15. – World energy supply by source, 1971–2019 and predicted 2019–2040 (Source: International Energy Agency, 2021).

- A Sustainable Development Scenario with a post-Covid recovery followed by a steady decline in overall supply, with coal, oil and natural gas all in decline, and coal "phased down" rapidly between 2025 and 2040.

Overall, the current level of investment in oil and gas is caught between two different visions of the future: it is too high for a pathway aligned with limited global warming to $1.5\,^{\circ}$C, but not enough to satisfy rising demand [14].

The rapid increase in energy demand as the world emerged from the Covid-19 pandemic led to a severe demand-supply imbalance and a consequent rapid increase in global oil and gas prices. Between April 2020 and the end of 2021, natural gas prices rose from about \$3-\$4 per MMbtu to about \$40 per MMbtu, a 10-fold increase [15]. The demand-supply imbalance was then further exacerbated by the Russian invasion of Ukraine in February 2022, leading to concerns about energy security and potential gas shortages, particularly in Europe, resulting in further increases in the price of gas in Europe.

There are no easy solutions that balance the growing need for energy with the need to dramatically reduce carbon emissions.

So, how do we meet our future energy needs while, at the same time, reducing carbon emissions from fossil fuels? Will forecasts for sustained oil demand growth "prevail" over scientific warnings of the consequences of that growth?

9. – Why is it so hard to decarbonise?

Some parts of the global economy are more difficult to decarbonise than others. Most projections of global energy demand indicate significantly increasing demand for energy for electricity generation, industrial use and transportation (*e.g.* fig. 16). Only in the residential/commercial sector is the demand for energy expected to remain rel-

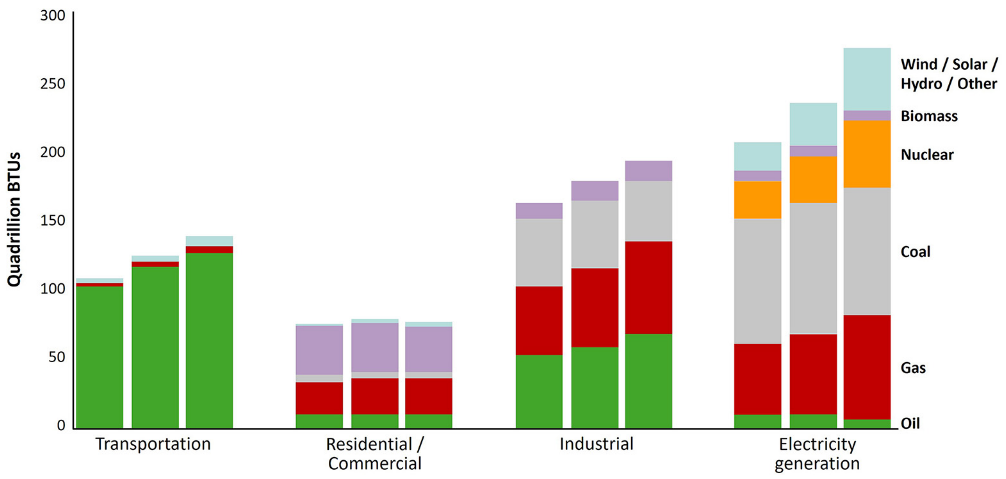


Fig. 16. – Global energy demand by sector, 2016–2040 (Source: ExxonMobil, 2017).

atively flat, partly due to the expectation of improved efficiency in the insulation of buildings. Heating remains the largest source of greenhouse gas emissions in the UK. Most of the heating in our buildings and industries is delivered by fossil fuels; natural gas remains the predominant source of heating for most customers connected to the grid.

Renewable energy sources are expected to make a significant contribution to energy demand in the future, but by 2040 oil and gas are still expected to account for about 30% with the proportion of oil declining and gas increasing.

There is predicted to be very little contribution of renewable energy to the industrial sector by 2040 as this is primarily feedstock for petrochemicals and industrial processes. Crude oil is a vital raw material used in the manufacture of everything from mobile phones to fabrics, lubricants, agricultural chemicals, pharmaceuticals, and many other items (fig. 17). Wind turbines will not work without durable hydrocarbon-based coverings for the blades and electric vehicles will not achieve driving ranges exceeding 300 miles without high strength and lightweight plastics. Each electric vehicle requires 772 pounds/c.350 kg of petrochemicals for its paint, vents, headlights, mirrors, tires, handles, seats, computers, dashboard, trim, body and steering wheel. About 1 billion barrels of oil will be required for the petrochemicals needed to make the 300–500 million new electric vehicles expected to be manufactured over the next 20 years [16].

The petrochemicals industry is growing extremely fast (+6% per annum in 2022), primarily due to increasing demand in the construction, textile, medical, pharmaceuticals, consumer goods, automotive and electronics industries. Asia is the fastest growing petrochemical market. The highest demand is for ethylene, propylene and benzene, used for packaging, electronics, plastics and rubber [11].

Fig. 17. – Benefits and uses of oil and gas. Natural hydrocarbons and their derivatives are central to modern life today. In many demand sectors there are no viable substitutes yet.

In 2019, 6% of global oil demand went into production of plastic. By 2050, as other parts of the economy decarbonise, plastics may well be responsible for 15% of all greenhouse gas emissions [17].

The transportation sector is expected to remain predominantly reliant on oil to 2040 and probably beyond. Of the ca. 100 million b/d of global oil demand today, fuel use for light vehicles and two-wheelers accounts for over 28 million b/d. This is expected to rise slowly to 29 million by 2025 (largely due to the impact of increases in engine efficiency) and then decline after 2030 due to an accelerating shift to electric vehicles. 97% of vehicles still run on fossil fuels and this proportion is only expected to reduce to 42% by 2040. Fuel demand for cars and two-wheelers in India is expected to increase by over 50% between now and 2025.

Increased use of electric cars could be an important "tipping point" in the Energy Transition and could have a significant impact on oil demand within the next few years. The passenger fleet will probably be the first sector to make the switch to electric vehicles. Electrifying the lorry and agricultural vehicle fleets faces many problems. Sales of new cars powered by internal combustion engines are already subject to planned bans in some countries. In the UK the uptake of electric vehicles is slow —only about 2%— largely because the cost of an electric car is still in the range of £30000 (Nissan Leaf and VW e-Golf) to £70000 (Audi e/Tron), too much for the majority (even with the Government's

£3500 grant), and the maximum range is still only ca. 300 miles. The current nationwide network of about 25000 charging points needs to be rapidly expanded.

Only about 2% of passenger car sales in 2018 worldwide involved electric car technology. This is expected to increase to nearly 35% of total passenger car sales in 2040. However, if the Chinese government decided to shift China to electric cars this could happen within 4/5 years and Chinese power systems are already designed to accommodate this. The use of electric vehicles is a good way to decarbonise the transportation sector except in countries —like China and India— where a significant proportion of electricity generation capacity is from coal-fired power stations. The limiting factor for transition to an electric vehicle fleet in many countries will probably be the charging infrastructure. Fuel efficiency gains in transport are expected to have a larger impact than electric vehicles on reducing oil demand to 2040.

Oil has, so far, stubbornly resisted giving way to batteries. This is largely because vehicles need to carry their own source of power with them —the lighter the better. A kilogram of petrol stores as much energy as 60 kg of batteries and has the convenient property of disappearing after use. Empty batteries, alas, are just as heavy as full ones!

While electric cars are finally starting to break through, electric Jumbo jets are a much tougher challenge! Improvements in energy efficiency and increasing the use of biojet fuels is key to decarbonising the aviation sector. Diesel and aviation fuels will probably remain important for the foreseeable future. Transport and heavy industry are responsible for more than 45% of global CO_2 emissions (fig. 18 [18]).

How difficulty would it be to remove hydrocarbons from the energy mix by 2050? Answer: Very! (fig. 19).

Segment progress report

Sub-sector	% 2018 share emissions	What's being done	Challenge	Progress
Power	34%	Cost tailwinds allow RE to increase at pace	Long-duration storage a barrier	
Road Transport	18%	EV penetration growing in light-duty vehicles, policy support in cities	Cost, charging, heavy-duty transport and raw materials	
RCA (low temp heat)	10%	Fuel substitution (coal-to gas, or to electricity)	Economics and technology	
Aviation, Shipping, Other Ind.	20%	Pilot testing using electricity, Synfuels, Hydrogen, Ammonia	Economics and technology	
Steel	9%	Pilot testing using Hydrogen, HI-Smelt, biofuels and CCS	Economics and technology	
Cement	9%	Pilot testing using Hydrogen, biofuels and CCS	Economics and technology	
Agriculture and Farming	Included in RCA	Intelligent use of fertilizers, soil productivity, vertical farming	Economics and technology	

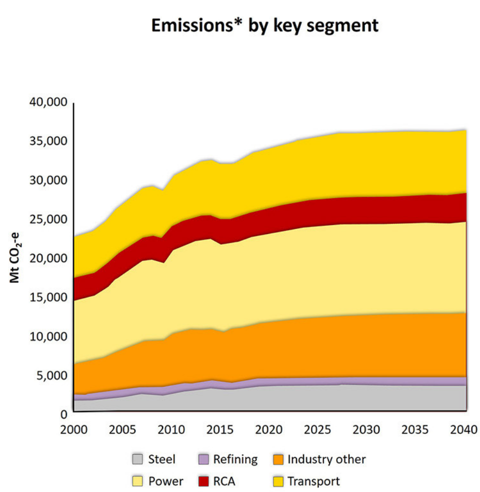


Fig. 18. – Why is it so challenging to decarbonise? Some segments of the global economy are hard to decarbonise (Source: Wood Mackenzie, 2019).

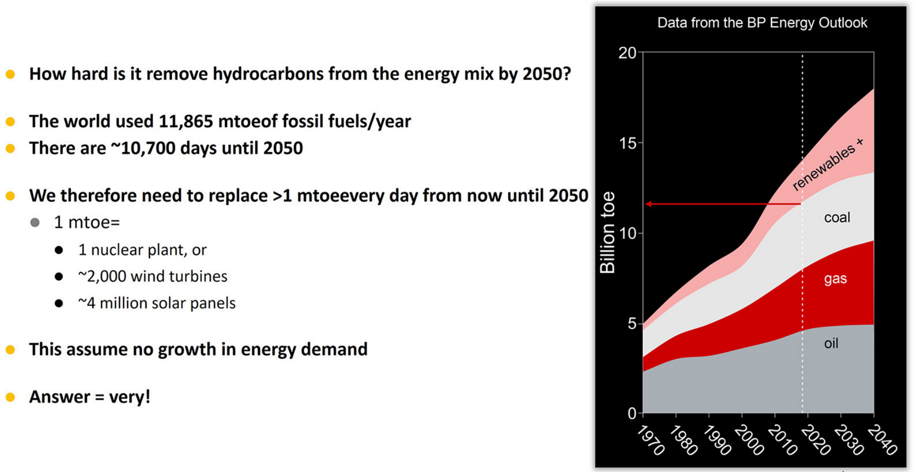


Fig. 19. – How hard is it to remove hydrocarbons from the energy mix by 2050? (Courtesy of Mike Simmons, Halliburton Landmark).

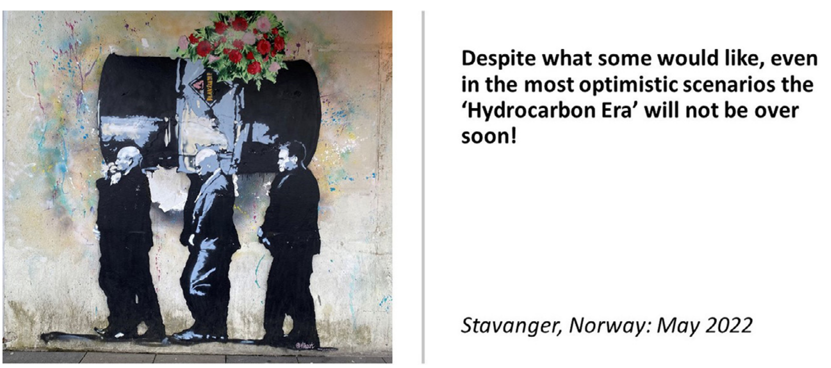


Fig. 20. – The end of hydrocarbons? Wall mural in Stavanger, Norway, May 2022.

Despite what some people would like to believe —even in Norway, it seems (fig. 20)— the hydrocarbon era will not be over soon!

10. – What are the big energy companies doing about their carbon emissions? What is their role in the "Energy Transition"

Collectively, the "Majors" (the world's largest independent integrated energy companies) account for only about 10% of global oil production. The largest, Exxonmobil, accounts for about 2%. The Majors cannot be expected to "lead the world into a low-carbon future", but they can, and must, "play their part". Like it or not, to billions of people around the world, they are the face of the global oil industry, they are instantly, emotive brands. They are integrated along the value chain in every part of the energy sector —including in low carbon energy and technologies, among the biggest companies on their respective equity markets and are woven into the fabric of everyday life.

Listed Energy companies are facing shareholder pressure and actively setting carbon reduction goals, but it would be quite naïve to think that large oil and gas companies can divest from billions of dollars of investment just because we need to decarbonise. Besides the fact that shareholders expect to have their investment renumerated, millions of people are employed in the oil and gas industry and all our economies still depend heavily on fossil fuels for materials, industry and transportation [18].

The Oil and Gas Climate Initiative (OGCI) —a group of 13 companies, including all the largest western International Oil Companies (IOCs) and some of the leading National Oil Companies (NOCs)— is "*dedicated to the ambition of the Paris Agreement to progress to net-zero emissions in the second half of this century*". At a meeting in October 2020, OGCI reported progress on curbing methane leakage, promising further support for investment in carbon capture, storage and use projects and pledging to set a common emissions intensity target in the year ahead. The CEOs of ExxonMobil, Chevron, Shell, Total, BP, Equinor, Eni, Repsol and Occidental were all present, together with high-level representatives from Saudi Aramco, CNCP and Petrobras. Methane leakage is one of the key areas of focus for OGCI —the group's members have set a collective target to cut methane leakage to 0.25% of their production by 2025.

There is an internationally accepted classification of Greenhouse Gas Emission into Scope 1, 2, and 3. In very simplified terms, Scope 1 emissions are those created by the company itself —the direct emissions from activities, Scope 2 are primarily indirect emissions produced by their suppliers and Scope 3 —the most difficult to address— are the indirect emissions produced by their customers (fig. 21).

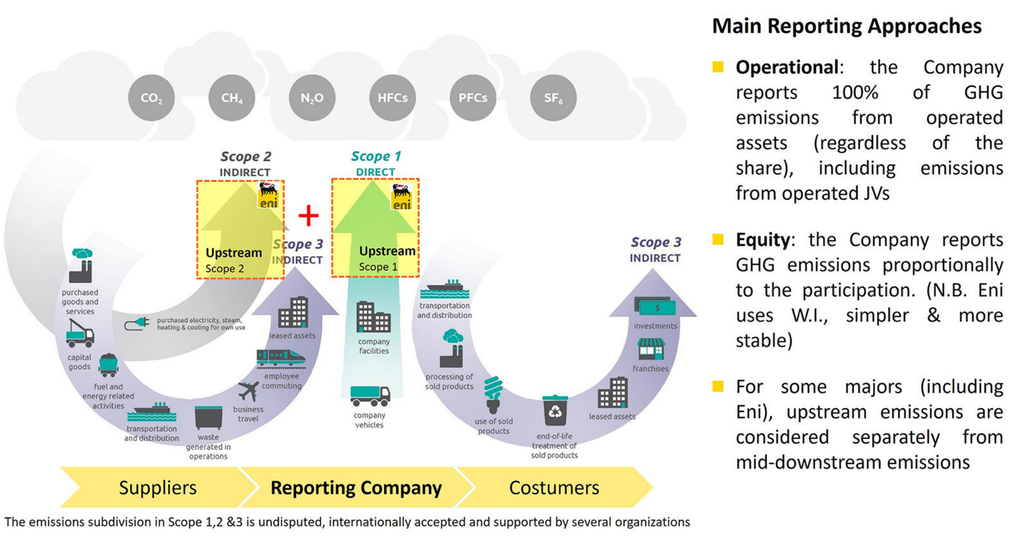


Fig. 21. – Greenhouse Gas (GHG) emissions classification, Scope 1, 2 and 3 (Source: Eni, 2020).

	ExxonMobil	Chevron	bp	eni		TotalEnergies	equinor
GHG Emissions Scope 1 – Scope 2	**reduction in Upstream carbon intensity** (vs 2016)* -15 to -20% @2025 -40 to -50% @2030 **Corporate emission** (vs 2016)* -20 to -30% @2030	**Net zero ambition** **reduction in Upstream carbon intensity** (vs 2016)* -35% @2028	**reduction in upstream GHG emissions*** (vs 2019) -20% @2025 -50% @2030	**Zero net carbon footprint** (equity) **Upstream @2030* Eni @ 2035**** **Upstream intensity -43% @2025 vs 2014** *(operated)*	**Net Carbon Footprint intensity** vs. 2016 (Scope 1+2+3) -6 to -8% @2025 -20% @2030 -100% @2050	**reduction in upstream GHG emissions*** (vs 2015) -15% @2025 -40% @2030	**Upstream CO2 intensity** <8 kgCO2/boe @2025 (100% op., Scope 1) **Carbon Neutral in Global Operations** @ 2030 (operated, Scope 1+2)
Scope 3	-	**reduction in carbon emissions intensity** (vs 2016) >5 % @2028	**Carbon intensity of sell products (vs 2019)** -5%@ 2025 -15 to -20%@ 2030 -100%@ 2050	**net carbon intensity** (equity, Scope 1+2+3) **-15% @2030 vs 2018**		**Carbon Intensity of energy products** (Scope 1+2+3) -20% @2030 vs 2015	**reduction of carbon intensity*** -20% @2030 vs 2019
Methane Emissions	**methane intensity** (vs 2016) -40 to -50%@2025 -70 to -80%@2030	**methane reduction** (vs 2016) >50% @2028 **2 kgCO2eq/boe**	**methane intensity*** 0.2% @2025	**Upstream fugitives** (vs 2014) **-80% @2025**	**methane intensity** (operated Upstream & Integrated Gas) <0.2% @2025	**methane reduction** (vs 2020) 50%@2028 80%@2030	**Keep methane emission intensity** near zero by 2030 (100% operated)
Gas Flaring	**flaring intensity** (vs 2016) -35 to -45% @2025 -60 to -70%@2030 **Zero routine flaring by 2030**	**flaring reduction** (vs 2016) >60% @2028 **3 kgCO2eq/boe** **Zero routine flaring by 2030**	**Zero routine gas flaring @2030**	**Zero routine gas flaring @2025**	**Zero routine gas flaring @2030**	**Zero routine gas flaring @2030**	0,2% @2020 **Zero routine gas flaring @2030**
	**Operated assets*	**Equity emissions*	**Operational*	**Scope 1* *** Scope 1+2*		**Operated*	**Scope 1+2, 100% op. Scope 1+2+3, equity*

Upstream carbon intensity: $kgCO_2eq/boe$ or $tCO_2eq/Kboe$

Scope 3 Carbon intensity: gCO_2eq/MJ

Fig. 22. – The approach of Eni and its peers to setting Greenhouse Gas (GHG) emissions targets (Source: Eni, 2022).

Not surprisingly, the different "Majors" have set a variety of different targets —covering not only GHG emissions, but also for methane emissions and gas flaring. It is quite difficult to compare between different companies because they use different metrics (fig. 22). There is, at least, a common ambition to have "Zero Routine Flaring" by 2030 —or in Eni's case by 2025.

In 2021, Eni launched a new strategy that will enable it to provide a variety of fully decarbonized products, through the development of bio-refineries and biomethane production, exploiting circular processes, the sale of low-carbon energy carriers, and the use of carbon sequestration and blue and green hydrogen technologies (fig. 23).

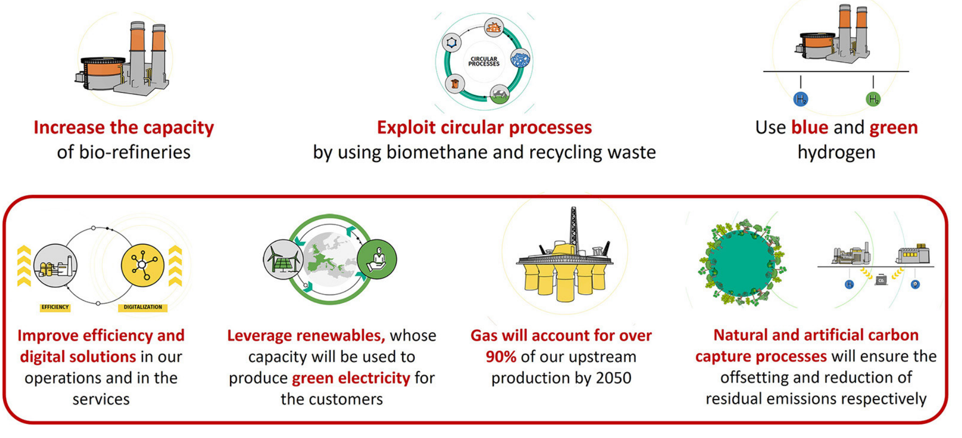


Fig. 23. – Eni's strategy for decarbonisation (Source: Eni, 2022).

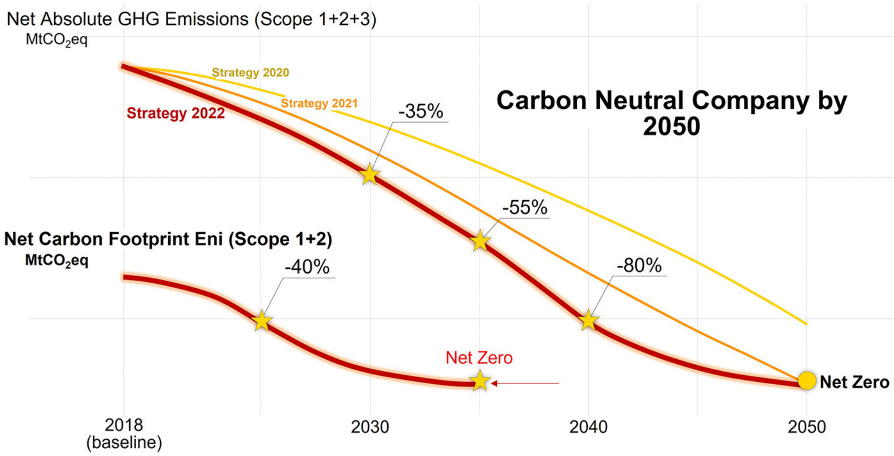


Fig. 24. – Accelerating Eni's Greenhouse Gas emission targets (Source: Eni, 2022).

One key target for Eni is that by 2050 gas will account for over 90% of our upstream production (fig. 23).

Eni aspires to contribute to the achievement of the UN's Sustainable Development Goals, supporting a just energy transition that meets the challenge of climate change with concrete and economically sustainable solutions while promoting efficient and sustainable access to energy resources, for all.

Today Eni has the most aggressive timeline of all the Majors for "net zero" Scope 1 and 2 emissions and, even more challenging has committed to reach "net zero" from Scope 3 on all products sold and reducing absolute emissions to net zero by 2050 (fig. 24) —one of the most ambitious emissions-reduction goals of any energy company in the world.

Eni has set an objective to achieve net-zero emissions in its upstream business by 2030, through increased efficiency to minimise direct upstream CO_2 emissions and offsetting residual upstream emissions through planting 20 million acres of forest in Africa. The forests planted in South Africa, Zimbabwe, Mozambique and Ghana should be removing 20 million tons a year of CO_2 from the atmosphere by 2030. Eni has also invested in converting two of its crude oil refineries in Italy —Gela and Venice— to use vegetable oils. The Venice refinery is the first in the world to be converted from processing fossil fuels to biofuels. In September 2021 the International Renewable Energy Agency (IRENA) finalised a 3-year partnership agreement with Eni to collaborate in the promotion of renewable energy and accelerate the energy transition, it is the first such agreement with an oil and gas company.

Carbon Capture and Storage (CCS) will undoubtedly play a critical role in decarbonising of society in the future, particularly in those areas of industry and energy supply where renewable energy solutions are more difficult to apply, or where CO_2 is a by-product of industrial processes such as the manufacture of cement or fertilizer [19, 20].

Today, there are two key issues —price and scale. The carbon price needs to be in the range of \$60–\$100 per ton of CO_2 for direct CCS to be a truly economic proposition and if we want to sequester enough CO_2 to follow the "2-degree pathway" we need a CCS industry that is about twice the size of today's oil and gas industry. Most forecasts of what it would take to get the world to "net-zero" by 2050 require CCS to increase essentially 100 times from today's levels, as well as eliminating global coal consumption and reducing global oil production by 50% or more from current levels.

To get to net zero, it is likely that between 1 billion and 2 billion tons of CO2 will need to be sequestered each year. In 2022, the world's 27 operating CCS plants scrubbed and stored just a few thousand metric tons of CO_2 [21]. Some authorities recommend that the ultimate target should be to return one tonne of CO_2 to geological storage for every tonne generated by the continuing burning of fossil fuels by 2050 —so called "geological net zero"— including using technologies such as direct air capture [22].

Eni has already made a major commitment to CCS with projects such as the "Hynet" project in Liverpool Bay, which will produce hydrogen from natural gas and store the resultant CO_2 in Eni's depleted fields in Liverpool Bay in the UK, and the "Adriatic Blue" project in Italy which will be a major European hub for CCS using depleted gas fields in the Adriatic Sea (see Della Moretta and Craig, in this volume).

Hydrogen can be used as a fuel and, if stored in the subsurface, can be an energy storage medium feeding from off-peak electricity from renewables. Hydrogen will be one of the main drivers of the energy transition and many countries have announced plans to increase the role of hydrogen in their future green economies, among them the United Kingdom and India. To achieve net zero by 2050, production of low-carbon hydrogen probably needs to reach 650 Mtpa, generating a US\$475 billion per annum international traded market [8]. The UK government has launched a plan for a world-leading hydrogen economy. The "Hynet" project uses "Grey hydrogen" from natural gas, but the ultimate goal is zero-emission "Green Hydrogen" created through electrolysis of water —a zero-emissions process. Given India's major dependence on energy imports (85% of its oil and 53% of its gas), green hydrogen is expected to be a "game changer" for the county, leveraging its large land mass and low solar and wind tariffs to produce low-cost green hydrogen and ammonia for export. In many countries the future is increasingly likely to take the form of a significantly scaled-up electricity network underpinned by a hydrogen gas-based distribution and energy storage network [23]. Hydrogen is expected to provide about 10% of global energy demand by 2040.

The world's major energy companies are a key driver for the "Energy Transition", but reputation management is a priority as the low-carbon world still needs some fossil fuels. There is a need for State and National oil and gas companies to adopt the same disclosures as the IOCs —lack of transparency will affect the whole industry, both operationally and reputationally. About 65% of the world's proven oil and gas reserves are under the control of NOCs. Many of these companies hold huge portfolios of assets, manage complex projects, employ many thousands of people and are often major cash generators for their countries [2]. Almost all these national oil companies will still be expected to provide revenues for their governments. Many are also investing in alternative energy resources to help them, and their countries, move away from unsustainable dependence on oil, but some are also seeking to increase their production of both oil and gas while they still can. Of the top 20 oil & gas companies with the highest emissions, 12 are NOCs [4].

11. – What role will geoscientists play in the "Energy Transition"?

Geoscientists bring unique skills to the "Energy Transition", given their deep knowledge of climate change through geological time and their deep experience of solving highly complex problems, dealing with complex Earth Systems and managing "big data". Geoscience skills will still be needed to provide the increasing amount of energy the world needs in the decades to come. This energy will come from a more diverse set of sources and many require geoscience skills (*e.g.*, geothermal, minerals for batteries, wind turbines, grid infrastructure and power equipment etc.). Even if the move to renewable energy resources occurs more rapidly than anticipated, subsurface skills will still be required for environmental solutions, such as carbon capture and sequestration.

Of course, renewable energy and batteries at scale come with environmental impacts of their own, including mining, manufacturing, deployment and landfill disposal. The low carbon "2-degree economy" will create huge demand for new metals and materials for batteries, wind turbines, solar panels etc. with a 200% increase in demand for aluminium, iron, lead and nickel and a staggering 1000% increase for cobalt, lithium and manganese. If it has not been grown, then it has got to have been mined. At present we have little idea where these new supplies will come from and very little geological data. The mining and minerals sector is, and will be, central to the "Energy Transition" story. Geoscience skills will be critical to providing them.

Geosciences are data-rich, so digitalization, Artificial Intelligence (AI) and Machine Learning (ML) will materially change the way we work but will not materially reduce the need for geoscience skills. There will, however, be even greater need for people who are multi-skilled and can integrate geological knowledge with computer science. This will require universities to change the curriculum and the focus of the geoscience training they provide.

Geoscientists can be proud, indeed must be proud, of the huge contribution they have made to the progress of society over the past decades. The challenge now is for geoscientists to step forward and engage with the wider society on solving the dilemmas associated with the Energy Transition. Transforming from a traditional hydrocarbon business model to a decarbonised net-zero culture with a flexible working environment, while still providing opportunities for growth and career development, will be critical if we are to attract new young talent into the energy industry. Geoscientists —and the Energy Companies they work for— must become "part of the solution" to the huge challenge of simultaneously meeting the world's growing energy demand, eliminating energy poverty and reducing global greenhouse gas emissions to slow global climate change.

12. – Conclusions and key messages

How are our energy systems changing today, and how should we respond?

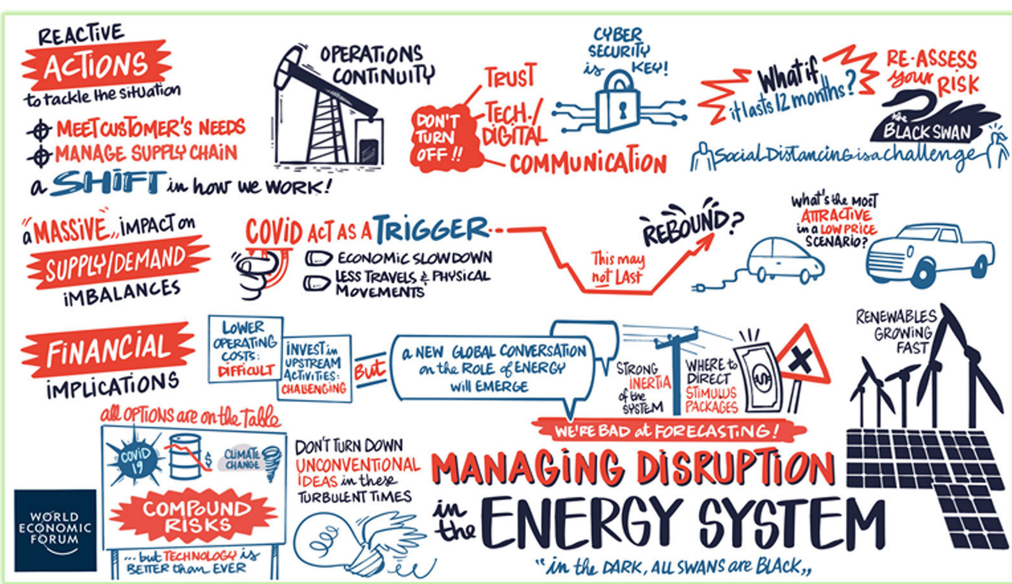
The figure below brings together all the various issues that are causing major disruption in the Energy System today: from supply/demand imbalances, the rapid growth in renewables to the Covid pandemic (fig. 25). Steering a course through these factors is exceptionally difficult. Uncertainty is crippling!

Given all these issues, increasing government regulation, competition for capital, shareholder and public pressure to decarbonise, many traditional oil & gas companies are asking:

"*Is it time to redefine the oil & gas industry and to find new directions for this new world?*"

One of the most critical issues is, undoubtedly, Global Climate Change. The predictions made by a wide variety of organisations still suggest an increase in oil demand from ca. 100 million b/d today to perhaps 105 to 110 million b/d in 2040 —projections that would lead to a global temperature rise of 3.5 to 5.5 °C by 2100, if not countered by very significant reductions in greenhouse gas emissions. To keep the rise in global temperature below 2.0, and preferably below 1.5 °C, by 2100 we would need to cut global oil demand from 100 million b/d today to about 65–70 million b/d by 2040.

In recent years a startling difference in approach has emerged between the European



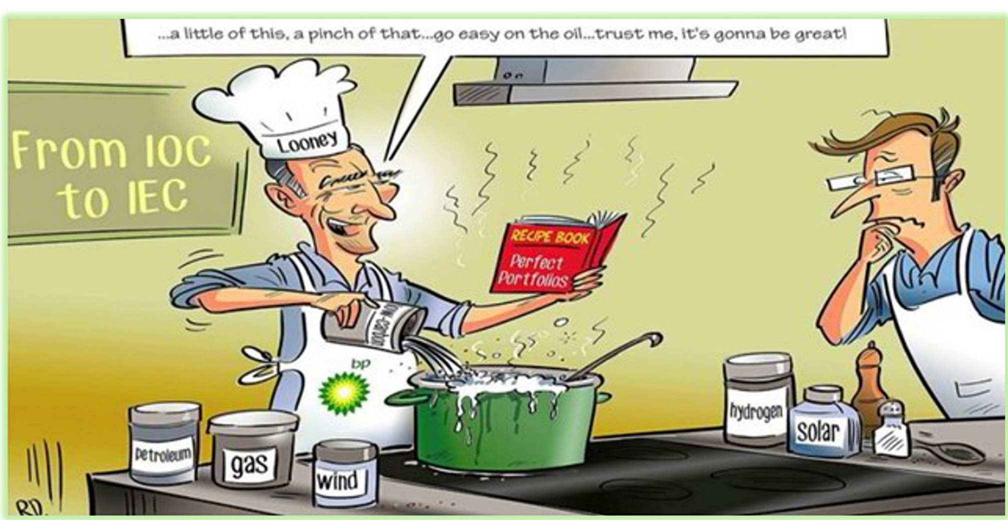
Source: World Economic Forum, 2020

Fig. 25. – How are our energy systems changing today? How should we respond? (Source: World Economic Forum, 2020).

"Majors" —Eni, bp, Repsol, Equinor, Shell, Total, who are all aiming for high levels of new energy diversification and a strong focus on carbon neutrality— and the U.S. "Majors", primarily ExxonMobil and Chevron, who, for now at least, are largely sticking to the old model of "hydrocarbons win". The European "Majors" are building up their renewable energy portfolios and looking for new income streams using their in-house knowledge and expertise, particularly in the broad area of "geoenergy".

But what is the right mix of traditional oil & gas, renewables —such as wind and solar— and new energy solutions, like hydrogen, for a company transitioning from an International Oil Company to an International Energy Company? What, indeed, is the recipe for success? (fig. 26).

Renewable energy has the power to change global politics! Wind, Solar and low-temperature geothermal are all available everywhere to some degree, so in the future many countries could be much less reliant for their energy supplies on, for example, the Middle East and Russia. Unfortunately, the materials needed to use renewable energy —the metals for wind turbines, solar panels, and rechargeable batteries, for example— are not so universally distributed. China controls almost the entire global market in the rare-earth elements used to make wind turbines. Cobalt and lithium are vital for making rechargeable batteries. A low-carbon "2-degree economy" will create huge demand for metals and materials. A World Bank study in 2017 estimated that the "Energy Transition" would result in a 200% increase in demand for aluminium, iron, lead and nickel, a 400% increase in graphite, a 600% increase in cobalt and a staggering 1000% increase in



Recipe for transition success? BP and chief executive Bernard Looney are cooking up something different for the supermajor's future

Fig. 26. – Transitioning from an International Oil Company (IOC) to an International Energy Company (Source: Rytis Daukantas/Upstream).

demand for lithium by 2050. Most of the known deposits of cobalt in the world are in the Democratic Republic of Congo where its production is linked to child labour. Chile is the world's largest producer of lithium, but indigenous communities are resisting continued lithium production there because of the environmental problems associated with consumption of scarce groundwater for solar evaporation. Lithium demand is expected to more than triple between 2020 and 2025, rising to a million tons by 2025 and outpacing supply by 200000 tonnes [24]. Demand for battery-grade nickel, another important component in electric vehicle batteries is expected to outstrip supply by 2024 [24]. There are substantial undeveloped nickel resources in Indonesia, but they are almost all in areas of extremely rich biodiversity. There were 10 586 active mines in the world in 2022 and a further 4 790 mining projects under construction. The largest mine in the world is La Escondida, a copper mine in the Atacama Desert in Northern Chile, but current global copper demand could sustain 20 additional mines the size of La Escondida [4]. It is estimated that 3 trillion new heavy-duty rechargeable batteries will be needed for electric vehicles over the next 20 years. Each electrical vehicle requires the mining of 250 tons of ore to produce the metals required for its batteries [16]. Imagine the possible environmental impact of the mining required if rigorous standards are not applied? There is a huge challenge facing the mining industry to provide the critical minerals required for the Energy Transition and a huge responsibility on mining companies to ensure that their operations have minimal environmental impact. Irresponsible, unsustainable and non-ESG compliant mining is a major issue and needs to be eliminated, but it will take time.

It is important to remember in any discussion about the "Energy Transition" that it is not the energy source that is the problem, it is the environmental impact of using it. This applies just as much to renewable energy resources as to fossil fuels.

Do not be fooled —there is no such thing as "clean energy", just more or less dirty forms of energy!

Most published predictions of World Energy Demand provide scenarios for the period through to 2040 or 2050. But what if we run a scenario that tries to meet the three great challenges of reducing greenhouse gas emissions, reducing energy poverty and satisfying growing world energy demand through to 2100? There are, of course, huge uncertainties and huge dangers in trying to predict this far into the future —we are notoriously bad at predicting the future— but one not completely unreasonable scenario looks like this (fig. 27) ...

There are some important assumptions involved in constructing this scenario —2 of the most critical are that:

- Global population will increase from 7.7 billion today to around 13 billion by 2100 with growth mainly in Asia-Pacific to 2050 and then in Africa from 2050 to 2100: this is the main driver of world energy demand.
- There will be social and political pressure in countries like India, China, Indonesia and across Africa to lift a substantial proportion of their populations out of energy poverty.

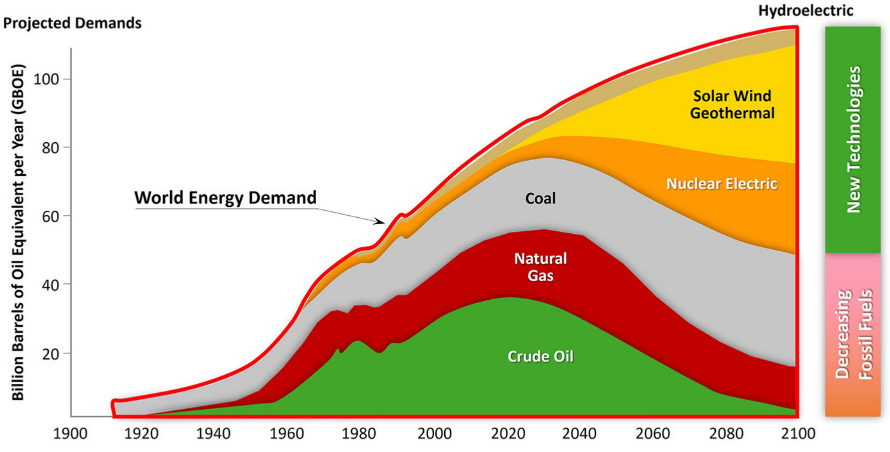


Fig. 27. – One possible forecast of sources of energy required to reduce greenhouse gas emissions, reduce energy poverty and satisfy growing world energy demand to 2100.

Based on these (and many other) assumptions, this model predicts peak oil demand will occur around 2025, with peak gas demand in about 2040. Coal will continue to be important for power generation until the end of the century because it is cheap and abundant —but we'll need to sequester the carbon dioxide produced— but by 2100, oil & natural gas will still be used to meet about 15% of global energy demand —and, on top of this, hydrocarbons will probably still be used as feedstock for at least some chemical processes. If you are wondering, this scenario gives about 2.5 to 3.0 °C temperature rise by 2100.

Ultimately, whether you consider the current "Energy Transition" to be a "myth" or a "reality" probably depends on your view about the timeframe over which the transition can and should occur and where you live in the world. If you live in Europe, Australia or North America and you believe the transition will take decades, then the "Energy Transition" is already very much a reality. If, however, you believe it can and should be completed in years rather than decades, or you live in large parts of Sub-Saharan Africa or parts of South America or the India Subcontinent where many people still have little or no access to affordable energy, it is certainly a myth and, worse, in the latter case, largely irrelevant... except.... except, that it is exactly these people, the poorest in the world, who will suffer the most from the effects of global climate change.

The worst possible scenario would be if the world cannot continue to meet its total energy demands, does not extend the availability of power and fuel to energy-starved communities, and also fails to avoid the most serious effects of climate change. Creating a new and sustainable energy system is certainly humanity's greatest challenge. The enormous and unprecedented challenge we face is to power the planet, reduced energy poverty and slash greenhouse gas emissions, simultaneously.

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