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The Role of Carbon Management Technologies in Meeting Net Zero

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Abstract

The pathway toward implementing the changes necessary in the energy sector to keep global temperature rises from breaking through catastrophic barriers is narrow and tenuous and will require a range of zero- and low-carbon technologies to be dispatched at a speed and scale that is virtually unprecedented. Decarbonization through renewables, matched with the more efficient use of energy in the end-use sectors will play a large part. But there is growing realization that there will be residual fossil fuel use long into the future, and that the emissions from the burning of these fossil fuels in power plants and factories will need to be mitigated through carbon management facilities including carbon capture, utilization, and storage, and direct air capture projects. This article presents the size of the challenge and takes stock of the gap between deployment today and the volumes required to effectively bring the energy system to net zero. It also investigates the increasing divergence between the worldviews of those who call for a “phaseout” of fossil fuels and those who call for the “phaseout of fossil fuel emissions,” i.e., those who believe that the bulk of decarbonization will occur through the substitution of fossil fuels with renewables versus those who argue that carbon management technologies mean that we can meet our environmental targets while maintaining the status quo in the energy sector.

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The Role of Technology in Reaching Net Zero Emissions in the Energy Sector

The fight against climate change will be won or lost on humankind’s ability to transform the energy sector, by some distance the single largest contributor to anthropogenic greenhouse gas emissions. The speed and scale of the transformation must be unprecedented, fundamentally changing the fossil-fueled system that has propelled economic growth and improved livelihoods since the Industrial Revolution, to a more sustainable pathway, all within a matter of decades.

To some extent, this is already happening. More than 90 percent of the net increase in electricity demand across the world in 2022 was met by renewables,¹ which are projected to meet virtually the entirety of the increase in electricity demand over the next three years.² While this appears promising, it is important that we do not assume that what is true for electricity is true for the energy sector more broadly. Electricity accounts for around one-fifth of global final energy consumption today—even if it were fully decarbonized, considerably more would need to be done across the end-use sectors to bend the emissions curve toward net zero.

The first option is to continue decarbonizing electricity through dramatically increasing the share of renewables, which sits at just 12 percent today, while concurrently promoting the substitution of fossil fuels with electricity across a range of final applications. Policy and changing circumstances are pushing in this direction too—the sales of heat pumps (which are three to five times as efficient as fossil fuel boilers) in Europe grew by 40 percent in 2022, as consumers sought to reduce natural gas consumption for heating, in part due to higher prices related to Russia’s invasion of Ukraine. Similarly, the share of electric vehicles in global sales has grown from around 5 percent in 2020 to almost one-fifth of the total,³ as increased cost competitiveness and government support policies in some significant developed economies have bolstered sales. These are two to four times as efficient as current internal combustion engine vehicles.

A further option is to focus on the demand side, through increased investment in energy efficiency measures to reverse the historical positive correlation between energy demand growth and wealth creation. Since 1990, the energy intensity of the global economy (i.e., the amount of energy it takes to produce one unit of additional economic output) has declined by almost two-thirds,⁴ but the majority of this improvement has been concentrated in the Organisation for Economic Co-operation and Development (OECD) economies. The rate of improvement needs to double by 2030, requiring a global push that includes support to developing and emerging economies, which would effectively result in a 10 percent decrease in energy demand, even as the economy continues to grow.⁵

However, even in the most bullish outlooks on energy transitions, there is a realization that the key prongs of decarbonization initiatives—electrification, increased efficiency, and a proliferation of low-carbon substitutes for fossil fuels (like electrolytic hydrogen)—cannot entirely displace fossil fuels from the system. Pockets of demand will persist in the “hard to abate” industrial sectors and in petrochemicals production, which currently accounts for 15 percent of global oil consumption. Demand for fossil fuels will also likely continue from parts of the existing electricity infrastructure fleet, particularly across swathes of Southeast Asia and China, where the average coal-fired power plant is just eleven years old (compared to forty-one years in the United States). These are difficult to retire prematurely without huge economic and financial loss, and, in many instances, without putting tremendous pressure on consumer prices and the reliability of the entire system.
Without addressing this gap in the energy system decarbonization question, power and industrial plants will still be emitting an estimated eight billion metric tons of CO₂ (BtCO₂) in 2050—around one-quarter of today’s annual energy-sector emissions.⁶

One of the more prominent nascent technologies that aims to square the circle of achieving net zero emissions while accommodating for some fossil fuel use in these limited applications is carbon capture, utilization, and storage (CCUS). This involves adding special facilities to existing energy infrastructure (like a power plant, steel mill, or even oil field) to capture emitted carbon that can then either be used for industrial processes or reinjected into the ground where it can be stored in depleted oil and gas reservoirs or similarly suitable geological structures. CCUS differs from direct air capture (DAC), which removes CO₂ from ambient air, and does not need to be attached to an existing emitting facility.

Current Capacity

Around forty commercial CCUS facilities are already in operation around the world, abating around forty-five million metric tons per year of CO₂ (MtCO₂) from the industrial processes, fuel transformation, and power generation facilities that they are attached to. A steadily growing pipeline of projects means that a further fifty new capture facilities could be in operation by 2030, increasing this capacity to around 125 MtCO₂ per year. While significant, this growth remains significantly below the levels envisioned by most net zero scenario pathways, which range in need from around 5,000 to around 18,000 MtCO₂ per year by 2050 for industrial and power generation facilities.

Part of the challenge to the proliferation at scale of CCUS is the associated cost and lack of financial incentives for polluters to make the large capital investments for the facilities. This was identified in the Inflation Reduction Act, passed in the United States in 2022, which updated the 45Q tax credit (a tax credit for every metric ton of CO₂ captured and permanently stored in geological formations), to include an 85 USD per metric ton incentive for CCUS. The credit rises to 180 USD per metric ton for CO₂ captured through direct air capture, approaching parity with the estimated marginal abatement cost of this technology.⁷ Europe has followed suit, setting a target (but not yet introducing financial incentives) in its “Net Zero Industry Act” released in March 2023, which proposes an annual CO₂ injection target of 50 MtCO₂ for 2030.

How Much of the Net Zero Heavy-Lifting Could Be Carried Out by CCUS and Carbon Management Technologies?

The debate surrounding carbon management options, which include CCUS but also direct air capture, is not limited to the efficacy of the technology and the viability of project economics, but also bleeds into broader philosophical and practical questions about the nature of climate action and the energy transition. To a passive observer, the debate between “fossil fuel emissions phaseout” and a “fossil fuels phaseout” may seem nuanced, but the similarity in nomenclature belies visions for drastically different energy sectors. A relatively modest rollout of carbon management technologies will, by definition, require decarbonization primarily through a focus on additional renewables and efficiency measures. Conversely, scenarios that foresee a massive rollout of such technologies mostly assume a significant role for fossil fuels in the future energy system.

This difference was thrown into sharp relief when, for the first time, OPEC, the Organization of the Petroleum Exporting Countries, included an “Advanced Technology Scenario” in its annual
World Oil Outlook report in 2022, which it says provides a “pathway consistent with the long-term goals of the Paris Agreement.” This scenario forecasts ninety-two million barrels of oil consumption in 2045. Though this scenario did not include a detailed explanation of the embedded assumptions for carbon management, a calculation based on the global average life cycle emissions of a barrel of oil points to a total need for around 15,000 MtCO\textsubscript{2} of carbon abatement—a level that would require CCUS and DAC projects to grow at a rate of 30 percent per year to 2045. This is one-and-a-half times the rate of growth in solar and wind power uptake over the last decade.

The vision articulated in the OPEC Scenario is, by design, meant to be an alternative to traditional pathways to energy sector decarbonization, which are predominantly underpinned by a large-scale energy transition. It accommodates more oil and natural gas use and less renewables uptake than virtually any scenario enunciated in the models considered by the International Panel on Climate Change. According to the International Energy Agency, achieving global climate targets while continuing under a business as usual oil and gas consumption trajectory would require investments in carbon capture to increase to 3.5 trillion USD per year, from just 4 billion USD in 2022.

This view builds on the outcomes of the G20 in 2020, where Saudi Arabia, which held the G20 presidency that year, put forward the concept of a “circular carbon economy,” proposing a “reduce, reuse, recycle, and remove” framework for carbon. While it was endorsed in the G20 outcomes in the joint communiqué, which described it is “a holistic, integrated, inclusive and pragmatic approach to managing emissions that can be applied reflecting a country’s priorities and circumstances,” there was no serious modeling or analytical work undertaken to attempt to enumerate just how much carbon can be “reused” in industrial processes, nor full explanations of a realistic pathway to large-scale carbon removal. Despite this, the articulation of the framework, and its endorsement at the ministerial level, effectively created space for an alternative climate action pathway that maintained a large role for oil and gas in the future energy system.

**The Role of Carbon Management Options in a Just and Equitable Transition**

In many ways, the carbon management-first view to climate action, enunciated in the “circular carbon economy” framework, is an understandable reaction of large fossil fuel exporters to the developing consensus view of a deep energy transition. The prospect that demand for oil and gas is decimated over the space of twenty-five years could devastate the currently undiversified economies of many of the world’s most prominent exporters. Some such countries, including Saudi Arabia and the United Arab Emirates, are making concerted efforts to diversify their sources of revenues through stimulating parts of their non-oil sectors. At the same time OPEC is making the case that continued oil and gas use and climate action are not mutually exclusive.

A growing component of the case for continued fossil fuel use is the case that they provide the most affordable and reliable pathway to energy not just to the 760 million people across the world currently without electricity access, but also to the far larger cohort of people who do not have levels of access to truly bolster their climate adaptation prospects.

These arguments are not entirely without merit. It is an undeniable truth that those who have contributed least to the issue are the most impacted by the effects of climate change. It is also true that the ability to adapt to warming and other changes in the climate is strongly correlated with energy consumption.

However, this point of view ignores two important considerations. First, the growing competitiveness of renewable electricity means that it is more often than not the least-cost option to bring access to communities that are currently unserved. Second, the argument that there is
room for fossil fuel use in a way that is compliant with climate targets rests on the assumption that the associated emissions are managed through technology, and this is highly dubious in the context of energy-poor low- and middle-income countries, where technology and cost barriers are particularly high.

Conclusions

The scale of the climate challenge requires a response, drawing on all low-carbon technologies currently available and under development, to be deployed in timely way. This will need a sequencing that ensures that capital is targeted in the right places at the right times. Vastly competing visions for the future could prove costly in this regard.

Carbon management technologies, including carbon capture, utilization, and storage, will have to play a part, particularly in young existing infrastructure like that in Southeast Asia, China, and India, where coal-fired power plants are, on average, several decades younger than they are in the countries of the OECD, and cannot be retired en masse without significant economic and financial loss.

The debate about the size of the role of carbon management technologies is important. Scenarios that imply CCUS will be able to mitigate the carbon from a fossil fuel system that resembles what it does today stretch the realm of plausibility. The fact that the main scenarios that posit this view, both at the G20 and OPEC, have not been accompanied by full-scale energy modeling, does the debate a disservice. The implied scale of carbon management technology rollout is so large that it raises questions that this is being presented as a panacea by those with an interest in maintaining the status quo. The debate requires more solid empirical evidence of what can be captured, stored, and used.

Notes

5 IEA (International Energy Agency), Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, 2023, https://iea.blob.core.windows.net/assets/d0ba63c5-9d93-4457-be03-da0f1405a5dd/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf.
8 Author’s calculations, assuming an average greenhouse gas (GHG) emissions intensity of 405 kg/barrel, and that ≈10 million barrels/day is used as petrochemicals feedstock and is therefore not combusted.