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THINK

POLICY BRIEF

A CARBON MANAGEMENT SYSTEM OF INNOVATION: TOWARDS A CIRCULAR CARBON ECONOMY

Task Force 2
CLIMATE CHANGE AND ENVIRONMENT

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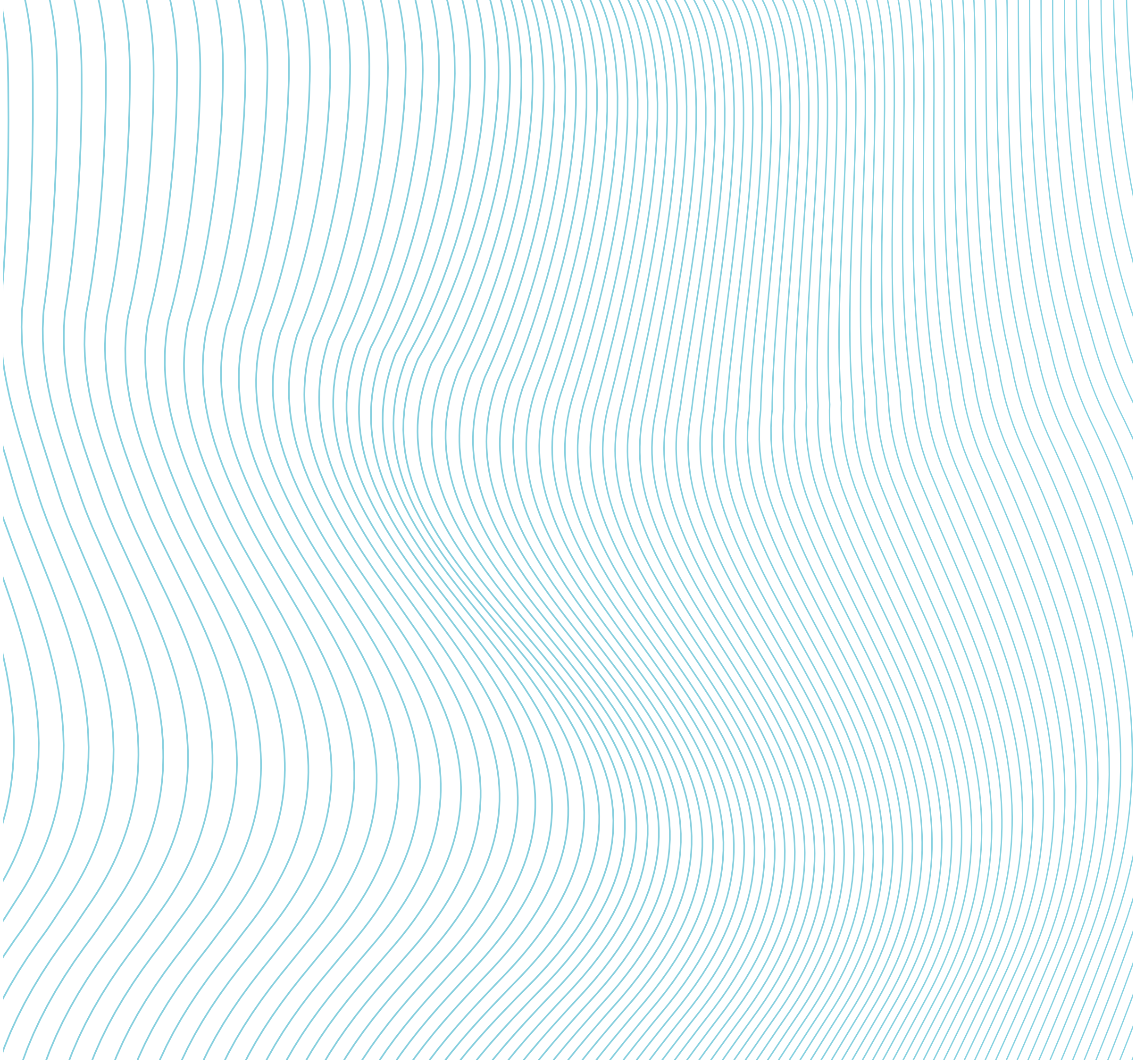

موجز السياسة

نظام مبتكر لإدارة الكربون: نحو اقتصاد دائري للكربون

فريق العمل الثاني

التغير المناخي والبيئة

المؤلفون

نورا يوسف منصوري، ألما الحسيني، نورة آل سعود، مشاعل الشعلان، مروة بن لحرش، يوشيكازو كوباياشي، راضية سيداوي، ماساكازو تويودا، ليوبوف ياروشينكو

ABSTRACT

This policy brief calls on the Group of Twenty (G20) governments to support a wide range of climate change mitigation approaches in hard-to-abate industries. It uses the Circular Carbon Economy framework, proposed by the Saudi G20 presidency, as an essential means to a low-carbon future through coordinated G20 efforts towards supporting carbon management technology innovations. This enables cooperation to consolidate efforts in upscaling carbon management technologies, and incentivizes carbon-neutralization across hard-to-abate industries. The socioeconomic shock due to the COVID-19 pandemic offers the opportunity for G20 governments to “build back better” using economic stimulus packages leveraging CCE for a more inclusive, resilient, and sustainable future.

يدعو موجز السياسة هذا حكومات مجموعة العشرين إلى دعم مجموعة واسعة من مناهج التخفيف من آثار تغير المناخ في الصناعات التي يصعب الحد من الكربون فيها (hard-to-abate)، وذلك باستخدام إطار الاقتصاد الدائري للكربون، الذي اقترحته الرئاسة السعودية لمجموعة العشرين، ويمكن ذلك من خلال تنسيق الجهود التي تبذلها مجموعة العشرين لدعم ابتكارات تقنيات إدارة الكربون، وتمكين التعاون لتوحيد الجهود في رفع مستوى تقنيات إدارة الكربون، وتحفيز تحييد الكربون في الصناعات التي يصعب الحد من الكربون فيها. وتوفر الصدمة الاجتماعية الاقتصادية الناجمة عن جائحة كورونا (كوفيد-19) فرصةً لحكومات مجموعة العشرين "لإعادة البناء بشكل أفضل" باستخدام حزم التحفيز الاقتصادي المعززة للاقتصاد الدائري للكربون (CCE) وذلك لمستقبل أكثر شمولًا ومرونةً واستدامةً.

CHALLENGE

Reducing CO_2 emissions drastically will require the participation of hard-to-abate sectors, such as oil, gas, aluminum, iron, steel, cement, and petrochemicals, as well as heavy transport, which includes heavy-duty road transport, shipping, and aviation. Combined, these comprise a total of 37% of CO_2 emissions (IEA 2019a, 2019b, 2019c, 2019d). IPCC models show that reaching the 1.5 °C or 2 °C target cannot be achieved without first reaching emission neutrality, coupled with significantly ramped up efforts to deploy and use negative emission technologies. In turn, these goals cannot be achieved without moving hard-to-abate sectors towards sustainability.[1]

The implications of the COVID- 19 pandemic further accentuate the challenges, as tackling climate change will prove more difficult with countries taking on additional debt to cushion the immediate impacts of the pandemic on their economies. In other words, stimulus packages will determine the rebound rate and charter the way towards a sustainable future. However, short-term stimulus priorities must not take away from clean energy and carbon neutrality targets. Large-scale investment in abatement technologies can benefit from re-energizing economies.

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The key challenges can be summarized as follows:

- The scale and capital intensity of the transport, building, power, and heavy industries make it hard to transform, given the need for reliable and safe sources, leading to a prolonged “carbon lock in” inertia in the system (Smil 2010.

- Greenhouse gas emissions (GHG) continue to increase, while solutions to address their residence time remain limited due to financial barriers to deployment (Friedmann, Ochu, and Brown 2020).

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1. The terminology used in relation to the transition to a carbon-neutral energy system is diverse, reflecting different national and disciplinary preferences. In this policy brief, we use various terms to refer to the transition to an energy system that meets the increasingly globally accepted goal of not emitting more carbon than is, at the minimum, taken out of the atmosphere, so as to hold climate change within an acceptable level. These terms include carbon neutral, carbon/emissions neutrality/circularity, sustainable energy system, sustainability transition, and moving towards sustainability.

- Varying national economic and social circumstances limit climate action, as some development areas are prioritized over others. Examples are choosing cheap, abundant, and reliable sources of energy that are carbon intensive, heavily dependent on fossil fuel export revenues, or shifting away from high-energy costs and scarce natural resources towards renewables (Davis and Caldeira 2010).

- Restarting economies following economic recessions has often been addressed by relaxed environmental regulations and less ambitious climate action.

- Impasse on the issues under the Paris Agreement (finance and market mechanisms) while current nationally determined contributions (NDCs) are insufficient even in case of best compliance (UNEP 2019).

- Generally, many NDCs mention "industry," with fewer mentioning "heavy industries." Therefore, concrete plans for industrial emissions reductions are rarely featured (Energy Transitions Commission 2018).

- CCS (carbon capture and storage) and CCUS (carbon capture utilization and storage) technology deployment remains slow (Global CCS Institute 2018).

Fossil-fuel-producing countries are exposed to different risk levels of "stranded assets" if the goals of the Paris Agreement are implemented (IEA 2013; Moret et al. 2020). Major fossil-fuel-exporting Group of Twenty (G20) countries such as Saudi Arabia, Australia, Russia, Indonesia, USA, and South Africa, who carry significant weight in climate negotiations, would be significantly affected economically. Specifically, estimates for the cost of stranded energy assets vary from \$900bn (FT 2020) to \$2.2trn for oil and gas companies (Euroactive 2019). Meanwhile, it is argued that one-third of oil reserves, half of gas reserves, and more than 80% of known coal reserves must remain unused (McGlade and Ekins 2015). Meanwhile, the equivalent of \$1–4trn in fossil fuel assets could be removed from the global economy; for example, a loss of only \$250bn triggered the 2008 crisis (Mercure et al. 2018).

Sustainable fossil fuel production is relevant for fossil fuel producers, especially for large scale, low-cost producers (e.g., Saudi Arabia) that expect to be "the last producers standing" (Alarabiya 2020). Therefore, coordinated G20 efforts become vital for the endorsement and support of carbon management technologies for carbon-neutral hydrocarbons.

PROPOSAL

The Saudi G20 presidency proposes the concept of a circular carbon economy (CCE) for approaching climate goals, which values all options and encourages all efforts to mitigate carbon accumulation in the atmosphere.

The CCE approach stems from the circular economy or the circularity concept, which is an alternative to the traditional linear economy of make, use, and dispose (McDonough 2020). Specifically, it maximizes the values of materials, products, and processes, while minimizing costs and wastes based on the famous 3Rs—reduce, reuse, and recycle—giving rise to new ways of designing, using, and disposing, such as "cradle-to-cradle" (McDonough and Braungart 2010).

The CCE approach adds the carbon dimension to circularity to reduce carbon emissions through the efficient use and utilization of energy, materials, and processes in the economy. Adding a fourth R to the 3Rs of circularity yields the following approach: reduce, reuse, recycle, and remove carbon/GHGs (Williams 2019; Al Khowaiter and Mufti 2020).

This policy brief explains the role of carbon management technological innovations across the 4Rs of the CCE (see Table 1 and Figure 1) to create sustainability pathways towards carbon-neutral hydrocarbons for the mitigation of CO_2 and the costs incurred by oil-based countries and industries to attain the Paris Agreement goals in the second half of the century. Post-pandemic economic recovery stimulus packages are expected to include fossil fuel bailouts, thus emphasizing the need for the CCE framework.

Reduce	**Reuse**	**Recycle**	**Remove**
Reducing the amount of carbon entering the system	Reusing carbon without chemical conversion	Recycling carbon with chemical conversion	Removing carbon from the system
• Energy and materials efficiency • Renewable energy, including hybrid use with fossil fuel • Nuclear energy, including hybrid use with fossil fuel • Advanced ultra-super-critical technologies for coal power plants • Hydrogen (blue/green) fuel cells for long-distance heavy-duty vehicles • Ammonia produced from zero-carbon hydrogen (blue/green) for power generation and ships • Direct reduction in steel making by using CO_2 free hydrogen (blue/green)	• Carbon capture and utilization (CCU) • Use CO_2 at carbon utilization facilities, such as at greenhouses for enhancing crops • Bio-jet fuels with reed beds • Algal synthesis	• CCU • Artificial photosynthesis • Bioenergy recycle in the pulp and paper industry • Bioenergy with carbon capture and storage • Carbamide (urea production using CO_2 as feedstock) • Coal ash concrete curing with absorbing CO_2 • Electrochemical reduction of CO_2 • Fine chemicals with innovative manufacturing processes and carbon recycling • Fischer-Tropsch exothermic of carbon dioxide with hydrogen syngas • Hydrogenation to formic acid • Oil sludge pyrolysis • Sabatier synthesis (CO_2 methanation: exothermic of carbon dioxide with blue/green hydrogen) • Thermal pyrolysis	• CCS • Direct air capture (DAC) • Carbon dioxide removal • Fossil fuels-based blue hydrogen

Table 1: **Portfolio of Carbon Management Technology Options across the 4Rs of the CCE Approach**

Source: **Redrawn from data provided by the WTO Secretariat, Geneva (Fig 5, Roy 2011).**

Table 1 provides a comprehensive yet non-exhaustive portfolio of carbon management technology options across the 4Rs at various levels of maturity: emergence, diffusion, and reconfiguration. The development of carbon management technologies allows the industry to continue driving economic development by directing the discussion towards extracting value from carbon rather than considering it a negative externality.

This is especially relevant for fossil-fuel-based industries and economies that are "locked in carbon"[2] (Unruh 1999, 2000). The Carbon Management System of Innovation framework (Mansouri 2013) allows directing efforts towards a CCE future. This could be achieved by spurring carbon management technological innovations and facilitating diffusion across hard-to-abate industries to encourage carbon circularity towards sustainability across the value chain and in an economy. Another solution involves creating pathways towards carbon-neutral hydrocarbons using top-down and bottom-up approaches to facilitate sustainability transitions (Mansouri 2013). This is presented as a guide for governments to accelerate the bottom-up approach of low-carbon innovations, as well as top-down policies, for a sustainable transition. It views current market dynamics and mature industries as opportunities to mobilize the vast resources of advanced industries and economies in the form of money, competencies, and technological advancement to enhance countries' innovative capacity for low-carbon cross-cutting technologies (Mansouri 2013).

Figure 1 shows the transition of a socio-technical regime (technology, policy, industry, markets, science, and culture) as a complex process determined by the degree to which these areas are "locked in carbon" (Unruh 2000). It is also determined by the nature of path dependencies (infrastructural and economic) (Arthur 1989) and how (technological) momentum (Hughes 1983) could spur innovations and speed up transitions to create systems innovations (Geels 2002). Thus, these factors determine the rate at which systems innovations occur and how they bring change to existing socio-technical regimes and create transition paths towards sustainability (Geels 2002).

Using this perspective, the over-arching socio-technical landscape (i.e., political, cultural, and economic structure; defined today using climate change and the demand for carbon-intensive industrial commodities), the current socio-technical regime of hydrocarbons, and energy-intensive hard-to-abate sectors must transition towards sustainability. For these sectors to be transformed and reconfigured, carbon management technological niche innovations must accelerate and be deployed fast enough to meet climate targets. At the same time, they must minimize stranded assets and the risks faced by existing firms and employees, maintain economic prosperity, and respect developing countries' rights to emissions and development.

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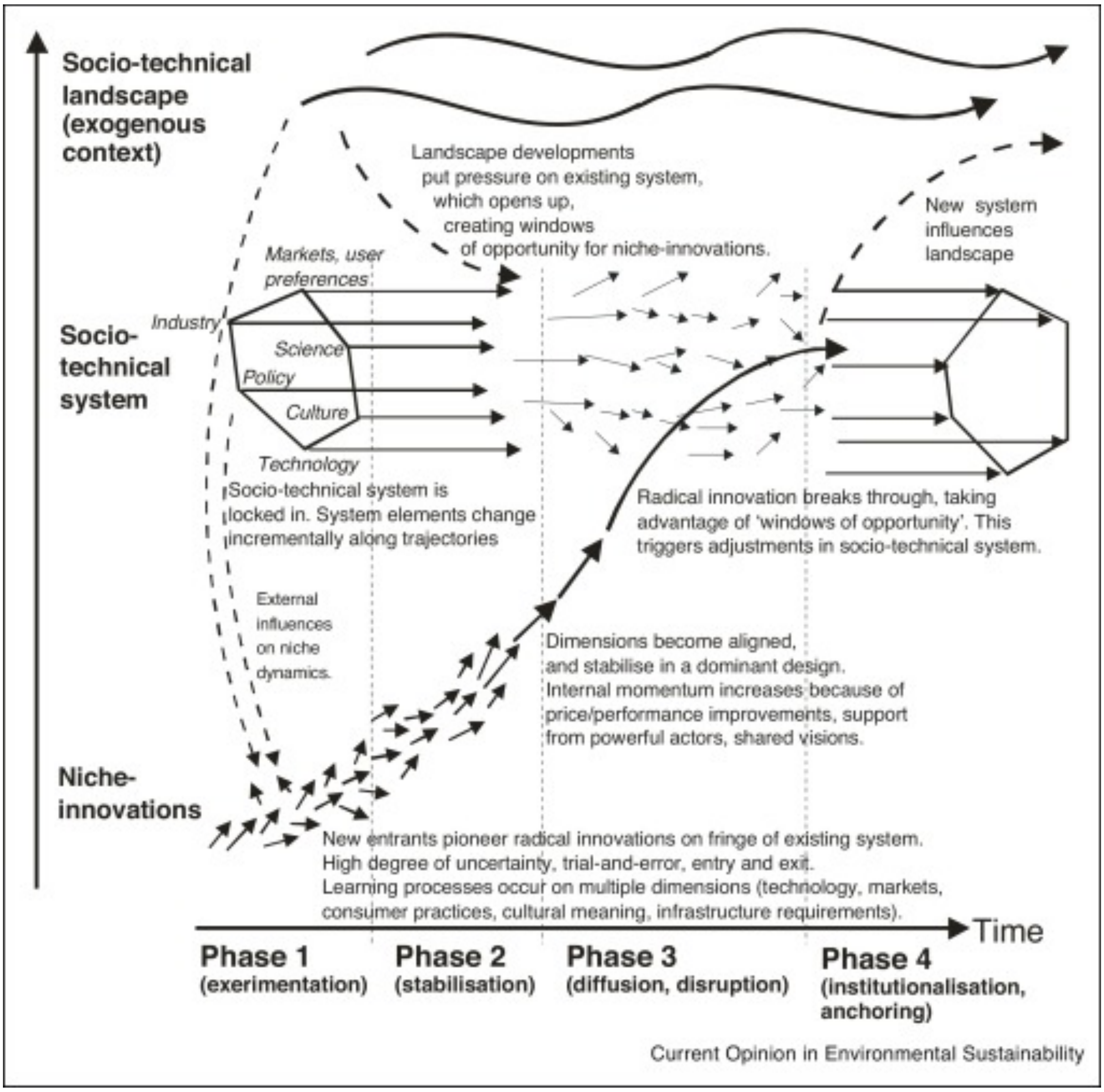
[2] This concept/term was coined by Gregory C. Unruh (1999) and explained in a subsequent study: "…industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale. It is asserted that this condition, termed carbon lock-in, creates persistent market and policy failures that can inhibit the diffusion of carbon-saving technologies despite their apparent environmental and economic advantages" (Unruh 2000).



Current Opinion in Environmental Sustainability

Figure 1: **Multi-Level Perspective on Transitions (Geels 2019)**

This policy brief calls on the G20 governments to: "build back better" through COVID-19 economic stimulus packages that promote a wide range of climate change mitigation approaches, including CCE as an essential bridge to a low-carbon future.

Proposal I

Support innovations in carbon management technologies including, but not limited to, negative emission technologies such as DAC and CCUS. This can be achieved by investing in R&D and accelerating the commercialization of neutral hydrocarbon technologies to reduce their costs and expand their portfolio and deployment.

Examples of specific innovations in carbon management technologies at commercial or near-commercial stages across the 4Rs include:

1. Reduce:

- **Concentrated solar panels** to generate the steam needed for heating, while integrating **enhanced oil recovery** by injecting natural gas and using **CCS**.
- Using **ultra-super critical** or **integrated coal gasification combined cycles**.
- **Carbon-free ammonia** produced from green/blue hydrogen as fuel for power generation and/or maritime vessels (Wang et al. 2018; The Royal Society 2020).

2. Reuse:

Using **captured CO_2** for vegetable-growing greenhouses to **enhance crop yield** to reach photosynthesis potential.

3. Recycle:

- Decomposition and combustion via a **pyrolysis** process that converts **oil sludge** into various useful materials, such as liquid fuel.
- **Captured CO_2** may be used in a petrochemical plant that converts it into urea when combined with synthetic ammonia.
- **Ecological concrete production** can achieve emissions neutrality/circularity using CO_2 storage under infrastructure by concrete materials (CO_2-SUICOM) (Yoshioka et al. 2013; Higuchi et al. 2014). Feasible via capturing CO_2 emitted from the cement production process and utilizing a special admixture to absorb this captured CO_2 in its hardening process and substitute the cement used in concrete production.
- Using **process heat waste** as energy for industrial purposes.

4. Remove:
Remove carbon from the steel industry through CCUS for enhanced oil recovery and utilize it for cement or with carbon dioxide removal (CDR) technologies or sequester carbon in a saline formation.

Policy tools that enable large scale investments in carbon management technologies include:

- Identify areas of joint concerns and create clubs (Victor 2006) within G20 countries to leverage and coordinate mutual policy instruments and regulations.

- Clarify and constrain choices to existing standards on carbon footprint disclosure to maximize measurement consistency (Carbon Trust 2020).

- Set global standards for carbon circular materials and products (Tecchio et al. 2017) and create a tamper-proof accounting mechanism for abatement using blockchain and artificial intelligence (Khaqqi 2018).

- Deploy targeted national policies that promote low or even negative carbon technologies and industrial processes to reach declining cost curves, with a focus on public procurement conditionality that promotes circularity (Meckling, Sterner, and Wagner 2017).

- Invest in R&D to accelerate the commercialization of carbon management technologies and broaden their portfolio to include emerging and near-commercial technologies, while connecting them to ongoing efforts, such as Mission Innovation or the Combined Heat and Power for Resiliency Accelerator, launched by the US DOE (see the Appendix).

- Develop a comprehensive industrial policy framework for carbon-neutral energy-intensive hard-to-abate industries and introduce stringent innovation and market-based policies throughout the value chain to transition emerging technologies from the development and near-commercialization phases to commercialization and deployment. For instance, performance-based tax credits, such as the 2018 amendment to the 45Q that encourages plants to deploy CCUS technologies (Perry 2018); and support for innovation in CCUS technologies (IEA 2019a), such as the DOE $30 million funding round for R&D in feed studies for carbon capture in fossil fuels plants (DOE 2019).

Proposal II

Institutionalize and incentivize heavy industries and corporate-wide initiatives to manage emissions for achieving climate goals. This can be achieved by utilizing and upscaling existing schemes and creating new policy tools for instituting carbon circularity in the hydrocarbons industry across the value chain. Guide mapping high-priority technologies to be targeted for financing would help align the technology investments of G20 countries. This guide could also provide an estimate of the required level of investment, an indication of the share the private sector could contribute, and suggestions for mechanisms to incentivize the private sector's participation.

Given the existence of hard-to-abate industries, the global economy's heavy reliance on carbon and carbon-based products, and the implications of the COVID-19 pandemic that shifts governments' focus on often fossil-fuel-based short-term economic relief, instituting carbon circularity is important for achieving neutrality. It requires new schemes to support technologies such as CCS and CCUS, while also building on existing efforts in the area of material circularity, which alone can reduce emissions from material by 33%, that is, the equivalent of 364 Mt CO_2 per year, including 54 Mt CO_2 per year for steel, 100 Mt CO_2 per year for chemicals, and 17 Mt CO_2 per year for cement (Turner and Mathur 2018). Process circulation suggests minimizing waste by utilizing existing industrial processes with added efficiency improvements.

Policy tools to support the transition of hydrocarbons at the industry level towards CCE:

- Tracking plants producing primary iron, steel, cement, chemicals, aluminum, and plastics and the energy type used for encouraging the identification and disclosure of carbon footprints per ton of primary products within hard-to-abate industries. This should be coupled with additional information such as chemical properties, tonnage, bulkage, and packaging format through interactive maps showing real time plant processes and emissions. Broad climate reporting scheme includes information on GHG emissions, consumption of resources and energy, strategy, practices and policies implemented by companies to address climate change, performance against targets, and main risks and opportunities expected by a company as a result of climate change (OECD 2015). Examples are the advanced mandatory schemes introduced by G20 for companies to report the carbon footprint such as Scope 1 and Scope 2 GHG emissions applied in France, Mexico, United Kingdom, and Australia including verification mechanisms and/or no penalties (OECD 2015). They can be used as a basis for common approaches on introducing carbon disclosure rules on various commodity exchanges.

- Establishing a “CCE fund” that supports all mitigation options and restructuring “green” funds to include carbon management (blue) technologies.

- Introducing “CCE indicators” to track progress on carbon mitigation across the 4Rs and qualifying these efforts by hydrocarbon companies to be included in NDCs.

- Upscaling energy efficiency and intensifying efforts towards economic diversification and job creation by restructuring energy incentives, implementing energy efficiency standards, and developing/enforcing energy performance labelling, such as Minimum Energy Performance Standards.

- Standardizing the definition of the “green supply chain” and “greener” product procurement and market through carbon footprint disclosure and certification per ton of primary product and creating a low-carbon asset class index at various trade exchanges. An example is the metals trade exchange-equivalent with carbon footprint and using LCA and materials passports by the EU.

- Rapidly enhancing and scaling up CDR technology penetration, such as DAC (see Figure 2). Although its current operational/maintenance cost and CO_2 capturing capacity are considered unfeasible, researchers have predicted a significant decrease in cost and an increase in capturing capacity in the long term. Its early and massive implementation will be vital for cost reduction through cost competitiveness (Babonneau, Haurie, and Vielle 2019; Fasihi, Efimova, and Breyer 2019; Nemet and Brandt 2012; Rubin et al. 2007; van den Broek et al. 2009; Rubin, Yeh, and Hounshell 2004). Without access to carbon management technologies such as CDR, the welfare loss in discounted GDP unit would be 3.8% worldwide, while the worldwide cost falls by 2.8% with access to CDR technologies (Babonneau, Haurie, and Vielle 2019).

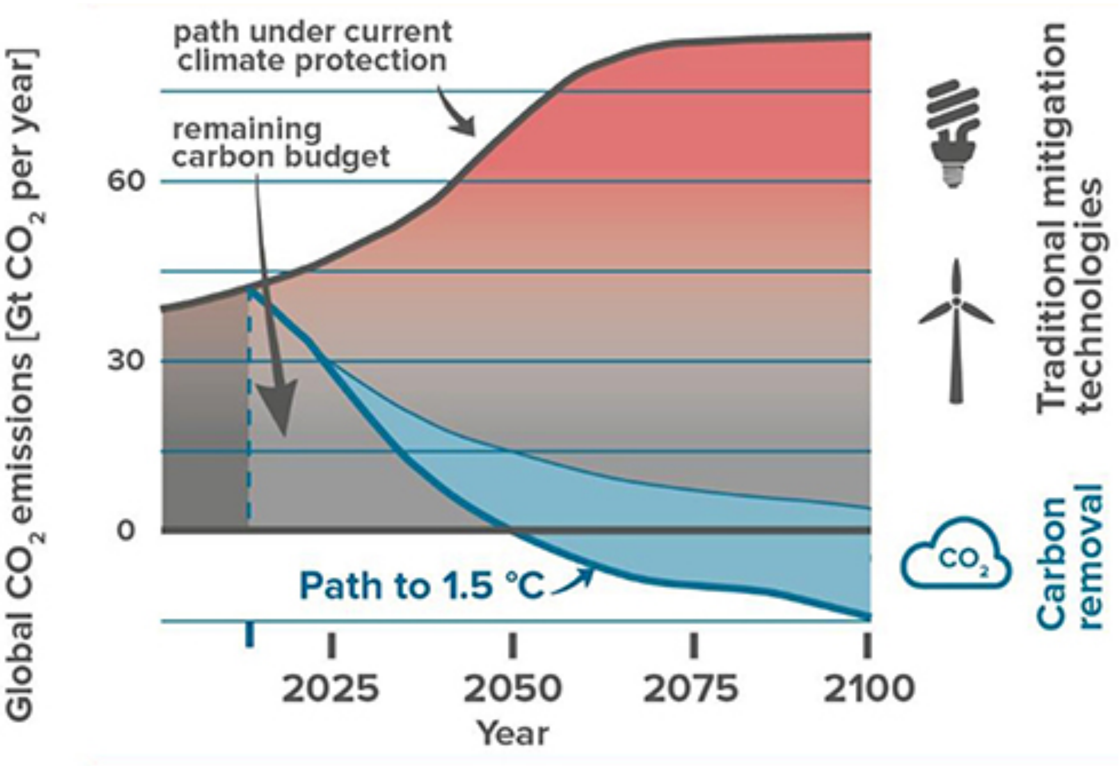


Figure 2: **DAC as an essential technology for reaching 1.5 °C**

Source: **Beuttler, Charles, and Wurzbacher 2019**

Proposal III

Provide a platform for cooperation among nations and consolidate the efforts to manage emissions in hard-to-abate industries. This would require the G20 to emphasize the need to deploy at scale and rapidly, as well as ensure institutional sustainability. This in turn provides powerful institutional structures and good governance principles around carbon-neutralization efforts sustainable in the long run.

This can be achieved by:

- Creating a G20 Working Group on Carbon-Neutral Hydrocarbons to merge existing relevant initiatives that utilize the CCE approach, such as the first Hydrogen Ministerial Meeting held in Tokyo in 2018, International Energy Agency, International Partnership for Hydrogen and Fuel Cells in the Economy, Clean Energy Ministerial, Mission Innovation, Mission Possible, Energy Transitions Commission, and the UN Industrial Transition Leadership group.

- Enhancing international collaboration to reduce the cost of carbon management technologies and increasing the speed of commercialization opportunities for carbon capture technologies for rapid and early deployment.

- Emphasizing the need for the rapid and early deployment of CCS technologies to avoid an increase in costs if deployment is delayed (Leeson et al. 2017).

- Promoting the free flow of information and technological advancements across borders, which facilitate deployment, enhance safety, and improve communication, education, and outreach activities around the deployment of carbon management technologies for carbon-neutral fossil fuels.

- Promoting policy dialogues for the integration of the 4Rs across government departments and between governments and the private sector through multi-stakeholder partnerships.

Key Recommendations

1. Support innovations in carbon management technologies including, but not limited to, negative emission technologies, such as direct air capture and carbon capture utilization and storage. This can be achieved by investing in R&D and accelerating the commercialization of neutral hydrocarbon technologies to reduce their costs and expand their portfolio and deployment.

2. Institutionalize and incentivize heavy industry and corporate-wide initiatives to manage emissions towards achieving climate goals. This can be achieved by utilizing and upscaling existing schemes and creating new policy tools for carbon circularity in the hydrocarbon industry across the value chain. Guide mapping for high-priority technologies to be targeted for financing would help align the technology investments of the G20 countries. This process could also provide an estimate of the required investment level, an indication of the share the private sector could contribute, and suggestions for mechanisms that would incentivize private sector participation.

3. Provide a platform for cooperation among nations and consolidate efforts to manage emissions in hard-to-abate industries. This approach would require the G20 to emphasize the need to deploy at scale and rapidly, as well as to ensure institutional sustainability. The latter provides powerful institutional structures and good governance principles for carbon-neutralization efforts sustainable in the long run.

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Disclaimer
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APPENDIX

Carbon Neutralization under G20 Presidencies

Since the US G20 presidency at Pittsburg in 2009 and, most recently, under the Japan G20 presidency at Osaka in 2019—where Saudi Arabia was part of the governing troika—member states agreed to phase out inefficient fossil fuel subsidies to limit emissions and inefficient consumption. Many cooperation initiatives materialized, such as data tracking, price monitoring, and managing volatility, in conjunction with international energy organizations such as the IEA and OPEC. It also resulted in the creation of new bodies such as the Joint Organization Data Initiative. Energy efficiency emerged as a main concern in 2014, the Energy Working Group being expanded to include energy efficiency, energy access, and renewable energy.

Other G20 initiatives have emerged, such as the major economies forum on Energy and Climate, which resulted in action plans for technologies applicable to the sectors responsible for 80% of global emissions in 17 of the largest emitters. Further, the US-led Clean Energy Ministerial launched a CCUS initiative in 2018 and Mission Innovation (MI), launched in conjunction with COP 21 in 2015 with 20 governments pledging to double individual R&D spending on clean energy over the next five years. MI launched an action plan for the Carbon Capture Initiative, known as Innovation Challenge 3 (IC3), focusing on finding markets for CO_2 utilization.

Under the Japanese G20 presidency, leaders confirmed “the need for a free, fair and non-discriminatory trade policy” to mitigate GHG emissions and reach neutrality in the second half of the century. Technological approaches have been signaled as vital for a sustainable future. Nevertheless, calls on G20 nations to phase out of fossil fuel subsidies and deploy ambitious carbon pricing schemes remain at the forefront of the efforts to transition energy systems to low carbon systems. Moreover, the UNEP has called on the EU to accelerate resource flows to address CCS for emissions from industry under its innovation fund. It also identified this area to be a focus for other countries, such as China, as a path towards a “zero emissions industrial process” strategy.

Examples of other carbon-neutralization efforts: The cement sector in India identified more than 300 projects for efficiency improvements in 2013 and had achieved 30% of its entire carbon emissions reduction potential (500 Mt CO_2 per year) as of 2017 (IEA 2019c, 16). Saudi Arabia's efficiency improvements and fuel switching policies have resulted in emission reduction from fuel consumption by 4% in 2018 compared to 2017 (Howarth et al. 2020); the Saudi oil and gas and petrochemical sectors have reached high levels of abated CO_2 over the past decades through efficiency improvements and operational excellence. SABIC, a key stakeholder in the Saudi economy and the world's fourth largest chemical company, is home to the world's largest CCUS plant. The facility can capture and purify up to 500,000 metric tons of CO_2 from the production of ethylene glycol, every year. SABIC's global utilization of CO_2, as a feedstock, increased to 3.3 million metric tons, reducing material loss intensity by 29% since 2010, mitigating GHG emissions (intensity has decreased by 7.8%), reducing energy intensity by 8.1%, and reducing water intensity by 11% (SABIC 2019). Additionally, gas flaring by Saudi Aramco is currently below 1% and its carbon emissions were cut by 25.8 million tons of CO_2 from 2000 to 2019 (Pinheiro 2019). Furthermore, the company's commitment to best practices and enhanced efficiency has reduced its upstream carbon intensity to more than 50% below the average country level, at a weighted average of 4.6 g of CO_2e/MJ or 10.2 Kg of CO_2e/barrel, which is the second lowest following Denmark (Masnadi et al. 2018). Saudi Arabia's futuristic city, NEOM, is home to the world's largest green-hydrogen project. This project aims to develop a $5 billion hydrogen-based ammonia plant, powered by renewable energy, to produce 650 tons of green hydrogen daily (NEOM 2020). The US DOE launched the Combined Heat and Power for Resiliency Accelerator to support the expansion of CHP as a solution for minimizing waste heat.

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