Why the IPCC believes that Bioenergy Carbon Capture and Storage (BECCS) is Critical to Limiting Global Warming to 1.5°C

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In its *2018 Special Report on Global Warming of 1.5°C*, the IPCC (2018) analyzed four CO_2 emission pathways and system transitions consistent with limiting mean surface temperature increase to 1.5°C, relative to pre-industrial levels (i.e., 1850-1900). Many environmental organizations and politicians have focused their attention on one of these pathways – the Low Energy Demand (LED) pathway. For example, this pathway is one of the bases of the Green New Deal proposed by some U.S. Democrats (Roberts 2019).

While the LED pathway has received much of the world's attention, it is important to understand how extraordinarily ambitious this pathway is. It models a future in which social, business, and technological innovations result in lower energy demand, thereby enabling an incredibly rapid decarbonization of the energy sector. As the IPCC notes, this pathway would require global anthropocentrically-caused CO_2 emissions to decrease by 58% in 2030 and 93% in 2050 (both relative to 2010 emissions) and global energy demand to decrease by 15% and 32%, respectively in 2030 and 2050 (IPCC 2018).

In fact, all four of the IPCC's 1.5°C pathways are unprecedented and present real challenges. As the IPCC noted, "pathways limiting global

Carbon Dioxide Reduction (CDR) Mechanisms

As the IPCC discusses in its 2018 Special Report on Global Warming of 1.5°C, the scientific literature describes a number of CDR approaches. These include:

- Terrestrial and coastal carbon storage enhancement in plants and soils, such as afforestation and reforestation, soil carbon enhancement, and other conservation, restoration, and management options for natural and managed land and coastal ecosystems,
- Terrestrial carbon storage via biochar sequestration,
- Atmospheric CO_2 storage in geological formations, such as by combining biomass-based energy production with carbon capture and storage (BECCS) and direct air capture with storage using chemical solvents and sorbents,
- Mineralization of atmospheric CO_2, including enhanced weathering of rocks, and
- Sequestration of CO_2 in the oceans, including by means of ocean alkalinization. (Rogelj et al. 2018, 121).

The IPCC's report focuses on, and its four emission reduction and system transition pathways include, only two CDRs: (1) agriculture, forestry, and other land use-based (AFOLU) and (2) Bioenergy Carbon Capture and Storage (BECCS) because these two CDR methods are most often analyzed in integrated pathways (IPCC 2018, 96). In all likelihood, AFOLU and BECCS will not be the only CDR mechanisms employed to move more rapidly towards carbon neutrality and/or produce net negative CO_2 emissions. Instead, it is likely there will be a portfolio of CDR options available, which will allow the flexible exchange of CDR mechanisms to address their technological feasibility and human sustainability, social, and economic objectives.

However, even if multiple CDR methods are available, it is likely that AFOLUs and BECCS will see widespread deployment in 1.5°C warming pathways. This is because AFOLUs, such as afforestation and reforestation have a proven track record of sequestering carbon and are often low cost and provide additional sustainability (e.g., wood products that sequester carbon) and environmental benefits. Assuming it overcomes technical and economical feasible issues, BECCS is also likely to see widespread adoption because unlike other CDR methods, it can help limit global warming to 1.5°C in two ways: (1) by sequestering carbon in geological formations, and (2) creating energy, which reduces the need to use fossil fuel-based energy.

warming to 1.5°C … require rapid and far-reaching transitions in energy, land, urban infrastructure (including transport and buildings), and industrial systems… . *These systems transitions are unprecedented in terms of scale,"* and require (1) deep emissions reductions in all sectors, (2) the use of a wide portfolio of mitigation options, and (3) significant increases in the economic and technologic investments in those options (IPCC 2018, 15) [emphasis added].

All four pathways modeled by the IPCC require the use of carbon dioxide removal (CDR) measures to compensate for residual and difficult to mitigate emissions (e.g., air travel emissions) and to prevent or limit temperature overshoot (i.e., the temporary exceedance of 1.5°C of global warming) (IPCC 2018) (see Box 1). While the LED pathway only uses agriculture, forestry, and other land use-based (AFOLU) CDR measures, the three other pathways utilize both AFOLU and Bioenergy Carbon Capture and Storage (BECCS) CDR mechanisms (See Box 2).

Before discussing the four illustrative pathways the IPCC believes would limit global warming to 1.5°C, this article describes the risks associated with not limiting such warming. It then explains the importance of CDRs in achieving three of those pathways, focusing on the role of BECCS. After examining gaps in our current knowledge of CDRs and BECCS and uncertainty regarding their deployment, it concludes by reviewing why investment in and eventual deployment of BECCS is so important if the world is unable to follow the ambitious LED pathway.

The Risks Associated with Not Limiting Global Warming to 1.5°C

Before describing the four pathways to limiting global warming to 1.5°C, the IPCC documented how human activities have warmed the world thus far. It then predicted the impact and explained the risks if warming exceeds 1.5°C or 2°C of pre-industrial levels.

Why are BECCS a CDR Mechanism?

BECCS involve two processes. Biomass such as wood, algae, municipal solid waste, and other biomaterials is converted into heat, electricity, or liquid or gas fuels. These bioenergy sources are nearly always produced using significantly less fossil fuels than energy produced by fossil fuels. Thus, bioenergy eliminates most of the GHG emissions associated with fossil fuel produced energy – the emissions that the IPCC states are the main cause of increasing CO_2 levels in the atmosphere and global warming.

With BECCS, the CO_2 emissions from bioenergy processes are captured during this biomass-to-energy conversion and stored in geological formations or embedded in long-lasting products, such as concrete. Since the carbon emitted by burning biomass is carbon that has already been circulating in the Earth's atmosphere, rather than fossil fuel-based carbon that is being added to the Earth's atmospheric cycle after being locked up for millions of years, BECCS reduce overall CO_2 concentrations in the atmosphere (ICRLP 2018).

As the IPCC noted, "pathways limiting global warming to 1.5°C … require rapid and far-reaching transitions in energy, land, urban infrastructure (including transport and buildings), and industrial systems.

The IPCC estimated that human activities "have caused approximately 1.0°C of global warming above pre-industrial level" (IPCC 2018, 4) and that "[w]arming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and … continue to cause further long-term changes in the climate system" (IPCC 2018, 5). It also noted that "these [past] emissions *alone* are unlikely to cause global warming of 1.5°C" (IPCC 2018, 5) [emphasis added]. However, the IPCC predicted that if current greenhouse gas (GHG) emissions continue to increase at their current rate, "[g]lobal warming is *likely* to reach 1.5°C between 2030 and 2052" (IPCC 2018, 4) [emphasis in original].

The report documented climate-related risks and their projected impacts at various temperature increases. For example, the IPCC summarized some of the projected impacts and risks for some natural, managed, and human systems (Figure 1). This figure uses colors to indicate potential risks and impacts at 1°C, 1.5°C, 2°C, and higher temperature increases, with the colors white, yellow, red, and purple representing a spectrum of risks and impacts ranging from no detectable impacts associated with climate change (white) to very high risks of severe impacts (purple). The letters L, M, H, and VH adjacent to the vertical bars indicate the IPCC's confidence in the predicted transitions.

As the figure indicates, the IPCC noted a very high risk for severe and irreversible impacts are associated with warm-water coral and coral-reefs, starting at temperature increases of approximately 1.0°C, and for the artic (i.e., polar regions) at around 2.0°C. Many other systems and impacts including coastal flooding, small scale fisheries, terrestrial ecosystems, and fluvial flooding have a high risk for severe and widespread impacts if temperatures exceed 1.5°C. Exceeding the 1.5°C target will impact a wide range of different systems around the world, which in turn will dramatically disrupt people's lives and economies around the world.

The Four Pathways

Based on the severe and widespread impacts of exceeding 1.5°C, the IPCC examined both supply and demand side changes to reducing global carbon emissions such has changes in forestry and agriculture land use practices, shifting to renewable sources of electricity, electrifying more energy use, reducing energy consumption, and CDR mechanisms

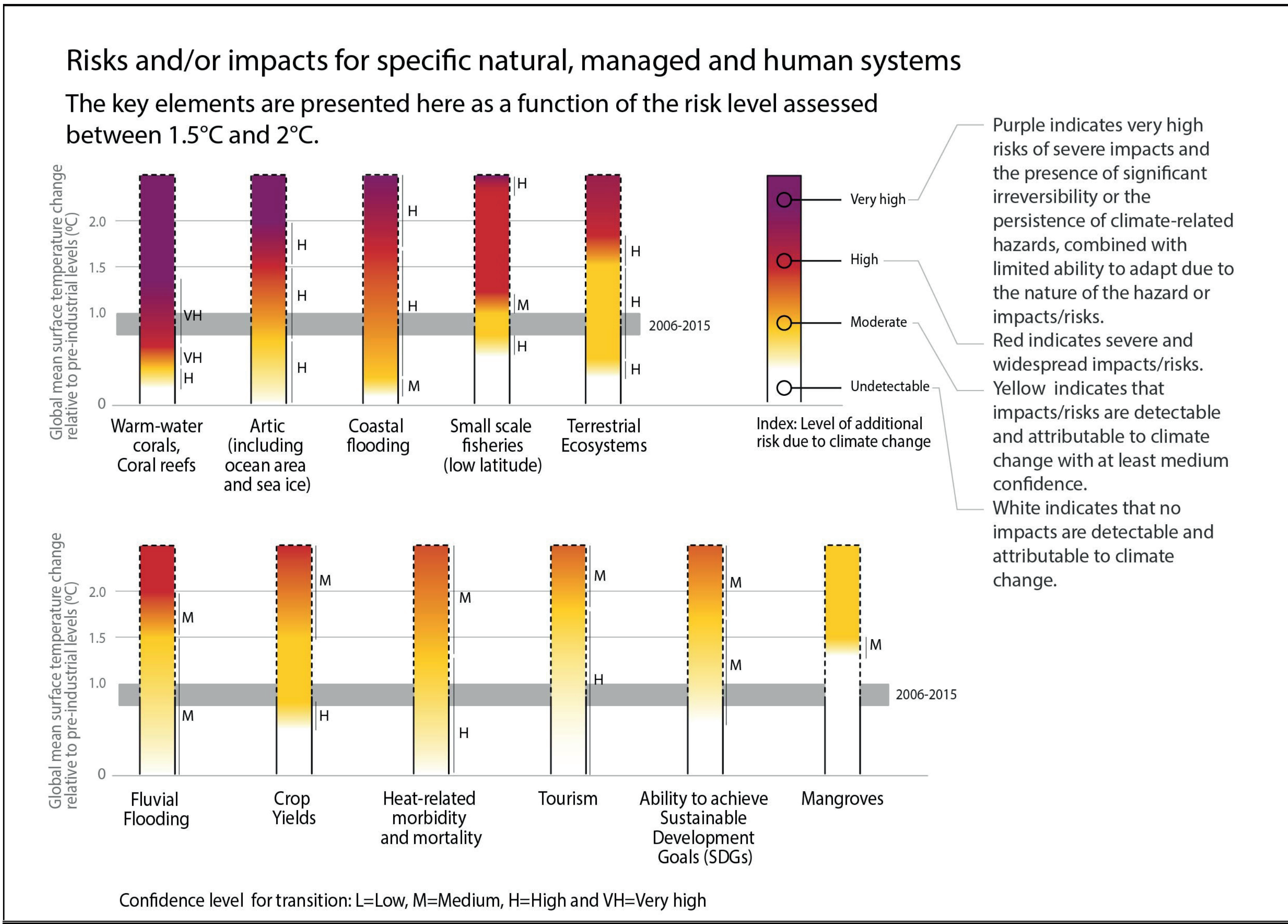

Figure 1: Risks and/or Impacts for Specific Natural, Managed, and Human Systems (Source: Hoegh-Guldberg et al. 2018, Figure 3.20).

(including BECCS). The IPCC then used these different approaches to managing CO_2 emissions, and developed four pathways to limit emissions so that global temperatures will not exceed 1.50C.

The IPCC noted that limiting warming to 1.5°C requires decreasing GHG emissions over the next decade because lower GHG emissions in 2030 lead to a greater chance of limiting peak warming to 1.5°C (Rogelj et al. 2018). Importantly, the IPCC also noted that current CO_2 reductions pledged by the world's nations under the Paris Agreement are not expected to limit global warming to 1.5°C. To do so, nations would need to supplement their currently pledged reductions so as to achieve net zero human-caused CO_2 emissions by 2045 (Rogelj et al. 2018).

Figure 2 summarizes the four illustrative pathways the IPCC analyzed and the corresponding emissions reductions and system transitions required to limit global warming to 1.5°C. The top of the figure describes each pathway's social, technical, and other characteristics. Pathway P1 corresponds to the IPCC's LED pathway. P2 represents a very aggressive sustainability-focused scenario that requires considerable international cooperation and social change, in relation to energy and land use, combined with technology development. The P4 pathway corresponds to a scenario where fossil fuels continue to dominate energy use but there is rapid development and deployment of CDR technology to reduce net emissions. P3 represents a middle-of-the-road scenario that includes a mix of societal changes and technology deployment. The scenarios use different approaches to reach zero net emissions, but all of them reach a net zero human-caused CO_2 emissions in 2050-2060 (green line). Fossil fuel and industry CO_2 emissions are represented in the top portion of the figure by gray shading, and CO_2 emissions reductions via AFOLU and BECCS are represented

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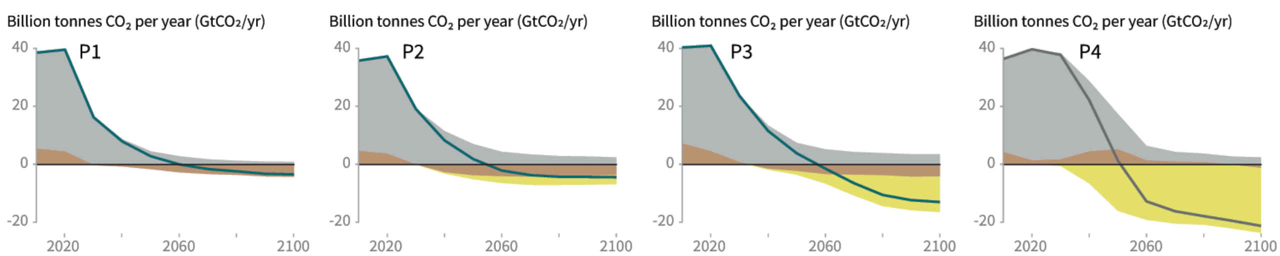
Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways

Fossil fuel and industry ● AFOLU ● BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
↳ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
↳ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
↳ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
↳ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
↳ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
↳ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
↳ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
↳ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
↳ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
↳ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
↳ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km²)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure 2: The IPCC's Four Modeled Pathways and their Characteristics. (Source: IPCC 2018, Figure SPM.3b). Notes: (1) The right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C (i.e., pathways P1, P2, and P3). (2) Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2 and S5 pathways assessed in the report's Chapter 2.

by brown and yellow shading, respectively.

The bottom of the figure quantifies the global CO_2 emission reductions and systems transitions that would be required in 2030 and 2050 for pathways with no or limited overshoot (P1/LED, P2, and P3) of 1.5°C of global warming, and P4, a pathway with a higher overshoot of 1.5°C of global warming. For example, the P1/LED pathway, would require CO_2 emissions to decrease by 58% in 2030 (relative to 2010 emissions) and by 93% in 2050. Whereas under P4, the fossil fuel-based pathway, CO_2 emissions would increase by 4% in 2030, but then decrease by 97% in 2050. This portion of the figure quantifies the vast differences between the pathways regarding CO_2 emissions, energy system transformations, CDR mechanisms, and agricultural systems changes. It also demonstrates the enormous transformations that will need to occur globally regardless of which pathway is followed in forty years if humans want to limit global warming to 1.5°C.

The Importance of Bioenergy and BECCS.

Along the gradient of scenarios from P1 to P4, the importance of the role of BECCS increases considerably. As noted above, the P1/LED scenario does not include BECCS and requires a 16% decrease in biomass use for primary energy by 2050, and an increase of 430% in non-biomass renewables. However, the role of biomass is essential to the success of scenarios P2 – P4, with increases of primary energy from biomass ranging from 49% to 418% by 2050. Much of this increase in biomass use is connected with using BECCS to remove CO_2 from the atmosphere (See Box 2). Under scenarios P2 – P4, BECCS remove between 151 to 1,191 $GtCO_2$ from the atmosphere and is an essential component for reaching the 1.5C warming target.

It is important to note that the decreases in biomass-based primary energy required by the P1/LED pathway (i.e., an 11% reduction by 2030 and 16% reduction in 2050) do not necessarily correspond to decreases in centralized electricity, thermal, and other bioenergy-based systems. This is because the primary biomass-based energy in these rows includes distributed and inefficient wood-based heating and cooking practices – some of which would be replaced by centralized energy systems based on renewables. In fact, the IPCC clearly states the importance of bioenergy in the future, "[b]ioenergy use is substantial in 1.5°C pathways with or without BECCS due to its multiple roles in decarbonizing energy use" (emphasis added) (Rogelj et al. 2018, 96).

The three pathways (P2, P3, and P4) that require large increases in biomass-based energy also require large quantities of carbon capture and storage of biomass-based CO_2 emissions "to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C following a peak" in temperature above 1.5°C (Rogelj et al. 2018, 96). As the IPCC notes, the "longer the delay in reducing CO_2 emissions towards zero, the larger the likelihood of exceeding 1.5°C, and the heavier the … reliance on net negative emissions [such as BECCS] after mid-century to return warming to 1.5°C" (Rogelj et al. 2018, 96).

All four pathways also require increases in bioenergy crops by 2050. As the table indicates, the IPCC estimates that the land area dedicated to energy crops in 2050 must increase by between 200,000 km^2 (P1/LED) and 7.2 million km^2 (P4). These bioenergy crops would, along with other biomass, be used as inputs into BECCS systems to concentrate biomass production and to reduce the pressure on natural forests to provide BECCS feedstocks.

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Knowledge Gaps and Uncertainty About CDRs and BECCS

The IPCC acknowledges technical, social, and environmental limitations, including knowledge gaps, may limit whether the pathways can actually limit warming to 1.5°C. For CDRs, these begin with the fact that CDRs have never been deployed at the scales required under pathways P2, P3, and P4, and even if they can be deployed as such scales, there is a risk they may not be able to limit warming to 1.5°C (Rogelj et al. 2018). In addition as the IPCC notes, "[i]ndividual CDR measures have different characteristics and therefore carry different risks for their sustainable deployment" at the scale required (Rogelj et al. 2018, 125) and widespread use of CDRs involves trade-offs with other sustainability objectives because of potential increased land, energy, water, and investment demands.

The IPCC also summarized specific risks for BECCS, such as the potential for substantial impacts on environmental services and ecosystems, agricultural and food systems, and for dedicated bioenergy crops increased water demand. BECCS also relies on CCS which will require safe storage space in geological formations, including management of leakage risks and induced seismicity. The IPCC also noted that potential issues with land-based CDRs such as AFOLUs and BECCS depend on multiple factors, including where they are deployed "(e.g., on marginal vs. productive land), socio-economic developments, dietary choices, yield increases, livestock productivity and other advances in agricultural technology, land policies, and [the] governance of land use" (Rogelj et al. 2018, 125) [references omitted].

Conclusion: Investments in BECCS Required Now

The IPCC's 2018 report describes unprecedented emission reductions and system transitions and the need to begin transitioning to these transformations as soon as possible. So it is understandable that some environmental organizations and the press have focused their attention and political actions on the IPCC's P1/LED pathway.

However, it is important to realize that the P1/LED pathway is amazingly ambitious, and may be more aspirational and motivational, than realistic. For example, can G20 nations, let alone the world, achieve the IPCC's 2030 emission and energy targets in ten years (e.g., a 58% reduction in CO_2 emissions, a 59% increase in nuclear energy, a 25% decrease in natural gas use) given current energy and lifestyle trends? If not, the IPCC is clear: BECCS and other CDR methods will be critical if the world wants to limit warming to 1.5°C and avoid all of the predicted changes not doing so will bring to natural, managed, and human systems.

Given the unique dual benefits the IPCC recognizes BECCS provide, namely carbon sequestration and the displacement of fossil fuels to produce energy, it is critical that the world not only attempt to follow the P1/LED pathway, but also invest its political and economic capital in the development and deployment of BECCS now. It is imperative that BECCS is technically and economically viable as soon as possible since it is extremely likely that BECCS and other CDR mechanisms will be required to offset residual emissions, prevent or limit temperature overshoot, and allow the world to achieve the net zero CO_2 emissions the IPCC believes are required by 2050.

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