# Aspen Global Change Institute Energy Project

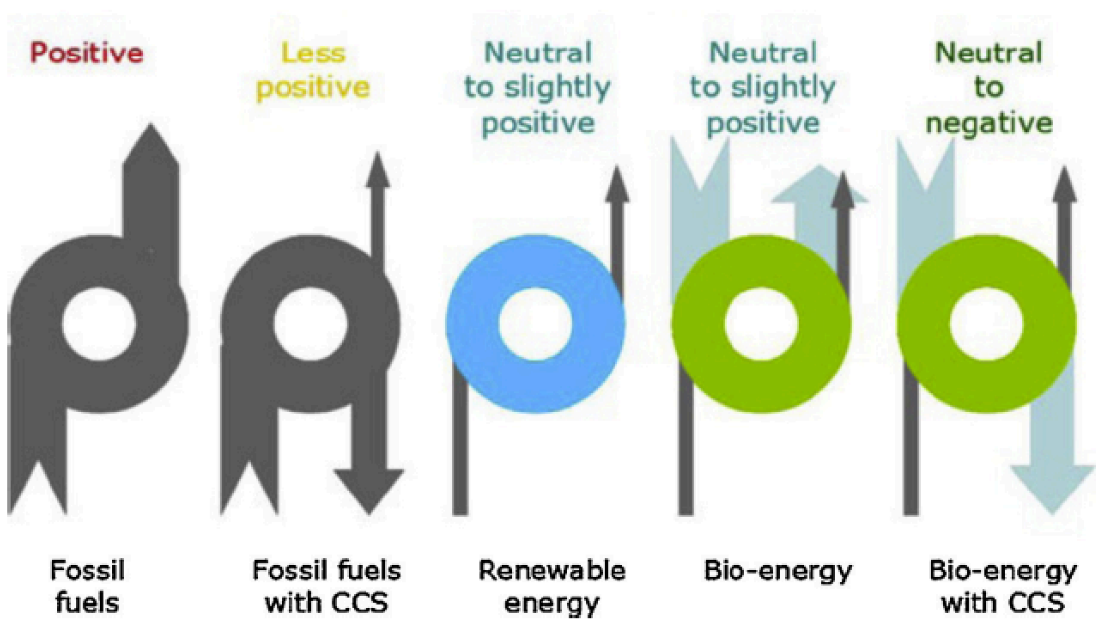
# September 2017 Quarterly Research Review

## The Role of Negative Emissions Technologies in Achieving the Paris 2° Goal

The International Space Station (ISS) has the challenge of creating an artificial life support system in a sealed vessel orbiting in a hostile environment. One of the critical functions is maintaining the air the astronauts breathe with acceptable levels of carbon dioxide, for which NASA created a Carbon Dioxide Removal Assembly (CDRA). Its function is critical because the volume of air in the ISS is limited and can quickly become overburdened with excess $CO_2$ due to crew respiration (NASA 2005). The CDRA is a complex machine requiring frequent attention to keep it functioning properly. Can a similar technology reduce carbon dioxide in Earth's atmosphere and stabilize the Earth's climate? The scale of such a feat is staggering. Rather than the exhale of a half a dozen crew members, the industrial age 'exhale' has grown to about 10 GtC per year (10 billion tonnes of carbon, ~ 37 Gt $CO_2$). A massively scaled-up version of a device similar in principle to the one aboard the ISS – essentially a chemical $CO_2$ scrubber – is but one approach being considered in the family of technologies known as Negative Emissions Technologies (NETs).

## Negative Emission Technologies

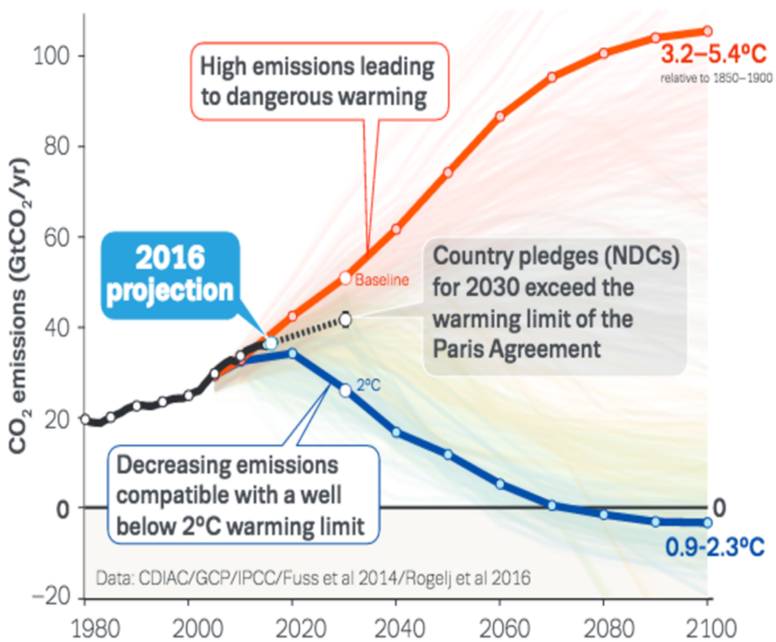
The suite of Negative Emission Technologies (NET) includes Direct Air Capture (DAC) where $CO_2$ is removed from ambient air with a variety of techniques – for example using a chemical sorbent (Keith et al. 2006). Another NET approach is Bioenergy with Carbon Capture and Storage (BECCS), where high yielding biomass in the form of trees or fast-growing grasses or crop residues are harvested and combusted to produce useful energy. The flue gas $CO_2$ is then captured and stored underground (Kemper, 2015). Yet another approach is Enhanced Weathering (EW) where $CO_2$ is disposed in carbonate minerals (e.g. Lackner et al. 1995, Rau et al. 2007). Afforestation/Reforestation (AR) is perhaps the simplest approach where biomass is grown capturing carbon as the cellulose in plant tissue. Mimicking nature at an accelerated pace is Soil Carbon Storage (SCS) which includes techniques for increasing soil carbon on agricultural and other lands. The technique can be further enhanced with Biochar where carbon is concentrated via pyrolysis and added to the soil (Smith, 2016). See Figure 2 for a subset of this list from the standpoint of carbon release to the atmosphere or capture to below ground reservoirs.




From a climate change perspective, two key questions emerge: 1) whether or not negative emissions are necessary, and 2) if any of these techniques can be scaled up commensurate with the challenge of climate change while mitigating unwanted effects.

## The 2° Goal

On the grand scale of the Earth, the early extraction and combustion of fossil fuels in the 1800s and early 1900s made only a minor change to the concentration of carbon dioxide in the atmosphere. But as the 20th century progressed, the additions exceeded the Earth's uptake biologically and chemically driving the concentration of $CO_2$ now some 43% above the pre-industrial level – a jump from 280 to over 400 parts per million. Yet this increase in $CO_2$ is still only about ~0.04% of the atmosphere. The trick in NET is to extract a portion of this $CO_2$ and keep it from reentering the atmosphere.




This human-caused increase in $CO_2$ is likely the defining environmental issue of the 21st century. On geologic timescales, the natural mechanisms of the Earth's carbon cycle will pull down the human caused excess through weathering, but in the meantime the global average temperature will exceed the internationally desired limit of 2°C above pre-industrial temperatures. The Paris Agreement Nationally Determined Commitments are an important step in the right direction; however fall far short of what is needed (Figure 3, GCP 2016).

The remedy is straightforward – global carbon emissions peak in the next several years and then by aggressive substitution of efficiency, clean energy technologies, and sustainable land management practices, transition to near zero emissions (the topic of 1998, 2000, 2003, 2014 and 2016 AGCI workshops). Some promising signs exist in that emissions have been relatively flat in the last several years even while the global economy has grown, but when the Earth's atmosphere is no longer a free dumping ground for fossil fuel combustion, is that enough to stabilize the climate below 2°C?

The last round of the Intergovernmental Panel on Climate Change reports (IPCC 2013, 2014) explored a set of socioeconomic scenarios labeled Representative Concentration Pathways (RCPs). One family of which is based on a radiative forcing of 2.6 watts per square meter (RCP2.6)

by 2100. This scenario has a better than even chance of holding the Earth's temperature to 2°C or lower, but as shown in Figure 3, it relies on net negative emissions that dip below zero around 2070.

In contrast to a more socioeconomic approach utilizing Integrated Assessment Models, a paper by Gasser et al. (2015) takes a more physical model approach in exploring combinations of conventional mitigation and negative emissions required for the RCP2.6 radiative goal. Using several Earth System Models (ESMs) they focus on emission trajectories consistent with the 2.6 target by 2100 followed by an assessment of technical pathways based on conventional mitigation deemed feasible. Then, from a mass balance of carbon standpoint, they calculated the negative emissions needed. From this they determined the shortfall and the negative emissions required. Not surprisingly delay in the decline of emissions and the rate of decline factor heavily in the annual negative emission rates and in the final storage capacity needed. In sum they find that negative emissions of greater than 1GtC per year are needed to meet the 2°C goal; that potential geologic storage capacity is adequate, but may be limited by social acceptance. See Figure 4 for how the allowed emissions for the 2°C target can be met with different mitigation rates and start dates coupled with the resulting negative emission requirement.

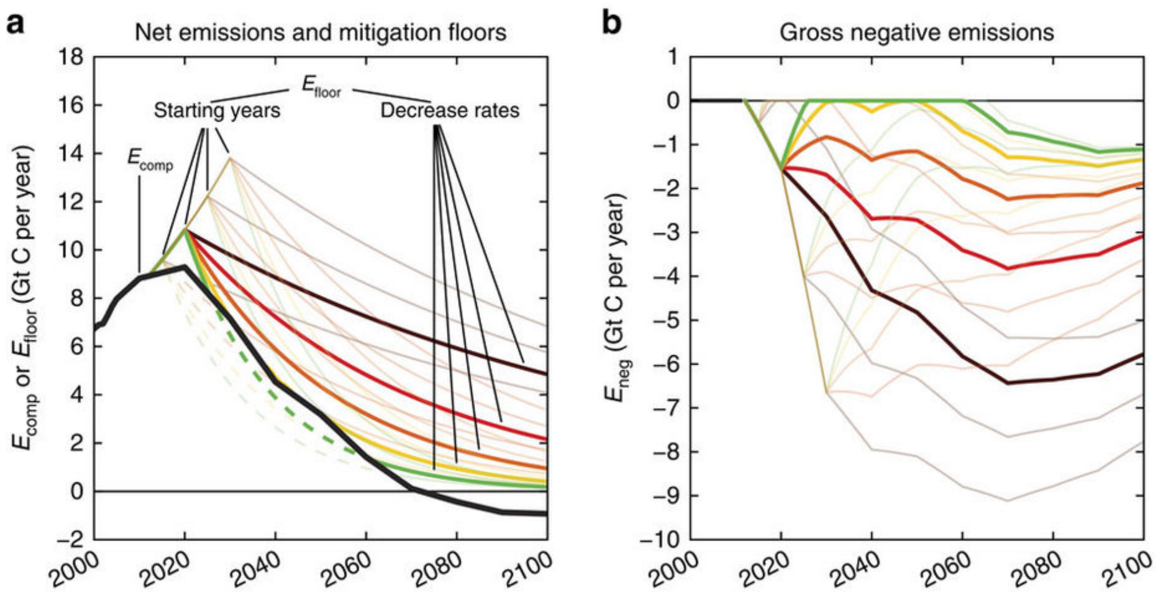
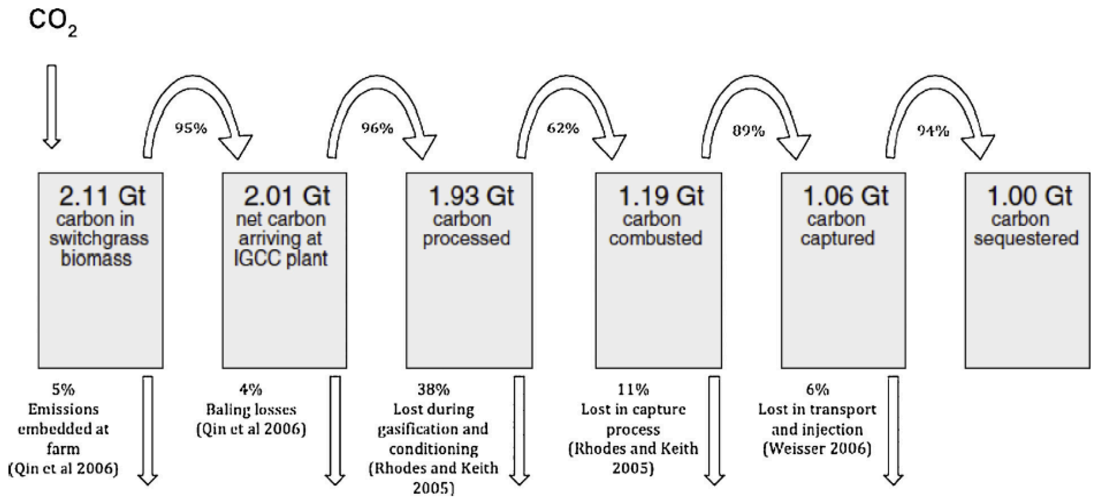



Figure 4.a The black curve is a modeled pathway to achieve the 2°C goal and the effect of different start years and emission decrease rates to achieve the desired trajectory (green 5%; yellow 4%; orange 3%; red 2%; brown 1%.). Figure 4b. The gross negative emissions associated with each decrease rate. From Gasser 2015.

## BECCS

BECCS offers one approach to NET. We explore it more here than other NETs consistent with dominant characterization in RCP2.6. From Figure 5 it can be seen that for approximately 2 billion

tons of carbon captured in biomass – in this case switchgrass – there is a cascade of losses. The eventual amount of carbon sequestered is about half of what was captured in the plant matter.




In a paper by Edmonds et al. (2013), the team used GCAM (Global Change Assessment Model), an Integrated Assessment Model, that interactively combines biogeophysical and human aspects of the Earth system to explore scenarios to achieve the 2°C goal with and without BECCS and along with varying degrees of national compliance, land use policies and conventional mitigation approaches. The authors point out numerous studies in the recent climate change literature that achieve a radiative forcing of 2.6 watts per meter squared consistent with a global mean temperature of 2°C by 2100, all of which rely on BECCS on a scale of 150 to 300 exajoules (EJ) per year of primary bioenergy towards the end of the century. Much attention has been placed on BECCS – at least in the integrated assessment modeling community central to the IPCC process. Edmonds's analysis explored whether or not BECCS can do the job alone and alternatively whether mitigation policies that aggressively deploy clean energy systems without BECCS would suffice. Short answers are that BECCS can't do the job alone, that there are conceivable pathways for meeting the goal without BECCS. Further they find nearly universal compliance is critical regardless of the mitigation path to the 2°C goal.

In addition to producing negative emissions, BECCS offers numerous co-benefits. It has the potential to deliver energy as liquid fuels, hydrogen and electricity – on the order of 170 EJ at an estimated annual cost mid-century of $138 billion for electricity/$123 billion all for biofuel. But there are important impacts to consider. Placing BECCS in perspective, the total global primary energy (IEA 2014) from all sources is 574 EJ with the contribution from bioenergy at about 44EJ. To scale up from today's bioenergy to the level envisioned in BECCS scenarios creates significant challenges to overcome in relation to environmental impacts. For example, one estimate of a BECCS system capable of 3.3 $GtC_{eq}$ negative emissions per year would appropriate 380 to 700 million hectares by 2100 while utilizing 720 cubic kilometers of water per year (Smith et al. 2016).

## Paths Forward

Much of the discussion of negative emissions hinges on technologies that are at their theoretical, experimental, or piloting stages. Some demonstration plants are in operation, but nothing is functioning at scale where more realistic performance, cost, and impacts can be better assessed. Challenges can be overcome by more aggressively moving pilot efforts into NETs built at scale, international agreements further pushing conventional mitigation, prioritization of the climate problem within nations, societal acceptance for deployment, and the resource allocation needed in pursuing the 2°C goal in a realistic manner. Delay in deployment of conventional mitigation and NETs exacerbates the magnitude of the task as $CO_2$ concentrations increase. In their closing discussion Smith and colleagues raise an additional risk with the idea of NETs. If they become considered a safety net for the future that allows for the rationalization of continued fossil fuel use in the present, valuable time in investing in alternatives may be lost (Smith et al. 2016). What if NETs don't meet expectations on technical, economic or environmental criteria? The window for action is still open to achieve the Paris goal, but it requires massive reductions in greenhouse gases and wise land use practices that gain increasing traction from the present moving forward.

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Global Climate Project infographic. Based on data from CDIAC, Fuss, and Rogelj 2016.

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