Negative Emissions Technologies
Sucking Carbon Out of the Air

Colin Cunliff and Erin Burns

April 18, 2019

Join the Conversation: #ITIF

@colin_cunliff

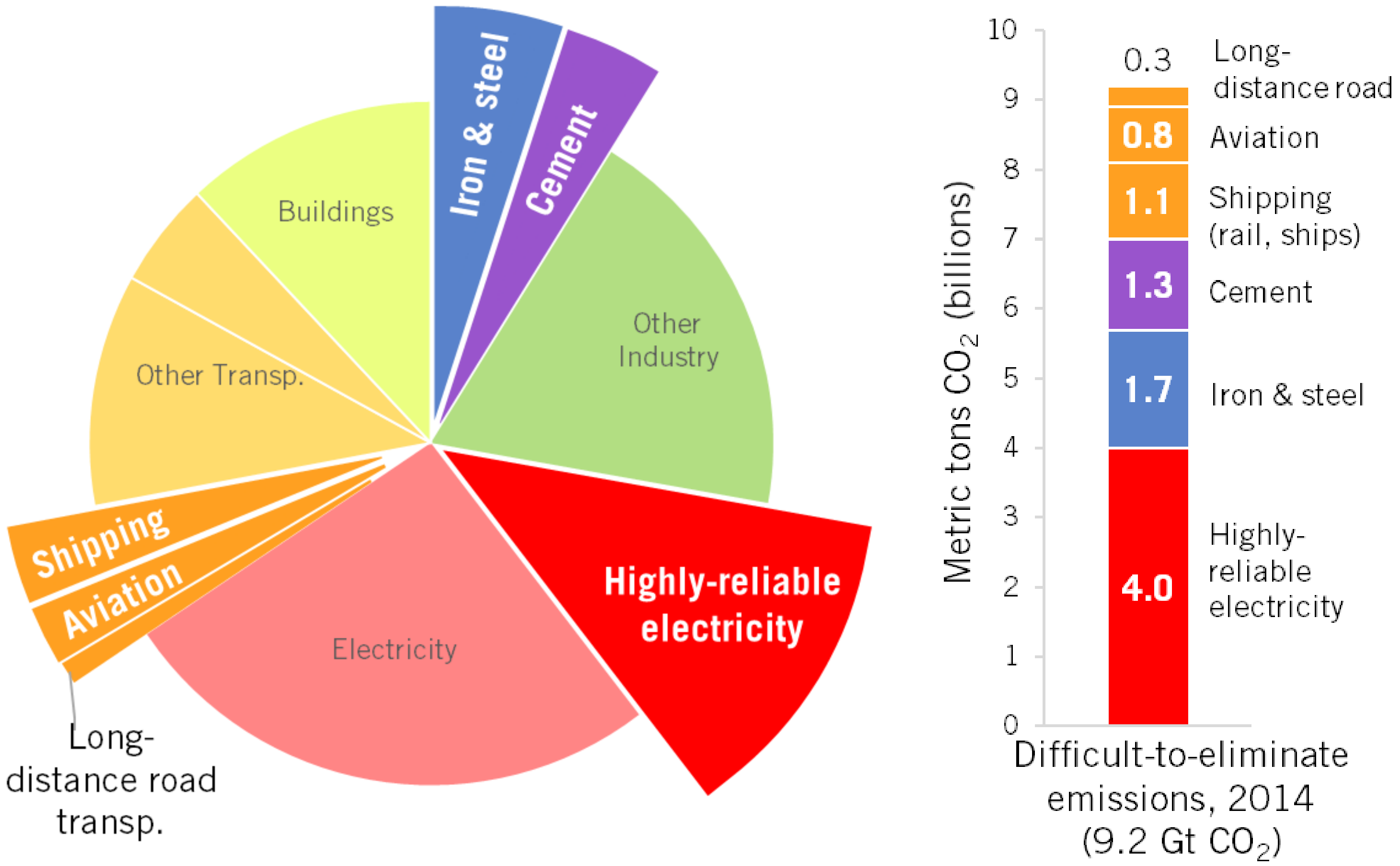
ITIF | INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

@ITIFdc

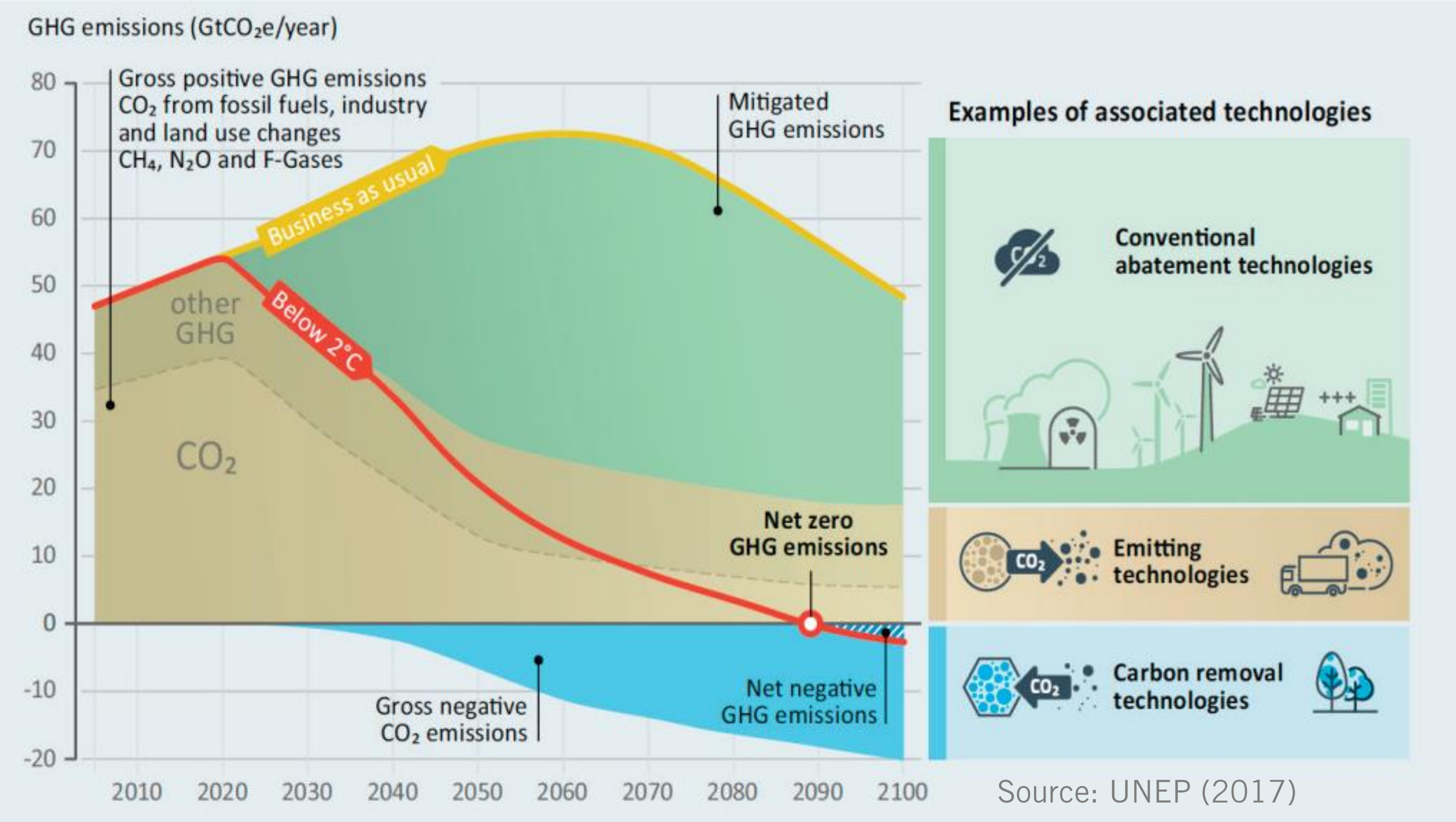
Carbon Mitigation Technologies reduce or eliminate carbon dioxide emissions from fossil fuel use, cement & steel production, and other anthropogenic sources.

Negative Emissions Technologies remove carbon dioxide from the atmosphere and store it underground or on the Earth's surface.

One Rationale for NET: Harder-to-Eliminate Emissions



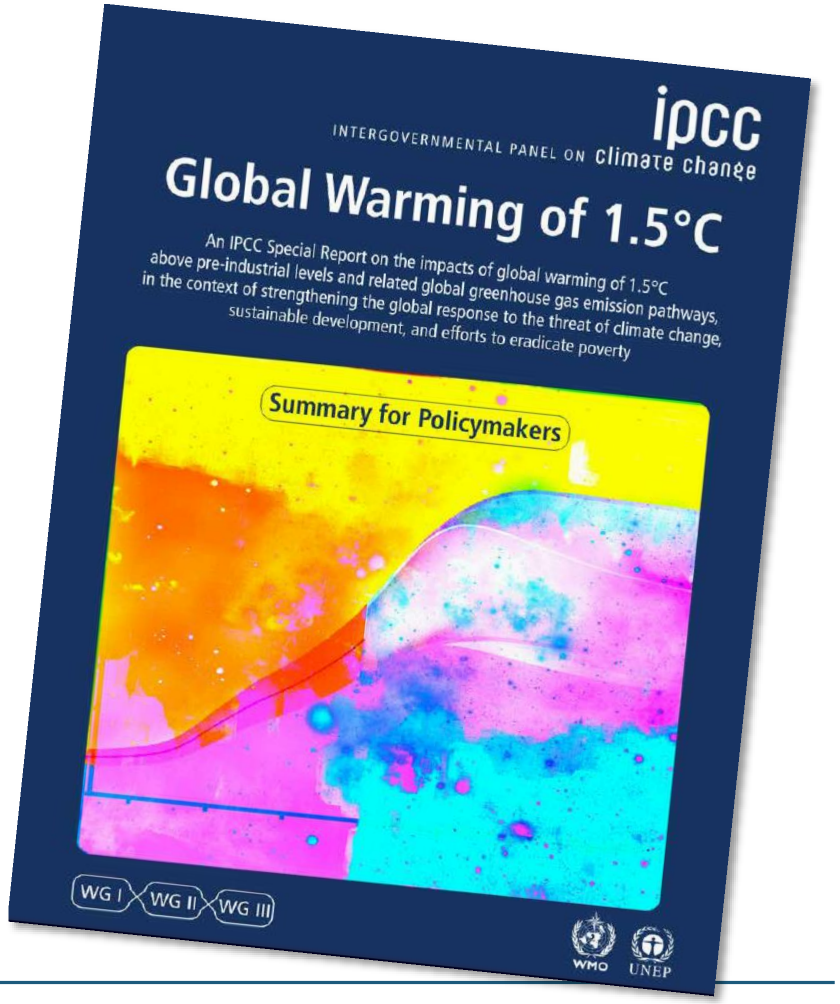
Source: Davis, et al., *Science* (2018) 1419.

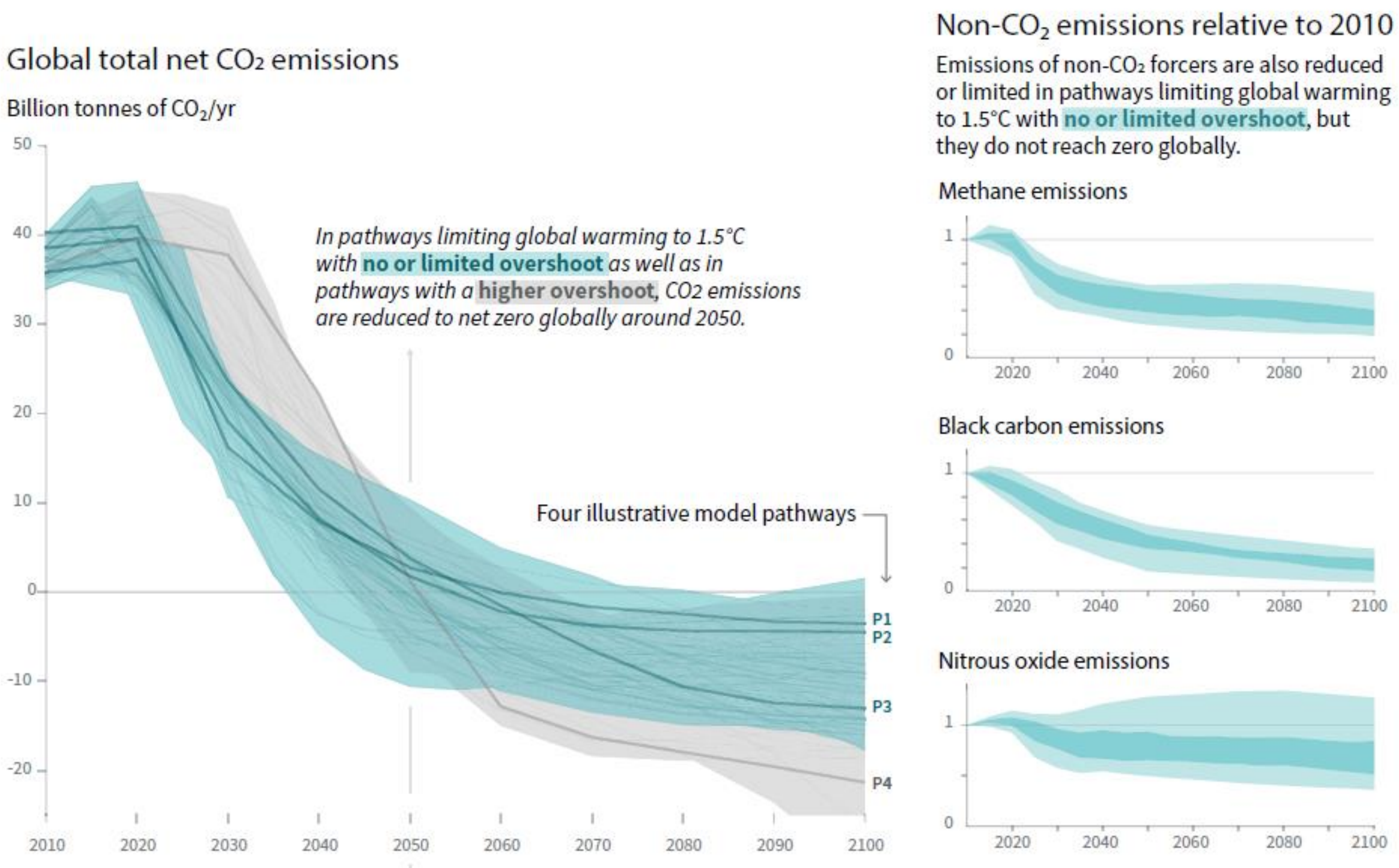


Source: UNEP (2017)

Carbon Removal in Climate Mitigation Pathways

"All pathways that limit global warming to 1.5 °C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100-1,000 $GtCO_2$ over the 21st century."

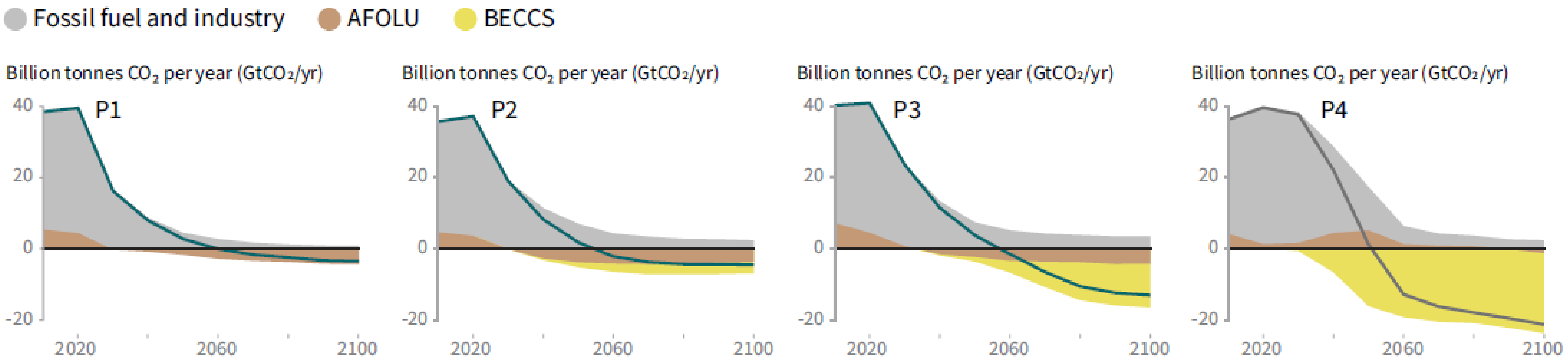




Source: IPCC (2018), Global Warming of 1.5 C, Summary for Policymakers, Figure SPM.3a

Four Model Pathways Consistent with 1.5 °C

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



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.

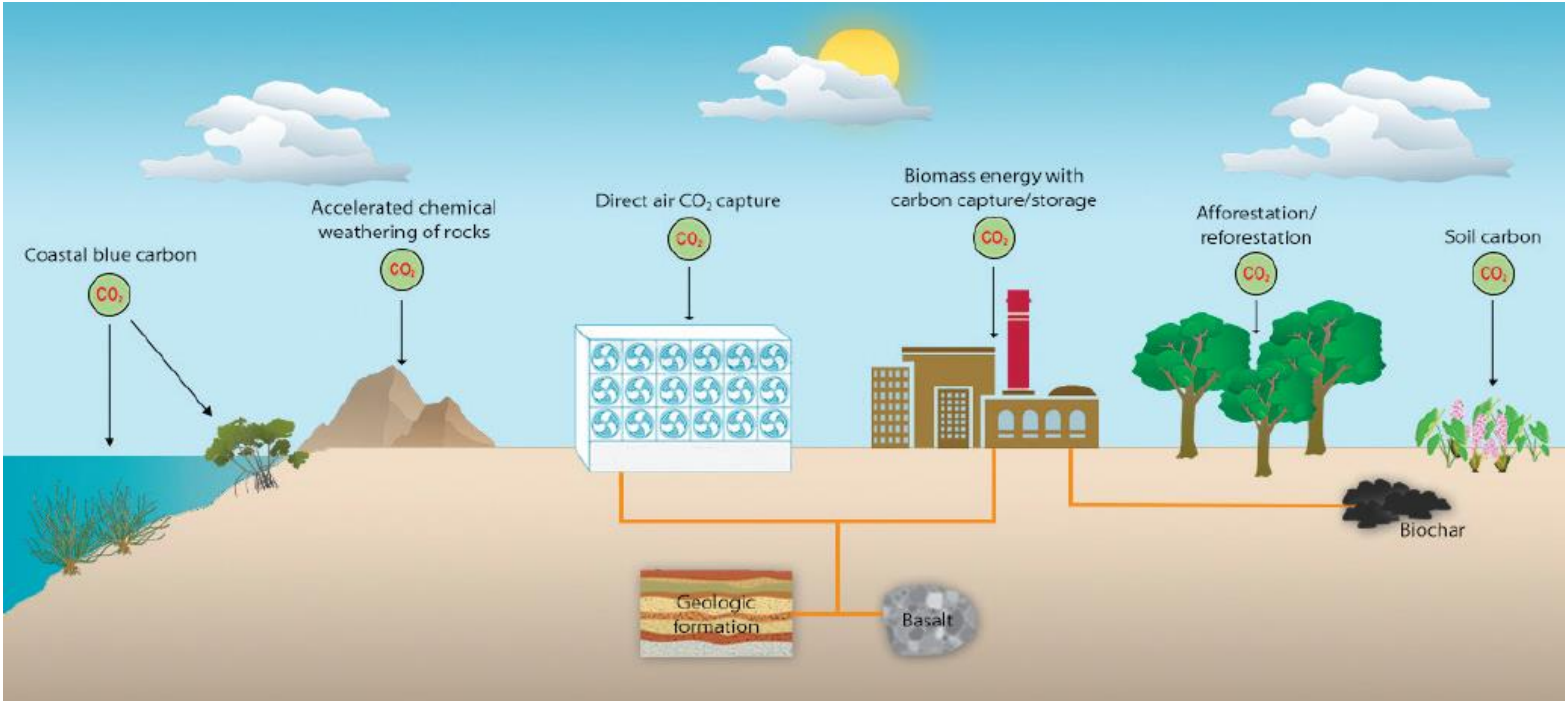
P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making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

Source: IPCC (2018), Global Warming of 1.5 C, Summary for Policymakers, p 20

Carbon Removal in Other Mitigation Pathways

Carbon Removal Strategies & Technologies

1. Terrestrial carbon removal and sequestration
2. Coastal blue carbon
3. Bioenergy with carbon capture and sequestration (BECCS)
4. Direct air capture
5. Carbon mineralization
6. Geologic storage & CarbonTech Markets



Source: NAS (2018), Negative Emissions Technologies, p 37

Land-based carbon removal
(Terrestrial carbon removal and sequestration)

- Afforestation / reforestation
- Forest management practices
- Changes in enhance soil carbon storage

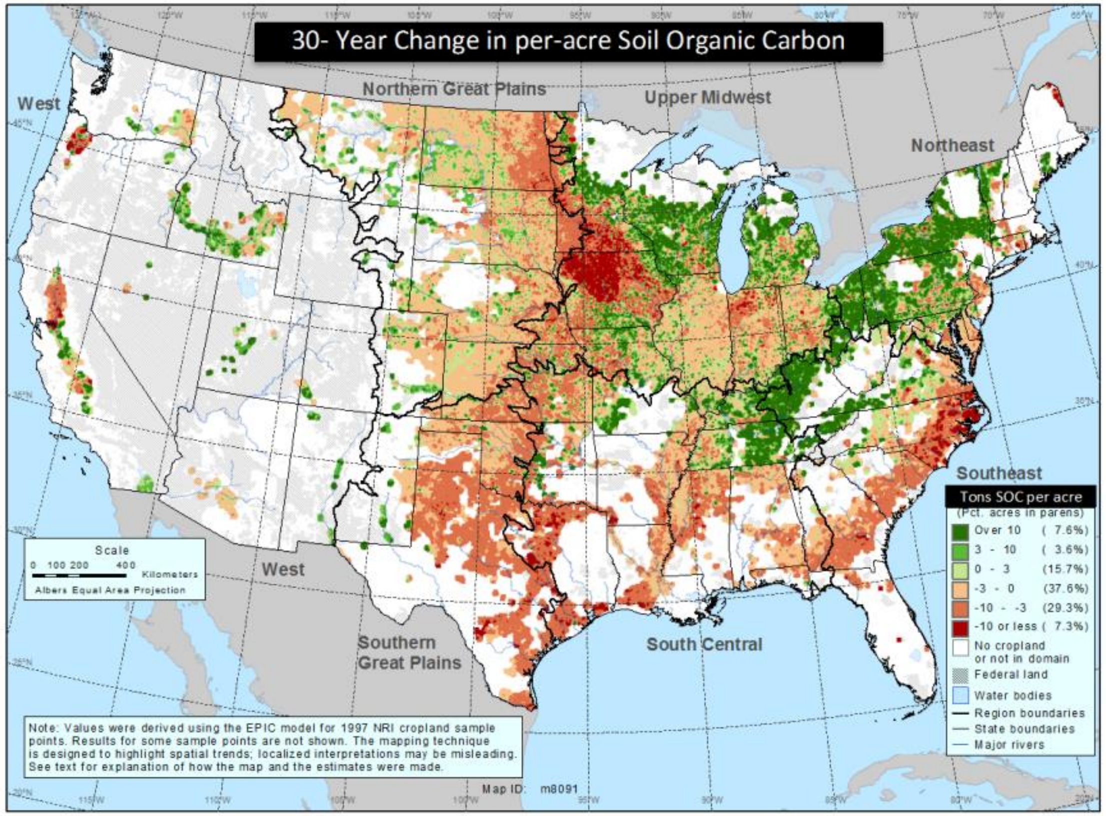
- **Benefits**: low cost, ecological co-benefits, improved resilience
- **Limitations:** easily reversible, comparatively low carbon removal capacity, competition for land use

Reversing Soil Carbon Loss

- Soils have enormous capacity to hold carbon.
- Heavily-used agricultural soils can lose 50-70% of their carbon.
- Nearly 75% of U.S. cropland acres have lost soil carbon over the last 30 years.

Benefits of increasing soil carbon absorption:

➢ improved soil nutrient & water retention, lower fertilizer use, improved resilience to extreme weather



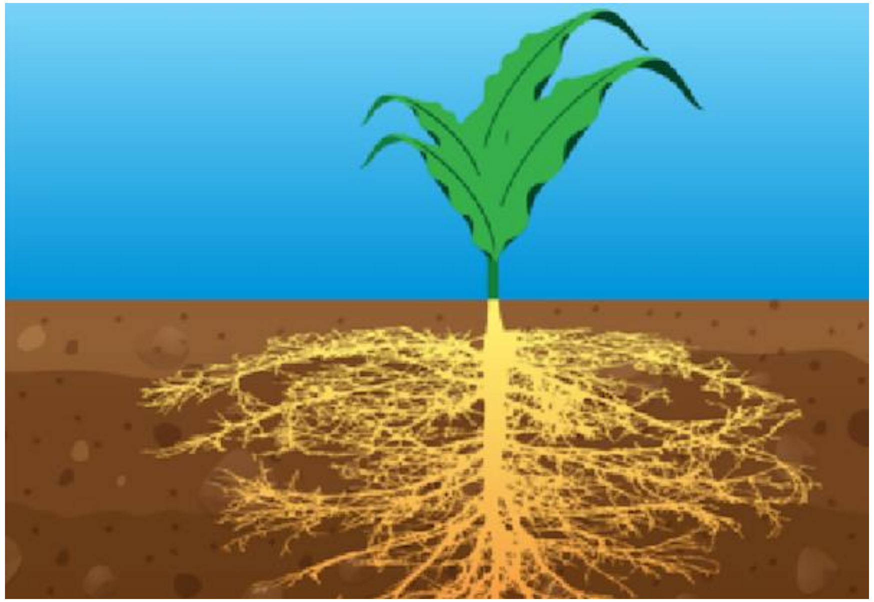
Source: ARPA-E (2016) ROOTS Program Overview, Fig 1

Carbon Farming (Soil Carbon Sequestration)

Improved Agricultural Practices

No or low-till practices, cover crop planting, and mulching can increase soil fertility, yields, and carbon storage.

Bio-Tech, e.g. ARPA-E ROOTS



Selecting for plants with deeper and larger root systems can increase the rate of carbon absorption to the soil.

Coastal Blue Carbon Restoration

- Carbon stored in plants or sediments in mangroves, tidal marshlands, seagrass beds, and other tidal or salt-water wetlands.
- Restoring and creating coastal wetlands increases coastal carbon

➢ **Benefits:** low-cost, resilience benefits

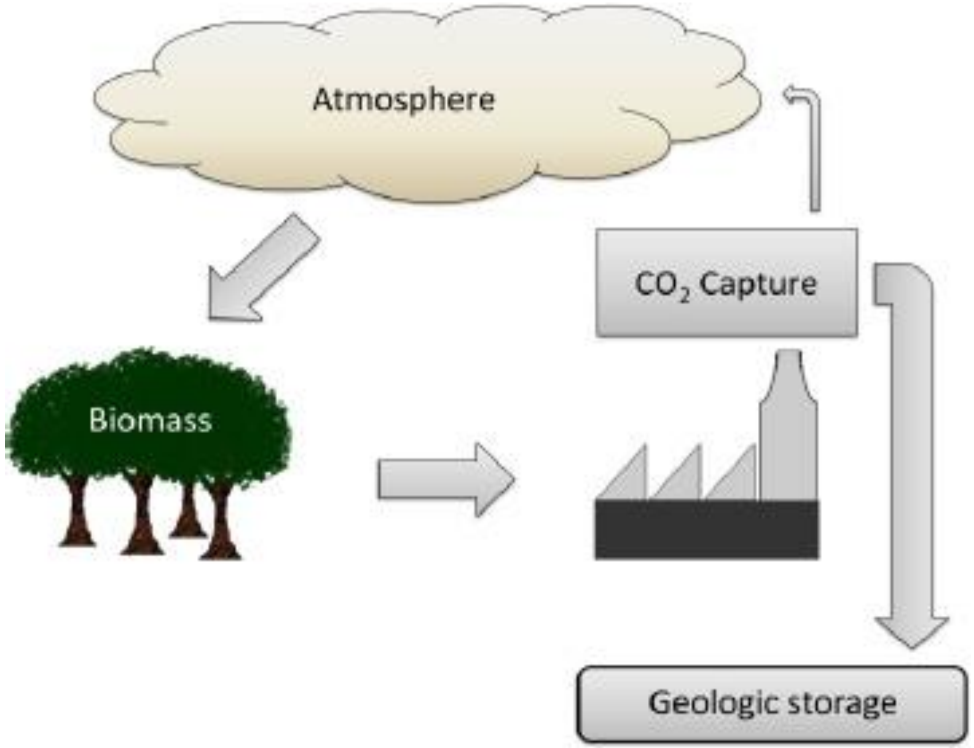
➢ **Limitations:** competition with coastal development

Bioenergy with Carbon Capture and Sequestration (BECCS)

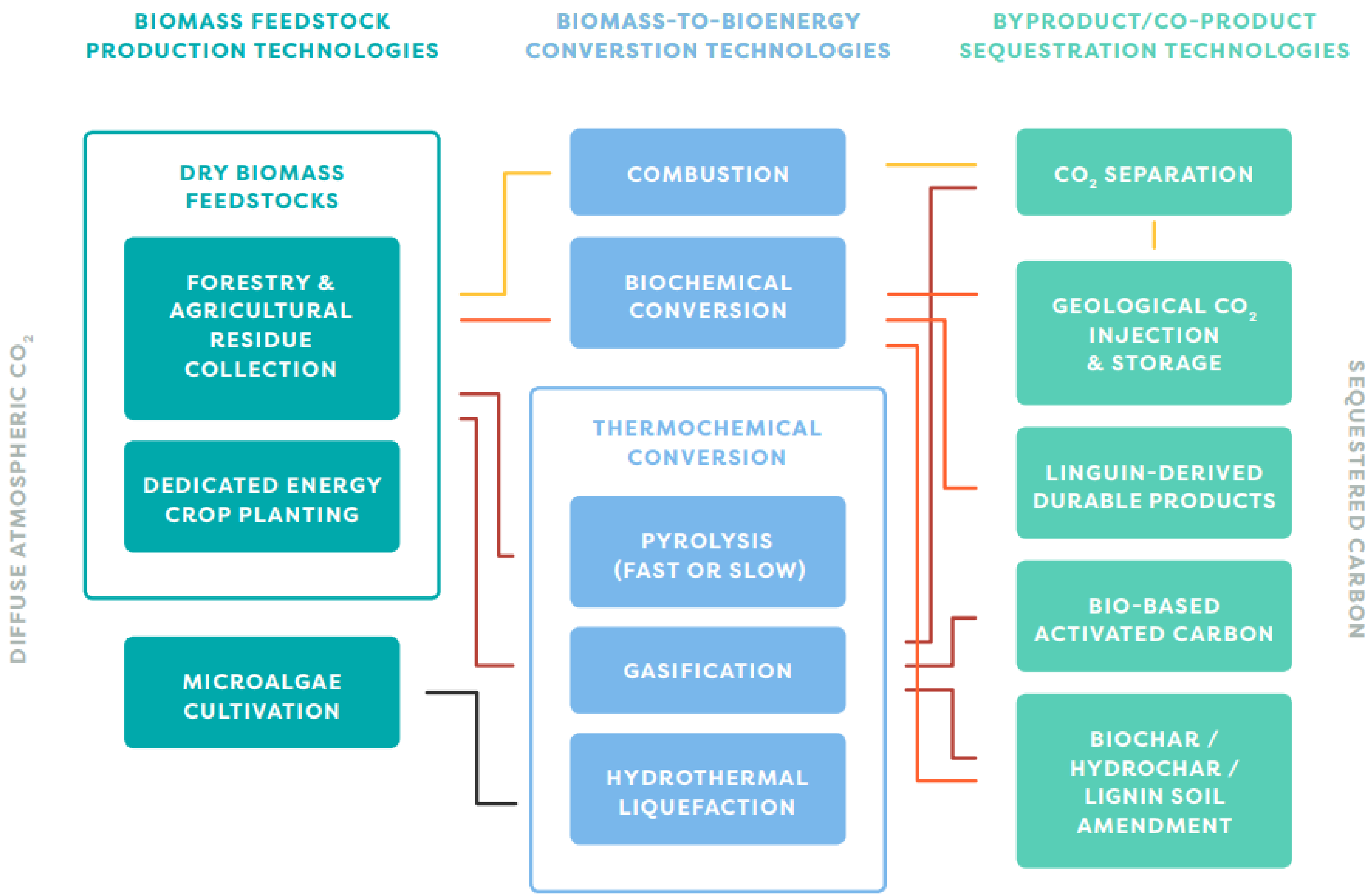
- Plant biomass is used to produce electricity, fuels, or heat
- Combined with carbon capture and sequestration (CCS) technologies, similar to those used for fossil power plants

➢ **Benefits:** produce energy as a valuable co-product to carbon removal

➢ **Limitations:** cost, availability of biomass, resource-intensive, not always carbon negative



Credit: GCCSI



Source: Carbon 180 (2018), Building a New Carbon Economy

Potential BECCS Pathways

Biofuel w/ CCS – viable now!

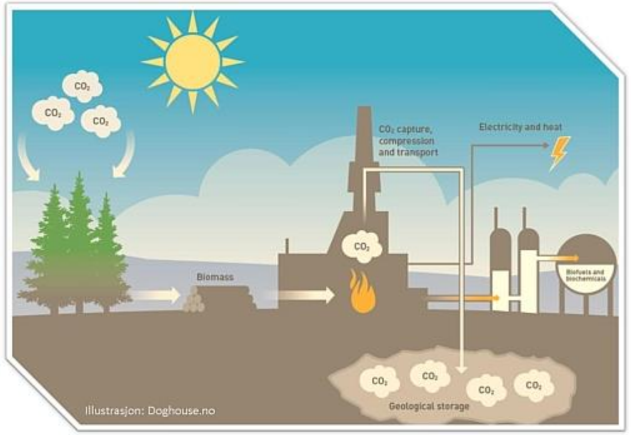
Fermentation of corn to produce ethanol provides the best near-term opportunity for BECCS deployment.

- Low capture cost
- ADM facility operating since April 2017, 1 $MtCO_2$/yr
- not carbon-negative

Biochar (charcoal)

Biomass is heated or gasified in the absence of oxygen to produce biochar + an energy product (syngas or bio-oil).

- Biochar can be used as a soil amendment to increase soil carbon



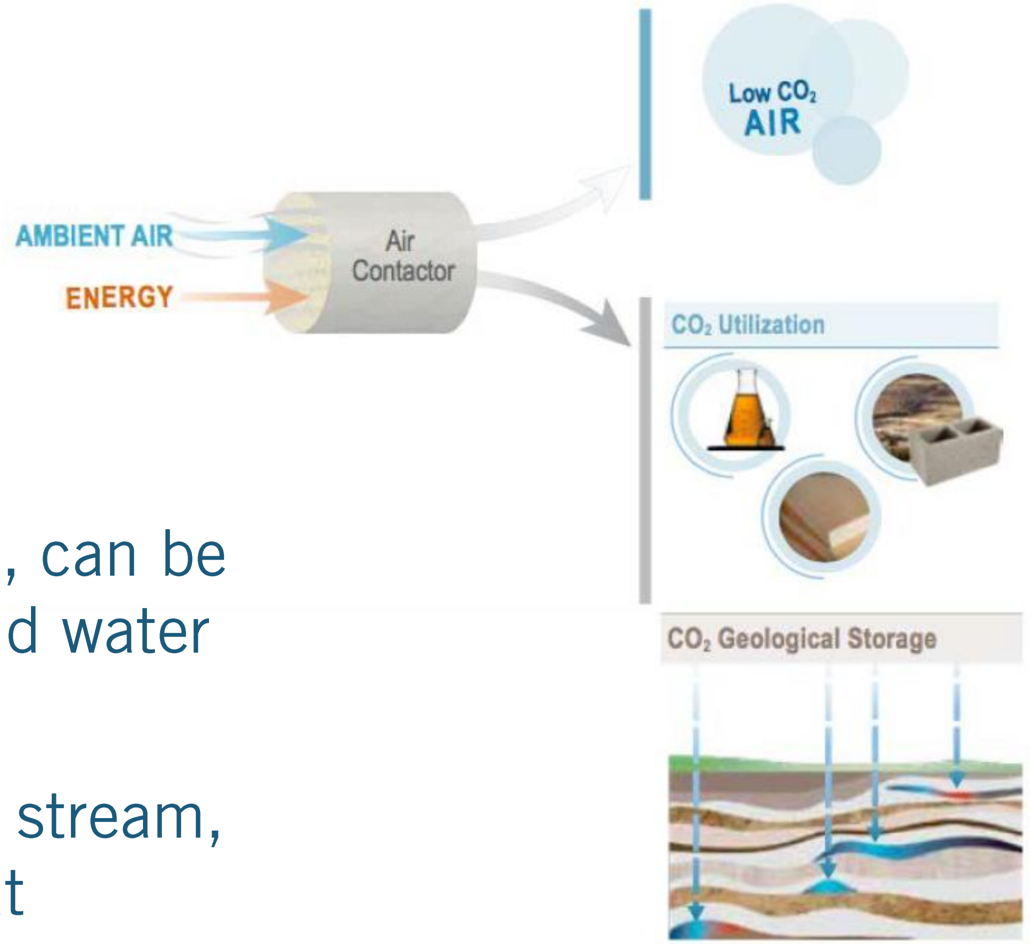
Biopower w/ CCS

Combustion of biomass to generate electricity, combined with CCS.

- Large resource potential
- Comparatively high cost
- Land- and resource-intensive, runs into biomass availability limits

Direct Air Capture (DAC)

- Chemical separation of CO_2 from ambient air, for subsequent use or storage
- DAC technologies exist today, but are expensive



➢ **Benefits:** effectively unlimited potential, can be sited anywhere, small land footprint and water needs, no impact to nutrient systems

➢ **Limitations:** high cost due to dilute CO_2 stream, need for low-carbon electricity and heat

Credit: ICEF (2018) DAC Roadmap

Direct Air Capture – How It Works, RD&D Needs

- Air contactor brings air into contact with a sorbent or solvent that selectively binds CO_2
- Sorbent or solvent is then regenerated—treated (usually with heat) to release CO_2

➢ Energy for regeneration is one of the main drivers of cost

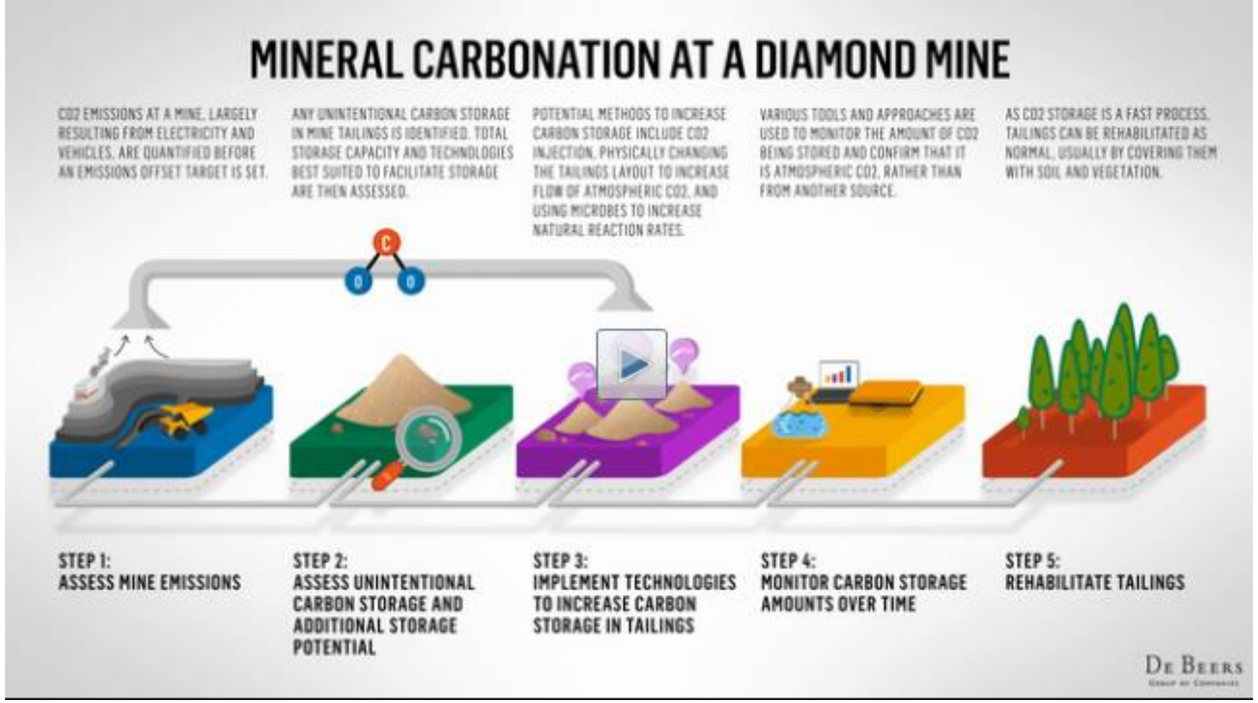
➢ **R&D needs**: improved air contactors, solvents or sorbents with low regeneration energy requirements and high CO_2 selectivity

Credit: ICEF (2018) DAC Roadmap

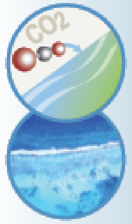
Carbon Mineralization

- Carbon mineralization is the process in which CO_2 (in the air or concentrated) reacts with naturally-occurring minerals to form solid mineral carbonates
- Opportunities: using mine tailings or industrial waste

➤ **Benefits**: stable over millions of years, large capacity
➤ **Limitations**: fundamental understanding of subsurface



Credit: De Beers, Mineral Carbonation

		Cost	Energy Requirements	Land Use	Water Consumption	Risk of Reversal	Verifiability	Implement Readiness
NATURAL 	Reforestation & Enhanced Forest Management	Green	Green	Red	Orange	Orange	Green	Green
	Wetland & Coastal Restoration	Green	Green	Green	Green	Orange	Orange	Green
	Soil Carbon Restoration	Green	Green	Green	Green	Orange	Red	Orange
TECHNOLOGICAL 	DACS	Red	Orange	Green	Green	Green	Green	Orange
	Terrestrial Enhanced Weathering	Orange	Orange	Green	Orange	Green	Green	Orange
	Ocean Alkalinity Modification	Orange	Orange	Green	Green	Green	Orange	Red
HYBRID 	Hybrid Bioenergy with CCS (BECCS)	Orange	Green	Red	Orange	Green	Orange	Green
	Bioenergy with Biochar Sequestration (BEBCS)	Orange	Green	Red	Orange	Orange	Red	Green

LEGEND
- Green: Generally Acceptable/ Available
- Orange: Exercise Caution
- Red: Potentially Unacceptable/ Unavailable

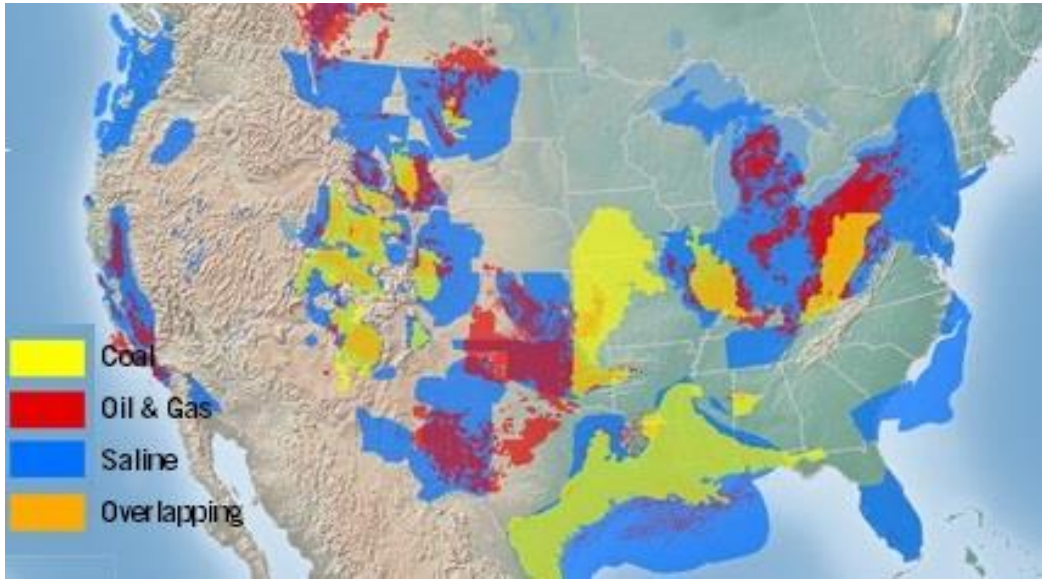
Source: ICEF (2018), DAC Roadmap

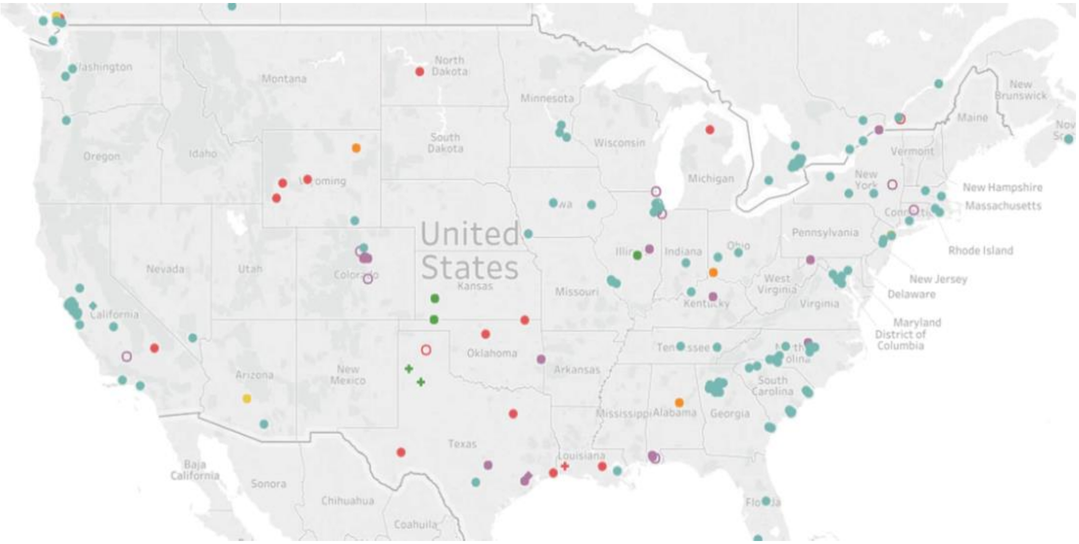
Negative Emissions Technology	Estimated Cost ($/t$CO_2$) L = 0-20 M =20-100 H = >100	Upper Bound* for Potential Rate of CO_2 Removal Possible Given Current Technology and Understanding and at ≤$100/t$CO_2$ (GtCO_2/y)	
		US	Global
Coastal blue carbon	L	0.02	0.13
Afforestation/ Reforestation	L	0.15	1
Forest management	L	0.1	1.5
Agricultural soils	L to M	0.25	3
BECCS	M	0.5	3.5-5.2
Direct air capture	H	0	0
Carbon mineralization	M to H	unknown	unknown
Total		1.02	9.13-10.83

* Upper bound assumes full adoption of agricultural soil conservat... practices, forestry management practices, and waste biomass capture.

Source: NAS (2018) Negative Emissions Technologies

What to Do with Captured Carbon—Store It or Use It!





Carbon dioxide can be stored in:

- Unmineable coal seams
- Oil & gas reservoirs
- Saline aquifers
- Other (basalts, shale basins)

Source: DOE (2015) Carbon Storage Atlas

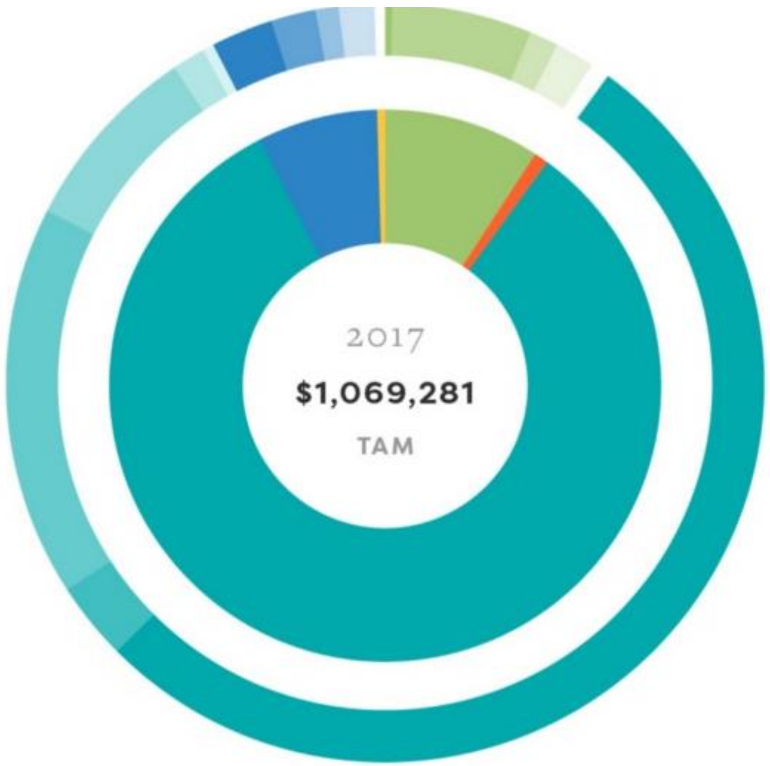
Or it can be turned into a valuable product!

- 49 companies in the U.S. are developing commercial uses for carbon.
- CO_2 can be turned into chemicals, building materials, plastics and rubbers.

Source: Burns (2017) Carbon Capture Projects Map

CarbonTech: A Trillion Dollar Opportunity

Current U.S. market for CO_2 is $8 billion annually, but the total available market is over $1 trillion.



Source: Carbon180 (2018), CarbonTech Market Report

PRODUCT	$ IN MILLIONS
BUILDING MATERIALS	$101,130
Cements	$1,240
Concretes	$65,000
Asphalts	$12,190
Aggregates	$22,700
WOOD-BASED PANELS	$12,508
FUELS	$882,149
Gasoline	$543,400
Jet Fuel	$38,760
Diesel	$186,660
Natural Gas	$83,705
Ethanol	$23,550
Biodiesel	$6,074
PLASTICS	$71,694
High density polyethylene	$25,393
Linear Low density polyethylene	$20,502
Low density polyethylene	$11,522
Polypropylene	$14,276
CHEMICALS	$1,800
AGRICULTURE AND AQUACULTURE	N/A
CONSUMER GOODS	N/A
TOTAL	$1,069,281

Thank You!

Colin Cunliff | ccunliff@itif.org | @colin_cunliff

Erin Burns | erin@carbon180.org | @erinmburns