The bioeconomy through the lens of carbon management

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The economy is deeply rooted in carbon

Pre-industrial revolution: virtually all carbon came from biomass – i.e., most everything was a bioproduct.

Industrial revolution: use of fossil hydrocarbons – mainly coal – grows rapidly for fuel

Early 20th century: petrochemical industry takes off (e.g., Bakelite 1907, PVC 1920's, PS 1930's, PE 1933)

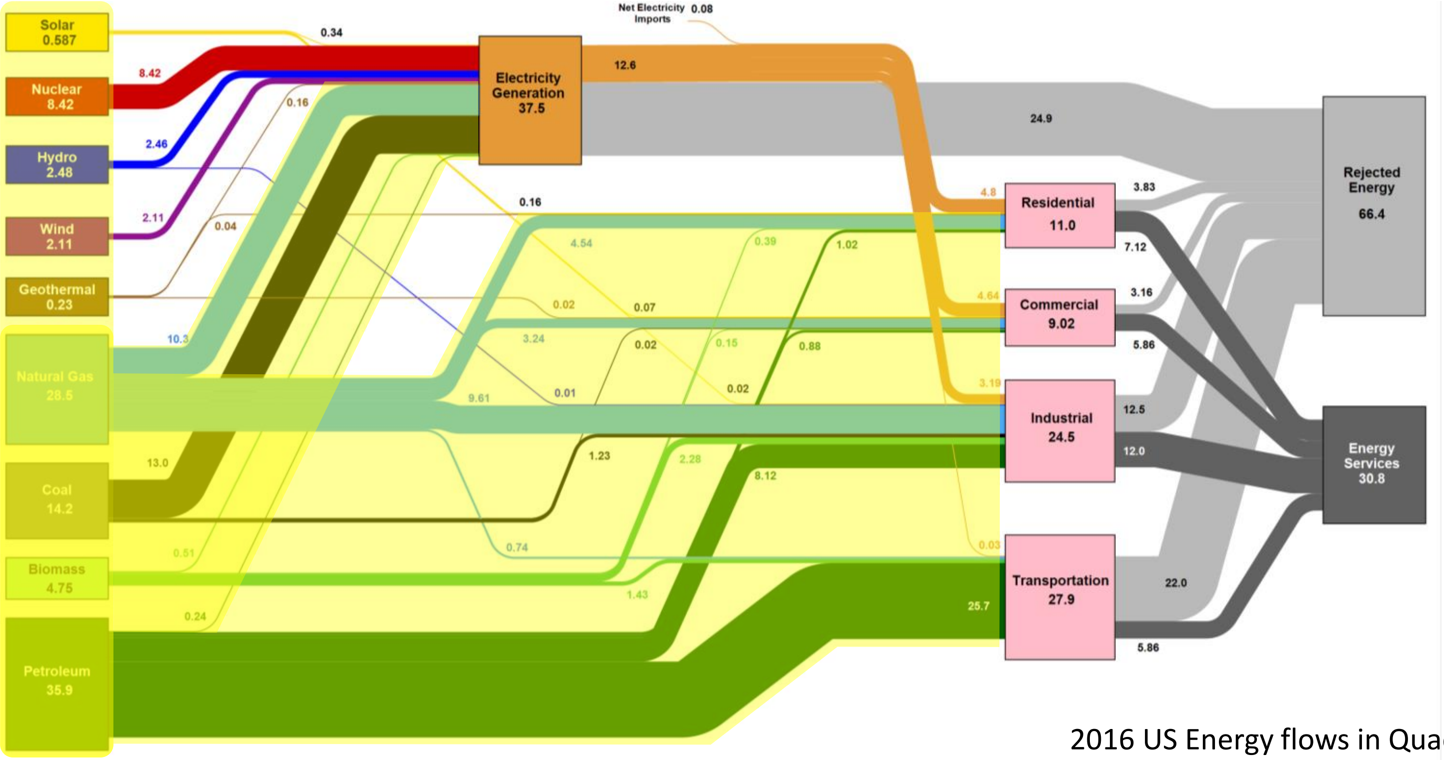
Early 21st century: Oil, Coal, and gas total 11,200 Mtoe/y; ~10% and growing as petrochemical feedstock (IEA, 2016)

Nicolás Pérez

Øyvind Hagen/Statoil

Wikipedia

The dominant energy vectors are carbon-based



Total Primary Energy: 102 EJ

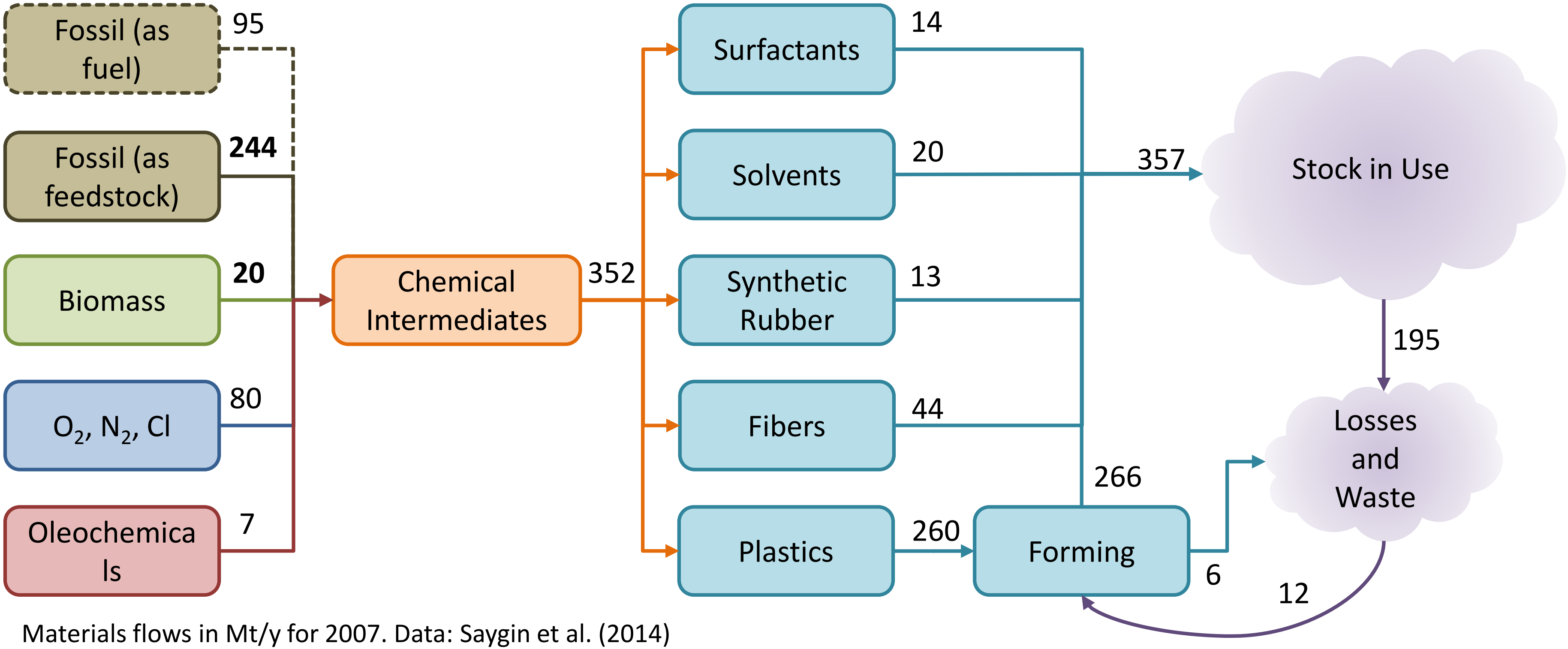
Delivered in carbon-based carriers: 88 EJ

Carbon-based carriers to Electricity: 25 EJ

Carbon-based carriers to other sectors: 63 EJ

2016 US Energy flows in Quadrillion BTU. Data: EIA (2017)

Carbon is the central element in materials all around us

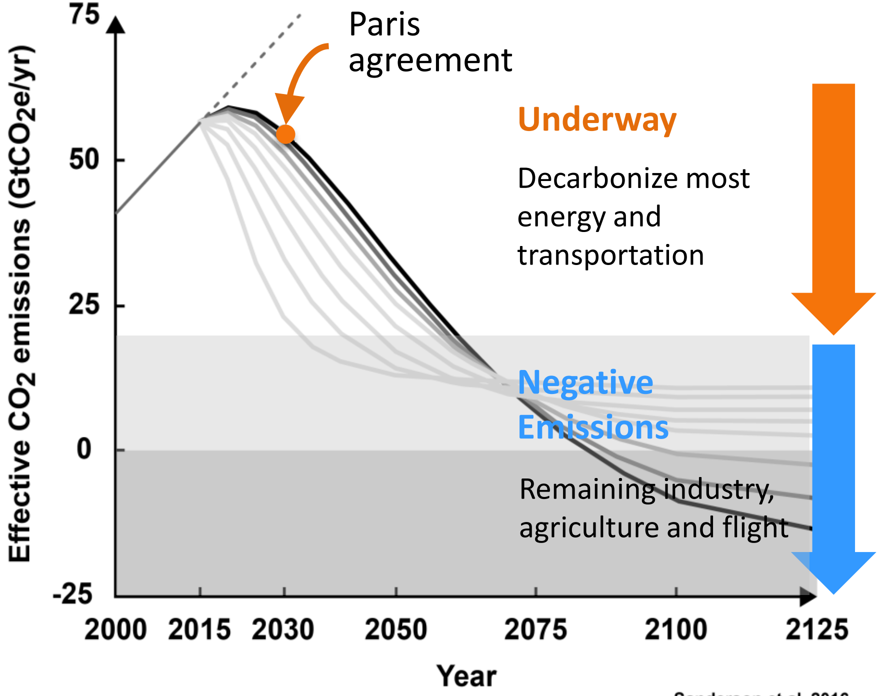


Materials flows in Mt/y for 2007. Data: Saygin et al. (2014)

CO_2 emissions to zero by mid-century, and then negative

- Fossil hydrocarbon use is not compatible with long-term climate goals
- Renewable electricity and hydrogen can be alternative vectors; but, hydrocarbons are still *really useful fuels and materials*
- Remaining options are bio- or direct air capture-based fuels and materials

How do we harness the bioeconomy to achieve net emissions reductions?



Sanderson et al. 2016

Biogenic CO_2 emissions from production matter

- Biogenic CO_2 emissions are not included in the emissions accounting by convention: biogenic-source CO_2 is returning to the air that which was already there…

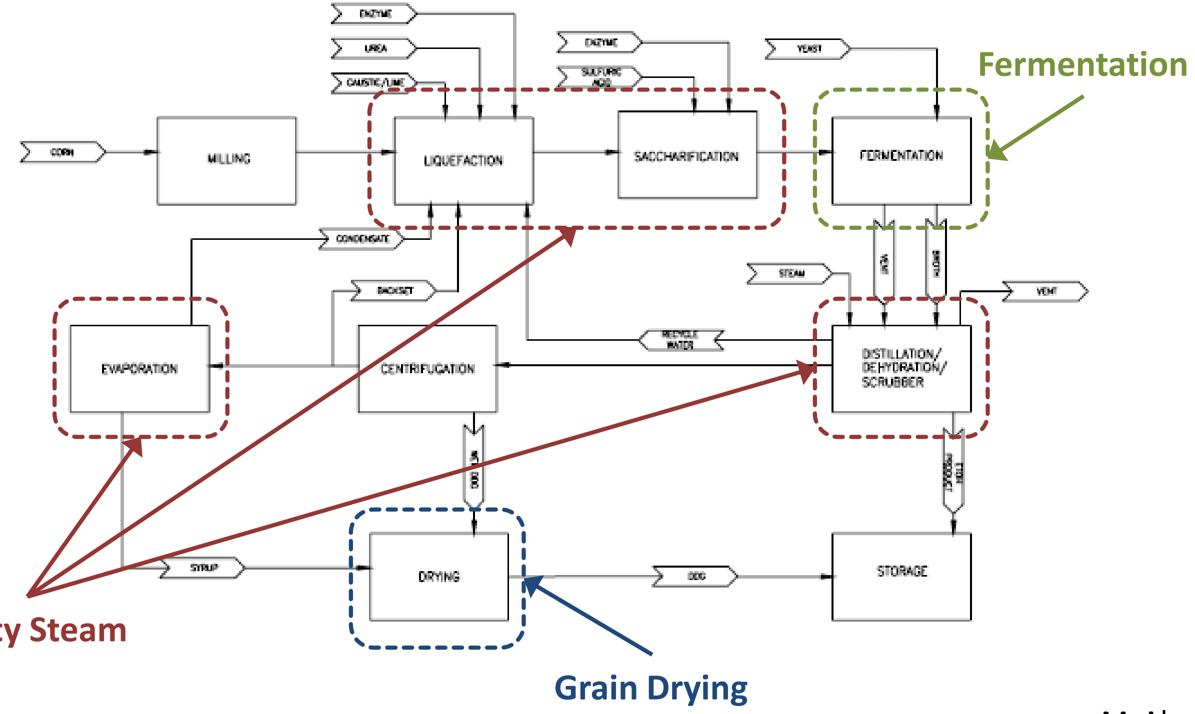
- However, a molecule of biogenic CO_2 has the same radiative forcing as any other molecule of CO_2 and the avoidance of it's emission as the same value

Measures to reduce the absolute carbon intensity of biofuels and bioenergy are attractive in climate constrained scenarios

Through the carbon management lens many technology options make sense

- Trade-offs between fossil and biomass fuels in production processes (e.g., burning wet solids v. natural gas)
- Sequestration of co-products rather than their energy use (e.g., biochar, lignin)
- Capture and geological sequestration of CO_2 from bioprocesses
- Synthesis of fuels and intermediates from waste CO_2 and renewable electricity
- End-of-life disposal options to minimize generation of greenhouse gases and maximize sequestration

Example: Applying CCS to existing dry-mill ethanol production



McAloon et al., 2000

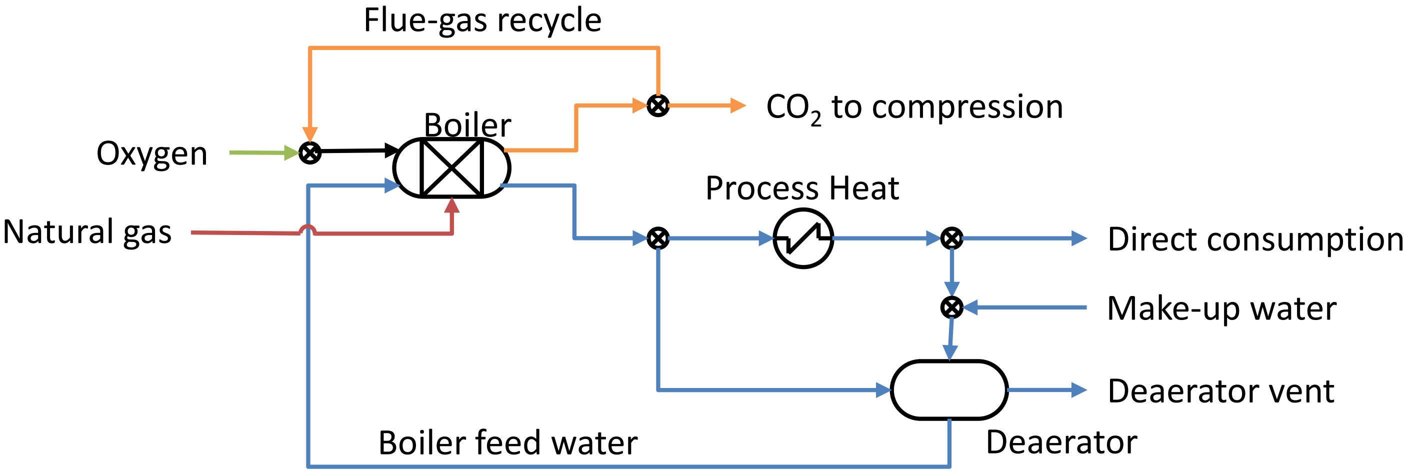
Baseline scenario represents modern, efficient facility without capture

Scenario	Description	Production Emissions (gCO_2/MJ)	Emissions Change (%)	Capture Energy (MJ/L)
Baseline	• Dry-mill, gas-fired DDGS dryer • 2.8 gal ethanol per bushel corn feed (10.3 L/bu) • 26,200 Btu/gal (7.3 MJ/L LHV) • 0.63 kWh/gal (0.6 MJ/L LHV)	30.3	-	-
Fermentation Capture	• Baseline plus capture of fermentation CO_2	33.6 *(-35.5)*	+11 *(-106)*	0.36
Full Capture	• Capture of emissions from fermentation and steam	17.3 *(-35.5)*	-43 *(-160)*	0.52

Production emissions contribute approximately 40% of the total lifecycle CI for corn-ethanol in the base case

Modify existing gas-fired boilers for oxyfuel operation

- 60 million gallon per year facility requires **30 MW_{th} of low pressure steam**, typically generated using a "package boiler"
- **Same duty as successful Total Lacq oxyfuel demonstration**, although a different boiler configuration
- **Corresponding oxygen demand of approximately 200t/d** – well within existing "off-the-shelf" oxygen plant capacities
- Technical assessments of package boiler configurations for oxyfuel combustion needed



Capture scenarios reduce production phase emissions

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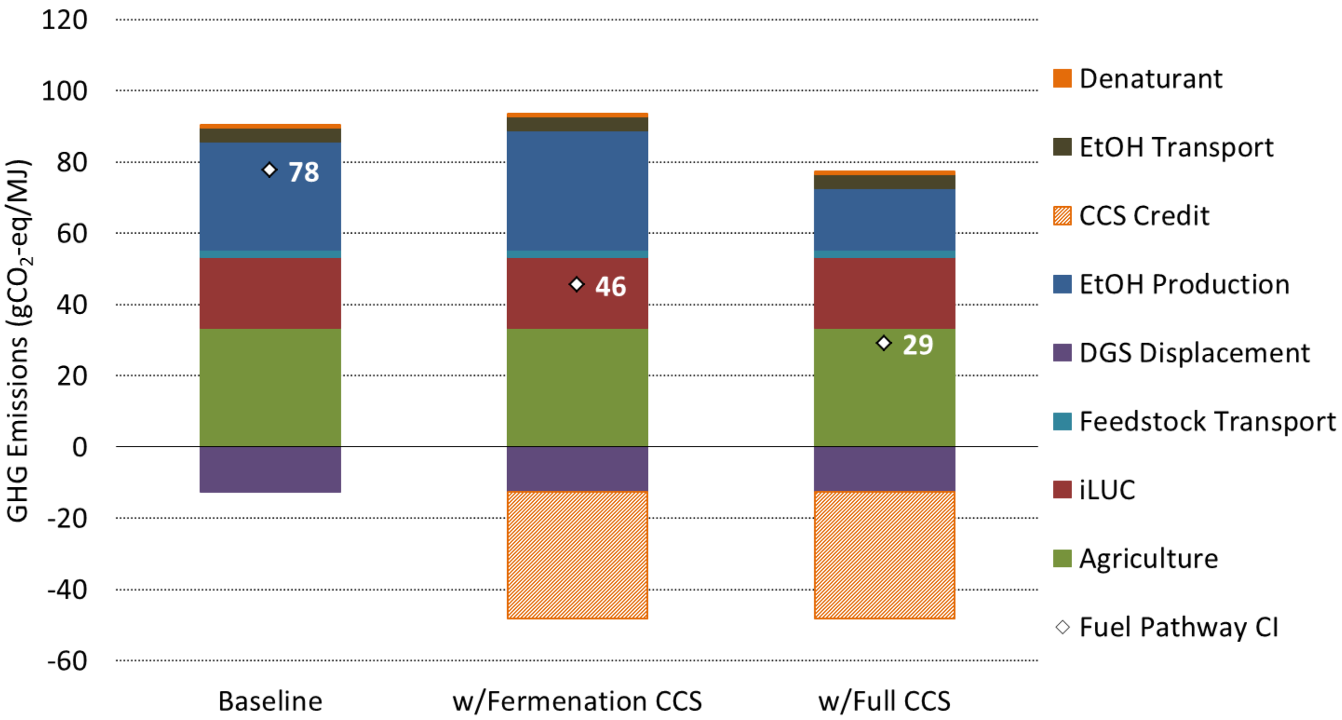
Fermentation emissions are, by convention, considered to be offset by biomass growth; capture is assumed to result in an offsetting credit

Lifecycle reduction of ethanol carbon intensity of over 40%

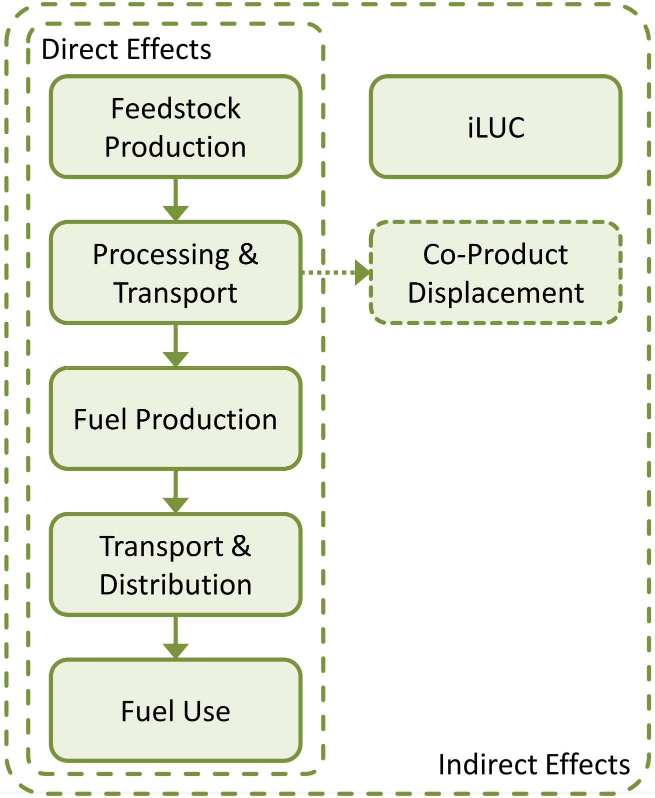


Carbon management policy for the bioeconomy

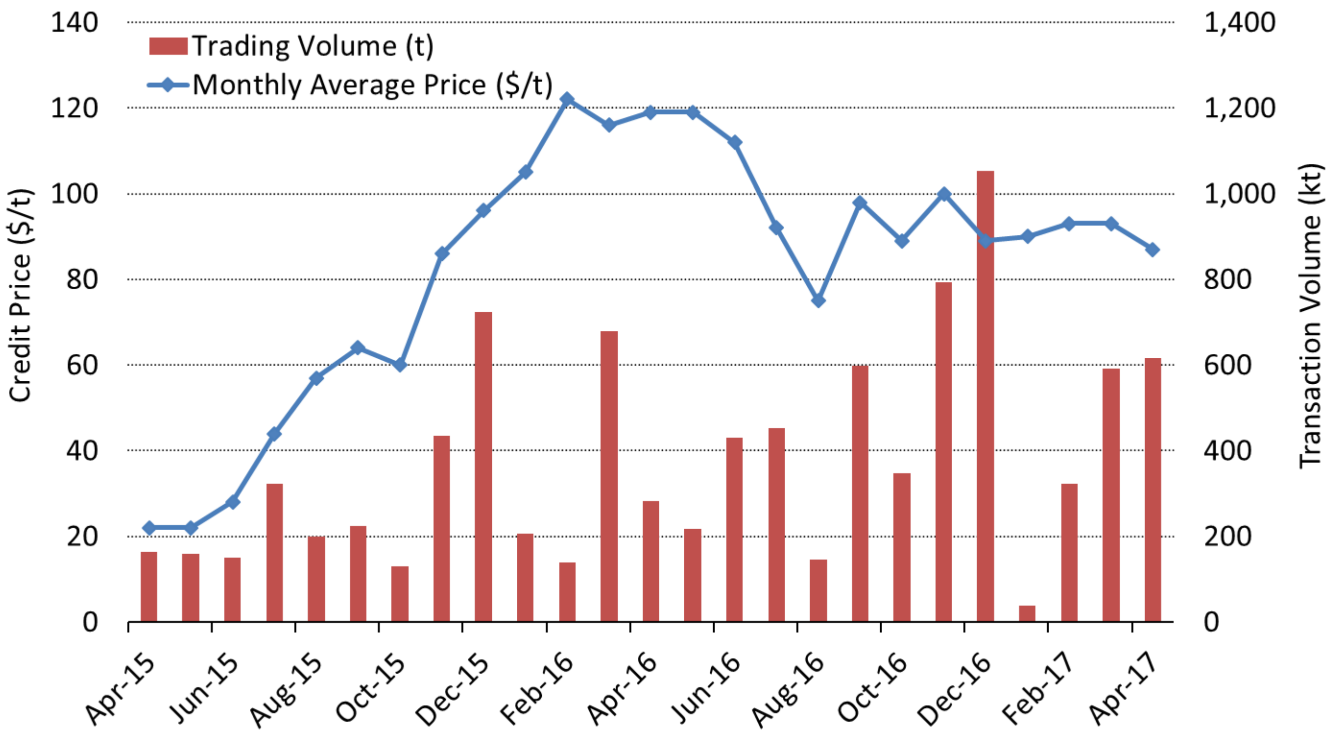
- Bioproducts do not necessarily have a lower climate impact than conventional fossil products (e.g., Mullins et al., Weiss et al., Posen et al.)
- Sorting the climate beneficial products from those that are not, and appropriately incentivizing them requires lifecycle-based policies
- Examples
  - Voluntary certification and labeling programs (e.g., "Energy Star" like programs);
  - Public sector procurement requirements;
  - Lifecycle emissions performance standards (e.g., RFS);
  - Baseline and credit systems (e.g., California LCFS).

California Low Carbon Fuel Standard drives reductions in carbon intensity of fuels

- Goal to reduce lifecycle carbon intensity (CI) of transportation fuels used in California 10% from the 2010 baseline by 2020
- Target CI declines through 2020: **fuels sold with a CI above the target generate deficits, below the target generate credits**
- Alternative fuel producers could reduce CI of their fuels with CCS
- Crude oil producers and refiners can generate credits by reducing emissions via CCS

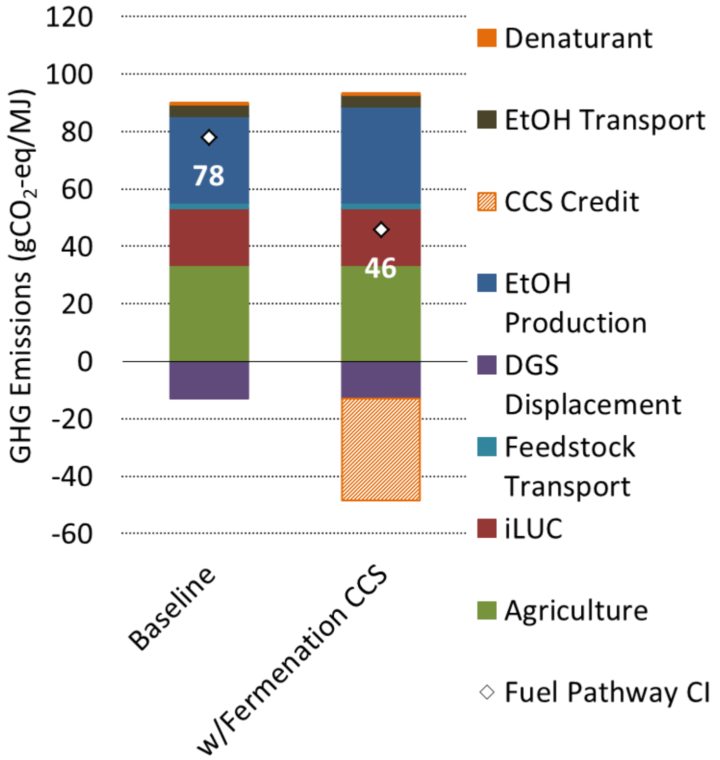


April 2017 LCFS price was $87/tCO_2$



ARB (2016) trading data

Capture of fermentation CO_2 makes sense at $35/t



- Project life of **10 years**
- 15% discount rate
- CAPEX and non-energy OPEX per US DOE supported Illinois Basin Decatur Project (IBDP)
- $40/MWh electricity cost (MISO)
- **$10/t transport and storage cost**

Total Capital Cost	$12,893,000
Fixed and Variable Cost	2,833,000/y
Incremental Cost	$0.09/gal
Avoidance Cost (LC Basis)	**$35/t**

Ultimately, carbon management polices have the potential to favor the bioeconomy

- Fossil carbon starts out at a disadvantage, and the best one can do is to approach zero emissions
- Biomass and atmospheric carbon start negative (by removing CO_2 from the biosphere) and we can minimize how much we return
- Smart policies can incentivize carbon management and create a revenue stream for bioproducts
- Emerging bioprocesses should be evaluated through the lens of carbon management and R&D supported where needed

Thank-you!

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