Reducing lifecycle biofuel emissions with CCS

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Why care about CCS in biofuel applications?

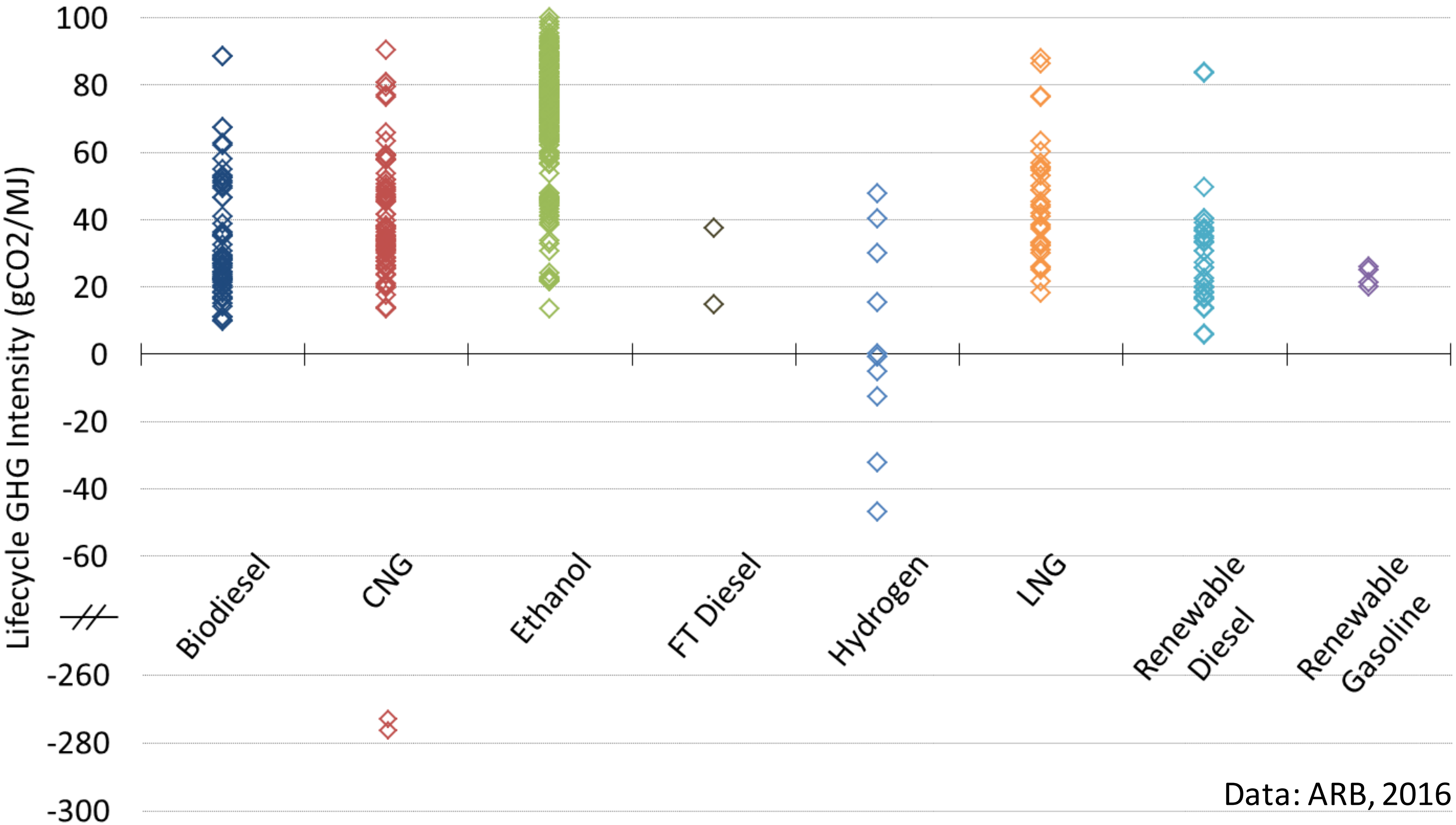
We must not only **reduce emissions rapidly** to reach the Paris target, but also **drive net emissions below zero** in the second half of the century (Sanderson et al., 2016)

1. On a lifecycle basis, greenhouse gas emissions from biofuels can be lower than petroleum fuels, but are generally *greater than zero* (Cherubini & Strømman, 2011)

2. Emissions intensity-based trading systems, e.g., the California Low Carbon Fuel Standard (LCFS), are driving reductions in fuel emissions intensity and *create a value proposition for CCS*

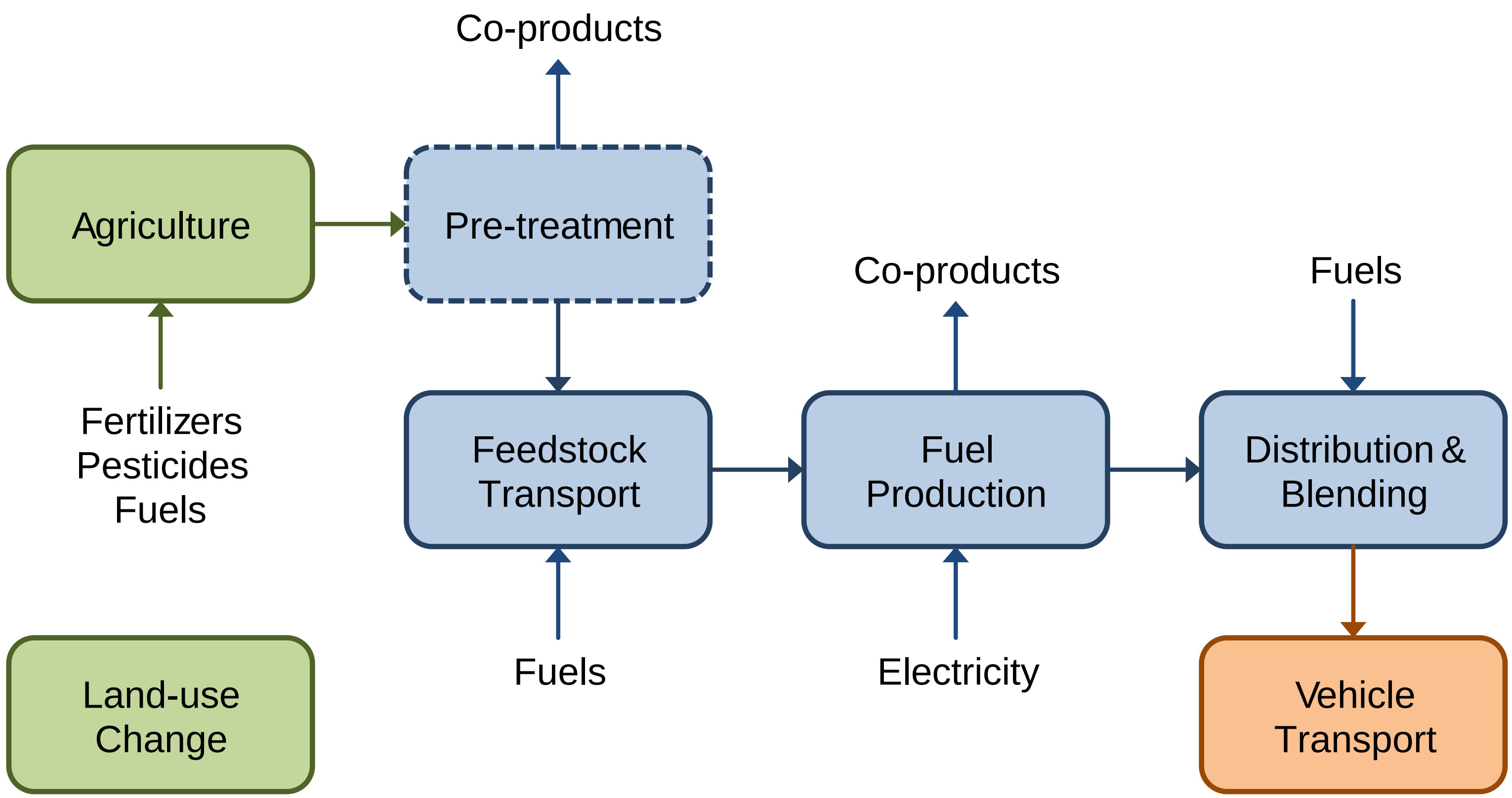
3. Use of CCS in biofuels can contribute to *learning and cost reduction* in capture, and *development of transport and storage infrastructure* for all potential applications

Lifecycle emissions intensity of fuels in the LCFS varies widely



Data: ARB, 2016

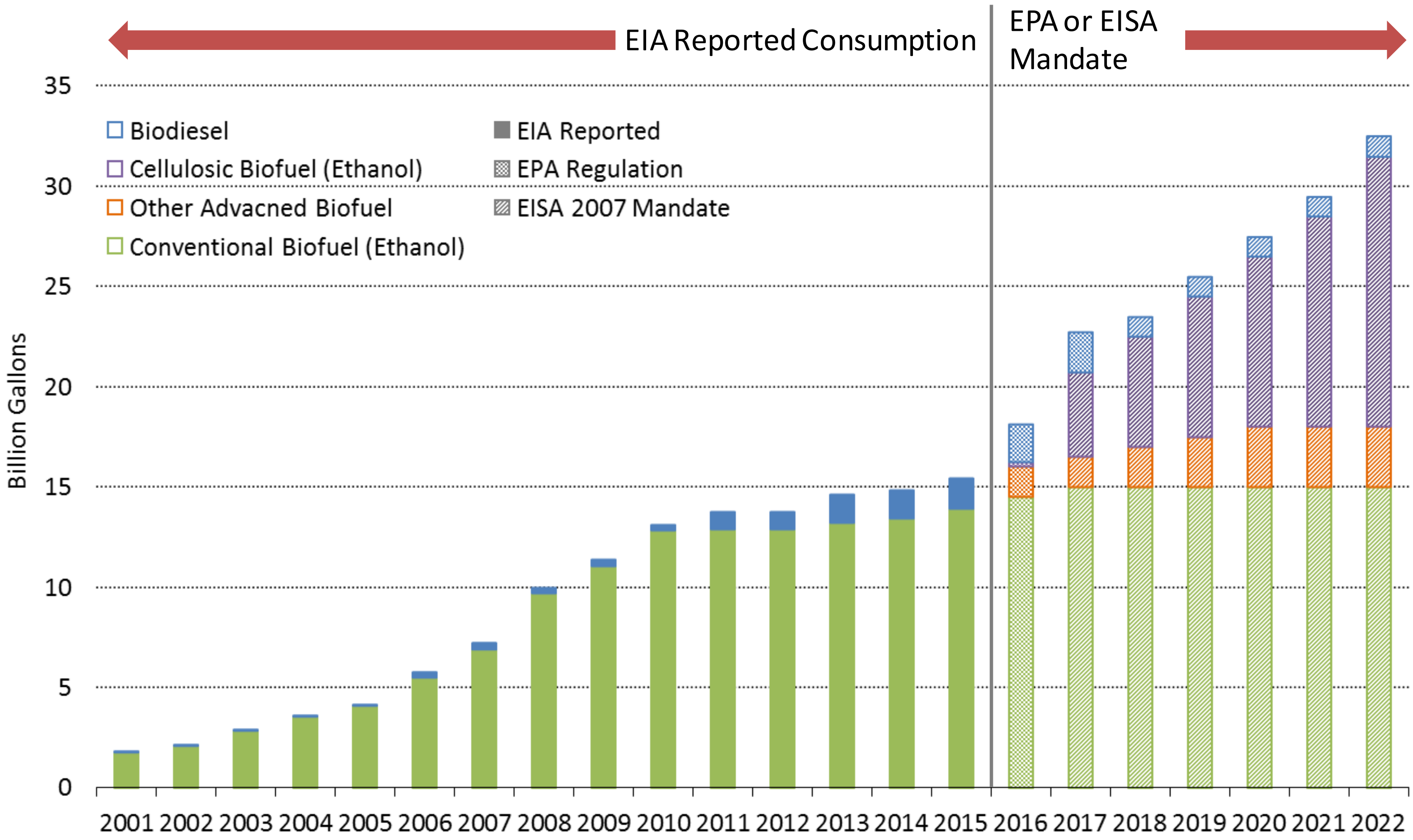
Where can CCS be applied in biofuel production?



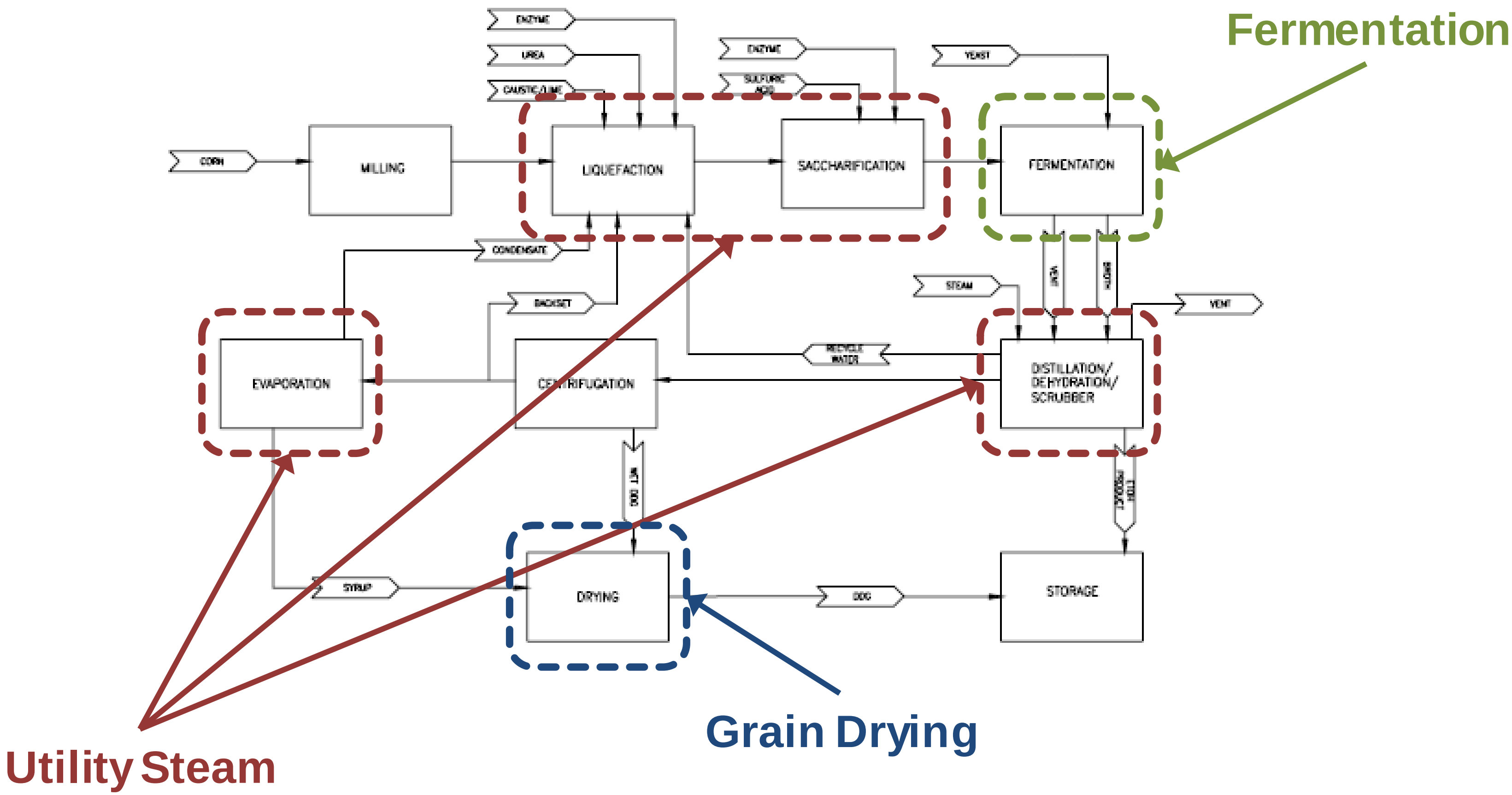
Case study: retrofitting CCS to corn ethanol plants

- The vast majority of fuel ethanol consumed in the U.S. – nearly 14 billion gallons (53 billion liters) in 2015 – is produced from corn starch
- Rapid growth in corn ethanol production was driven largely by the U.S. Renewable Fuel Standard, introduced in 2005 ("RFS1"), and expanded and refined in 2007 ("RFS2")
- 90% of US ethanol production comes from the dry milling process; the remainder comes from multi-product biorefineries that use the wet milling process (Chum et al., 2013; RFA, 2016)
- A representative dry mill ethanol plant produces about **60 million gallons** (227 million liters) of ethanol per year, and 340 million lb (156 kt) dry distillers grain solids (DDGS) and smaller amounts of corn oil as byproducts (Mueller & Kwik, 2013)

Historic and projected US biofuel consumption



Case study: the dry mill process and CO_2 capture options



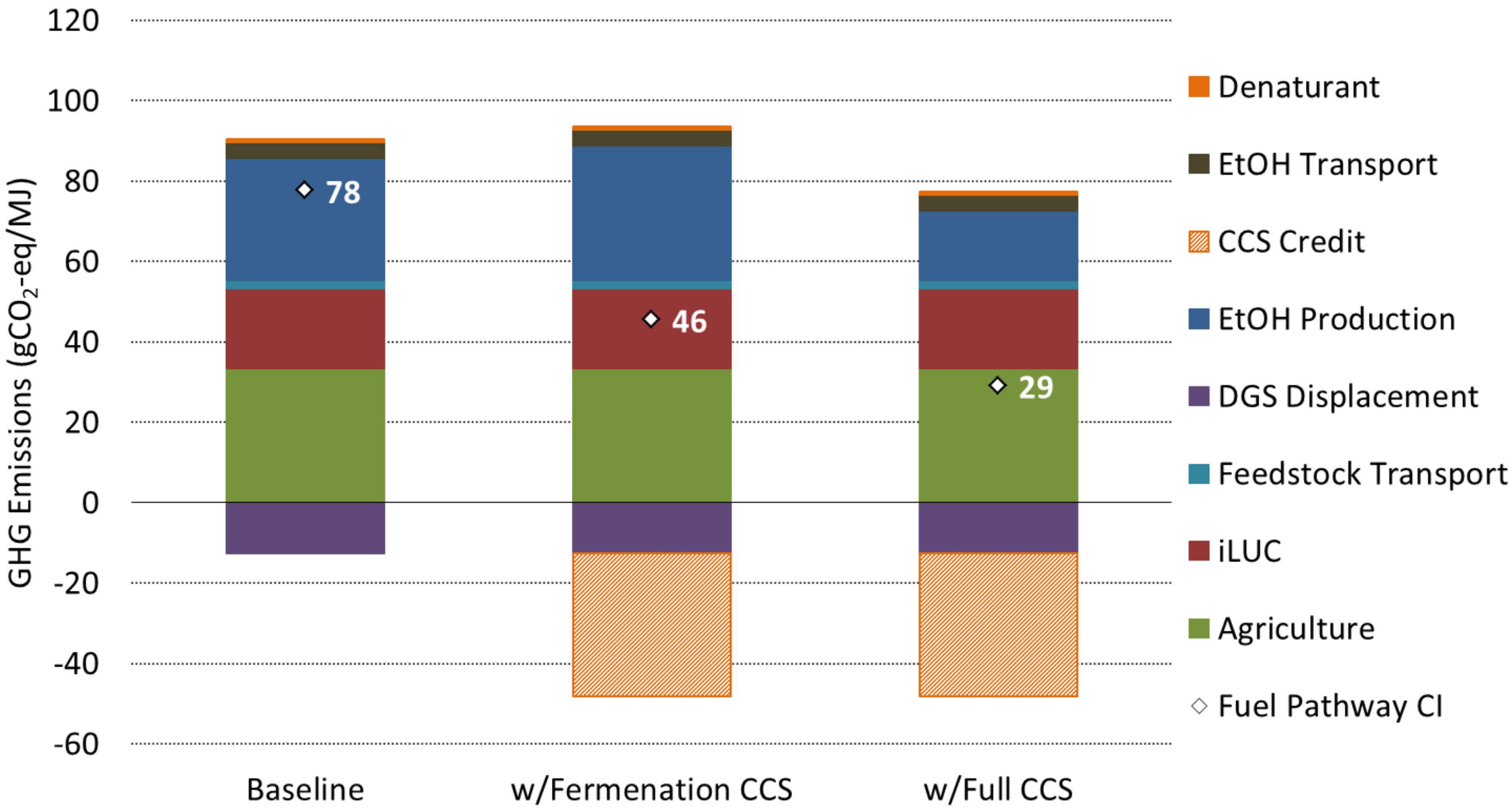
McAloon et al, 2000

Case study: three scenarios with differing levels of 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	0.36
Full Capture	• Capture of emissions from fermentation and steam	17.3 *(-35.5)*	-43	0.52

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

Case study: lifecycle impact of CO_2 CCS on ethanol carbon intensity



Monetizing the emissions reduction benefit

Federal Policy: RFS2

- The EPA establishes percentage standards for four nested categories of renewable fuels annually
- Suppliers of transport fuels meet their corresponding Renewable Volume Obligation by retiring Renewable Identification Numbers (RINs)
- RINs are generated by renewable fuel producers based on fuel production

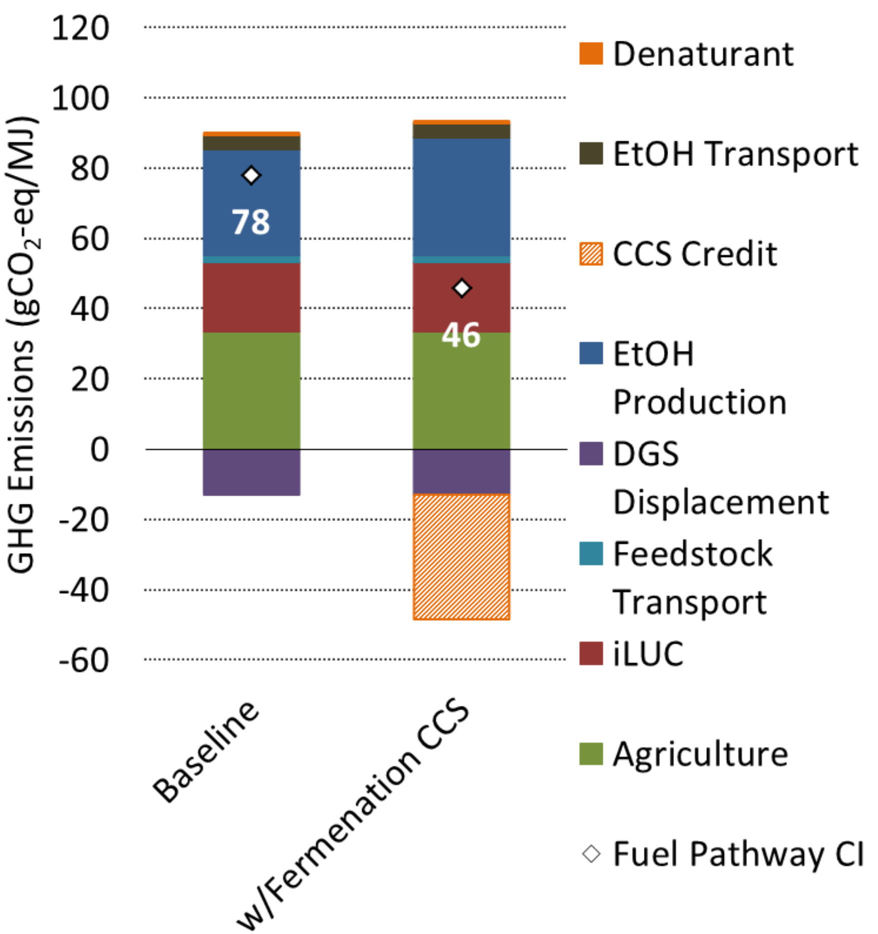
Value of RINs is highly variable, not related directly to emissions intensity, and "conventional biofuel" generates the least valuable RINs

California Policy: LCFS

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

Value of LCFS credits is a function of the fuel pathway CI and, while prices are variable, they are relatively high and increasing

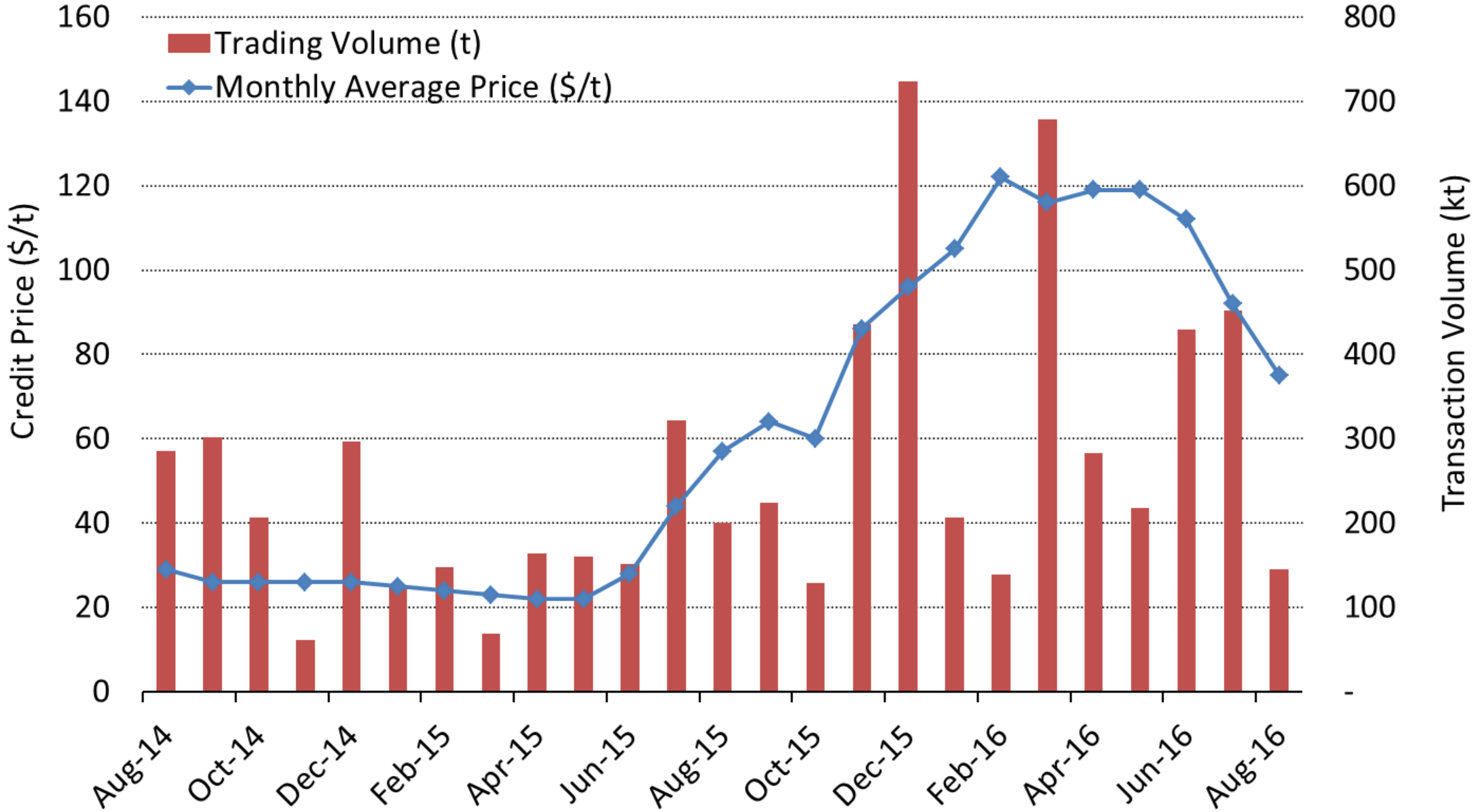
Case study: breakeven costs for capture of fermentation CO_2



- Project life of **10 years**
- 15% discount rate
- CAPEX and non-energy OPEX per Illinois Basin Decatur Project
- $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**

August 2016 LCFS price was $75/tCO_2$



ARB (2016) trading data

Where to from here?

1. A California Air Resources Board (ARB) "approved" CCS quantification method is critical - *this is in development, and targeted for release in 2017*

2. ARB clarification of whether credits can be awarded for capture and storage of biogenic CO_2 during ethanol production

3. Process-based LCAs to assess the potential impact of CCS on both alternative (including biofuel) and crude production pathways with different technology options

4. Suitability of current capture processes to alternative fuel pathways should be examined to determine what innovations will be valuable

Thank-you!

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