The Future of SAF:
Feedstocks, Conversion, and Innovation Beyond 2030

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Goals

- Overview and context
- Background on eFuels and EERE CO_2 utilization portfolio
- Initial technoeconomic and life-cycle analysis of e-fuels

The persistent need for carbon

A more sustainable economy is not a *low-carbon economy* as much as it will be a ***renewable carbon-based economy***.

How much biomass is out there?

- The Billion Ton Report sought to answer the big question: *"Do we have enough biomass to make a meaningful impact in our petroleum consumption?"*

- The Report concludes that the US has the potential to produce at least 1B tons of biomass (agricultural, forestry, waste, and algal materials) on an annual basis without adversely affecting the environment.

- This is enough to displace approximately 30% of 2005 U.S. petroleum consumption

How much renewable carbon will we need?

- 36B gallons of SAF = 600M tons of biomass
- ~9B gallons of marine fuel (EIA 2019) = 150M tons of biomass
- ~5B gal of diesel (~10% of today's use) = 80M tons of biomass
- 100M tons of chemicals (~50% of today's market) = 400M tons of biomass
- ~ 500M tons of carbon removal via BECCS or BiCRS = 500M tons of biomass (assumes roughly half of CDR uses biomass)
- **TOTAL = 1.8B tons of biomass**

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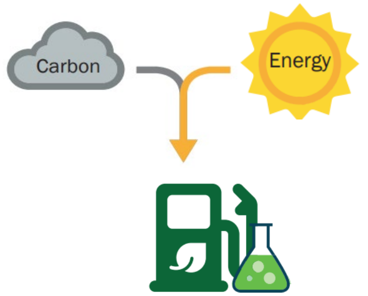
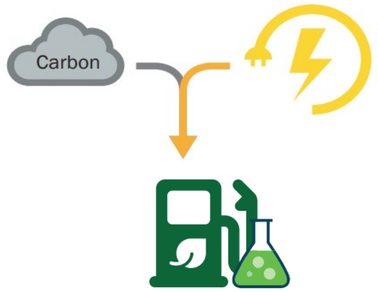
What is an e-fuel?

- Interchangeably called *synthetic fuels*, *power-to-liquids*, *power-to-gas* or *electrofuels*
- At its core, e-fuels are made by converting electricity into chemical bonds
    - This generally refers to CO_2 conversion to liquid or gaseous carbon fuels
    - There are many routes to make e-fuels, each with pros and cons and different TRL
- E-fuels provide an option for “electrifying” sectors where a battery or hydrogen cannot.
- E-fuels can have a very low carbon intensity IF they are made with renewable electricity



“Conventional biofuel”



“E-fuel”

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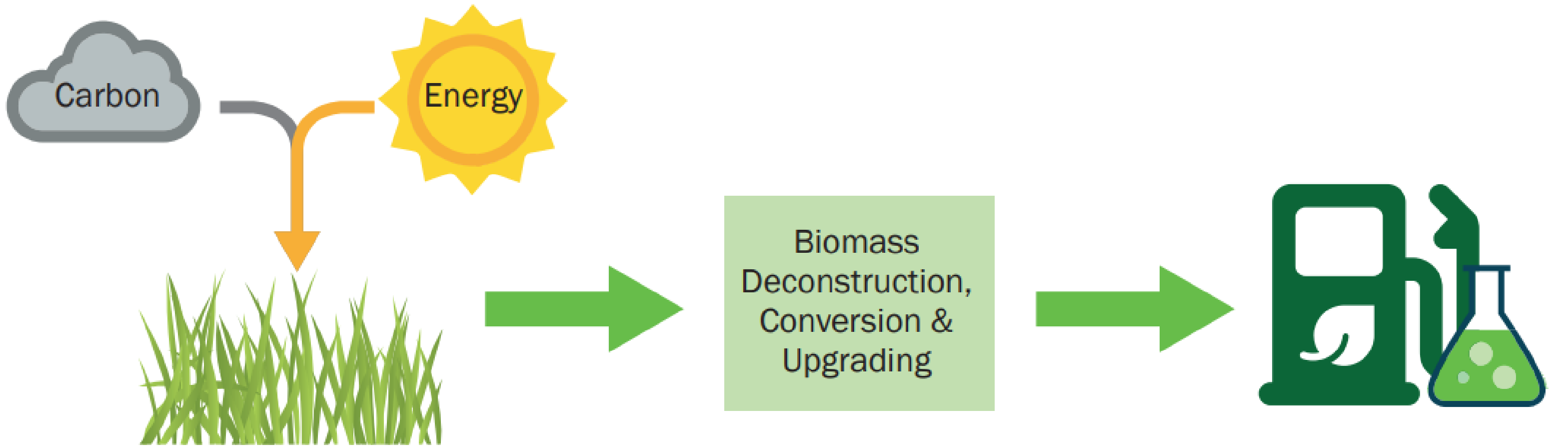
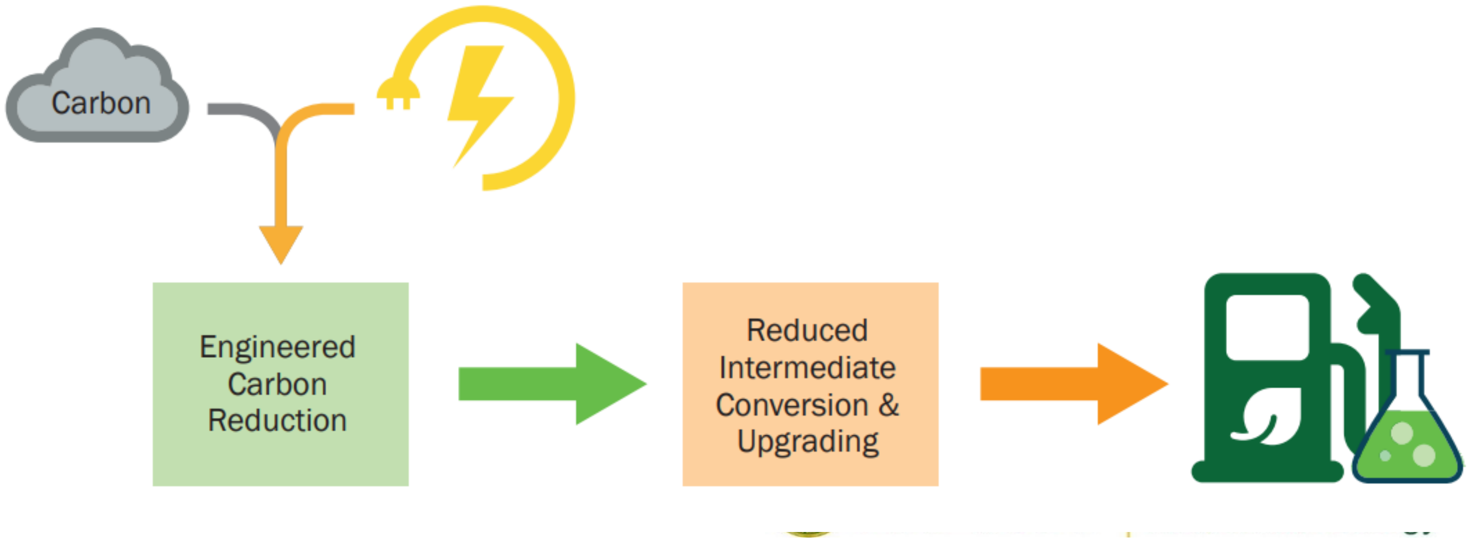
CO2-to-Fuels approach in EERE

Conventional biofuels



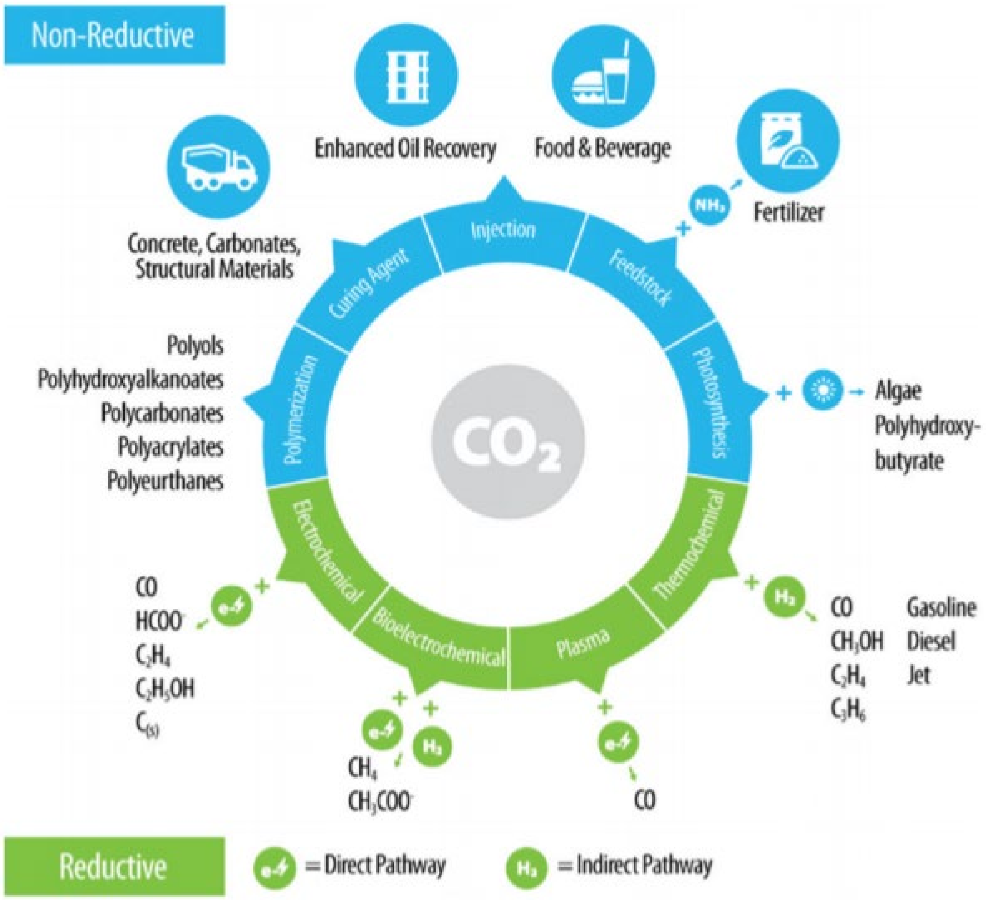
E-fuels



Assessing the viability of E-fuels

Transforming the carbon economy: challenges and opportunities in the convergence of low-cost electricity and reductive CO_2 utilization†

R. Gary Grim, Zhe Huang, Michael T. Guarnieri, Jack R. Ferrell III, Ling Tao * and Joshua A. Schaidle *



- Near term opportunities in indirect CO_2 conversion (i.e., making H_2 and reacting it with CO_2)
- Direct electrochemical are lower TRL but offer more efficient electron use
- Biotic routes have significantly higher specificity for C-C formation but lower rates
- Abiotic routes generally have higher rates of conversion

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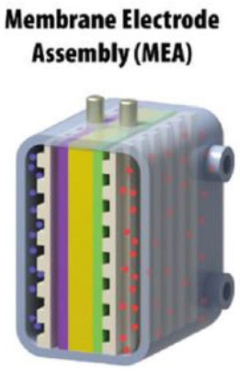
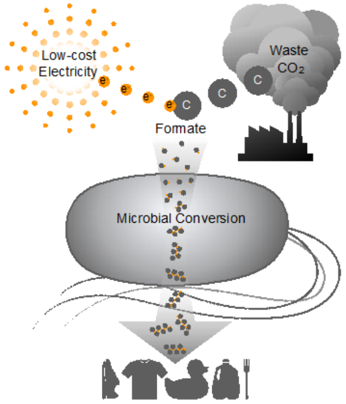
Select CO_2 utilization work in EERE

National lab projects to explore the key areas:

BETO/HFTO: Power-to-gas for energy storage



Electrolyzer design



Intermediate upgrading

<u>FY18 *Rewiring Carbon Utilization* FOA topic area</u>: $4.5M to 3 projects which coupled carbon reduction to biological upgrading

LanzaTech

twelve

University of Delaware

<u>FY20 *Scalable CO_2 Electrocatalysis* FOA topic area</u>: $7.5M to companies to push the limits of electrocatalysis

Dioxide Materials™ The CO_2 Recycling Company™

Assessing E-fuels from a life-cycle perspective

Comparing two pathways to make a fuel

DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

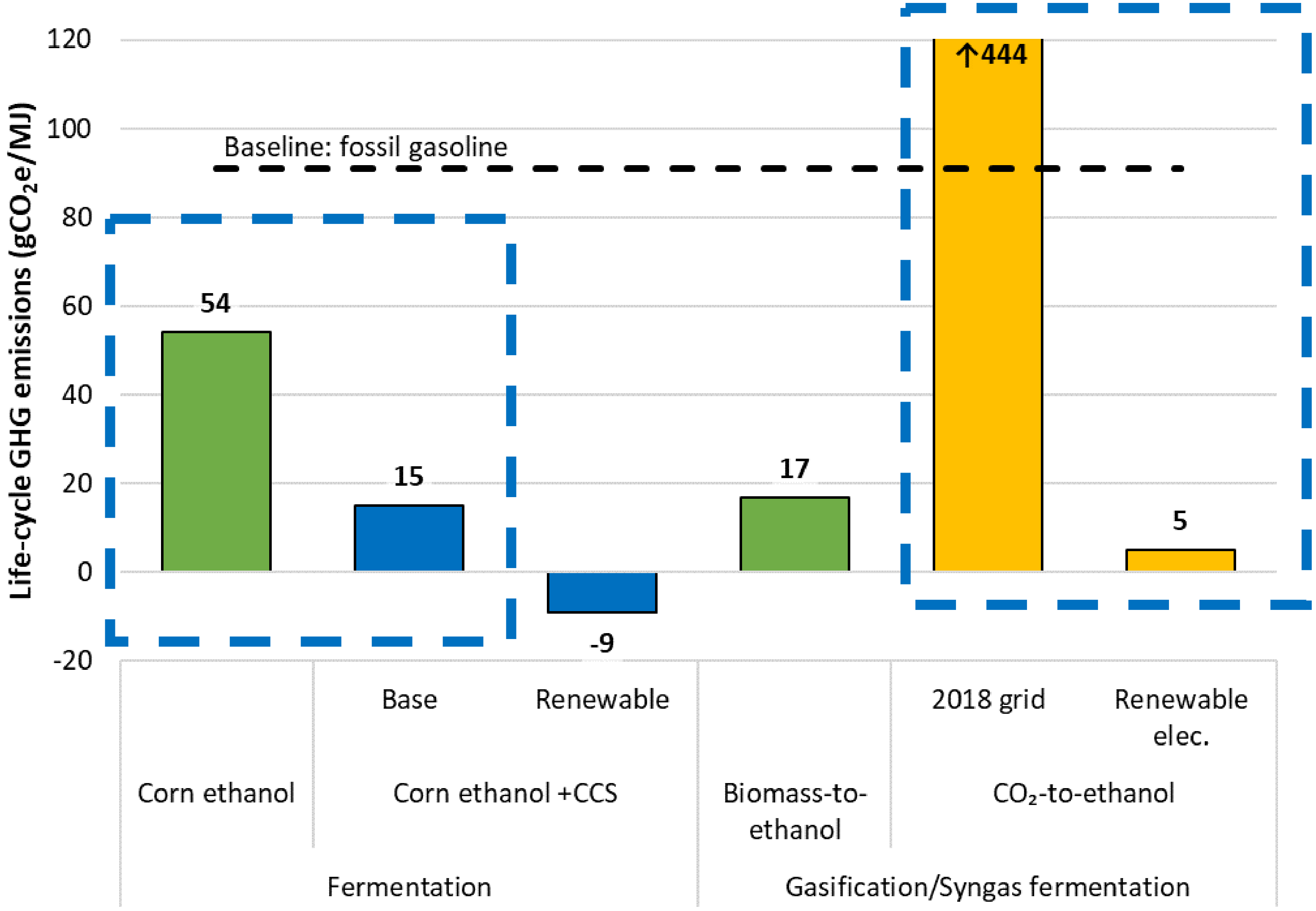
Net-Zero Tech Team

Corn ethanol + CCS

Vs.

CO_2 conversion to ethanol (e-fuel)

LCA of E-fuels



- CCS drops corn ethanol carbon intensity to ~75% GHG reduction
- Using grid mix electricity produces a fuel that is over 4X the carbon intensity of gasoline
- Grid mix needs to be ~80% renewables before you reach fossil parity on carbon intensity

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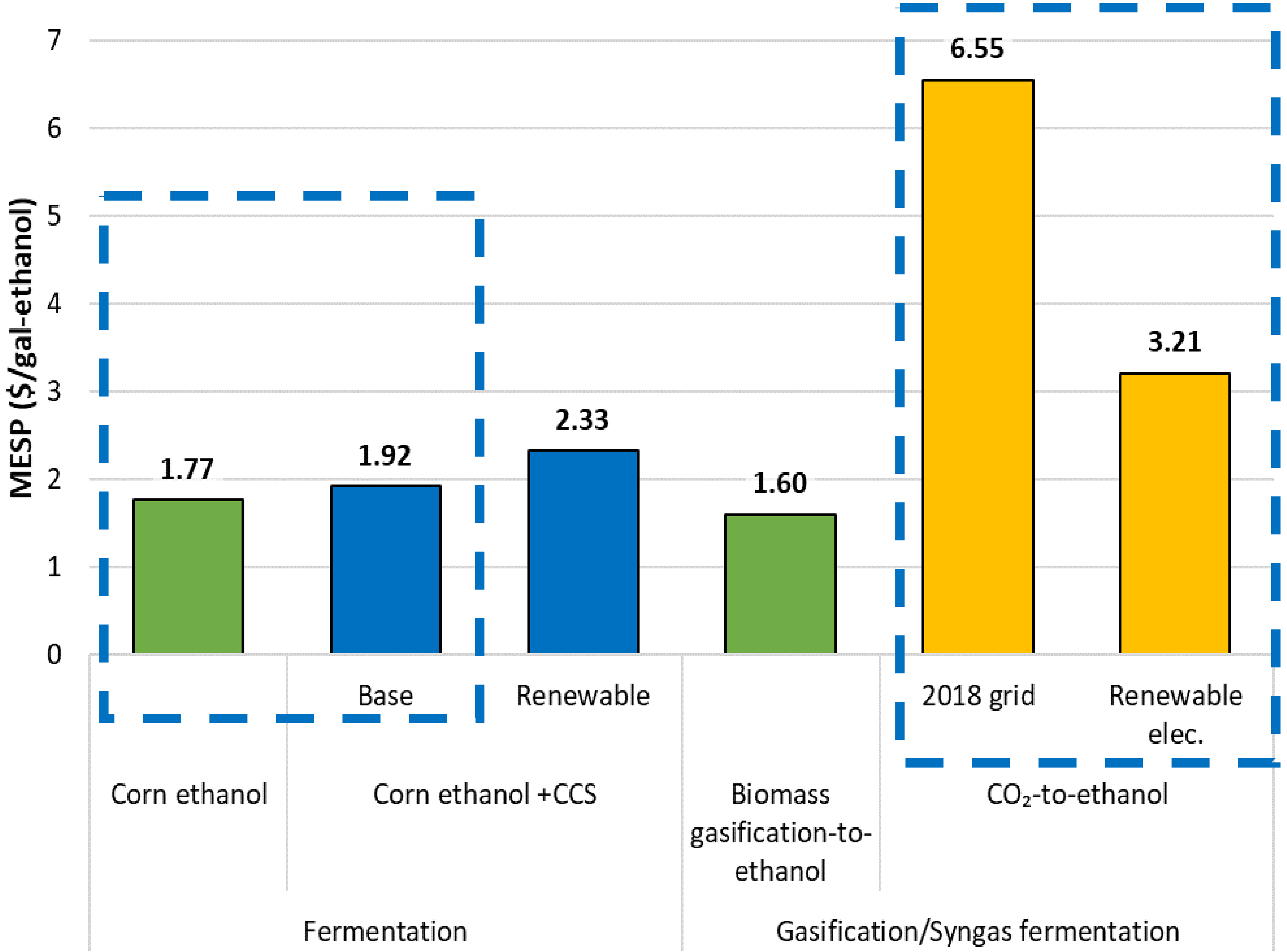
TEA of E-fuels



- CCS adds 15¢/gal (equal to 45Q value of $50/ton CO2)
- At 7¢/kwh, cost is over 3x higher for e-fuels (2018 grid)
- At 2¢/kwh, cost is much lower (renewable grid)

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Net-Zero Carbon Fuels vs “e-fuels”

Net-Zero Carbon Fuels: Renewable fuels made from some carbon feedstock that have a net life-cycle of zero

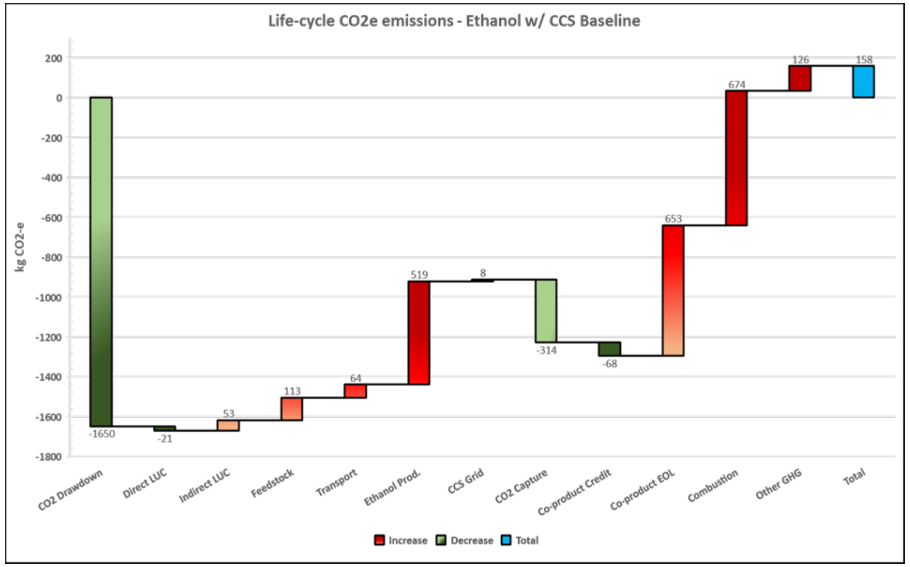
E-fuels: Synthetic fuels made from combining CO_2 and electricity/hydrogen

E-fuels CAN be net-zero carbon, but they are not inherently so and are not necessarily the easiest way to achieve low carbon intensity fuels

Questions

Initial findings: Corn EtOH + CCS

*Preliminary/draft results. Do not cite.



Although not carbon-neutral, the Ethanol with fermentation CCS case decreases the carbon intensity of ethanol by 29 gCO_2/MJ.

Gasoline baseline: 92 gCO_2/MJ

Corn ethanol today: 56 g CO_2/MJ; 40% GHG reduction. (USDA average)

Corn EtOH w/CCS: 15 – 27 gCO_2/MJ; ~70-85% GHG reduction*

Minimum Ethanol Selling Price: $1.77/gal

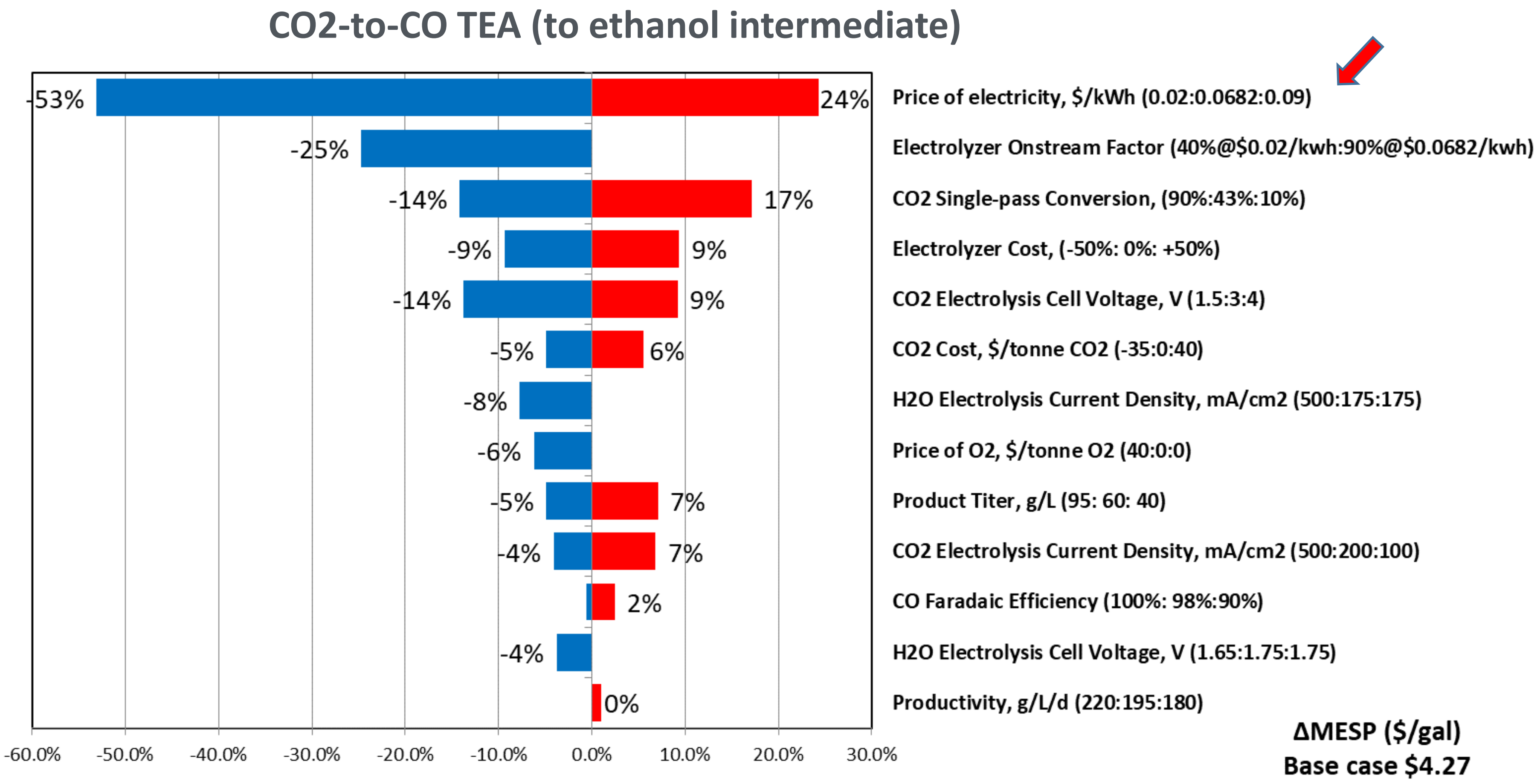
Minimum Ethanol Selling Price w/CCS: $1.92/gal

This additional $0.15 per gallon price ends up being about **$52/ton CO_2**

(for reference, 45Q tax credit = $50/ton)

*Depending on initial ethanol plant carbon intensity

Initial findings: Fuels via CO2 Electrocatalysis (“E-fuels”)



Price of electricity is the key factor in TEA

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