Net Zero

Ethanol-to-Jet: Navigating Business Case Challenges

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Our message

Ethanol-to-Jet technology commercialization is here.

But these early stages of commercialization pose a new set of challenges much different than other renewable fuel pathways.

Successfully navigating these challenges allow ETJ projects to remain innovative and competitive.

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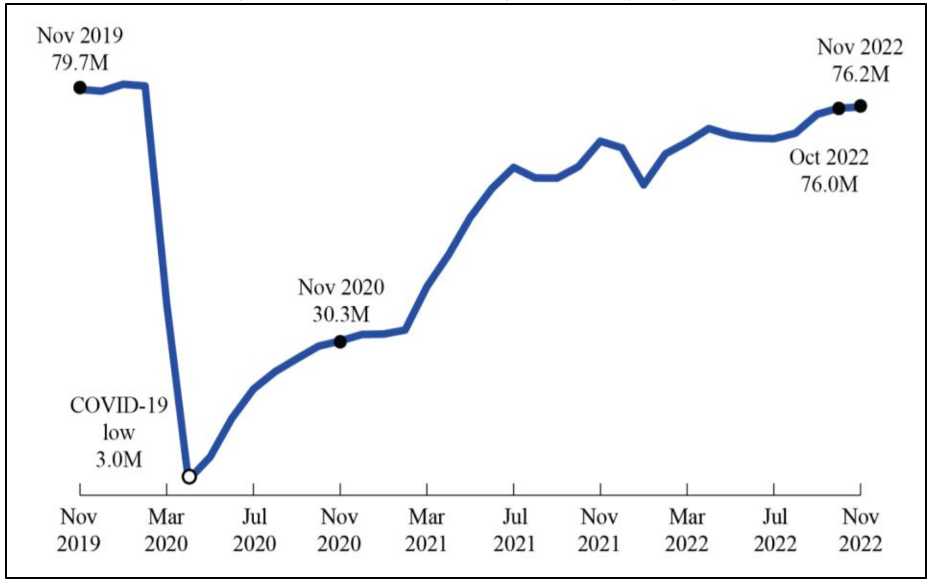
Aviation GHG emissions growing

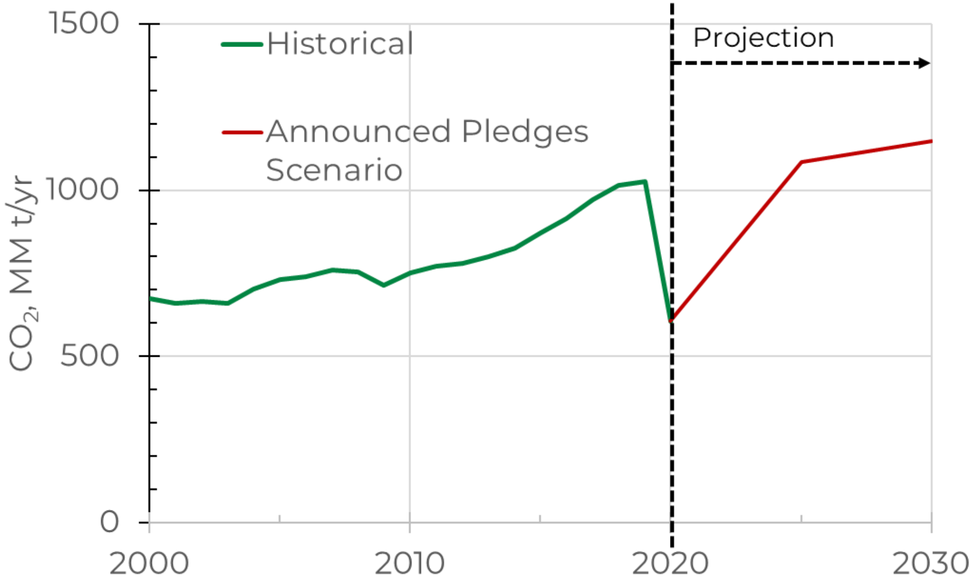
- Air travel is nearly back to 2019 levels
- Air transport contributes 2.1% of global GHG (4.9 %, including non-CO_2 effects)
- Without intervention, GHG from air transport is projected to grow to 4.6% (IEA) by 2050 (excluding the non-CO_2 effect)
- 2021 US average daily Jet Fuel Demand was about 1.4 MMBPD
- 2022 US average daily Jet Fuel Demand is approaching 1.7 MMBPD

Monthly Passengers on US Scheduled Airlines
(Domestic + International), Seasonally Adjusted



Source: US DOT - Bureau of Transportation Statistics (Nov 2022)

Direct CO_2 Emissions from Aviation



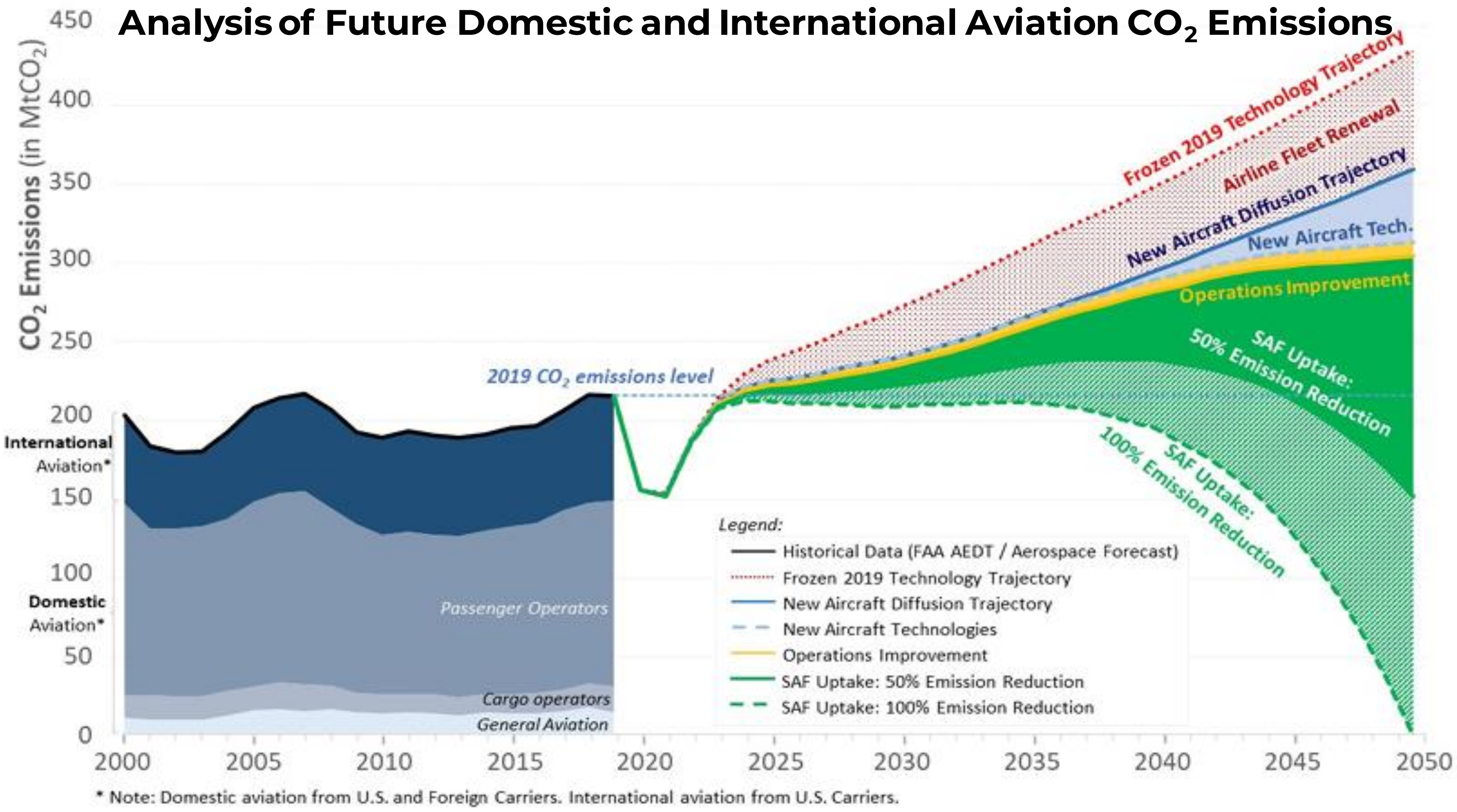
Source: IEA (2021), Aviation, IEA, Paris https://www.iea.org/reports/aviation

Low-carbon fungible liquid fuels are the likely solution for a long time

SAF grand challenge to accelerate US SAF use

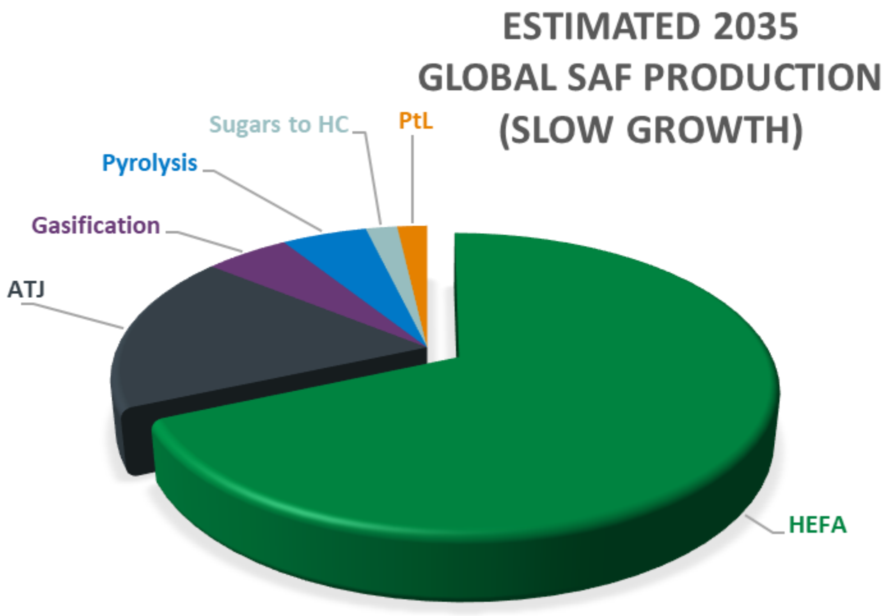
US DOT, USDA, and US DOE program to increase SAF use in the US

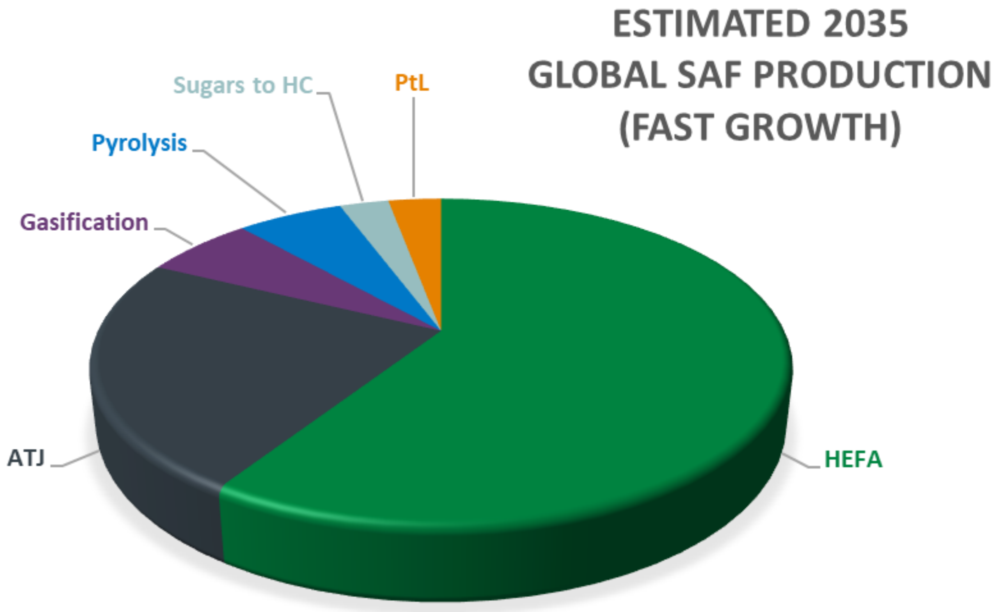
- 3 billion gal/yr by 2030 (0.2 MM BPD)
- 35 billion gal/yr by 2050 (2.3 MM BPD)
- SAF is the major contributor to decarbonizing aviation.
- IRA-2022 offers $244.5 MM for projects relating to SAF production, transportation, blending, or storage



Source: United States 2021 Aviation Climate Action Plan, FAA, 2021, www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

Projected Global SAF Production by Pathways





Source: UK Sustainable Aviation Fuel Roadmap Report

Business Case for Ethanol-to-Jet: ETJ Pathway Challenges

- Ethanol Feedstock
- SAF Carbon Intensity Requirements
- Sell Low CI Ethanol or Convert to SAF
- Integrated Technology Offerings
- Right-Size Capacity
- Navigating Tax Incentives
- CO_2 Capture and Pipelines
- Ethanol Transport
- Offtake Agreements

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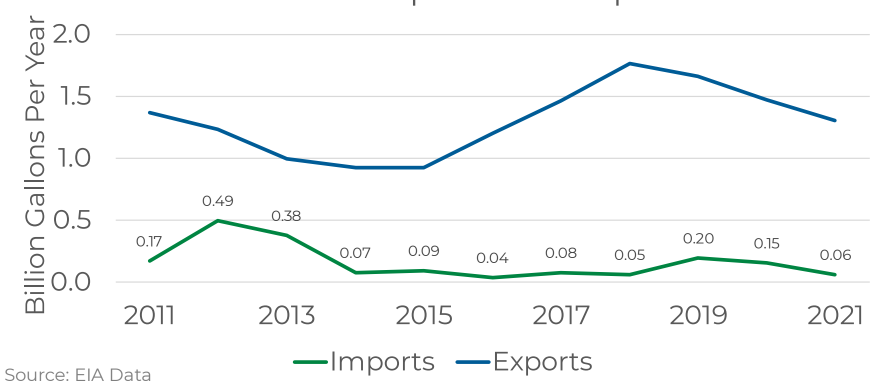
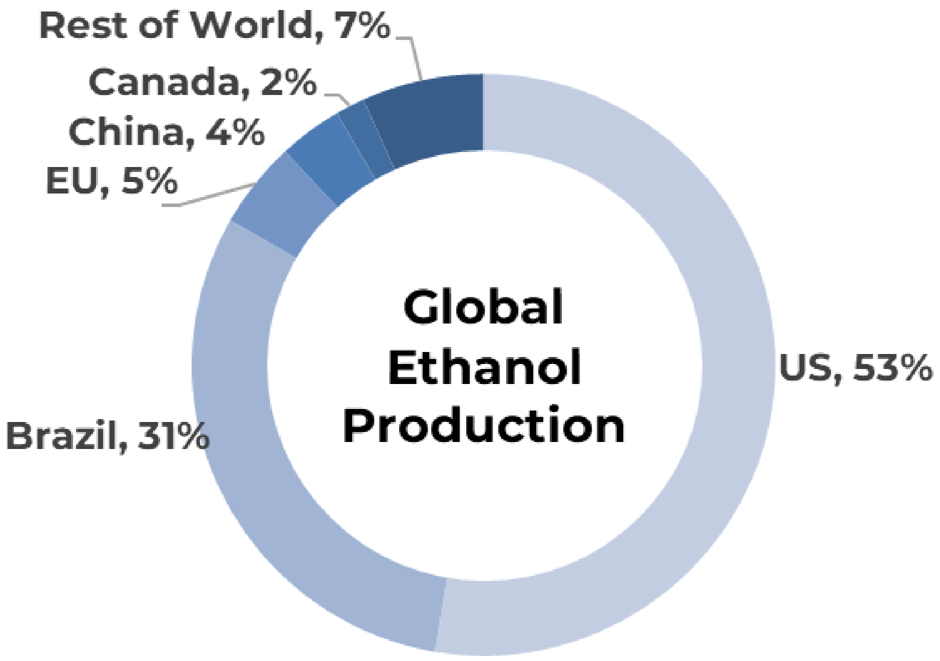
Ethanol Feedstock Availability

- PADD 2 – The midwest is the heart of the Corn Ethanol Industry
- US Total production 17.4 billion gallons (414 million barrels) per year
- Iowa produces more than twice as much ethanol as any other state
- US is a net exporter of over 1.3 billion gallons (31 million barrels) per year of corn ethanol to 87+ countries



Source: EIA Data



Source: Renewable Fuels Association Data

SAF Carbon Intensity (CI) Requirements

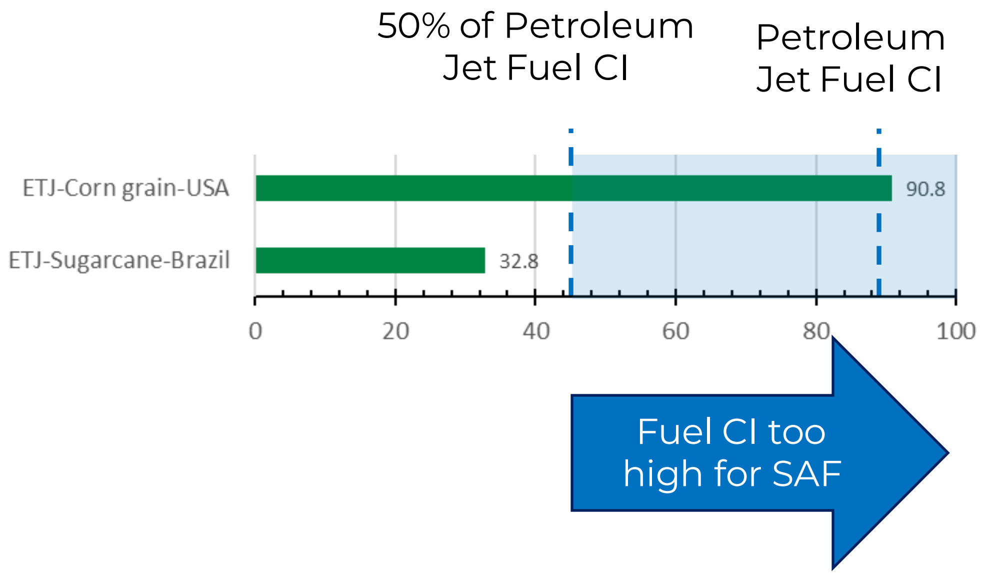
IRA credits

- Blender's tax credit: ≤50% of petroleum jet fuel CI
- Clean fuel production credit: < 50 kg CO_2e/MM BTU

Some ethanol to jet CI is too high

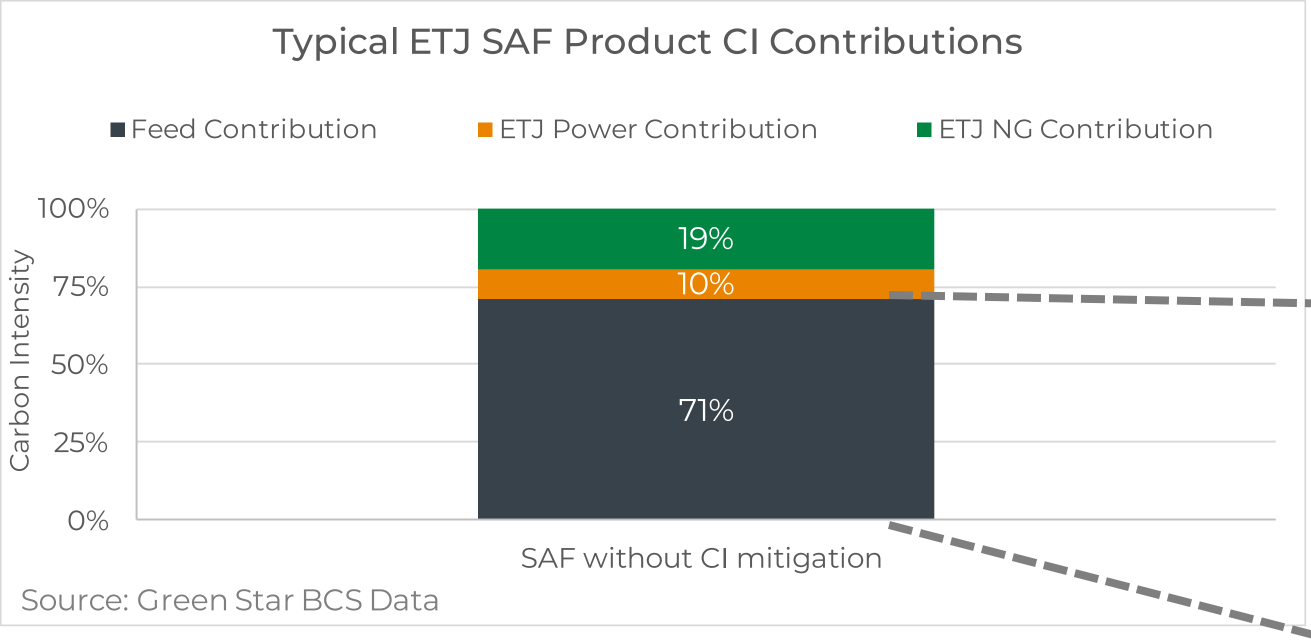
- Corn ethanol
- Even with the capture of CO_2 from fermentation, corn ethanol, may have a CI too high for SAF

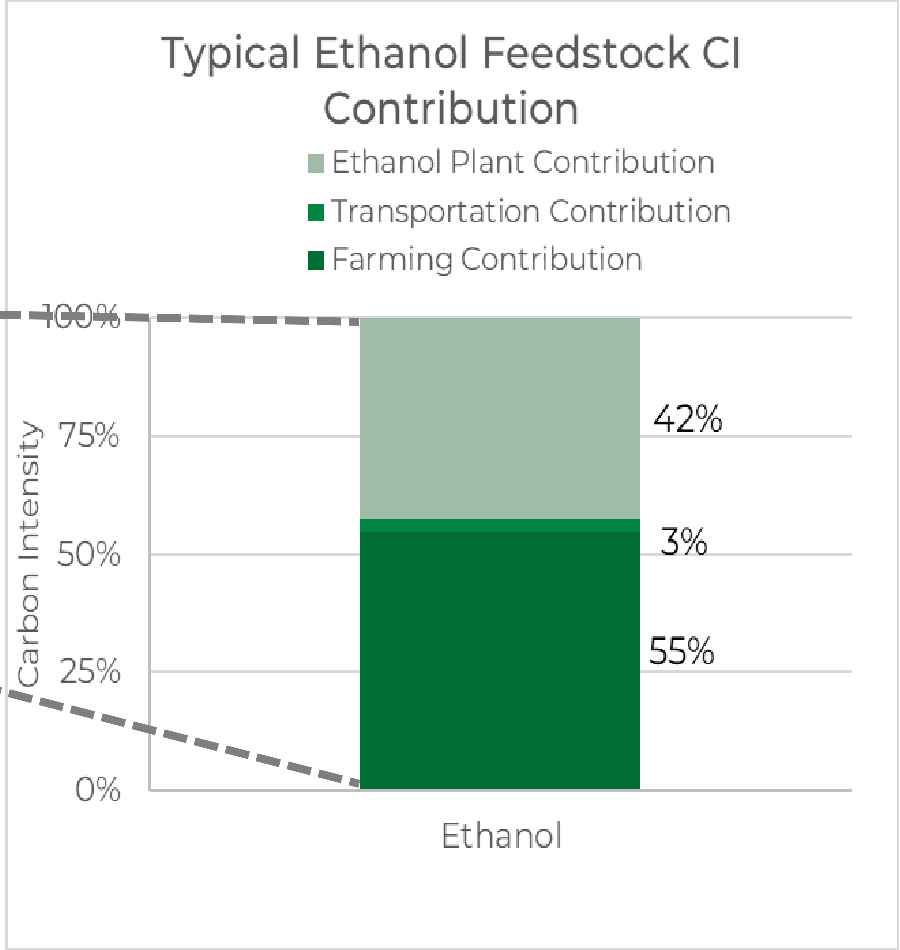
SAF Lifecycle CI*, g CO_2e/MJ



*CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation)

SAF CI Requirements – Typical Contributions





SAF CI Impact

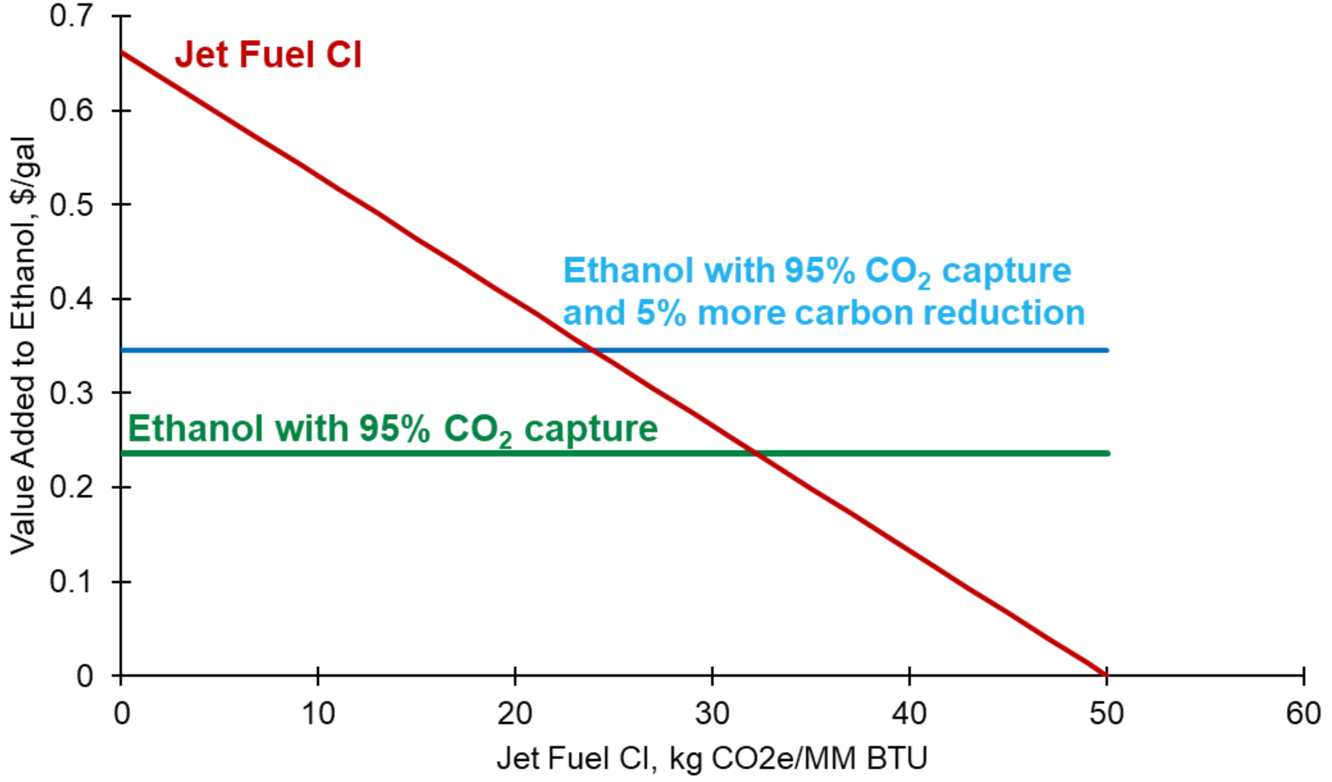
Breakdown of contribution to total CI measured on finished SAF.

- **ETJ Feed Contribution** is directly related to incoming EtOH CI
- **Natural gas** varies with feedstock quality
- **Power** varies with ETJ technology pathway

Sell Low CI Ethanol or Convert to SAF

- CI average for corn-based ethanol from CARB LCFS lookup table: 69.9 g CO_2/MJ
- Evaluate which option provides highest return per gallon of ethanol
    1. Sell low CI ethanol using CO_2 capture from fermentation at 95% recovery
    2. Further reduce ethanol CI
    3. Convert low CI ethanol to jet fuel with additional carbon reduction. Assume 53% yield of jet from ethanol
- Other factors to consider in converting ethanol to jet vs. selling low CI ethanol
    - Feedstock cost
    - Capex
    - Market demand

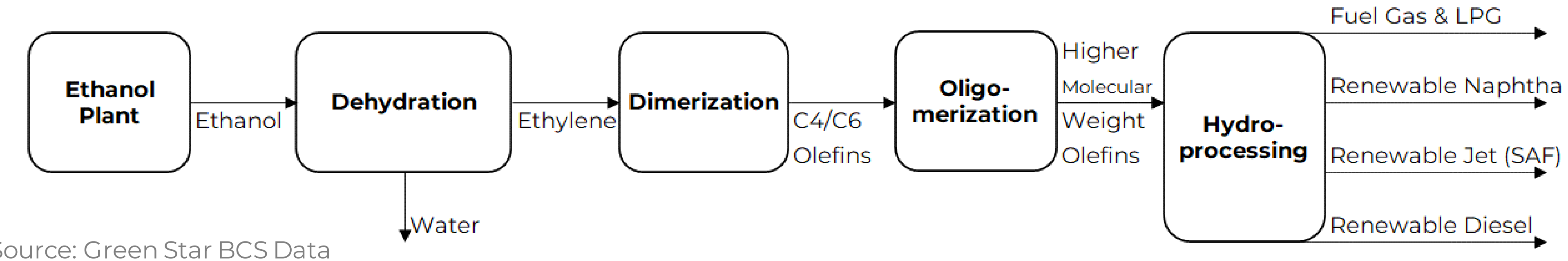
45Z Credit from Low CI Ethanol vs. Low CI Jet Fuel



Source: Green Star BCS

Integrated Technology Offerings

Ethanol conversion to jet is accomplished in the steps as shown below:



Source: Green Star BCS Data

Several licensors offer portions of the process units required for the ETJ process

- Ethanol-to-Ethylene Dehydration was primarily developed in the 1970 - 1980s

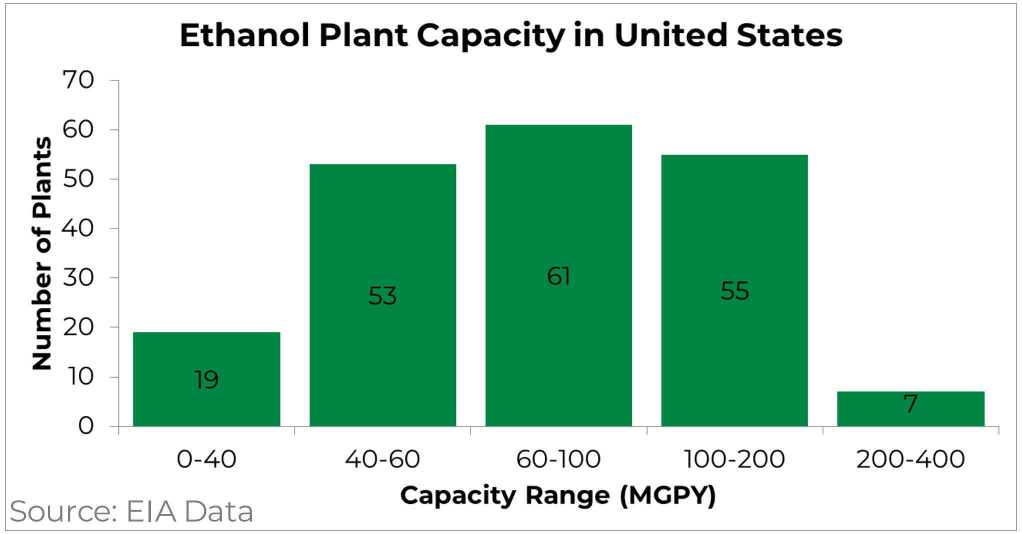
Licensor Technology Package Offerings (alphabetical)

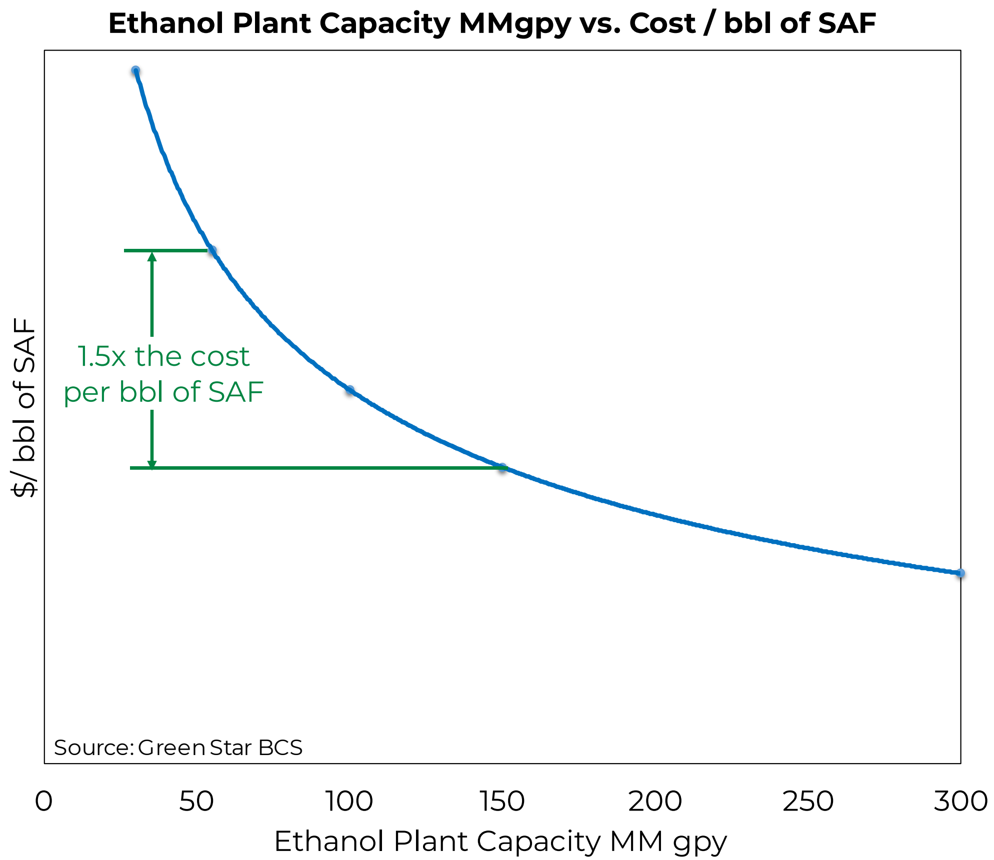
- Axens/Gevo
- KBR
- LanzaJet
- Lummus
- Technip
- UOP

Only three licensors offer the full suite of process units required for the ETJ technology

Right-Size Capacity

- What is the best Ethanol Plant capacity for an ETJ Facility?
- What is the optimal balance between Economies of Scale and CAPEX risk?





Navigating Tax Incentives

1. Renewable Fuel Standard and RINS - federal
2. Blender's tax credit – federal
   - 40A/B – Blender's tax credit – IRA expansion of existing programs – ends Dec 31, 2024
3. Low Carbon Fuel Standards – state/province
4. Inflation Reduction Act (IRA) of 2022

   Applies to new projects whose construction begins Jan 29, 2023
   - 45Q – CO_2 capture – expansion of existing program
   - 45V – Clean hydrogen – a new program
   - 45Z – Clean fuel production – a new program – starts Jan 1, 2025
   - All credits will be inflation adjusted.
   - Credits multiplied by 5 for meeting prevailing wage and apprenticeship requirements (programs do not have to be union)

Carbon Intensity Dependent (items 3–4)

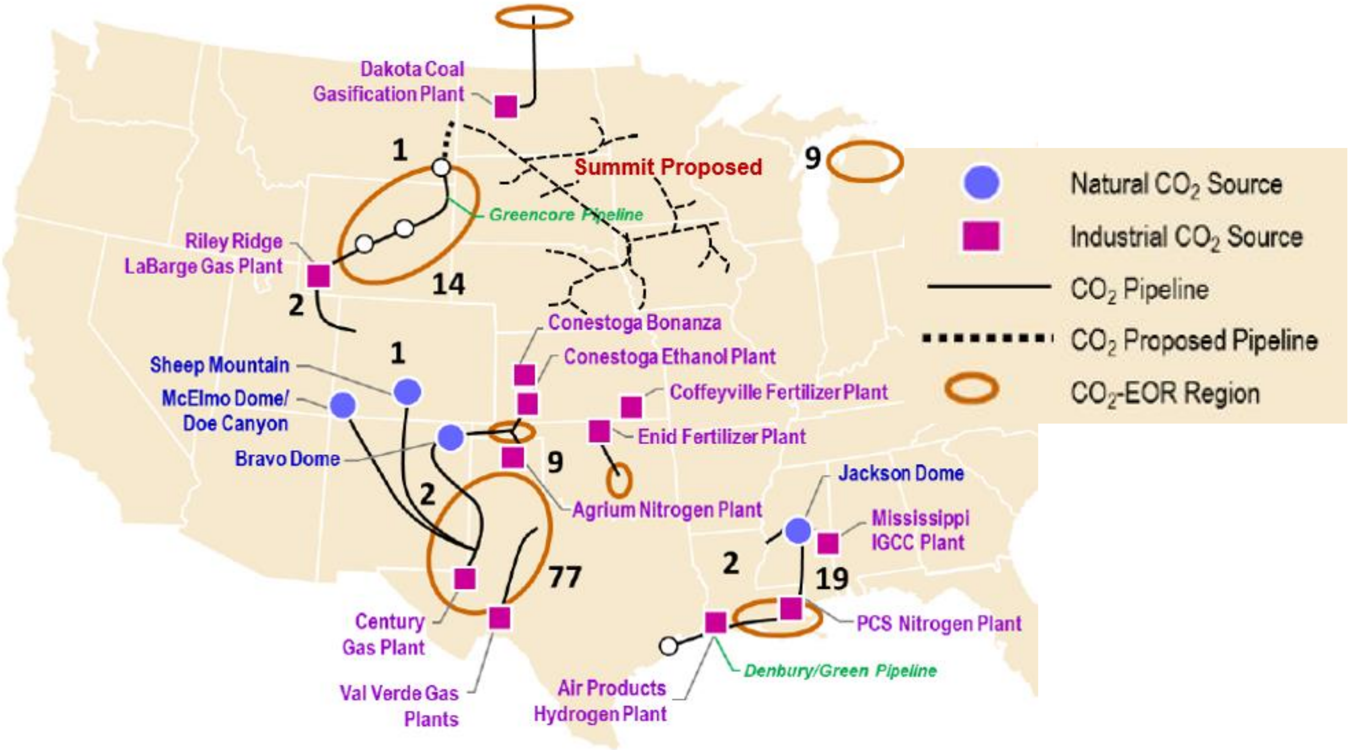
Inflation Reduction Act of 2022 offers greater incentives to decarbonize liquid fuel products

Total incentives can add $3 to $7 per gallon of liquid drop-in fuels, depending on feedstock, fuel, and market

CO_2 Capture and Pipelines

- **Limited CO_2 pipelines** of ~ 5,000 miles – mostly in the West and mostly for EOR
- **Public resistance to CO_2 pipelines** – growing opposition to new Midwest pipelines for CO_2 from ethanol and ammonia plants (Summit's Midwest Carbon Express, Navigator's Heartland Greenway, and Wolf Carbon Solutions' ADM pipelines).

CO_2 capture for reducing ETJ SAF carbon intensity comes with its own challenges



Source: A Review of the CO2 Pipeline Infrastructure in the U.S. April 21, 2015, DOE/NETL-2014/1681L

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Ethanol Transport

- "According to the U.S. Department of Agriculture, 90% of ethanol is transported by train or truck. A tanker truck can carry 8,000 to 10,000 gallons of ethanol, and one rail car can carry approximately 30,000 gallons of ethanol. The remaining 10% is mainly transported by barge, with **minimal amounts transported by pipeline**.
- "Delivering ethanol by pipeline is the most efficient option, but **ethanol's affinity for water and solvent properties require the use of a dedicated pipeline or significant cleanup** of existing pipelines to convert them into dedicated pipelines." - EIA

All train, truck, and barge transfers will increase the product lifecycle carbon intensity

Off-take Agreements

- Securing multiple off-taker agreements:
  1. Refiners / Governments
  2. Airlines / Airports
  3. Aerospace companies / test facilities

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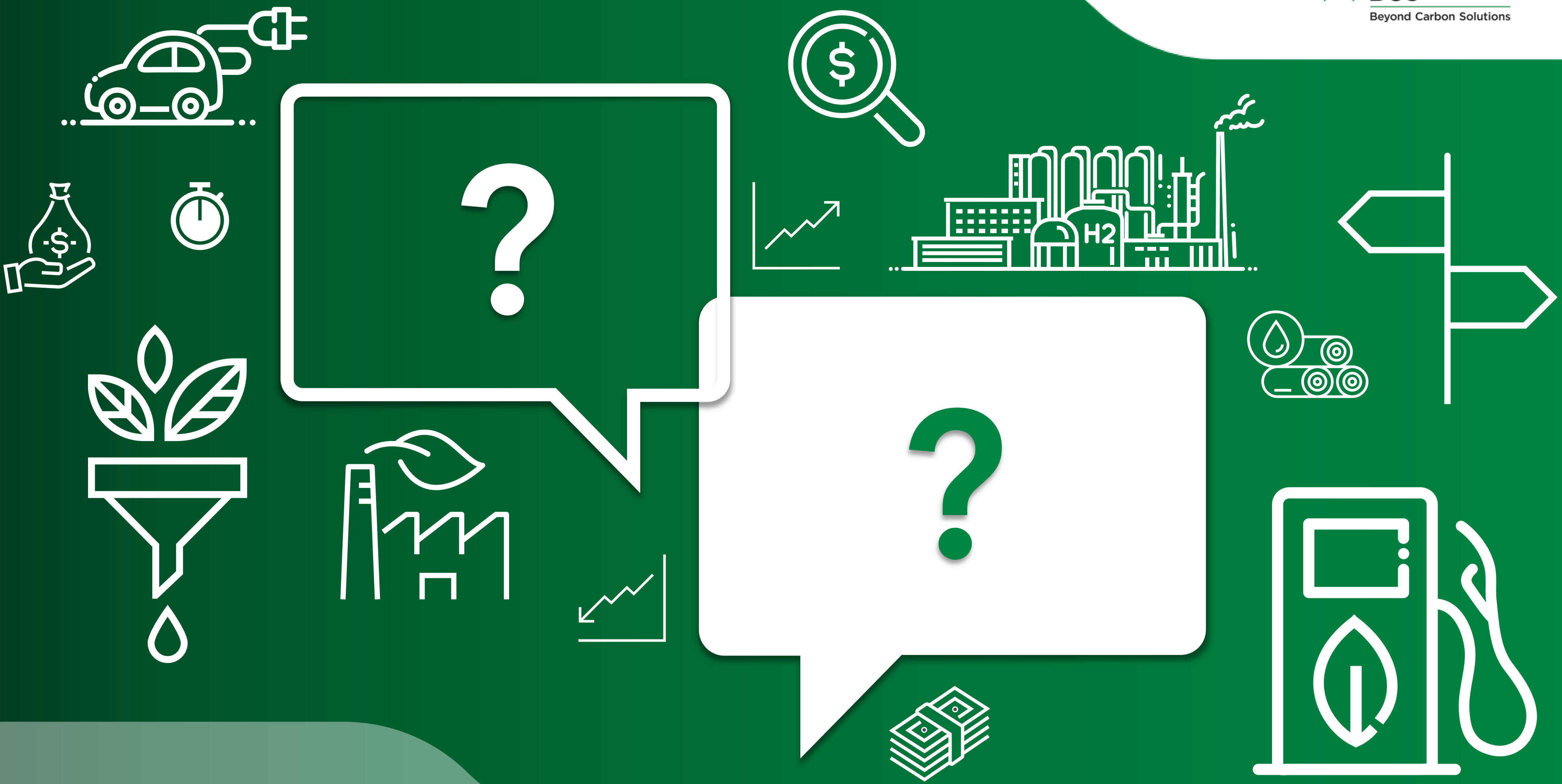


Strategy Deployment Plan

FRAMING → ANALYSIS → EVALUATION → TRIGGERS → PLAN → OUTPUT

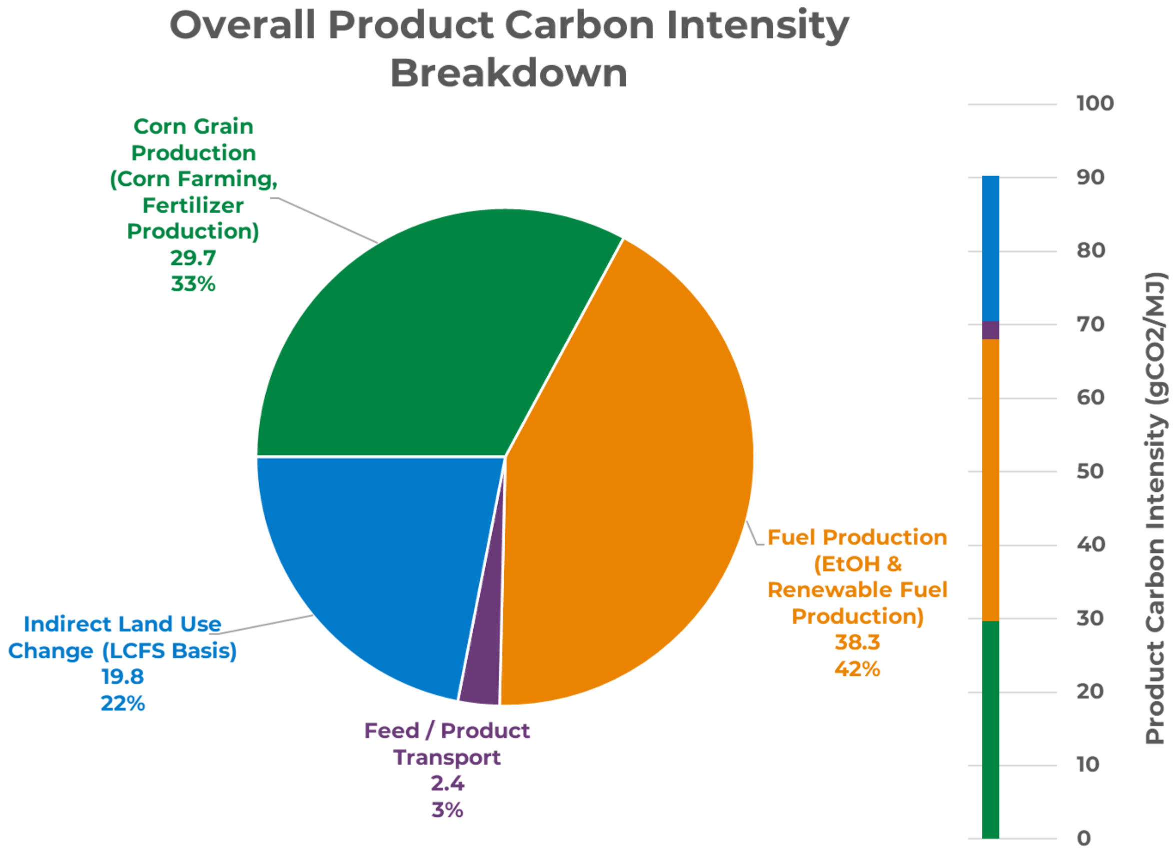
FRAMING	ANALYSIS	EVALUATION	TRIGGERS	PLAN
Objectives & Boundaries	**Business Dynamics**	**Solution Concepts**	**Decision Tree**	**Decarbonization Roadmap**
Strengthen, Diversify or Transform	Timeline & Targets	Techno Economics and Financial Modelling	Decision Drivers	Scenario Mapping with Defined Entry & Exits

Green Star BCS Proprietary Tools

- Renewable Feedstock Database
- **Carbon Accounting Program (GS CAP)**
- Carbon Economics Financial Model
- Cost Estimate Database
- Linear Program Model
- Decarbonization Roadmap

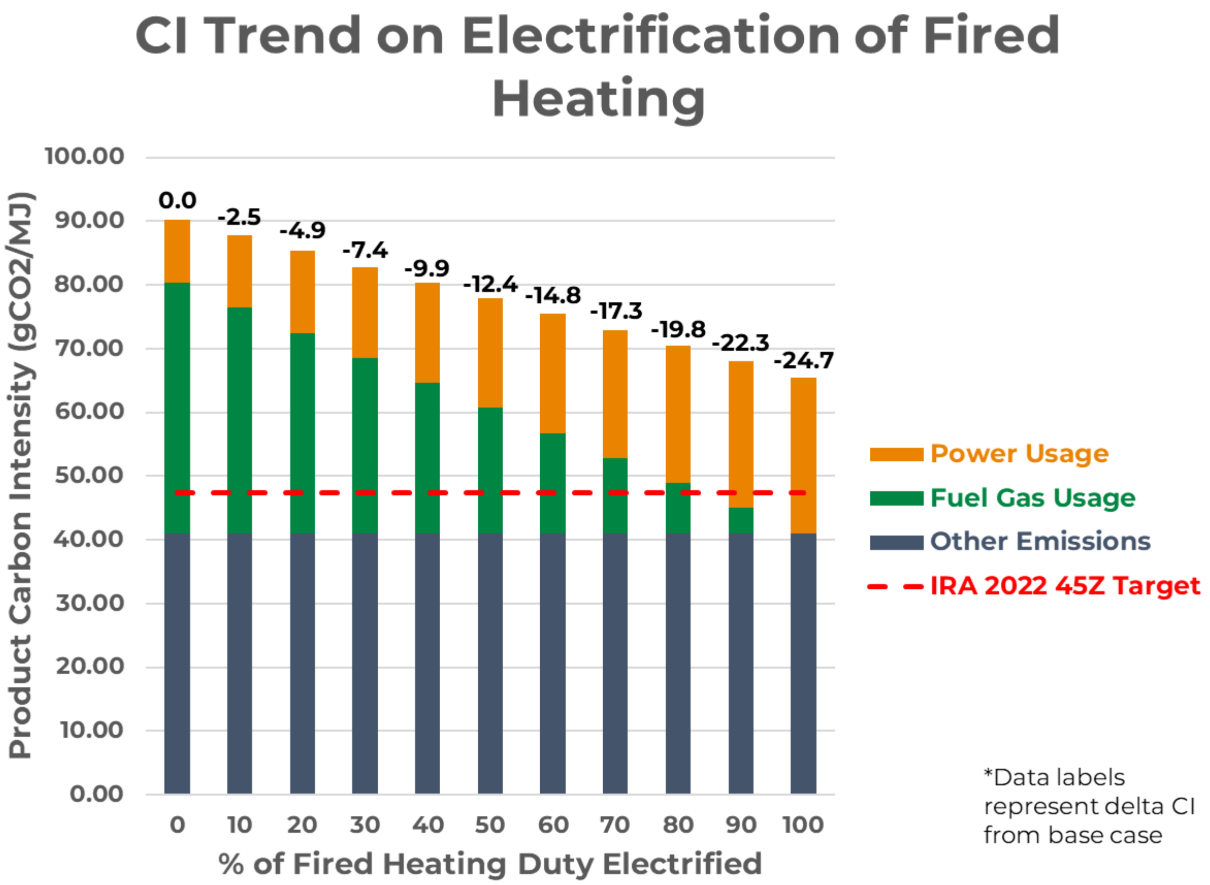
Defining and sticking with a plan with decision gates, entry and exit points, and market triggers is crucial

Base Case – Corn EtJ Carbon Intensity

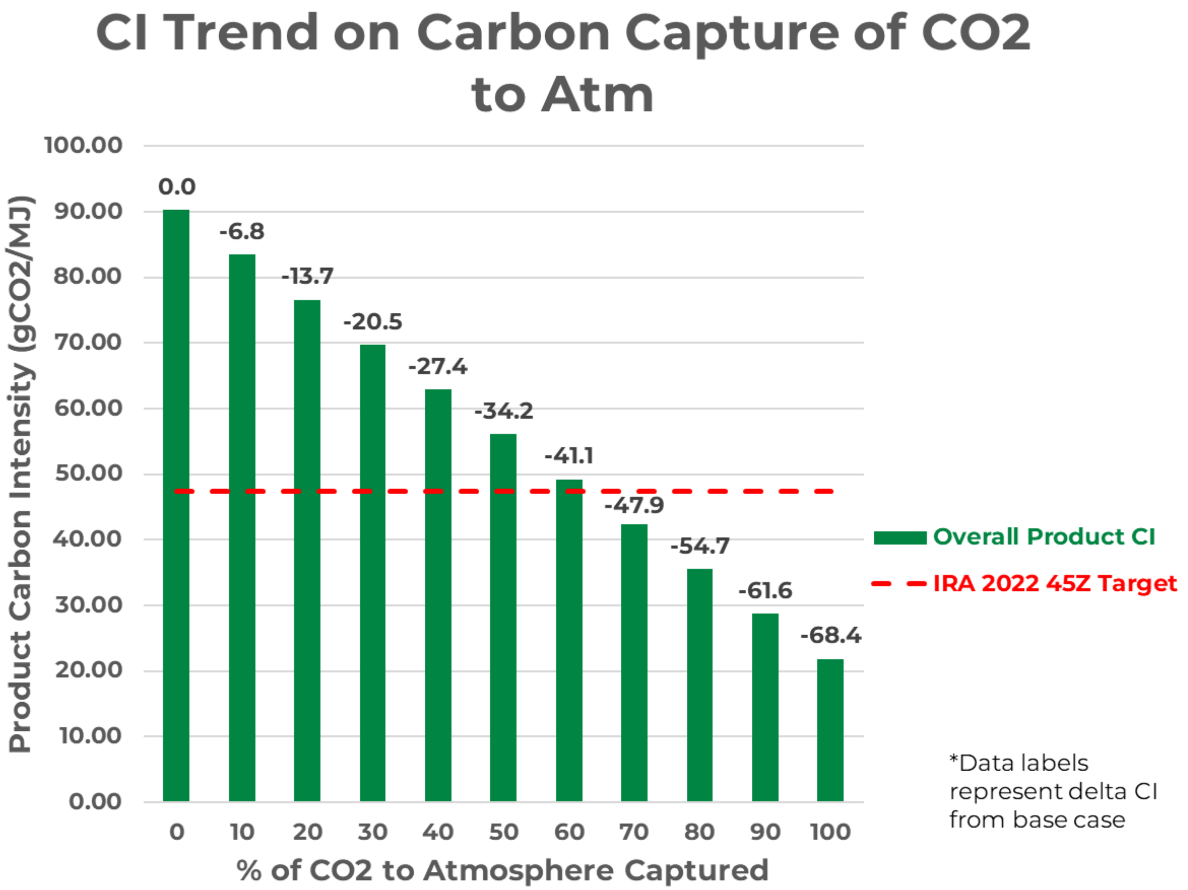


Product Carbon Intensity Breakdown	
	Carbon Intensity gCO2/MJ
Corn Grain Production (Corn Farming, Fertilizer Production)	29.7
Fuel Production (EtOH & Renewable Fuel Production)	38.3
EtOH Fermentation Carbon Capture	0.0
Co-Production Credit	-10.9
Power Usage	9.9
Fuel Gas Usage	39.3
Hydrogen (Import) Usage	0.0
Feed / Product Transport	2.4
Feed Transport	1.1
Product Transport	1.4
Indirect Land Use Change (LCFS Basis)	19.8
Overall Product Carbon Intensity	90.3

Test Case 1 – Corn EtJ Carbon Abatement Trending



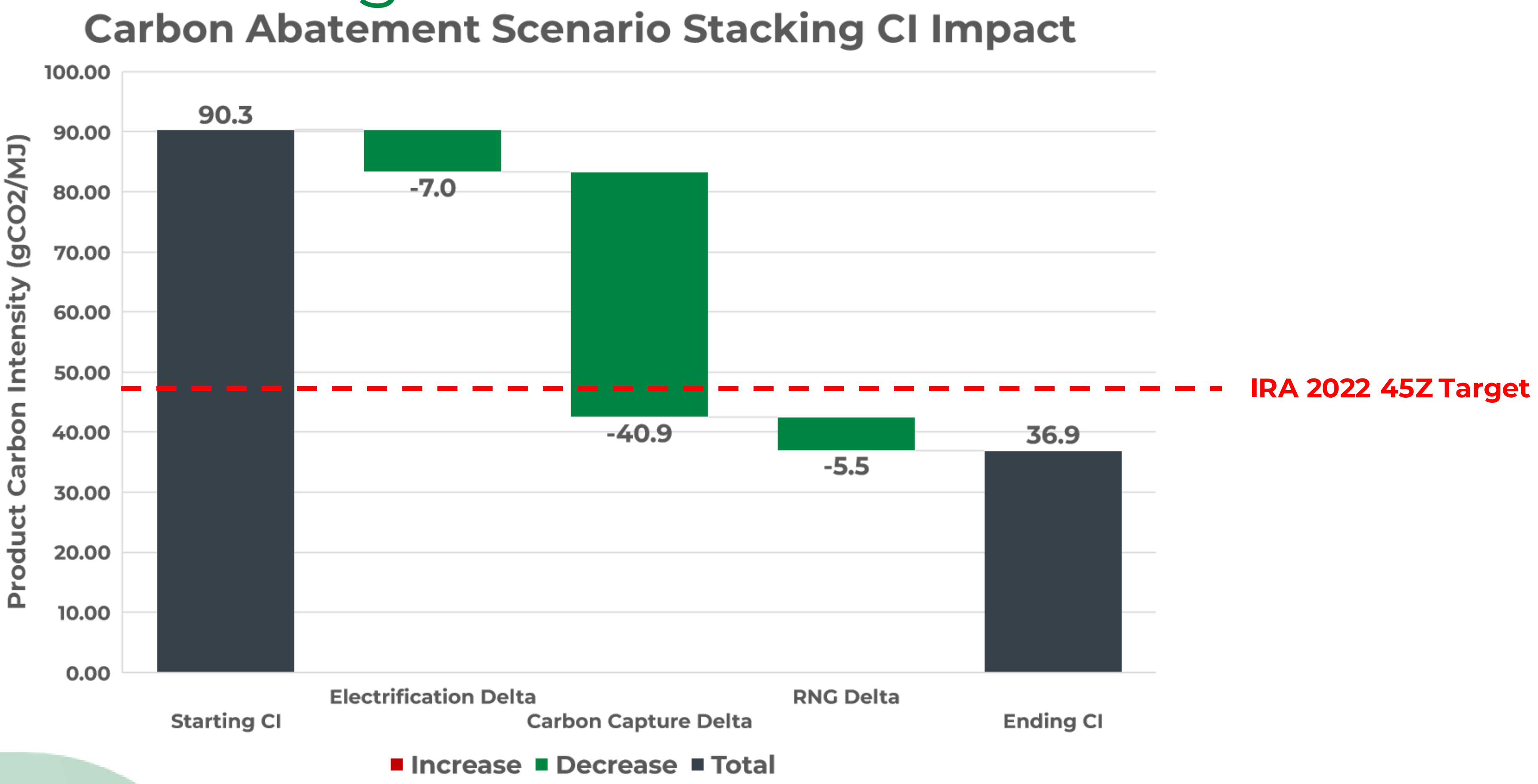
*Data labels represent delta CI from base case



*Data labels represent delta CI from base case

The Other Emissions category represents categories in the CI Breakdown from prior slides such as: corn grain production, co-production credits, hydrogen usage, feed/product transport, and indirect land use charge.

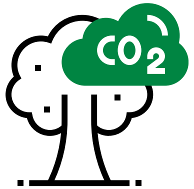
Test Case 2 – Corn EtJ Carbon Abatement Trending



Independent Consultant Value Added

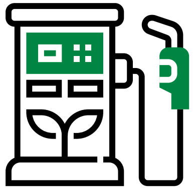
ESG Pressure

Decarbonization pressures are likely to continue to increase, even while liquid energy products are in high demand and energy security is paramount



Investment Decisions

Uncertainty related to market, regulation, and technologies can complicate investment decisions

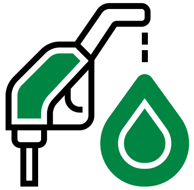


Modeling Tools

Traditional toolkit can help, but needs to be re-imagined

Break-Point Identification

Trigger or break points are critical to understand impact



Market Response

Strategies are subject to change over time as a response to external influences

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Our message

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But these early stages of commercialization pose a new set of challenges much different than other renewable fuel pathways.

Successfully navigating these challenges allow ETJ projects to remain innovative and competitive.

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Contact Us

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Soheil is the Chief Carbon Technologies Officer at Green Star BCS. He has served in various positions (Vice President of Low Carbon Group, Group Manager, and Refining Technology Manager) and provided consulting services to numerous Refining, Petrochemical, and Energy Sectors.

He has established his reputation and career on his front-end consulting for refining and petrochemical clients, for whom he has routinely reduced GHG emissions and project costs over the past 35 years. His expertise includes Renewable Fuels, Hydrotreaters, Hydrocrackers, Crude, FCC, Coker, and Hydrogen.

Soheil is a world-renowned leader in Energy Transition and renewable fuels strategy development. He led the major Refineries conversion, including the world's largest renewable fuel production facility in the US, and identified many Energy/ GHG Reduction Projects (listed on the CARB website). He has worked on **70+ renewable fuels studies** and projects globally, with a combined capacity of **450+ MMBPD renewable fuels**.

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