Engineering and Managing Terrestrial Ecosystems for Optimized Carbon Dioxide Removal and Negative Emissions Pathways

Bioenergy’s Role in Soil Carbon Workshop
Bioenergy Technologies Office
U.S. Department of Energy
March 28, 2022 (Virtual)

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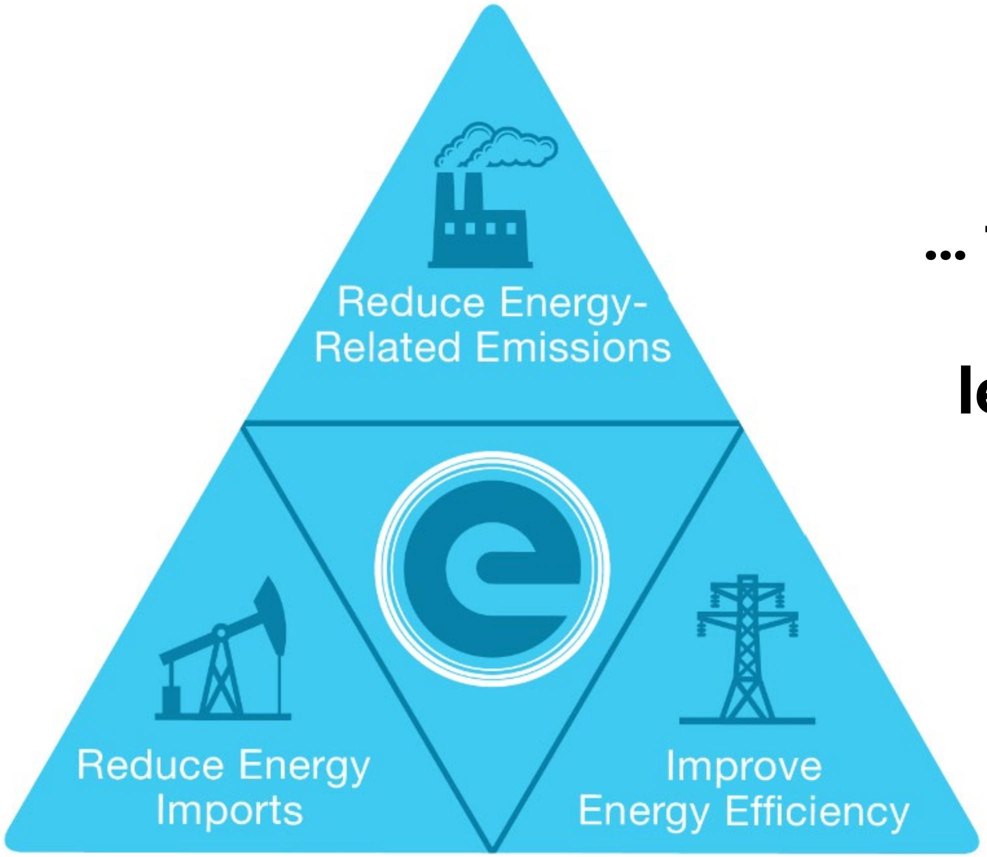
Who is ARPA-E? Advanced Research Projects Agency - Energy

Mission

Overcome long-term and high-risk technological barriers in the development of transformative technologies …



… that ensure U.S. national security, technology leadership, and economic prosperity

Moonshot Targets

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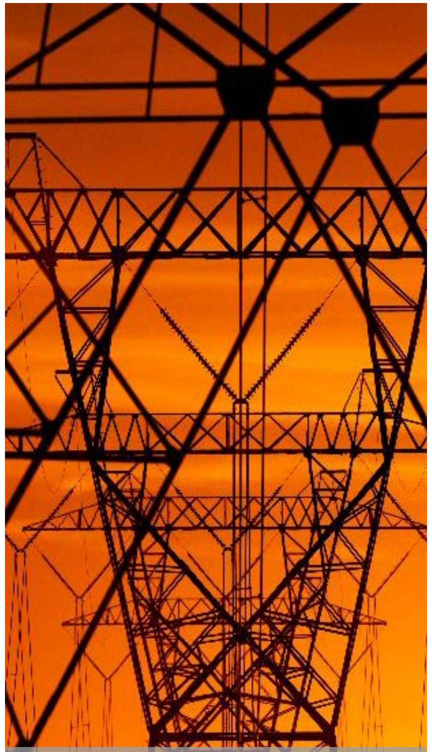
What solutions are we working to offer?



Resilient energy infrastructure

Affordable, sustainable energy

Climate change mitigation

U.S. economic development

Leadership in science and technology

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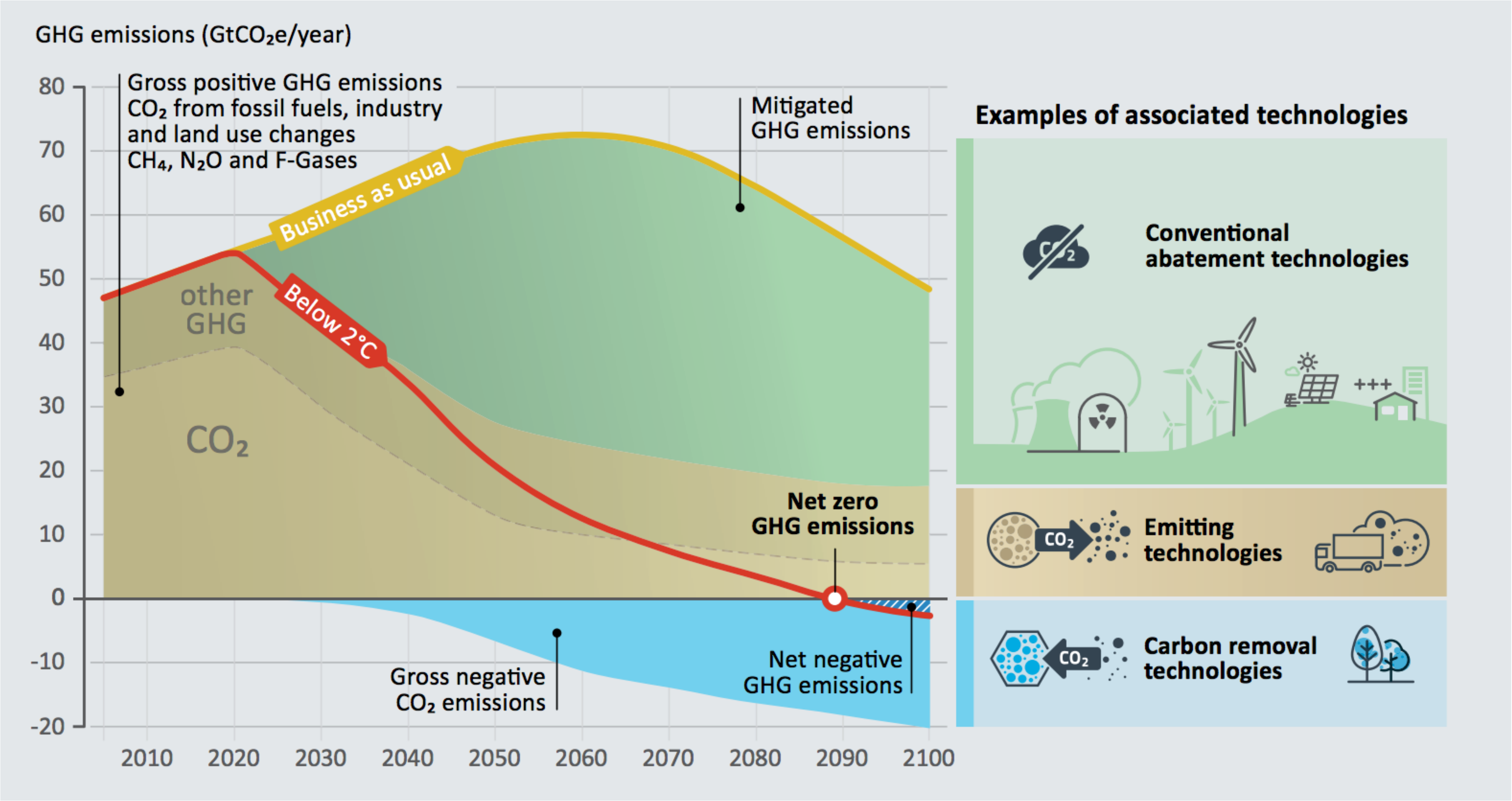
All paths to 2^0 C go through zero



National Academy of Sciences. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* 2019. p. 3

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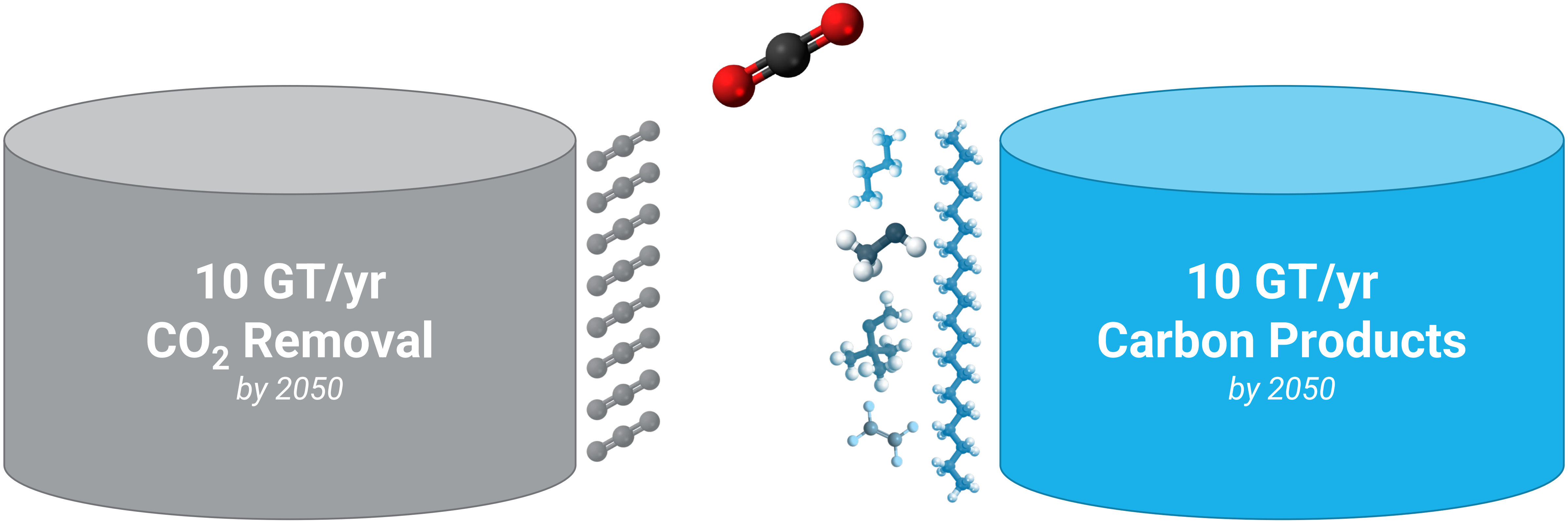
There are <u>two *new carbon* buckets</u> that need to be filled

Where *new carbon* is sourced, where it is directed, or how it is used matters a lot.

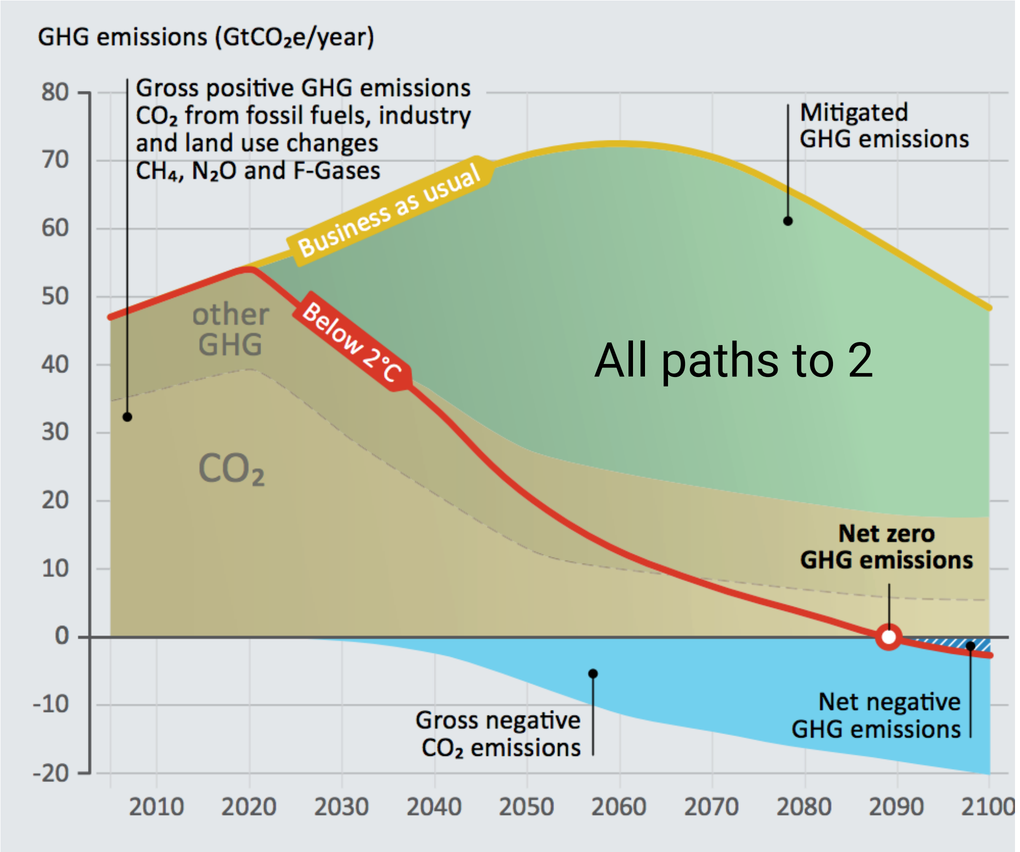


Low energy

High energy

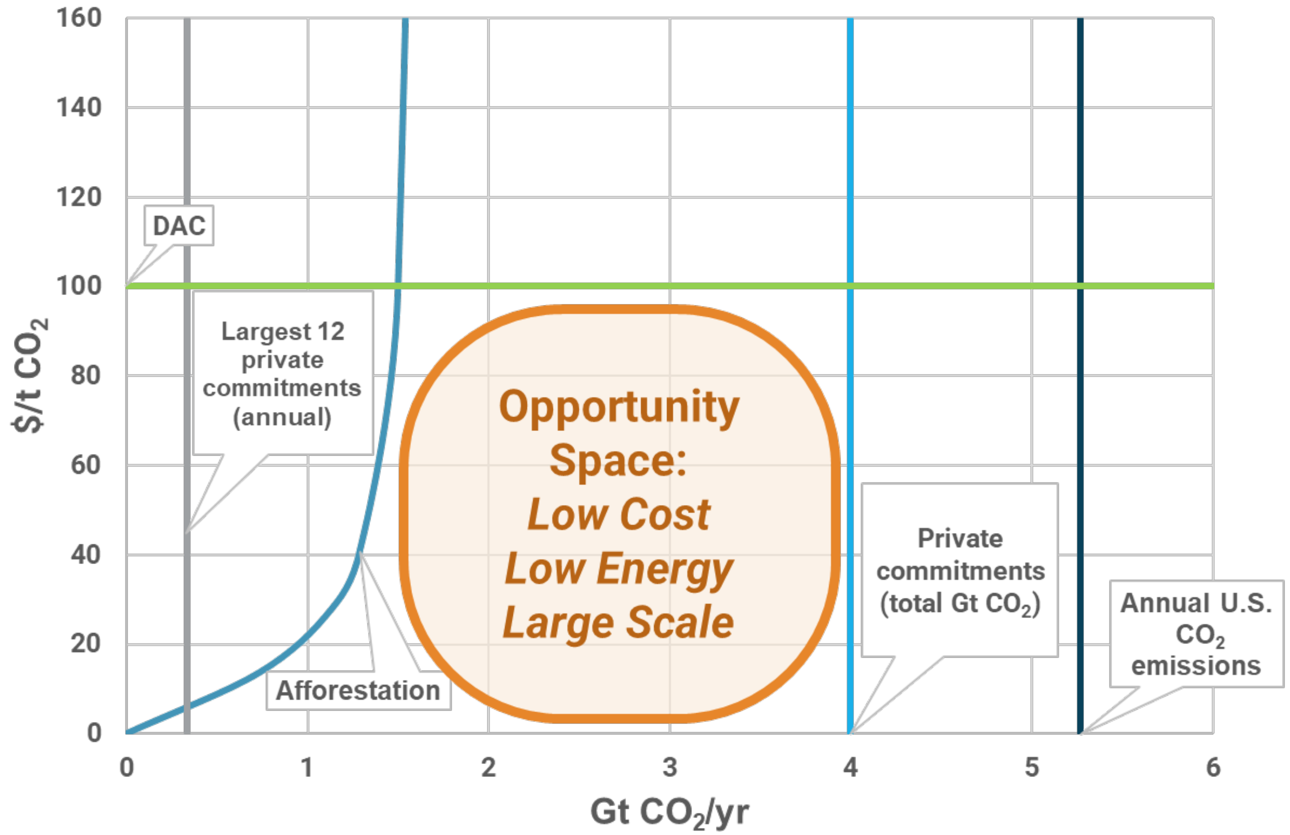
The carbon removal industry will be large and diverse

All paths to 2° C go through zero



National Academy of Sciences. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* 2019. p. 3

Biological sequestration can play a major role



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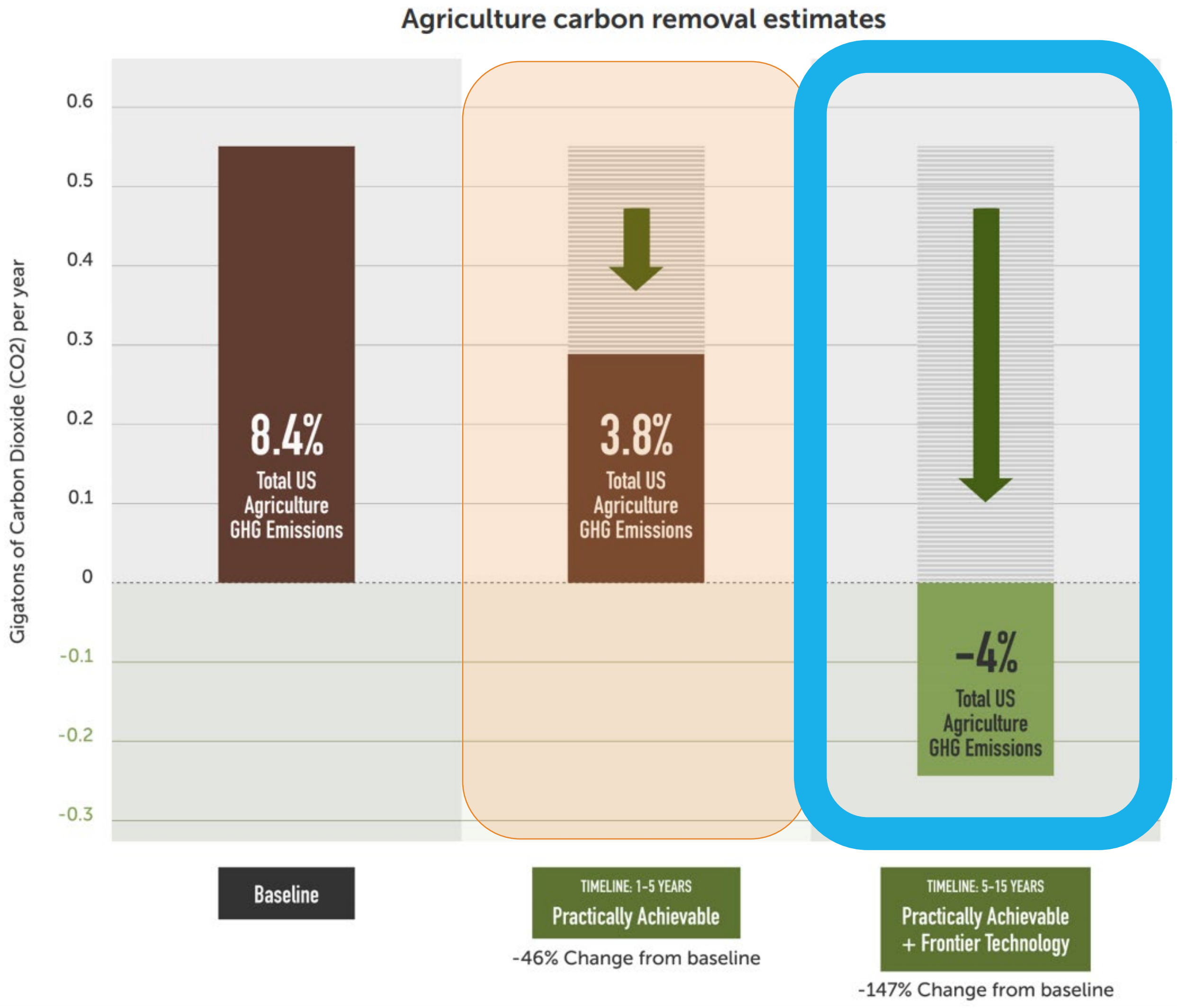
Removal potential estimated to be 12% of U.S. emissions



Practically achievable: cover crops, no-till, precision animal manure and rotational grazing

Frontier technology: biochar amendments, advanced crop breeding or phenotyping for high carbon input root systems

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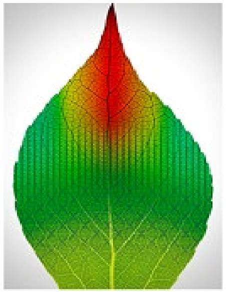
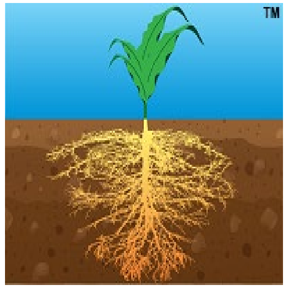
U.S. Farmers and Ranchers Alliance, 2019 - The power of resiliency in agriculture's ecosystem services
NAS 2019 - Negative Emissions Technologies and Reliable Sequestration: A Research Agenda

ARPA-E seeks to transform the bioeconomy value chain

Feedstock Production	Conversion

TERRA / ROOTS





SMARTFARM

ECOSynBio

Genetics x Environment x Management x Processing

Identify Improvements

Identify genetics for enhanced crop characteristics, deeper more robust roots

Measure Outcomes

Supply-chain-wide lifecycle accounting to measure the "carbon harvest"

Maximize Output

Maintain and maximize carbon and resource efficiency throughout the supply chain

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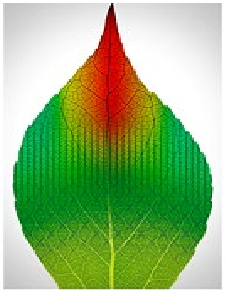
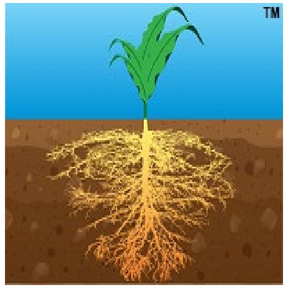
ARPA-E seeks to transform the bioeconomy value chain

Feedstock Production		Conversion
TERRA / ROOTS	**SMARTFARM**	**ECOSynBio**





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TERRA - ROOTS Program Vision

THE CONVERGENCE OF BIOLOGY, ENGINEERING AND COMPUTER SCIENCE TO ACCELERATE BREEDING GAIN

Transportation

Energy

Resources from

Renewable

Agriculture

Increased

Phenotyping +

Data Analytics

=

Increased

Genetic Gain

Crop Genetic Gain

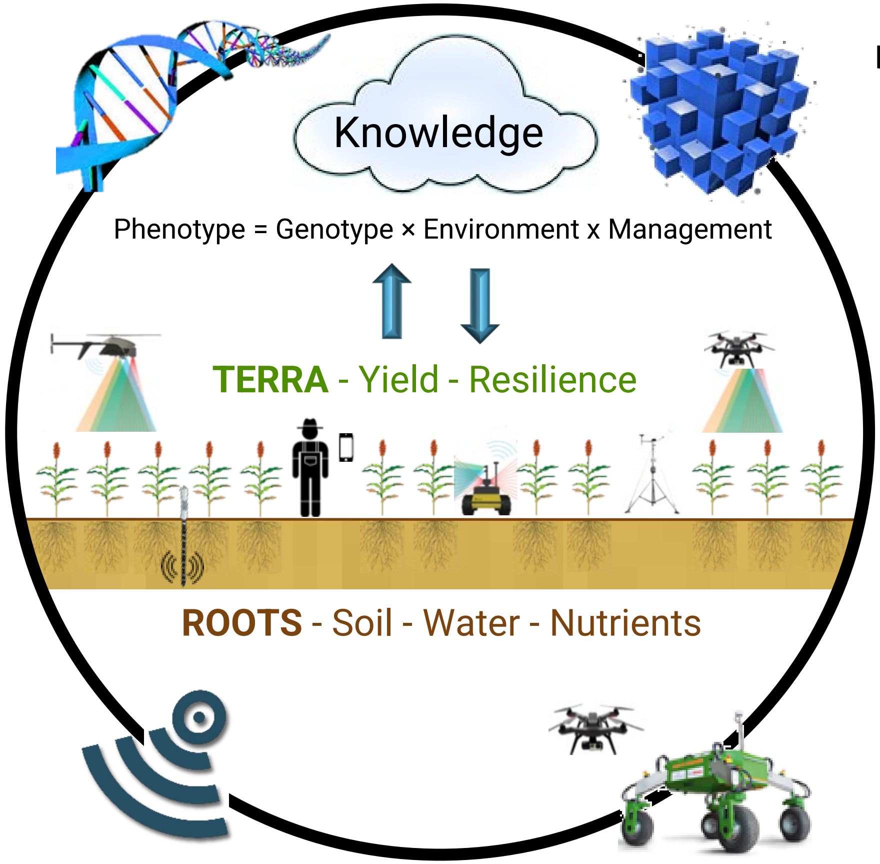
Genetics
Molecular Biology

Gene and Trait Associations

Agriculture
Physiology and Agronomy

High Resolution Phenotypes

Sensors
Abiotic and Biotic



High Throughput Field Data Acquisition

Data
Distributed and Secure

Crop Prediction Algorithms

Analytics
Computational Pipelines

AI Systems Machine Learning

Robotics
Scalable and Reliable

Rhizosphere

Observations

Optimizing

Terrestrial

Sequestration

Tools to

improve crop

nutrient

utilization and

carbon

sequestration

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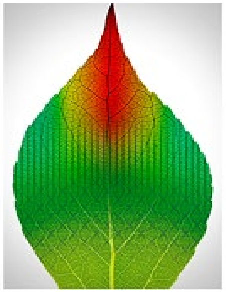
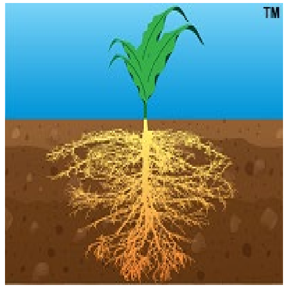
TERRA / ROOTS	**SMARTFARM**	**ECOSynBio**





Genetics x Environment x Management x Processing

Identify Improvements	**Measure Outcomes**	**Maximize Output**
Identify genetics for enhanced crop characteristics, deeper more robust roots	*Supply-chain-wide lifecycle accounting to measure the "carbon harvest"*	*Maintain and maximize carbon and resource efficiency throughout the supply chain*

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Biofuels are (ethanol is) the U.S. bioeconomy

Biofuel production in 2018 ~ 1.5 Q of energy to the transportation sector			
Gallons of Ethanol	**Energy**	**Gallons of Biodiesel**	**Energy**
15 Billion	1.17 Quads	3.9 Billion	0.29 Quads

Carbon Intensity (CI) =

$$\frac{\text{grams } CO_2 \text{ equivalent } (CO_2e)}{\text{megajoule (MJ)}} \quad \textit{OR} \quad \frac{\text{Total emissions from fuel production}}{\text{Total output of fuel}}$$

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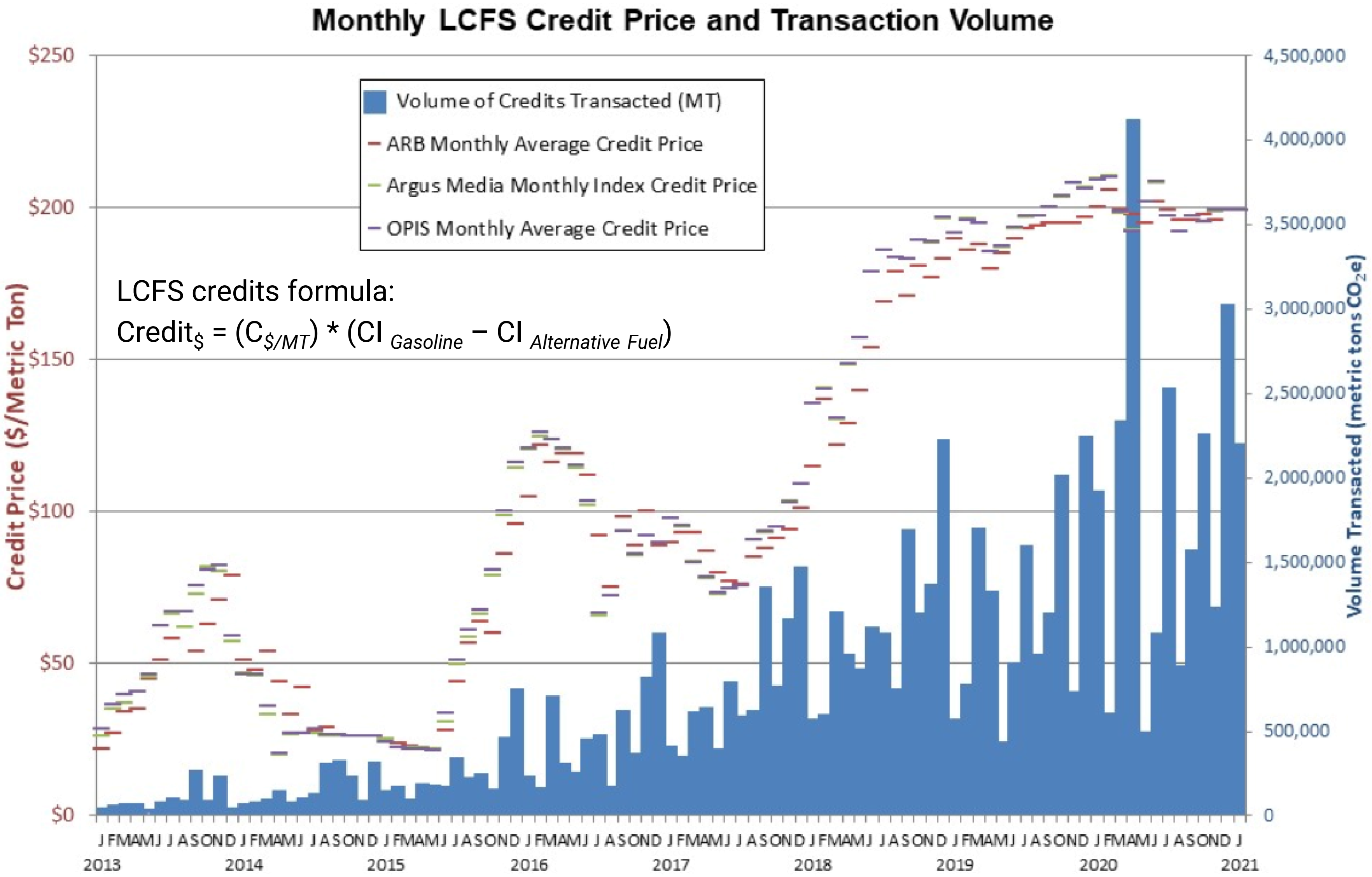
Average credit prices >$100/ton over the last 3 years



LCFS credits formula:

$Credit_{\$} = (C_{\$/MT}) * (CI_{Gasoline} - CI_{Alternative\ Fuel})$

https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

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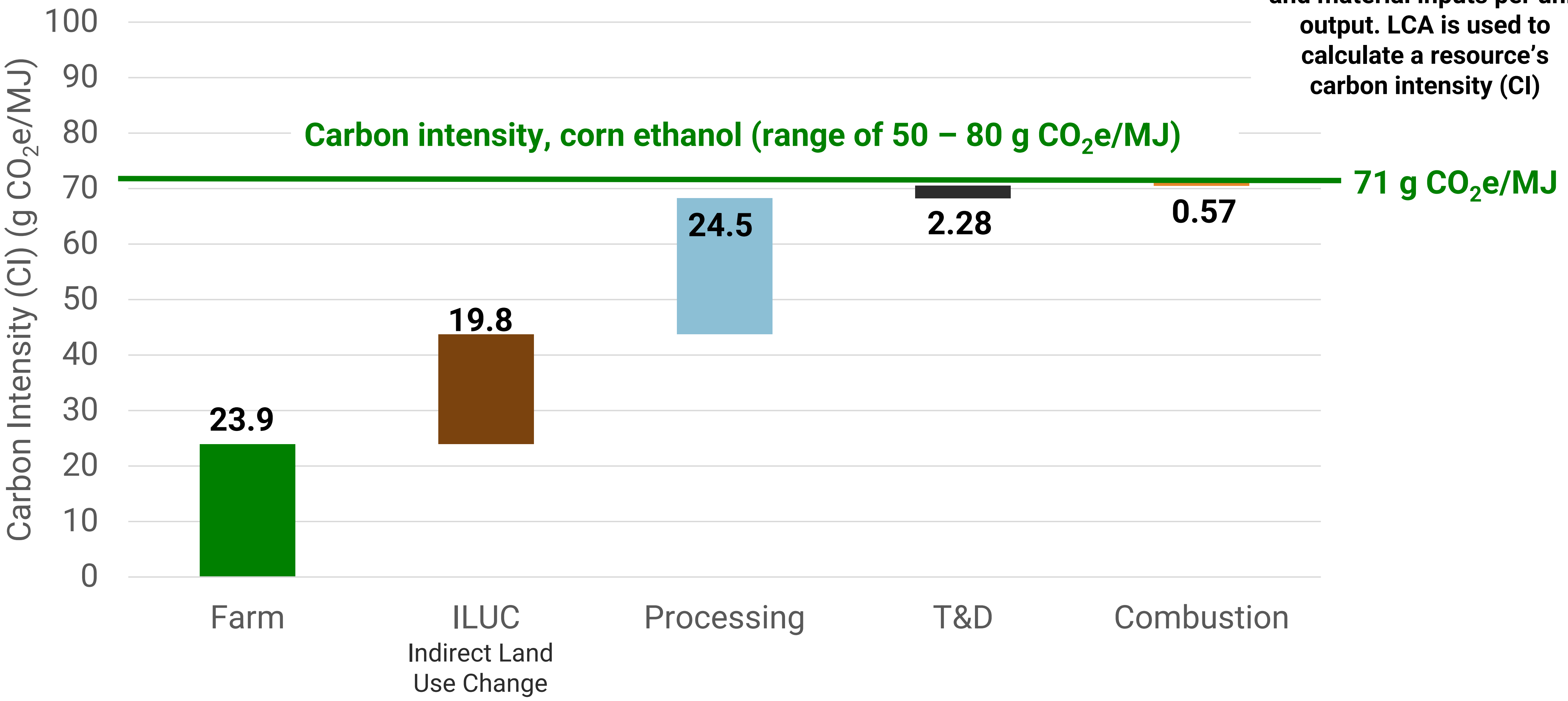
What is an LCA and what is fuel CI?

Life-Cycle Analysis (LCA)

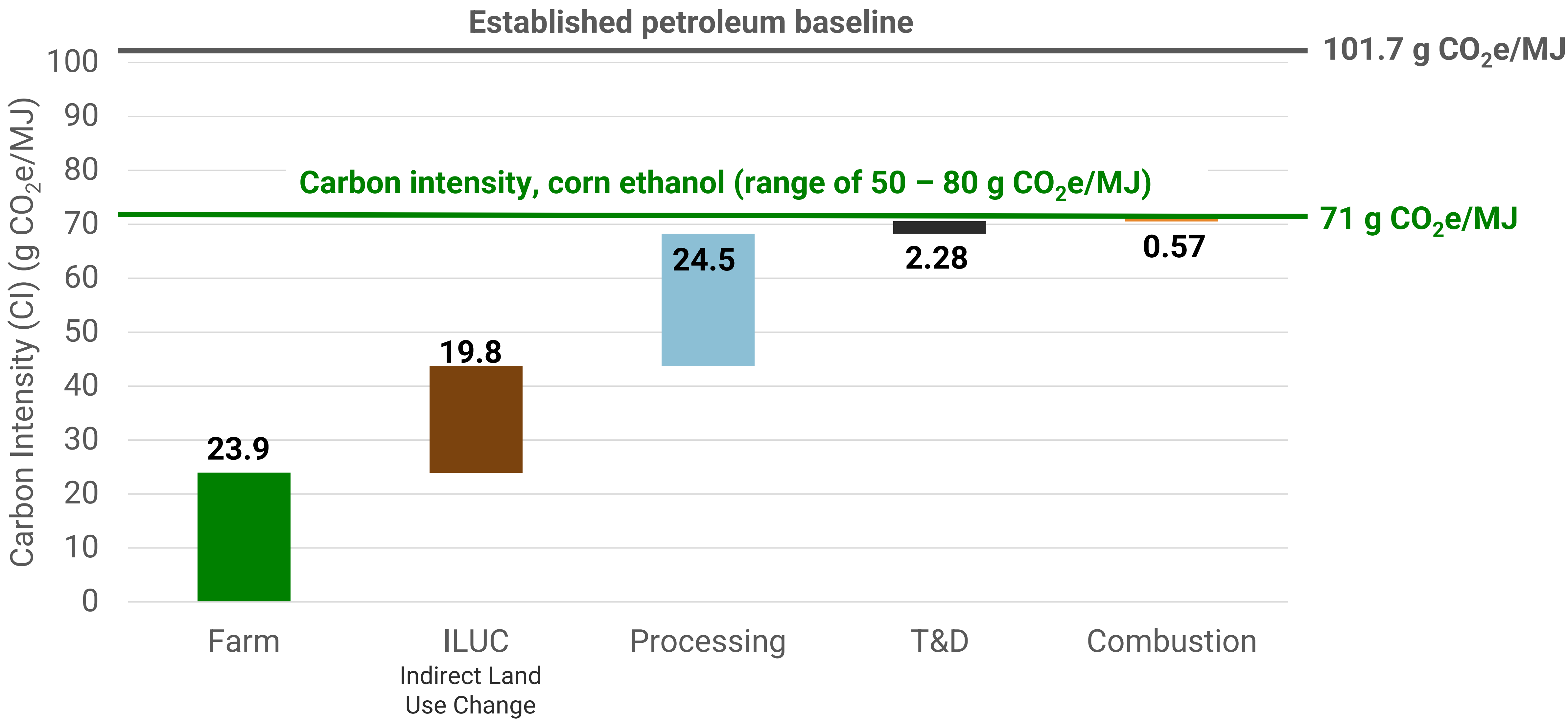
Used to estimate energy and material inputs per unit output. LCA is used to calculate a resource's carbon intensity (CI)



Data from M. Wang presentation on GREET ethanol LCA at 2018 ARPA-E Workshop

What is the significance of fuel CI in the LCFS?

LCFS: Low-Carbon Fuel Standard



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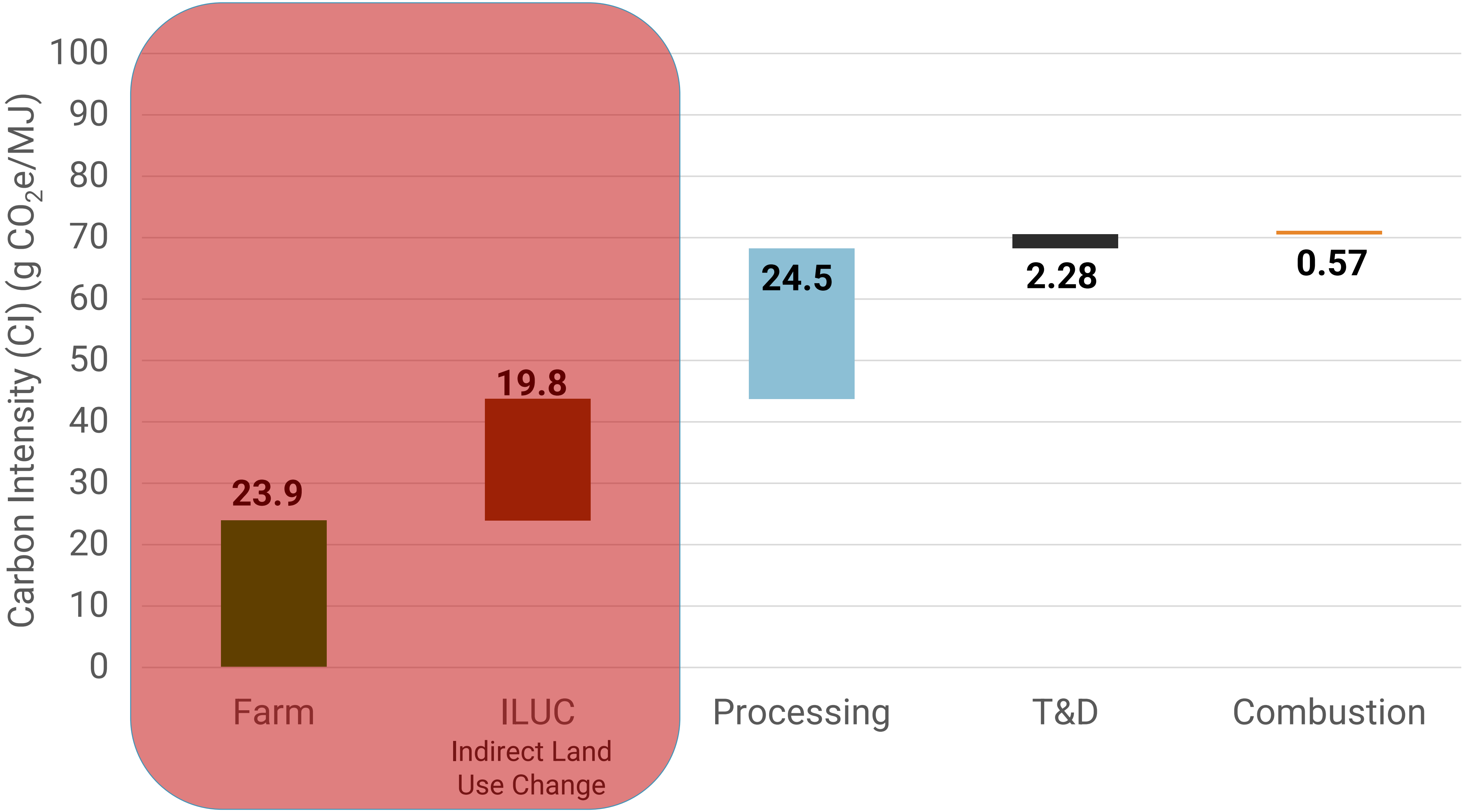
Data from M. Wang presentation on GREET ethanol LCA at 2018 ARPA-E Workshop

LCFS market signals do not reach feedstock production



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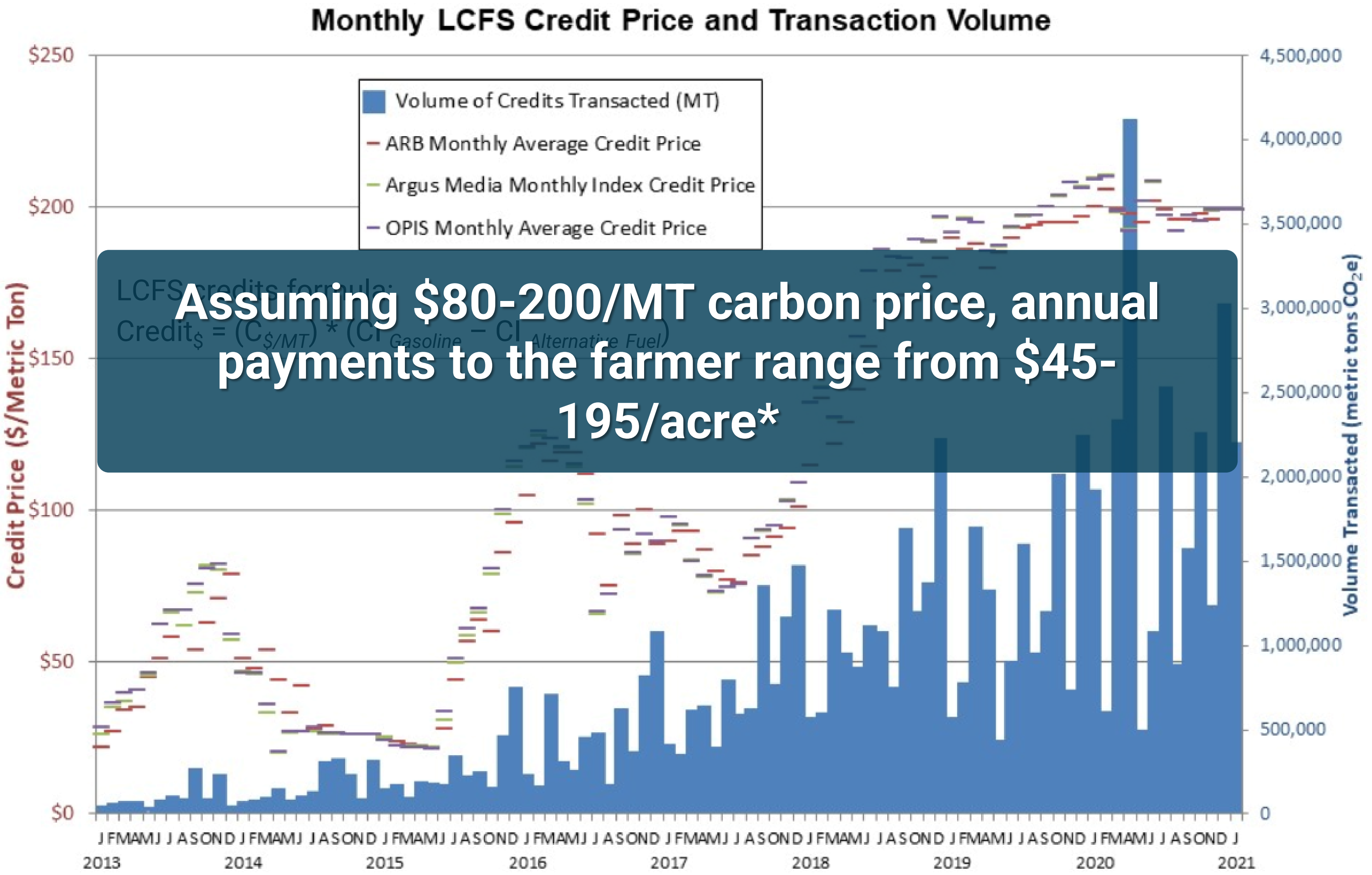
Feedstock producers are missing a large revenue stream



Assuming $80-200/MT carbon price, annual payments to the farmer range from $45-195/acre*

https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

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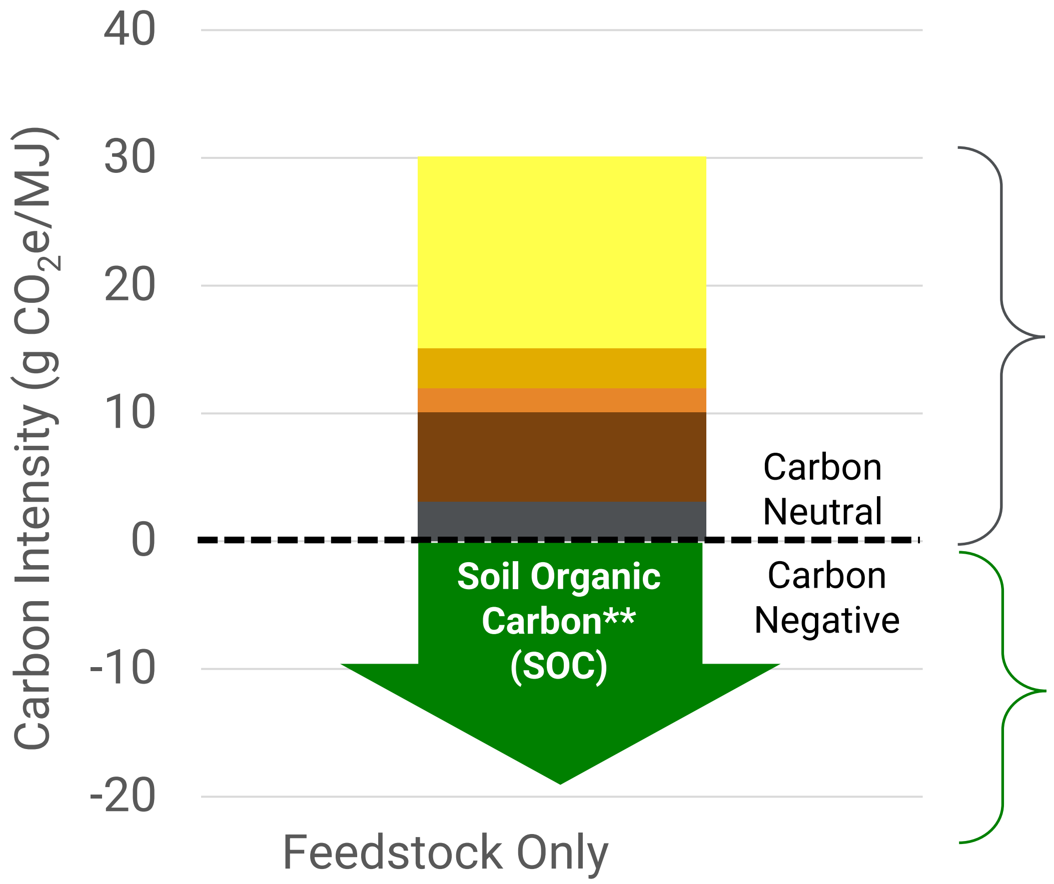
Negative emissions feedstocks are possible with financial drivers



Annual timescales, spatial/temporal variability, trace amounts

Long timescales, questions of additionality and permanence, cost/accuracy of measurement

Improving the net-carbon estimate is not going to happen without data and $$$

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SMARTFARM Vision:

Make it possible and profitable to optimize for yield ***and*** carbon intensity

Technical Goal: Reliable, accurate, and cost-effective quantification of feedstock carbon intensity at the field level.

Phase 1

- Set a baseline with SOA tools; $1,000s per acre
- Ground truth in real-world conditions
- Explore market mechanisms

Phase 2

- Reduce cost and footprint
- Increase system reliability, resilience
- Embed IoT, analytics, support tools

Focus on emissions drivers (N_2O) and net-negative strategies (soil carbon)

Phase 1 verification fields generate high-res datasets

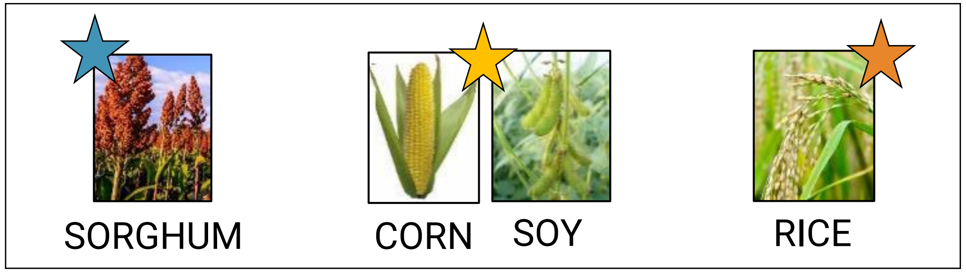
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

OKLAHOMA STATE UNIVERSITY

UNIVERSITY of NEBRASKA LINCOLN

ARVA INTELLIGENCE

BERKELEY LAB
Lawrence Berkeley National Laboratory



Plant Data

- Nutrient levels during growth
- Composition at harvest (fiber, ash, macronutrients, etc.)
- Yield

Soil Data

- Temperature, pH
- Moisture
- Soil carbon, organic material
- Bulk density

Environmental Data

- Wind
- Precipitation
- Gas fluxes (CO_2, N_2O, CH_4)
- Management practices

Remote Data (TBD)

- Civilian and commercial acquisitions, including hyperspectral, being pursued with NASA Harvest

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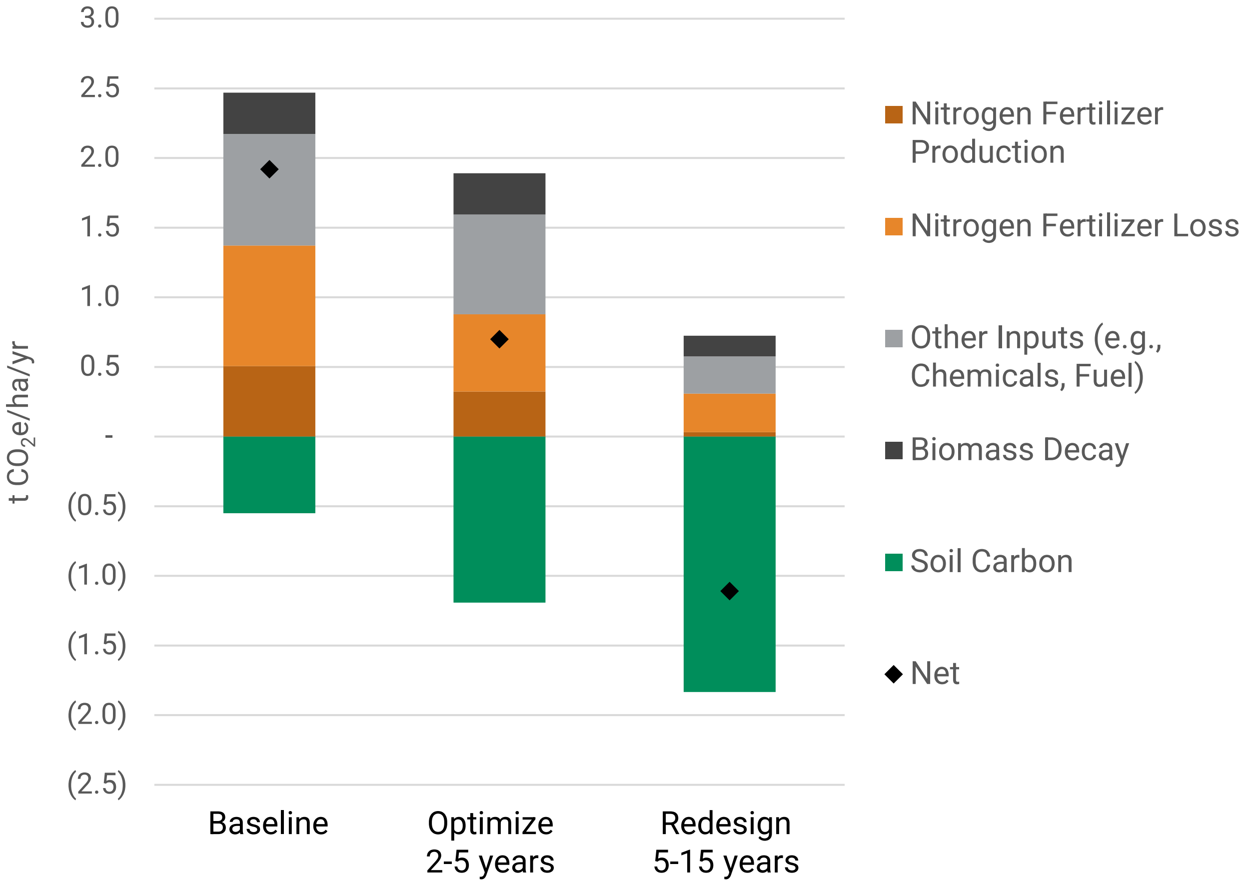
Phase 2 seeks to achieve accuracy and precision at a lower cost

N_2O	Carbon
PRINCETON UNIVERSITY — Autonomously monitor N_2O emissions using atmospheric laser imaging	
MICHIGAN AEROSPACE — Drone-mounted optical, LiDAR, and image sensing fused with AI	
	THE UNIVERSITY OF UTAH — Distributed low-cost sensors buried in soil to sense carbon and carbon flux
	Yard Stick — Handheld probe and machine learning to measure and calculate carbon
regrow — Developing a field measurement system to inform a subfield-scale process model capable of quantifying uncertainty and being optimized for profitability	
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN — A “system of systems” solution that integrates remote sensing, process-based modeling, deep learning, atmospheric inversion, field-level sensing, and high-performance computing.	

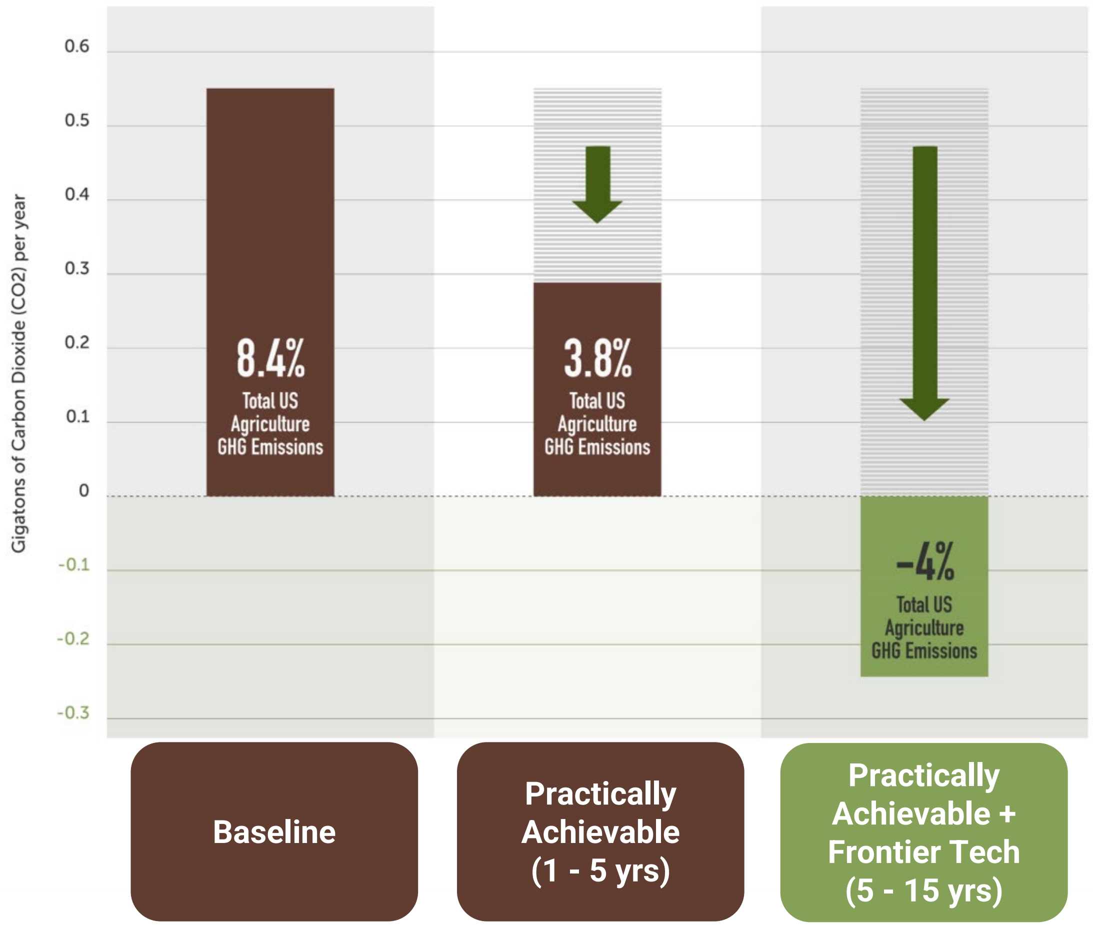
Perimeter | Drone | Model | Sensor Network

Near- and long-term strategies for carbon-negative feedstocks are in sight

Carbon Farming Pathway – U.S. Corn



Carbon Removal Potential – U.S. Agriculture



How do we get today's solutions in the hands of growers?

What needs to happen for frontier approaches to gain traction?

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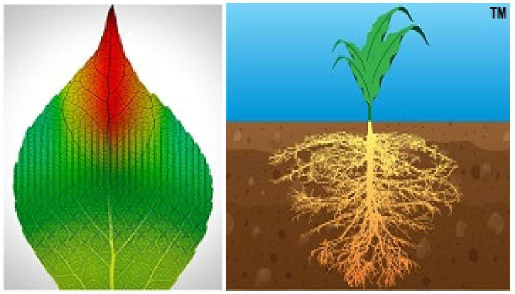
Northrup et al. 2021 | NASEM 2019 | CDR Primer 2020 | USFRA, 2019

ARPA-E programs enable innovation in terrestrial biomass

Established ARPA-E Programs

TERRA / ROOTS



SMARTFARM

SMART FARM

Identify Improvements

Identify genetics for enhanced crop characteristics, deeper more robust roots

Measure Outcomes

Supply-chain-wide lifecycle accounting to measure the "carbon harvest"

"Carbon Farming"

Implement Systems

Develop new crops, soil amendments, management strategies, and market enablers for carbon-negative land management systems

Carbon farming approaches span current and projected supply chains

Integrated systems solutions are needed to ensure beneficial outcomes

Genetics x Environment x Management

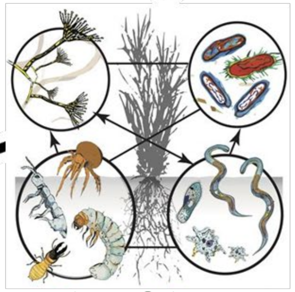
Parallel

Exclusive

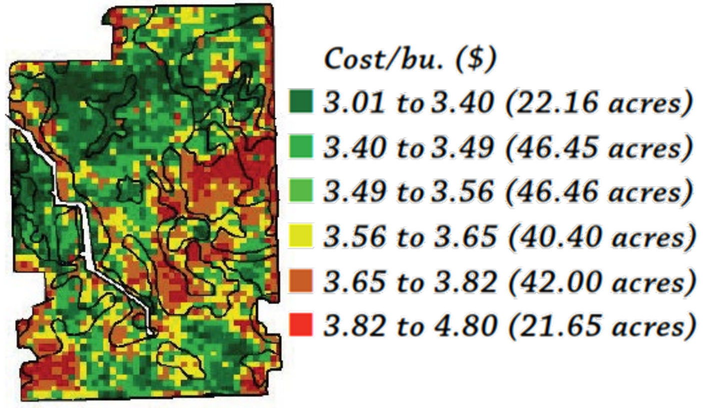
Plant engineering for biomass carbon optimization

Soil amendments

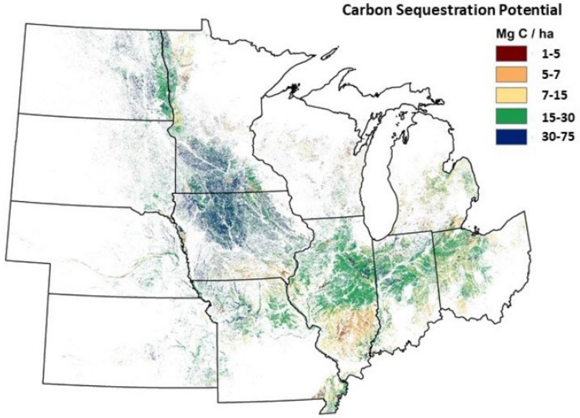
Rewiring the cover crop



Microbiome engineering



Management tools for system integration and decision support



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Thank you!

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