Advanced Research at the Nexus of Energy, Water, and Food

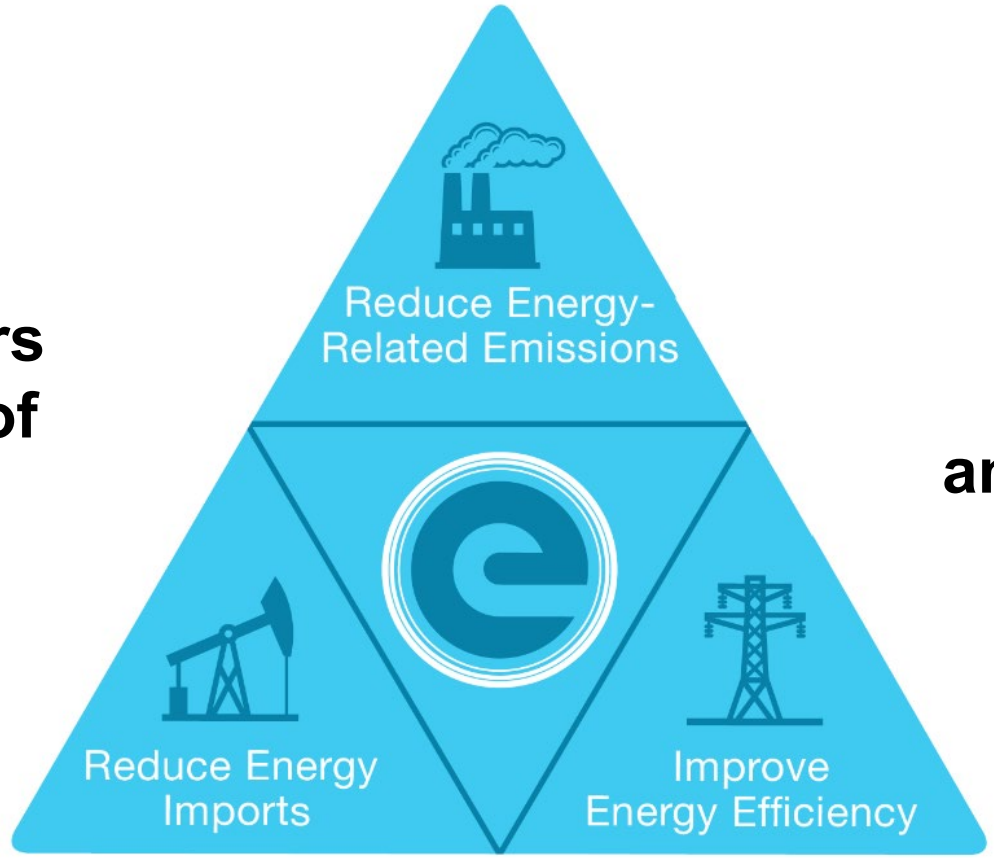
David M. Babson, Ph.D. | Twitter: @realDavidBabson
Program Director
Advanced Research Projects Agency – Energy

Princeton Andlinger Center Annual Meeting
Princeton University | Princeton, NJ
November 8, 2019

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

Mission

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

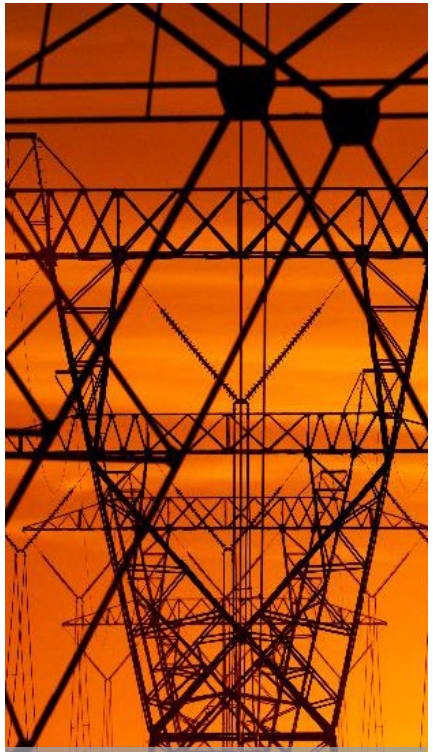


… that ensure U.S. national security, technology leadership, and economic prosperity

arpa·e
CHANGING WHAT'S POSSIBLE

Moonshot Targets

What problems are we trying to solve?



Resilient energy infrastructure

Affordable, sustainable energy

Climate change

U.S. economic development

Leadership in science and technology

ARPA-E Program Portfolio

ARPA-E Impact Indicators

Since 2009 ARPA-E has provided **$2 billion** in R&D funding to more than **800 projects**

145 Projects have attracted more than **$2.9 billion** in private-sector follow-on funding

76 projects have formed **new companies**

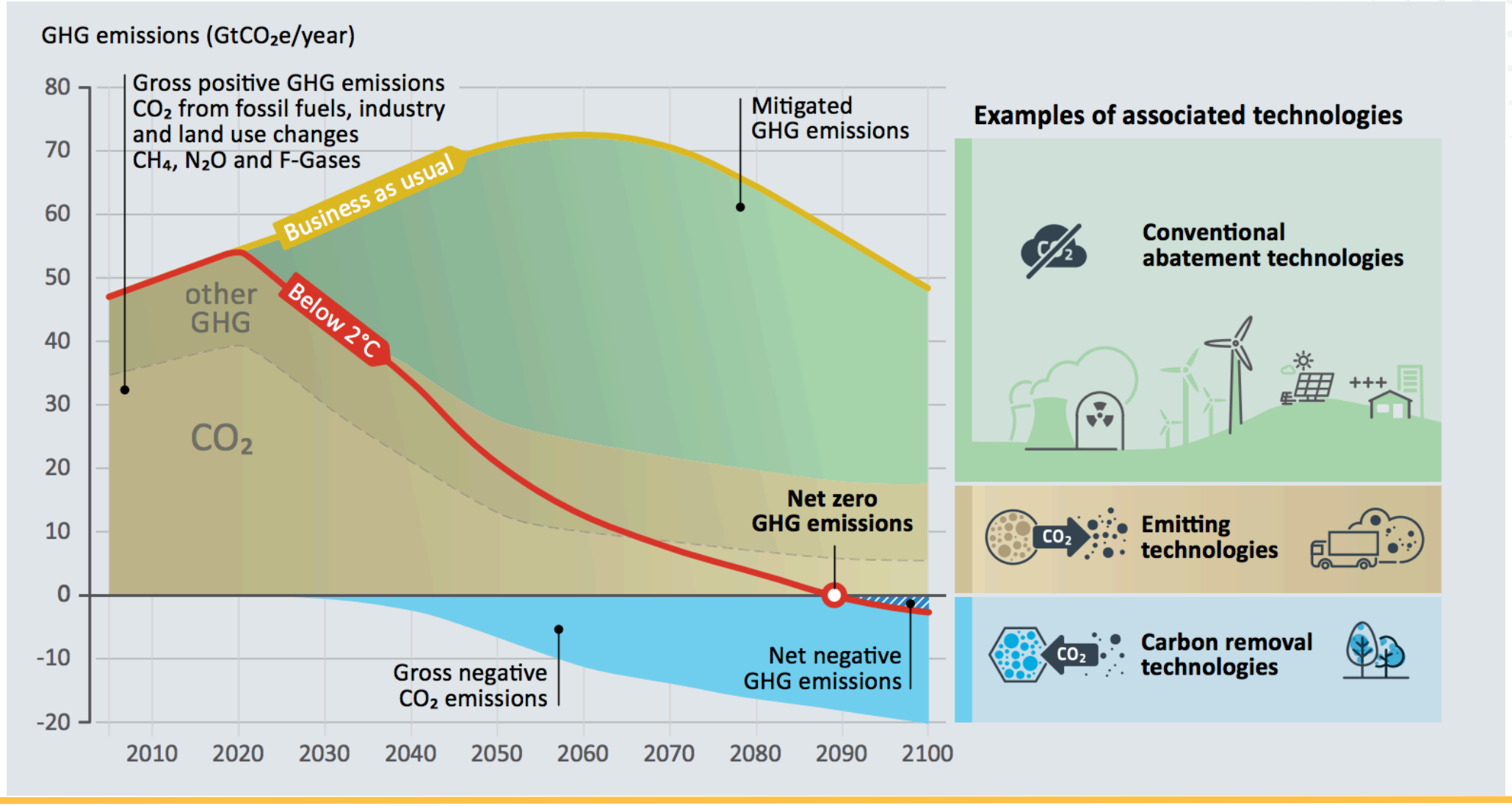
131 projects have **partnered with other government agencies** for further development

2,489 peer-reviewed **journal articles** from ARPA-E projects

346 patents issued by U.S. Patent and Trademark Office

The context for considering the nexus of advanced energy, water, and food systems

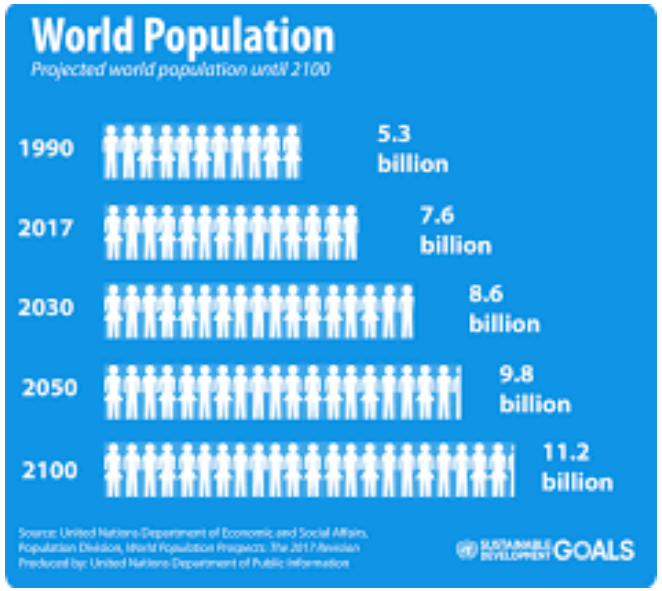
All paths to 2^0 C go through zero



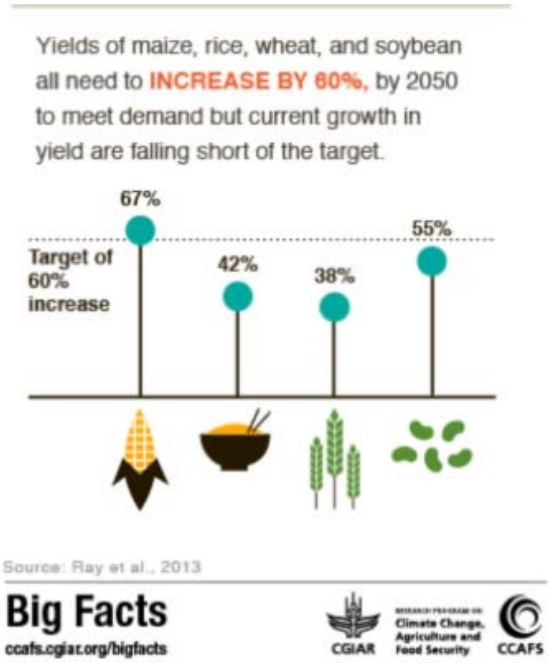
National Academy of Sciences. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* 2019. p. 3

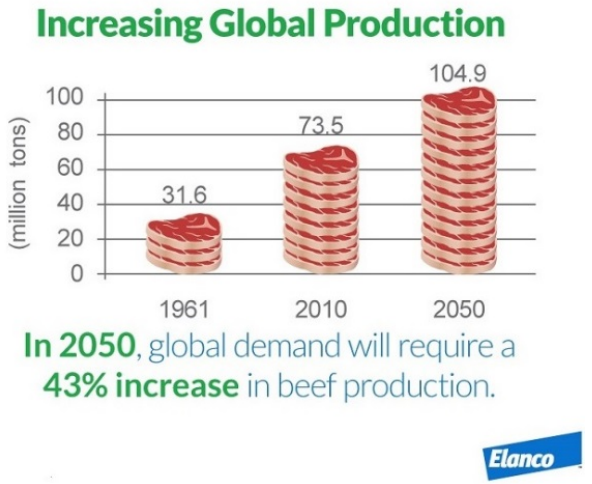
Beyond climate and carbon - FOOD

Population



Affluence

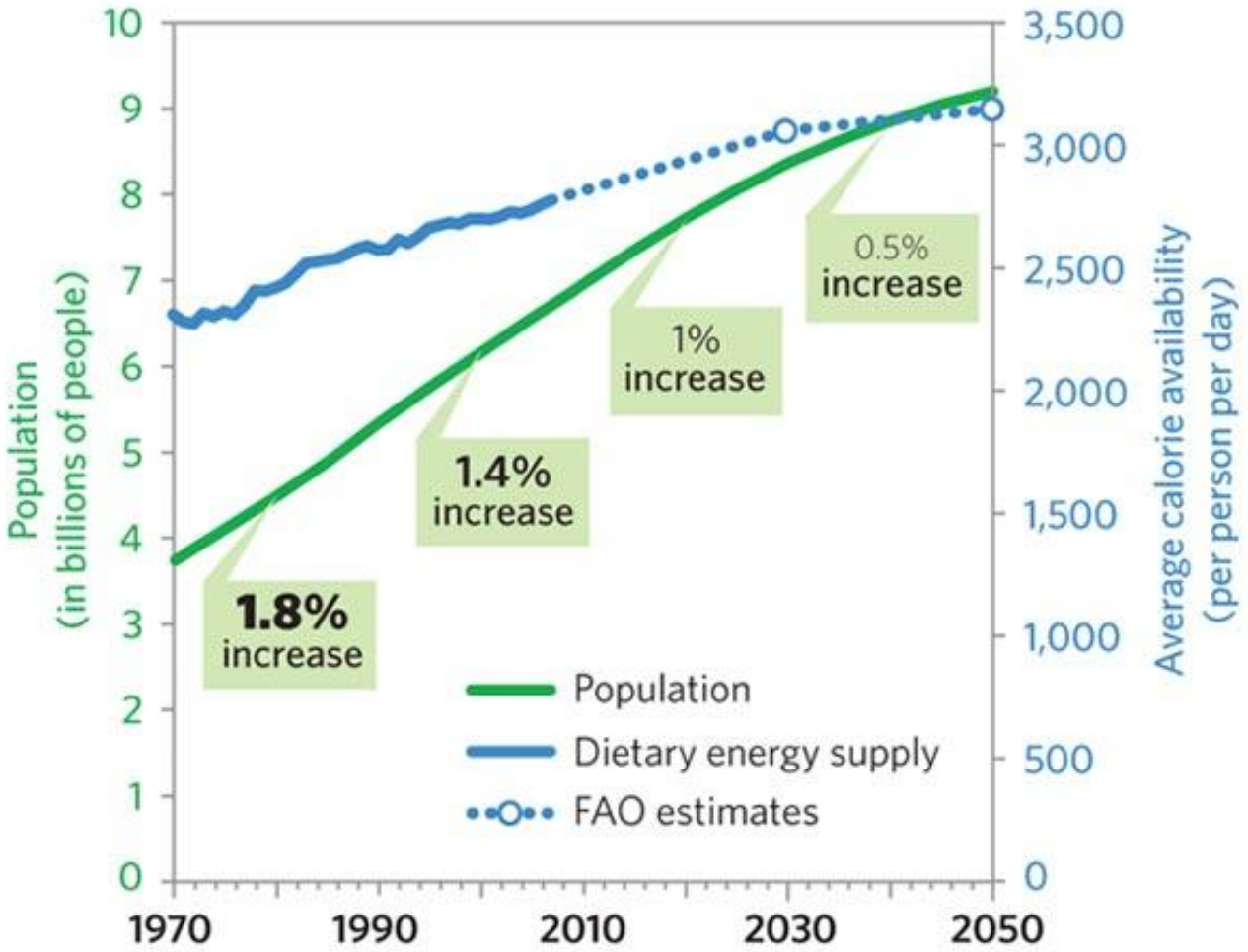




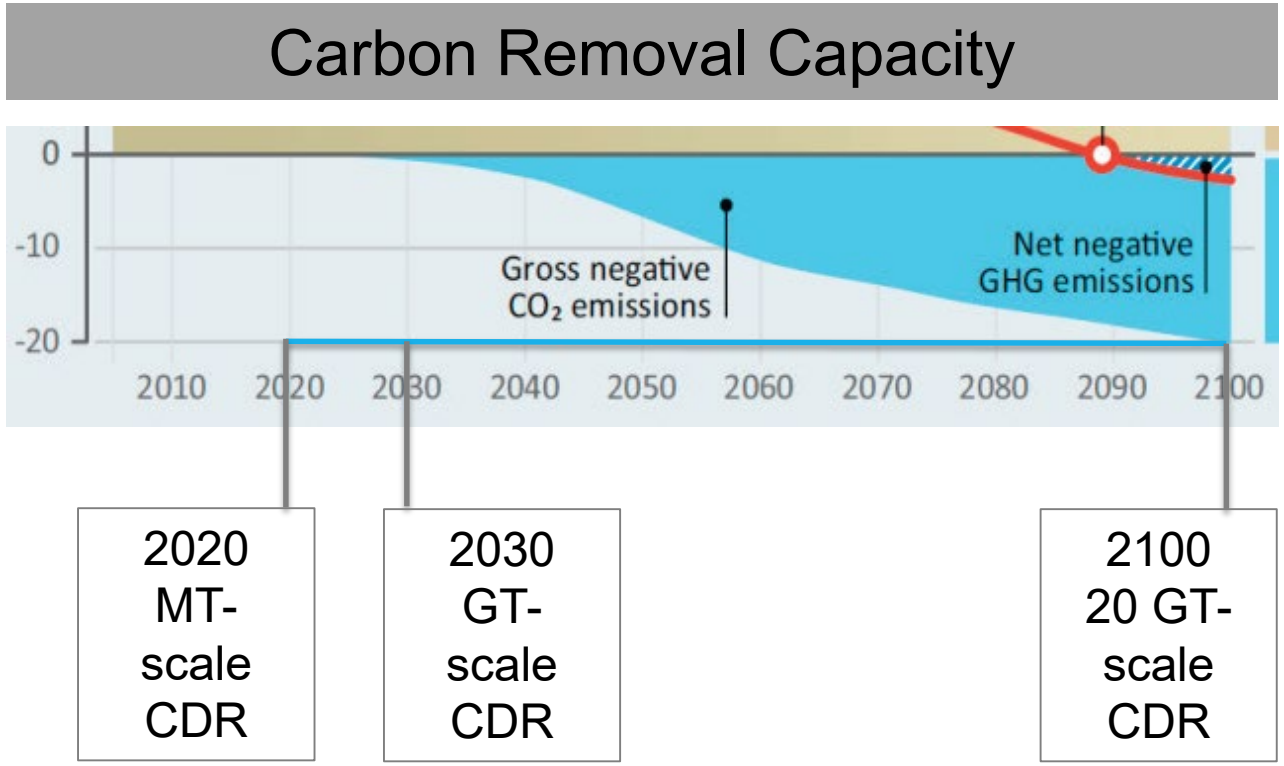
Land

An estimated 10^9 ha of new land will be required to feed global population in 2050

Anticipated food productivity gap

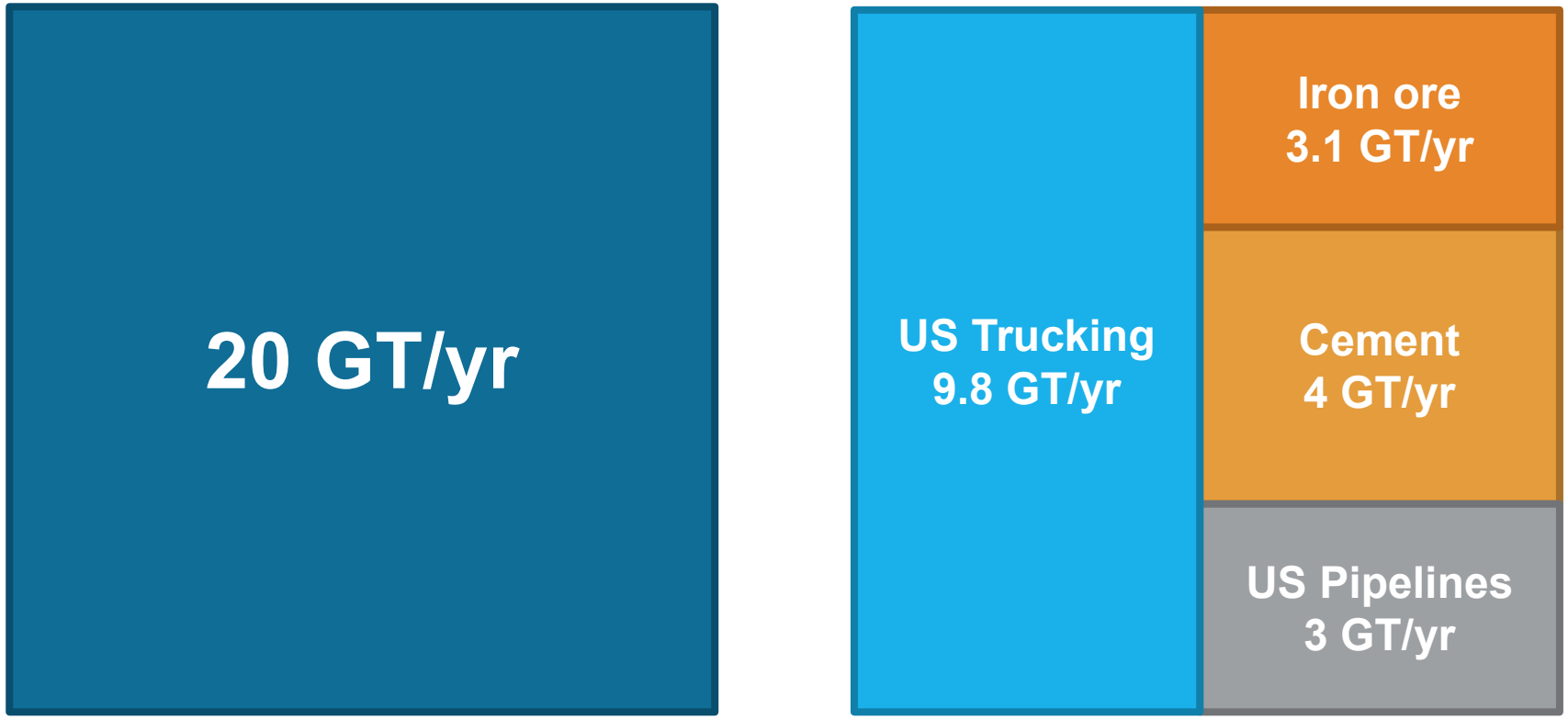


Rapid growth of a massive carbon removal industry



CDR = carbon dioxide removal

Just how much is 20 gigatons?



× ***55,000***
(every year)

US Bureau of Transportation Statistics, USGS National Minerals Information Center

Environmental Drivers for Innovation

Carbon / GHG Emissions	Land	Water
		

Our global economy needs to be structured in a way that incentivizes not only land and carbon ‘neutrality’, but promotes becoming both carbon and land negative. In this environment the bioeconomy wins.

Simultaneously innovate in a number of areas

GHG emissions and land sparing strategies must be widely and simultaneously deployed

Vertical Agriculture & Engineered Ecosystems

Landscape Design & Agroecology

Living fertilizers for agriculture systems

Carbon Utilization and Removal

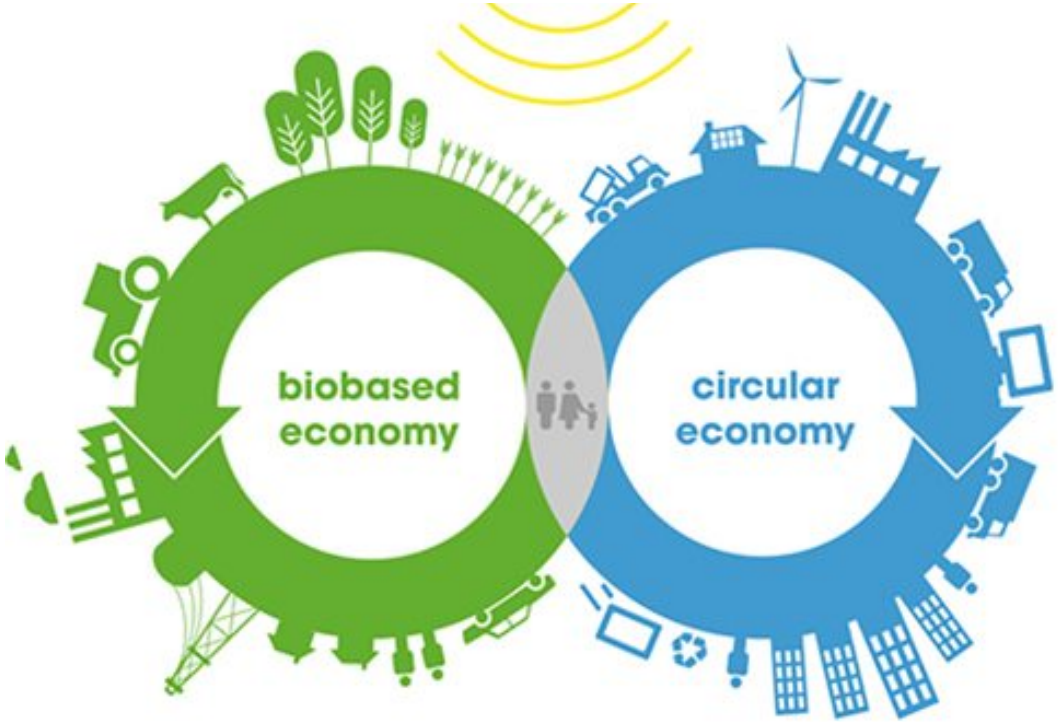
Precision Agriculture

Food – What and How

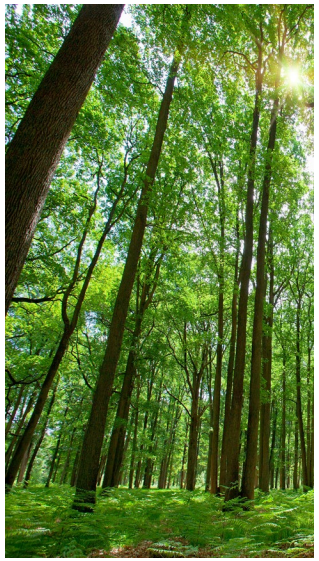
Do more and make more with less land; Remove carbon

The new carbon economy refers to a prosperous, growing economy that captures and stores more carbon than it emits

Managing carbon in the economy
Circular new carbon strategies



Managing to get carbon out of the economy
Negative Emission Technologies (NETs)



Biological NETs

Engineered NETs

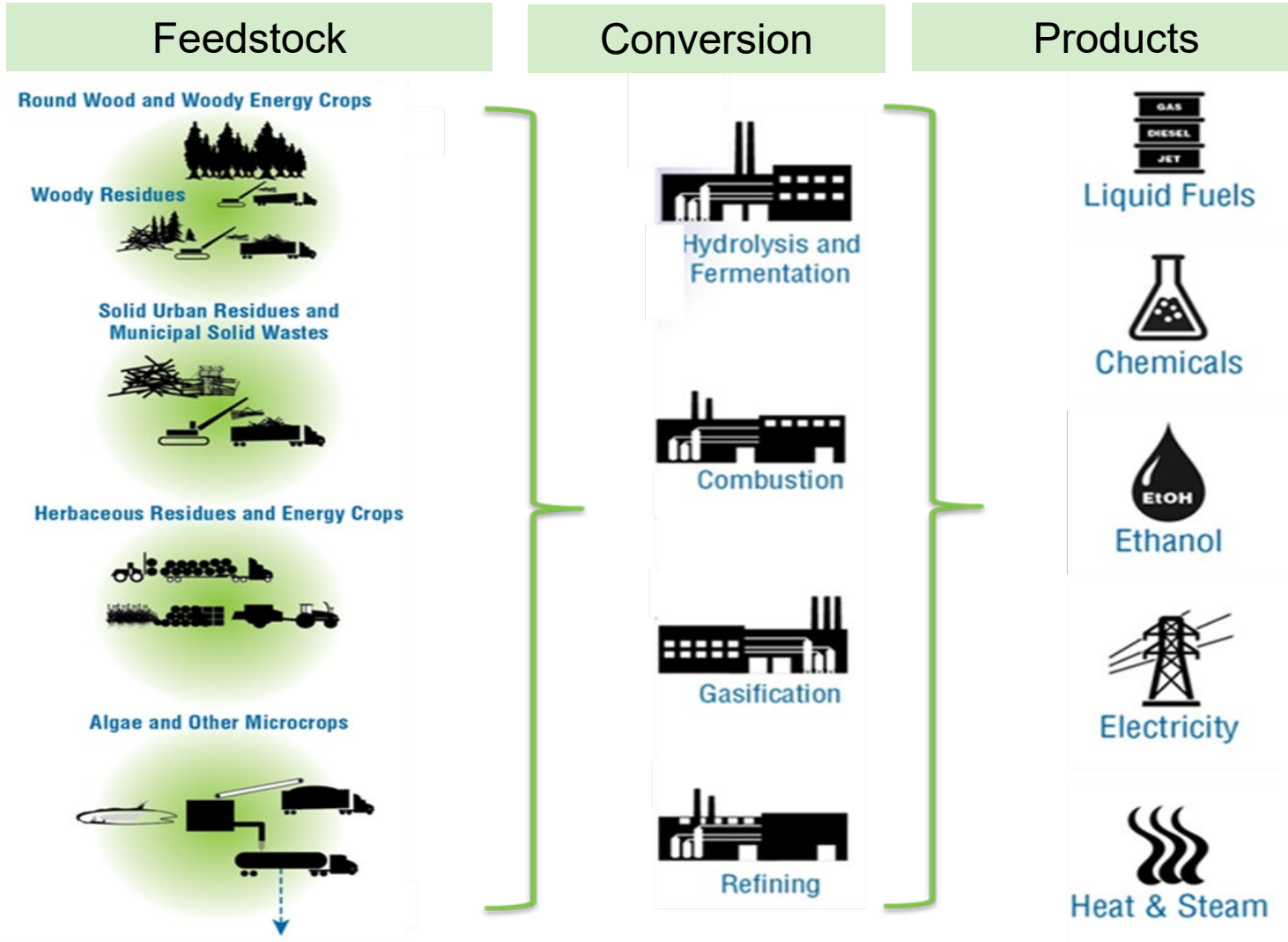
Hybrid NETs

A carbon-conscious economy is not a *low-carbon economy* as much as it will be a *renewable "new" carbon economy*

The low carbon economy incentivizes carbon reduction

The new carbon economy will incentivizes carbon optimization

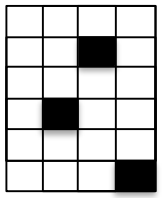
The bioeconomy concept

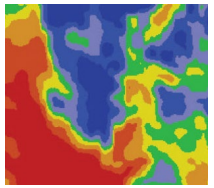


- **Revenue and economic growth**
- **Broad spectrum of new jobs**
- **Rural development**
- **Advanced technologies and manufacturing**
- **Reduced emissions and Environmental Sustainability**
- **Export potential of technology and products**
- **Positive societal changes**
- **Investments and new infrastructure**

New technologies throughout the entire biomass supply chain

TERRA
Crops × Bots × Bytes
ROOTS





Crop Breeding
G x E

TERRA & ROOTS programs leverage data to identify the best genetics for biofuel productivity

Feedstock Production
G x E x M

Data capture in commercial production settings is too costly; value proposition is unclear.

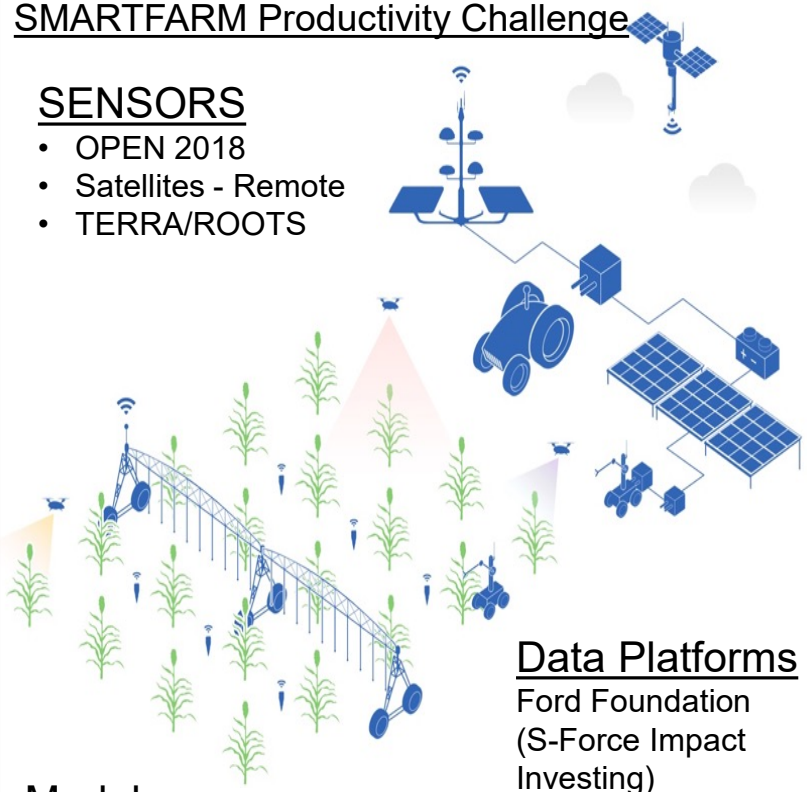
Downstream Processing
G x E x M x P

Limited upstream visibility presents a barrier to paying a premium for sustainable feedstocks.

Potential New ARPAe programs under development

Digital Agriculture, Carbon Management, and Carbon Removal

SMARTFARM Productivity Challenge



SENSORS
- OPEN 2018
- Satellites - Remote
- TERRA/ROOTS

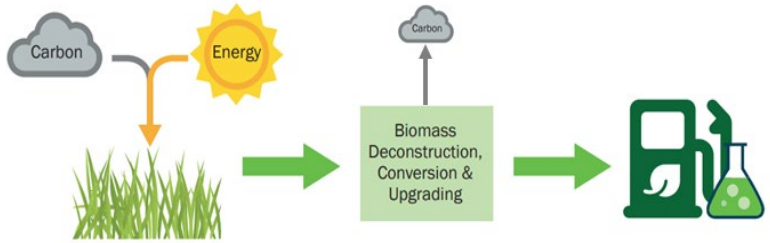
Data Platforms
Ford Foundation (S-Force Impact Investing)

Models
- GREET® (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model)
- DNDC (DeNitrification-DeComposition Agroecosystem Model)

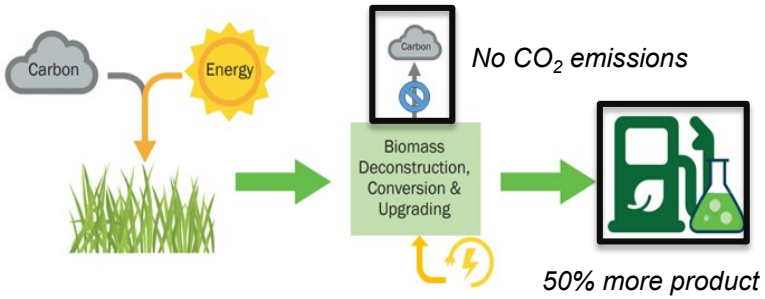
ENERGY CARBON OPTIMIZED SYNTHESIS FOR THE BIOECONOMY (*ECOSynBio*)

Leveraging low-carbon power for carbon-optimized biorefining

Traditional fermentation

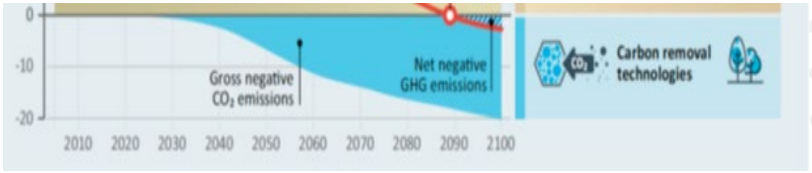


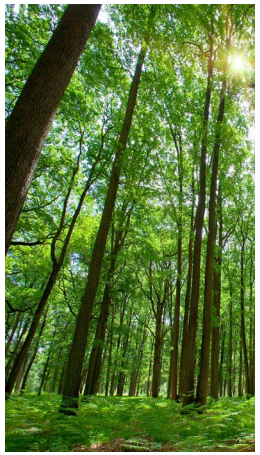
ECO-fermentation



Enabling 100% carbon efficient conversion

NEGATIVE EMISSIONS ADVANCED TECHNOLOGIES (*NEAT*)





Biological Solutions

Engineered Solutions

Hybrid Solutions

Developing technologies to enable inexpensive and energy efficient carbon removal

arpa·e
CHANGING WHAT'S POSSIBLE

ARPAe before me: TERRA - ROOTS Program Vision

The Convergence of Biology, Engineering and Computer Science to Accelerate Breeding Gain

***T**ransportation*
***E**nergy*
***R**esources from*
***R**enewable*
***A**griculture*

Increased Phenotyping + Data Analytics = Increased Genetic Gain

Genetics
Molecular Biology

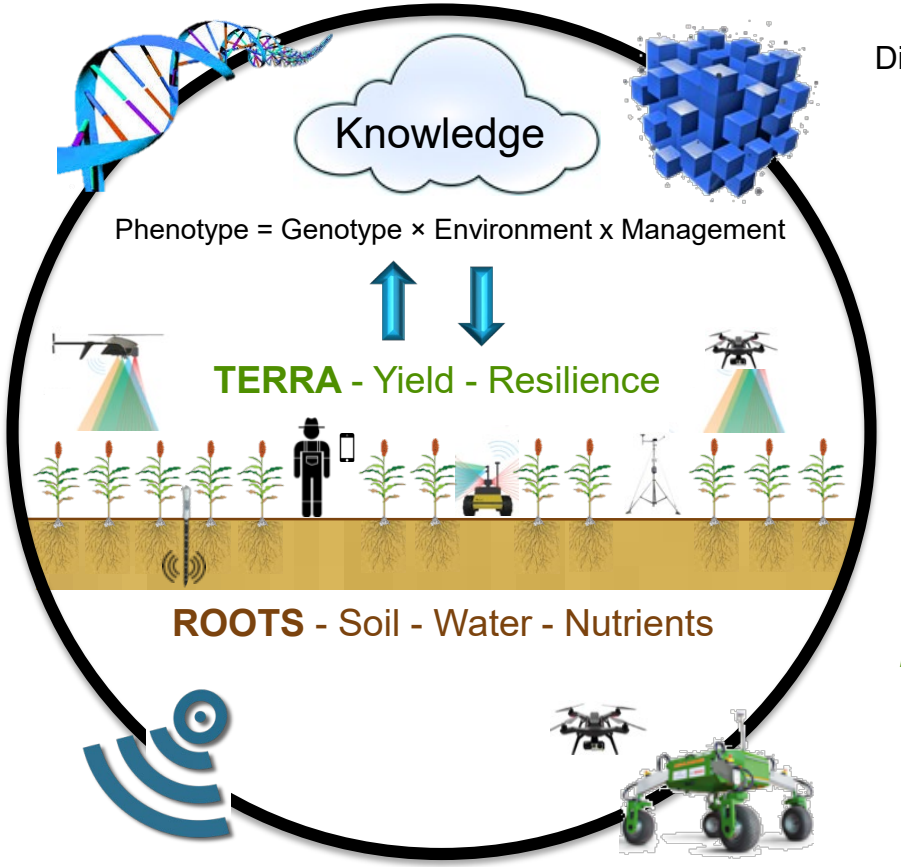
Gene and Trait Associations

Agriculture
Physiology and Agronomy

High Resolution Phenotypes

Sensors
Abiotic and Biotic

Crop Genetic Gain



High Throughput Field Data Acquisition

Data
Distributed and Secure

Crop Prediction Algorithms

Analytics
Computational Pipelines

AI Systems Machine Learning

Robotics
Scalable and Reliable

***R**hizosphere*
***O**bservations*
***O**ptimizing*
***T**errestrial*
***S**equestration*

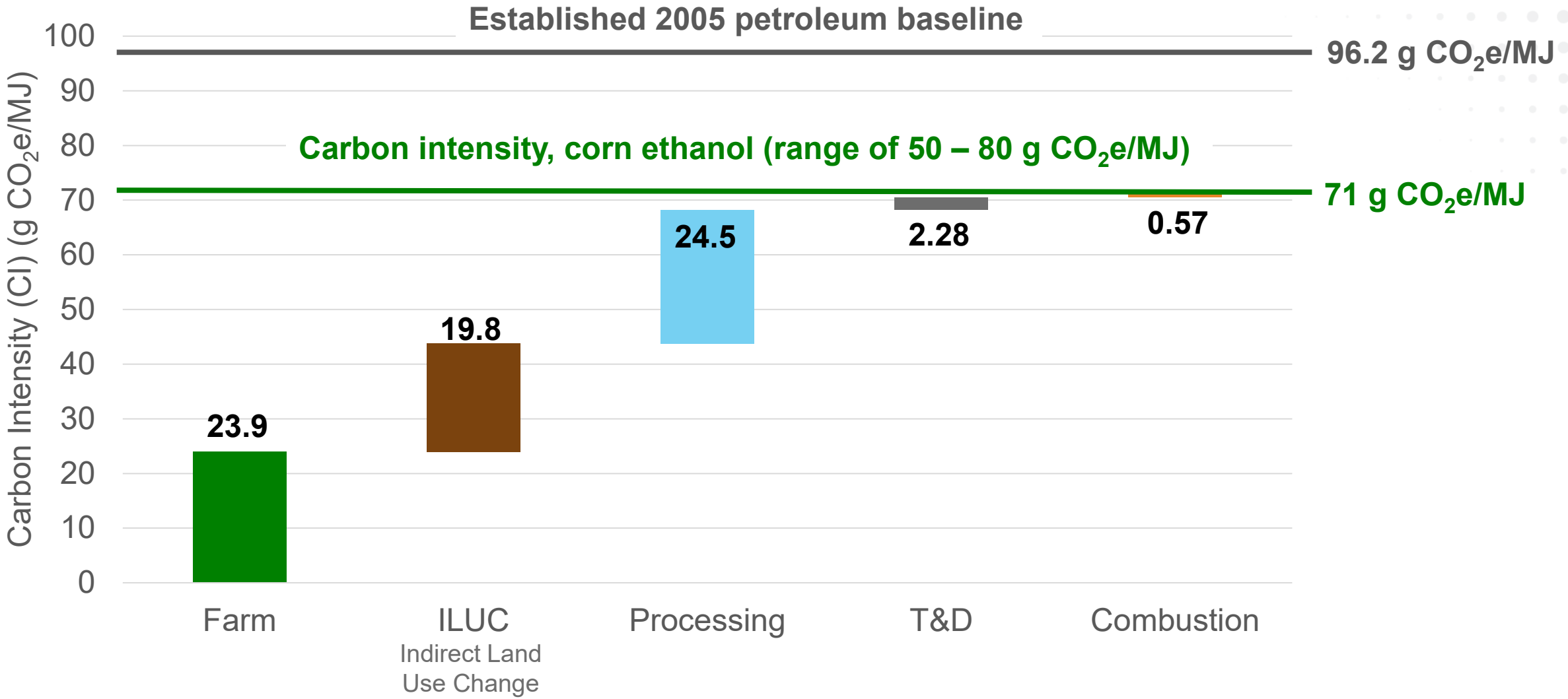
Tools to improve crop nutrient utilization and carbon sequestration

arpa·e
CHANGING WHAT'S POSSIBLE

SMARTFARM:
Systems for Monitoring and Analytics for Renewable Transportation Fuel from Agricultural Resources and Management

What is the significance of fuel CI in the LCFS?

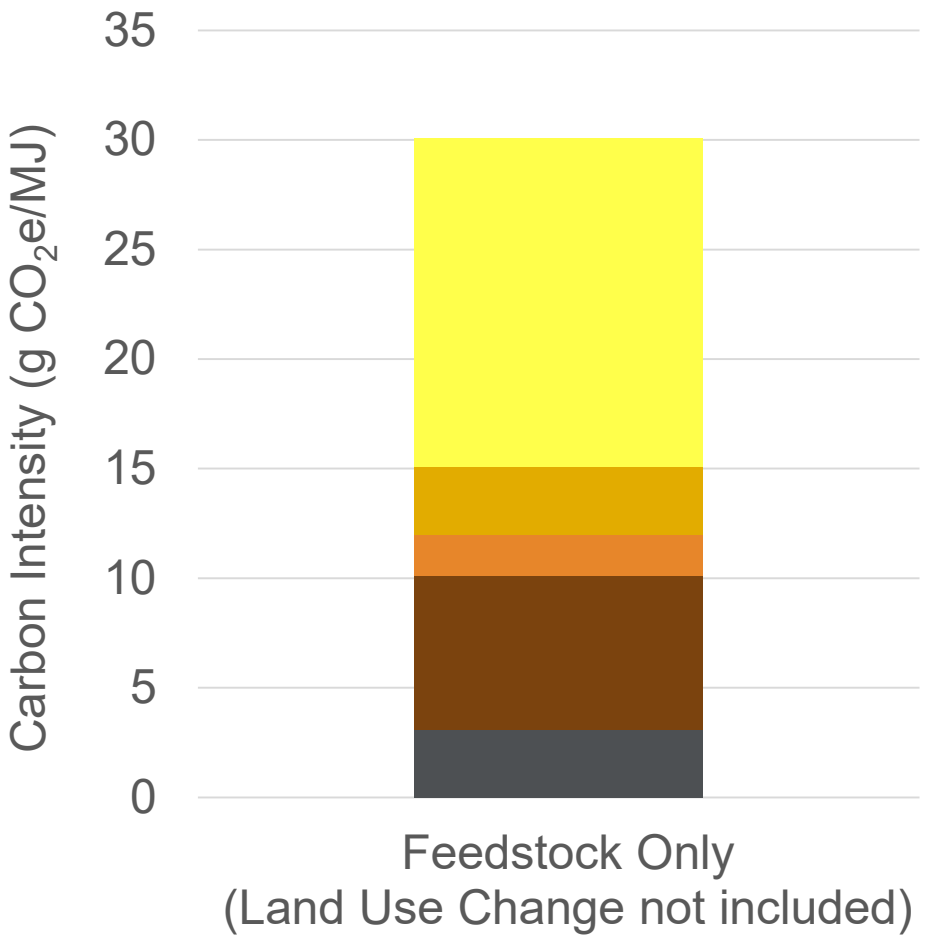
LCFS: Low-Carbon Fuel Standard



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

What goes into a feedstock carbon intensity (CI) score?

Lacking methods of quantifying field-level CI, feedstock producers are given the national average



- N2O - Land Mgmt
- CO2 - Land Mgmt

(emissions resulting from management, including input type and application, tillage, residue cover)

- Chemicals (pesticides, herbicides)
- N Applied (nitrogen production)
- Energy Use (fuel inputs)

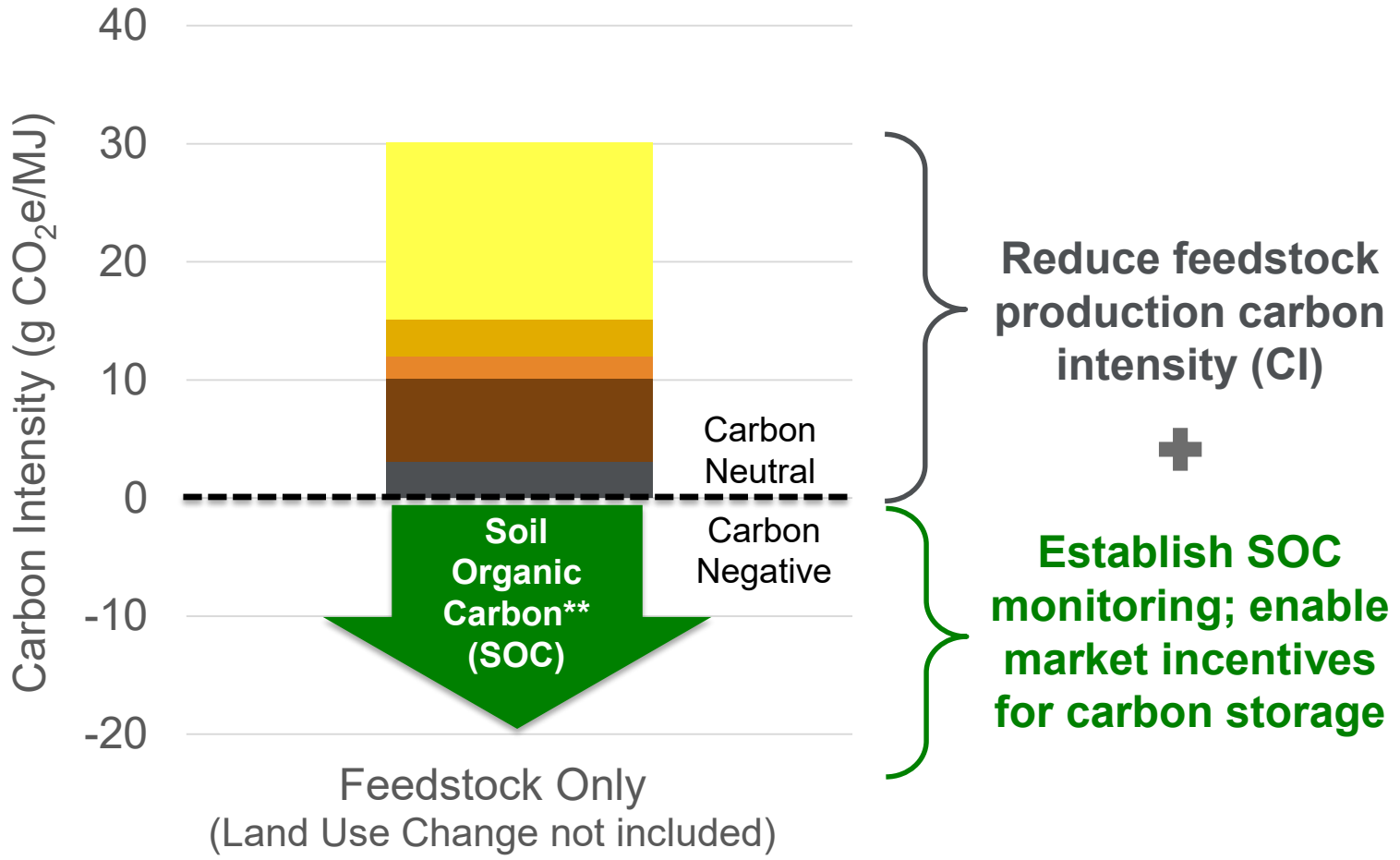
Measure CI to

$\frac{g\ CO_2e}{MJ}$

- Adopt best practices (e.g. no-till, cover crops)
- Improve productivity (i.e. yield per unit input)

Updated feedstock CI from Argonne Final Report to ARPA-E (2019):
Developing a Framework for Lifecycle Analysis of Biofuels on the Farm Level

How do we get to carbon negative?



***SOC not currently counted in CI*

Updated feedstock CI from Argonne Final Report to ARPA-E (2019):
Developing a Framework for Lifecycle Analysis of Biofuels on the Farm Level

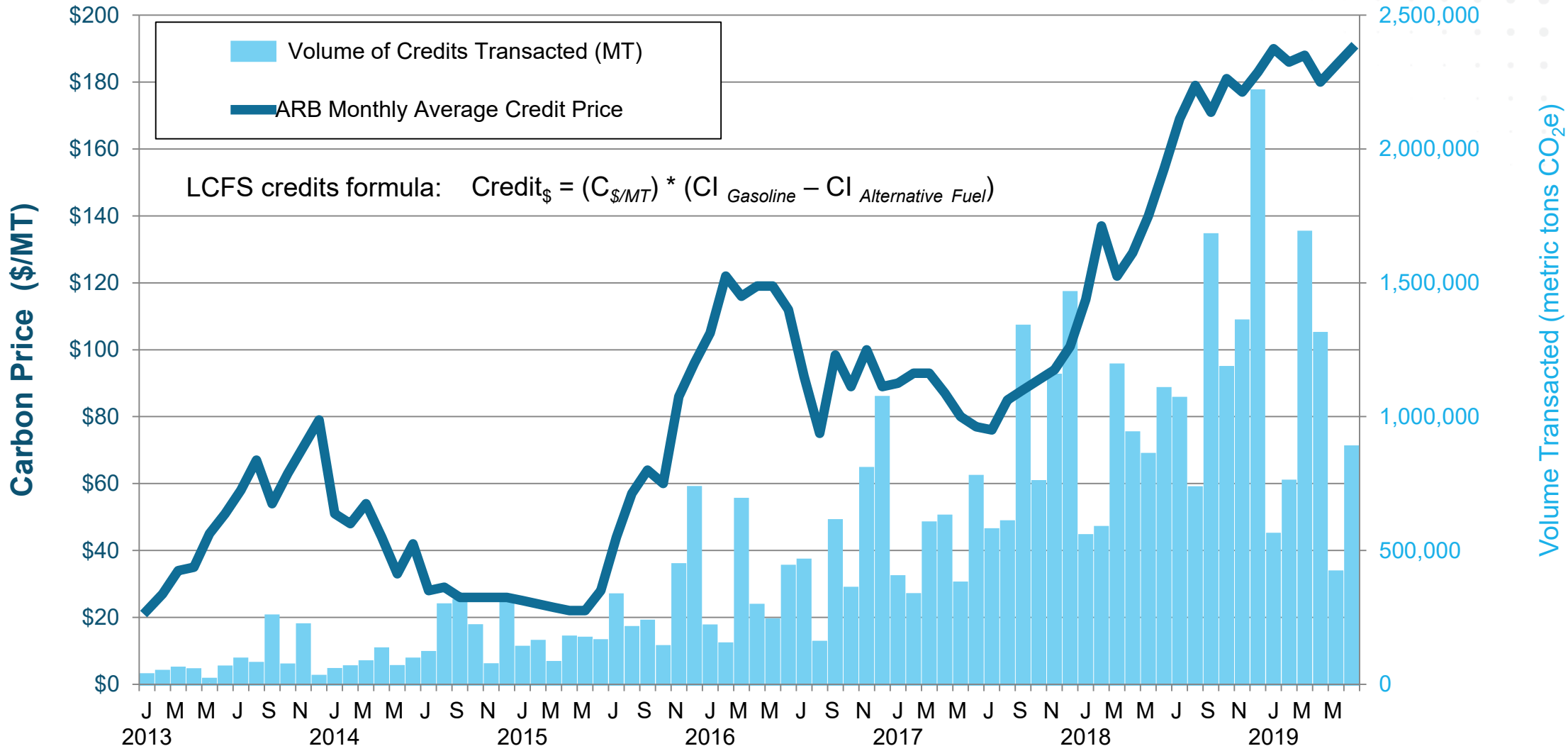
Biofuels are, by far, the largest product from the bioeconomy

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

Estimated Sustainable Biofuel Production in the U.S.	
Gallons of Biofuel	**Energy**
50 Billion	3.85 Quads

The value of biofuels is tied to its carbon intensity (CI)

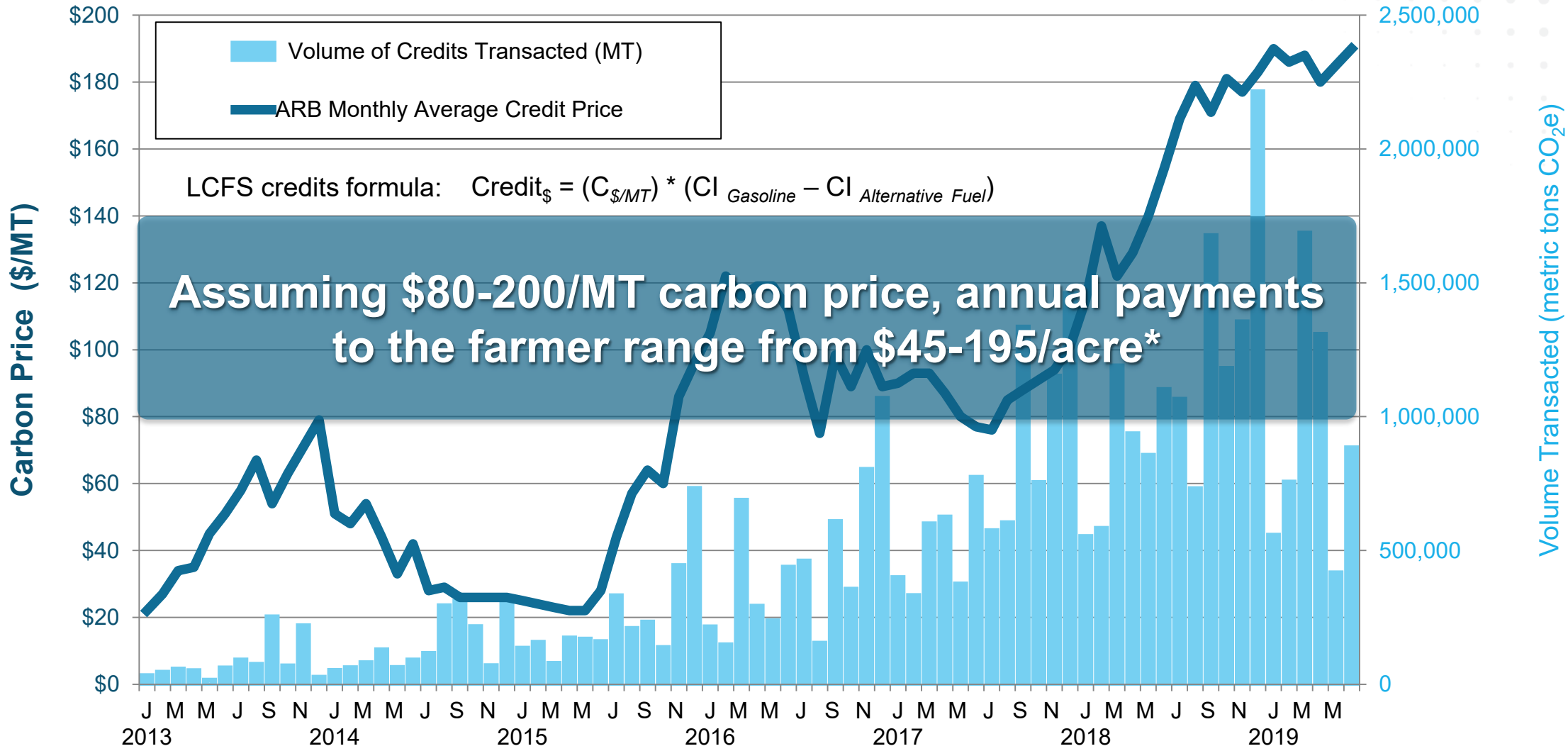
Average credit prices >$50/ton over the last 3 years



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

arpa·e
CHANGING WHAT'S POSSIBLE

Feedstock producers are missing a large revenue stream

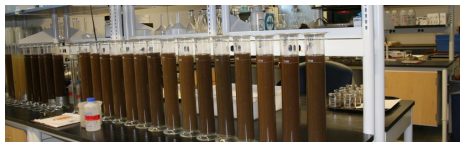


https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

*Estimate assumes 30-60% reduction in feedstock CI, and that additional CI payment (i.e. $/MT tied to feedstock CI) goes to farmer.

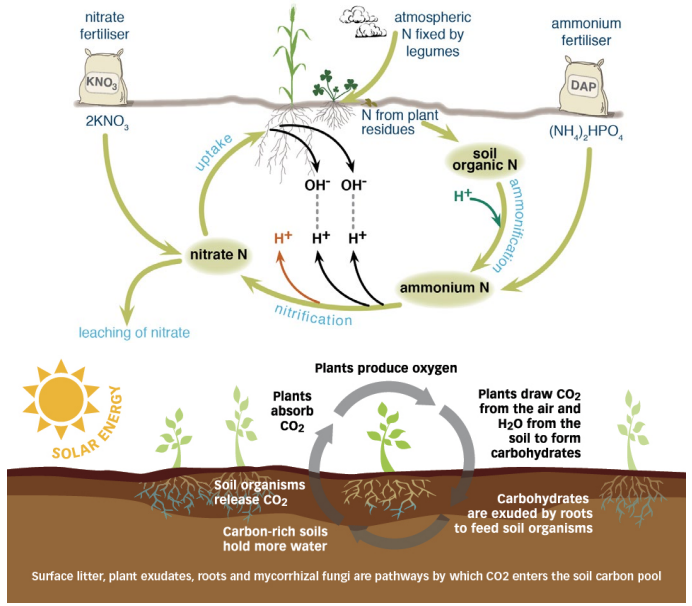
A three-stage approach to establish upstream carbon optimization incentives

1. Set a Baseline



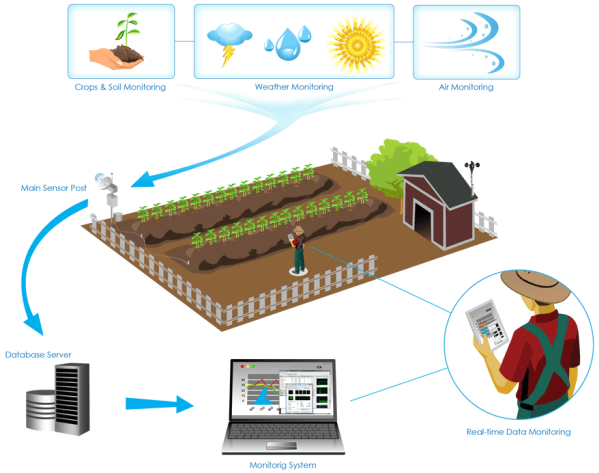
- Establish ground truth in real-world conditions
- Pilot market mechanisms
- Higher cost, higher resolution

2. Develop New Methods



- Directly measure N & C flux
- Increase reliability, resilience
- Reduce cost and footprint
- Incorporate IoT hardware

3. Provide Decision Support



- Management ⟺ Outcomes
- Aggressive cost targets
- System optimization
- Field-level data product

Program elements build off each other while individually providing valuable contributions to industry and the R&D community

Gold-Standard Data

Assess new technologies
- High resolution
- Open access
- Production environment
- Multiple regions
- Grain for ethanol

Accurate Accounting

Audit outcomes
- N_2O emissions (CO_2e)
- Soil carbon storage
- Deployment optimization

Grand Challenge

Advise growers
- Low-cost system solutions
- Broad-acre monitoring
- Agronomic Support

ARPA-E Moonshot: Carbon-optimized feedstock production for the bio-economy

Fall 2019
Ground truth testing sites and gold-standard datasets
3-5 years

Winter 2019 - Spring 2020
Sensor development for emissions/storage validation
~2 years

Fall 2021
System solution compete for millions in prizes
2-3 trials (1/season)

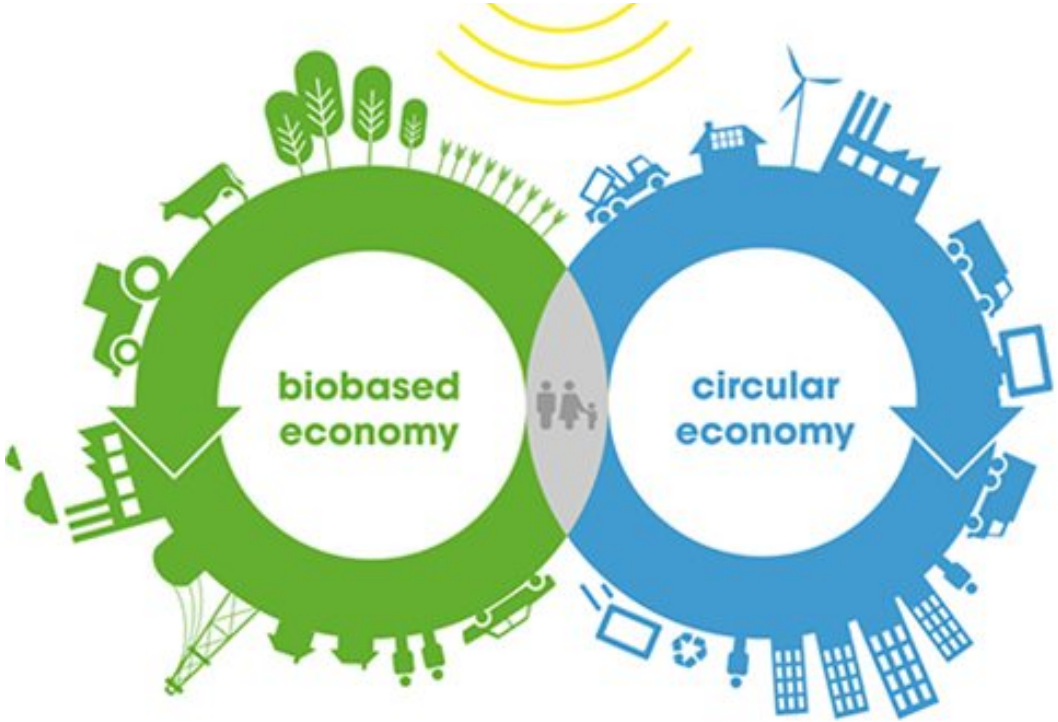
arpa·e
CHANGING WHAT'S POSSIBLE

Three complementary tracks over 5 years

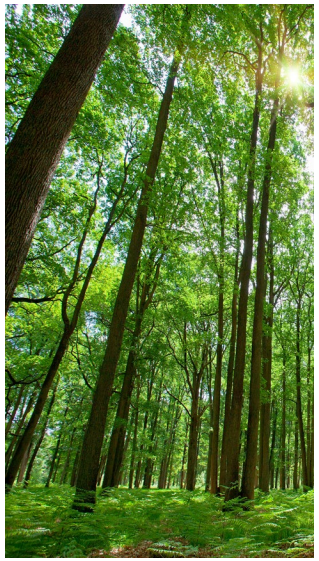
Summary

ARPA-E is advancing technologies to support a circular economy, a carbon negative economy, and a 20 gigaton carbon removal industry.

Managing carbon in the economy
Circular new carbon strategies



Managing to get carbon out of the economy
Negative Emission Technologies (NETs)



Biological NETs

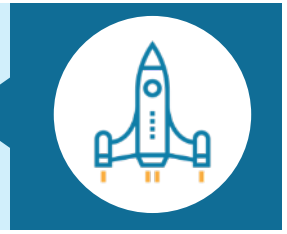
Engineered NETs

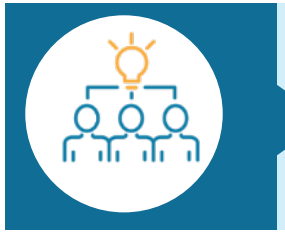
Hybrid NETs

ARPA-E could be the hallmark of your career

CONTRIBUTE TO A BETTER ENERGY FUTURE

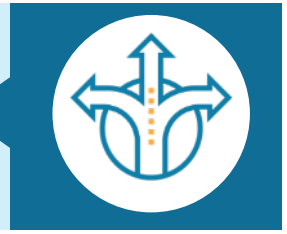
JOIN OUR INNOVATIVE STARTUP CULTURE





COLLABORATE WITH OTHER EXPERTS

WORK IN DIVERSE TECH AREAS



Learn more and apply: **arpa-e-jobs@hq.doe.gov**.

Join the team that is transforming the energy of tomorrow

PROGRAM DIRECTOR

- ✓ Program development
- ✓ Active project management
- ✓ Thought leadership
- ✓ Explore new technical areas

TECHNOLOGY-TO-MARKET ADVISOR

- ✓ Business development
- ✓ Technical marketing
- ✓ Techno-economic analyses
- ✓ Stakeholder outreach

FELLOW

- ✓ Independent energy technology development
- ✓ Program Director support
- ✓ Organizational support

Learn more and apply: **arpa-e-jobs@hq.doe.gov**.

Thanks for having me!

Contact me

David M. Babson, Ph.D.
Program Director| Advanced Research Projects Agency - Energy
U.S. Department of Energy
o. 202-586-6907 | David.Babson@hq.doe.gov

Follow me

Twitter: @realDavidBabson