Biological and Environmental Research Biological Systems Science Division Update

Todd Anderson, Ph.D.
Director, Biological Systems Science Division

April 11, 2024

Update on Programmatic Activities

- ☑ Annual Bioenergy Research Center (BRC) Reviews – Nov, Dec, Jan, Feb
- ☑ LBNL-Berkeley Synchrotron Infrared Structural Biology (BSISB) Onsite Review – Nov
- ☑ 2024 Genomic Science PI Meeting - April 2-4: Hybrid Meeting
- ☑ 2024 Enabling Capabilities PI Meeting - April 2-4: Hybrid Meeting
- ☑ DOE KBase Reverse Site Review – April 8-9

Upcoming Activities

- ❑ Bioimaging Research and Approaches for the Bioeconomy and the Environment FOA Full Applications Due: 3/5/24
- ❑ Low Dose Radiation Research FOA Full Applications Due: 4/2/24
- ❑ Early Career Research Program FOA and Lab Call Full Applications Due: 4/25/24
- ❑ Funding for Accelerated, Inclusive Research (FAIR) FOA Pre-Applications Due: 4/23/24
- ❑ Reaching a New Energy Sciences Workforce (RENEW) FOA Pre-Applications Due: 4/30/24
- ❑ BNL Laboratory for BioMolecular Structure (LBMS) Onsite Review – May 2024
- ❑ LLNL Biofuels SFA Reverse Site Review – July 2024
- ❑ UCLA-DOE Institute for Genomics and Proteomics Review – Fall 2024
- ❑ JGI Reverse Site Review – December 2024
- ❑ Frontier Science for the Bioeconomy Workshop Series – starting Summer/Fall 2024!

Bioscience Continues to Take Center Stage

SEPTEMBER 12, 2022

Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy

BRIEFING ROOM › PRESIDENTIAL ACTIONS

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Policy. It is the policy of my Administration to coordinate a whole-of-government approach to advance biotechnology and biomanufacturing towards innovative solutions in health, climate change, energy, food security, agriculture, supply chain resilience, and national and economic security. Central to this policy and its outcomes are principles of equity, ethics, safety, and security that enable access to technologies, processes, and products in a manner that benefits all Americans and the global community and that maintains United States technological leadership and economic competitiveness.

MARCH 13, 2024

FACT SHEET: President Biden's 2025 Budget Invests in Science and Technology to Power American Innovation, Expand Frontiers of What's Possible

OSTP › NEWS & UPDATES › PRESS RELEASES

President Biden's Budget makes strategic investments in science and technology (S&T) to ensure that America continues to lead the world in innovation and that S&T breakthroughs benefit all of America. The Budget includes ↗$202 billion for federal research and development (R&D) to tackle the great challenges of our time and achieve our nation's great aspirations—promoting robust health and ample opportunity for each person in every community, addressing the climate crisis, sustaining global security and stability, and realizing the benefits of artificial intelligence (AI) while managing its risks.

Administration Priorities The Record

MARCH 22, 2024

The White House Advances Biotechnology and Biomanufacturing Leadership with the Launch of the National Bioeconomy Board

OSTP › NEWS & UPDATES › OSTP BLOG

By Sarah Glaven, Principal Assistant Director for Biotechnology and Biomanufacturing, Industrial Innovation, White House Office of Science and Technology Policy

Biotechnology harnesses the power of biology to create new services and products, which provide opportunities to grow the U.S. economy and workforce and improve the quality of our lives and the environment. This week, the Biden-Harris Administration took an important step toward realizing the potential of biotechnology for the U.S. economy by launching the National Bioeconomy Board. The Board will work with partners across the

ENERGY earthshots U.S. DEPARTMENT OF ENERGY

Crosscutting activities across DOE connected to BSSD research:

- **Carbon Negative Shot**
  - Capture carbon dioxide from the atmosphere and store it at gigaton scales for less than $100/net metric ton of carbon dioxide-equivalent
  - Roads to Removal: Options for Carbon Dioxide Removal in the United States report by BETO, ARPA-E, FECM
- **Industrial Heat Shot**
  - Develop cost-competitive industrial heat decarbonization technologies with at least 85% lower greenhouse gas emissions by 2035.
  - 2023 Summit – October 23, 2023
- **Clean Fuels and Products Shot**
  - Decarbonize fuel and chemical industry through alternative carbon sources to advance cost-effective technologies with a minimum of 85% lower GHG emissions by 2035.
  - 2024 Summit – April 8-9, 2024
  - 2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Resources by BETO

Fiscal Year 2023-25 BSSD Budget

	FY23 ENACTED	FY24 ENACTED	FY25 President's Request
Genomic Sciences	328,685	319,435	316,420
Biomolecular Characterization and Imaging Science	45,000	45,750	43,910
Biological Systems Facilities and Infrastructure	90,000	92,250	93,565
BSSD TOTAL	**463,685**	**457,435**	**453,895**

Reasonable top-line number but with some constraints:

- Systems Biology of Bioenergy-Relevant Microbes
  - Not releasing a FOA this fiscal year
- Energy Earthshot Research Centers
  - Significant budget shortfall

*** All in thousands of dollars**

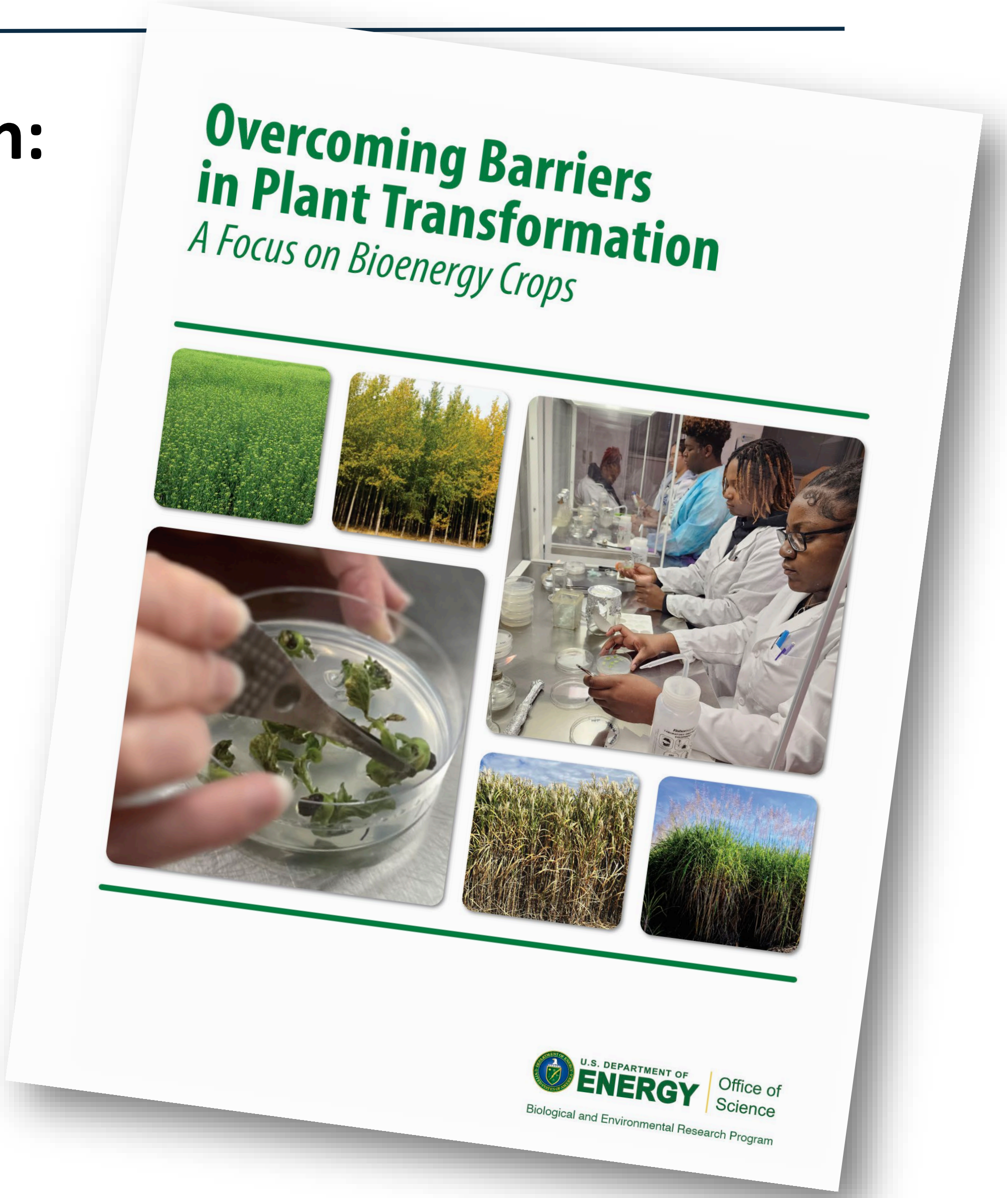
Workshop Report

New Overcoming Barriers in Plant Transformation: *A Focus on Bioenergy Crops*

EXECUTIVE SUMMARY AVAILABLE NOW

Full report:
genomicscience.energy.gov/plant-transformation/

Wayne Parrott - Chair (UGA)
Jeremy Schmutz (Hudson-Alpha, JGI)
Sally Assmann (Penn State Univ.)
Bill Gordon-Kamm (Corteva)
Margaret Young (ECSU)
Veena Veena (Danforth Center)



Thank you!

Frontier Science for the Bioeconomy Workshop Series

Microbial Design for a Developing Bioeconomy

How do we accelerate our ability to harness and leverage the diverse genetic and metabolic potential of microbes as a platform to efficiently produce the biofuels, bioproducts, and biomaterials?

Microbiome Research: Engineering Microbial Communities

How do we harness the behavior of microbiomes and to manipulate them to facilitate microbial solutions to challenging bioeconomy and environmental problems?

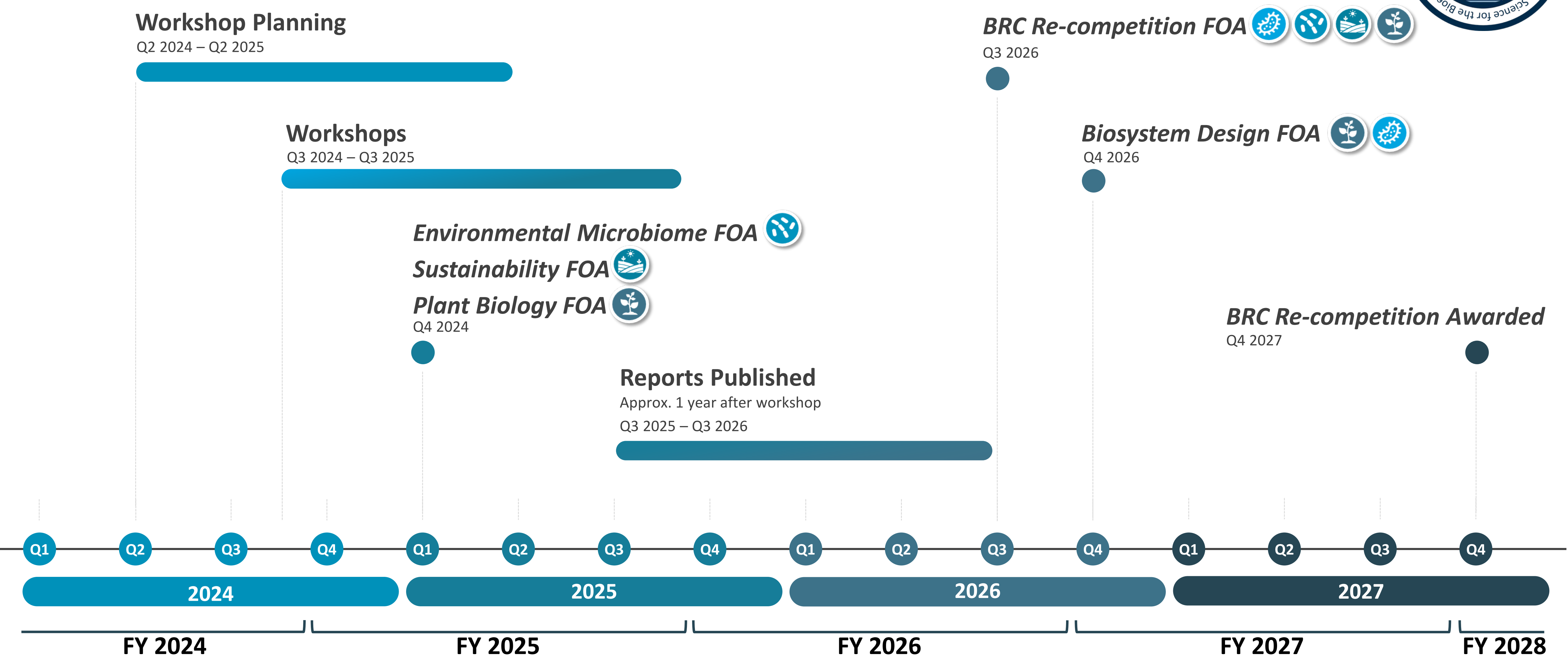
Resilient Bioenergy Crop Production

How do we predict and improve both plant and plant microbiome responses to a changing environment to optimize biomass feedstock production?

Plant Design for a Developing Bioeconomy

How do we understand and transform bioenergy plants into advanced factories that generate clean, renewable, and sustainable biofuels, bioproducts, and biomaterials?

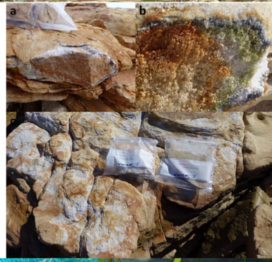
GSP Workshops Timeline



BSSD Science Highlights

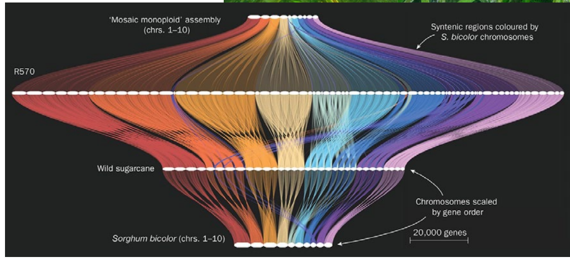
104 JGI Publications October 1, 2023-March 29, 2024

JGI JOINT GENOME INSTITUTE
A DOE OFFICE OF SCIENCE USER FACILITY



Selected Highlights

- The complex polyploid genome architecture of sugarcane. ***Nature***
- Unraveling the functional dark matter through global metagenomics. ***Nature***
- Metatranscriptomics sheds light on the links between the functional traits of fungal guilds and ecological processes in forest soil ecosystems. ***New Phytologist***
- Metagenomics untangles potential adaptations of Antarctic endolithic bacteria at the fringe of habitability. ***Science of the Total Environment***
- IMG/PR: a database of plasmids from genomes and metagenomes with rich annotations and metadata. ***Nucleic Acids Research***
- Oxygenation influences xylose fermentation and gene expression in the yeast genera *Spathaspora* and *Scheffersomyces*. ***Biotechnology for Biofuels and Bioproducts***
- Seagrass genomes reveal ancient polyploidy and adaptations to the marine environment. ***Nature Plants***
- Viral potential to modulate microbial methane metabolism varies by habitat. ***Nature Communications***



JGI News Releases and Highlights:

- jgi.doe.gov/news-publications
- jgi.doe.gov/category/science-highlights

JGI IMG/PR INTEGRATED MICROBIAL GENOMES / PLASMID

Harnessing JGI and KBase Data Resources

Objective

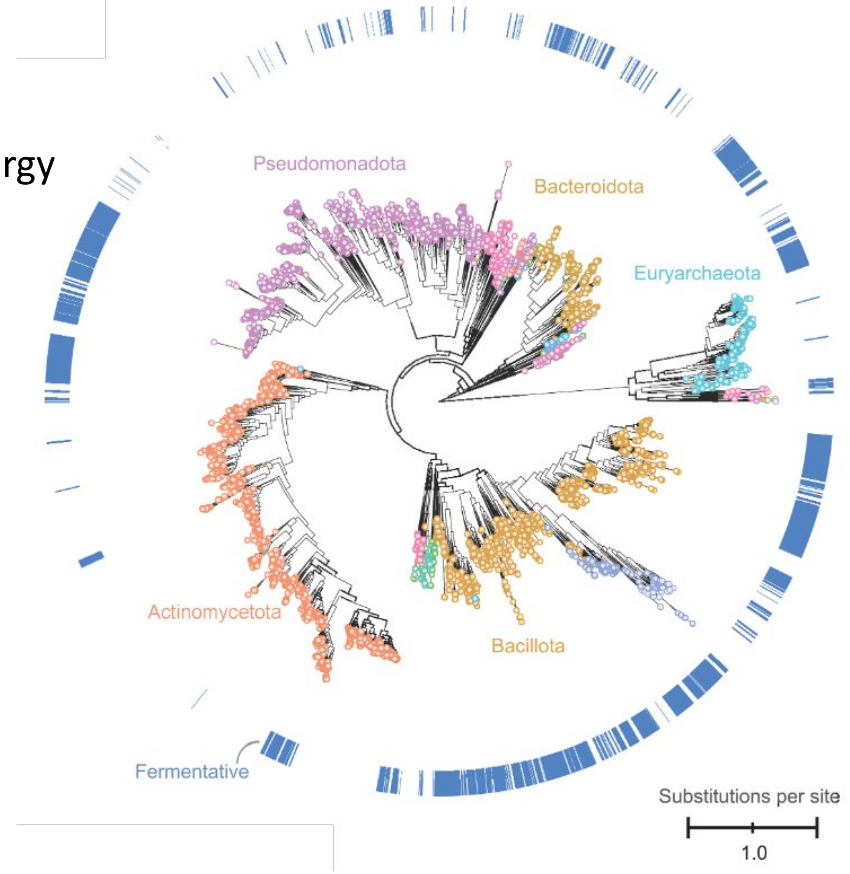
- Generate a comprehensive list of bacteria/archaea that use fermentation to produce energy

Approach

- Integrated phenotypic records for 8,350 organisms with 4,355 genomes and 13.6 million genes
- Build workflow via JGI's IMG and GOLD and other databases, plus KBase tools and apps to understand diversity of fermentative organisms

Result/Impacts

- A third of prokaryotes can use fermentative metabolism, forming ~300 combinations of metabolites.
- Fermentative prokaryotes are found throughout the phylogenetic tree and are more abundant on some branches than others.
- Predicted the fermentative products of five previously uncharacterized prokaryotes
- Developed an online, interactive tool called "Fermentation Explorer"
- Added list of organisms accessible on "Fermentation Explorer" to IMG
- Highlights the value and utility of JGI and KBASE resources for novel data synthesis and discovery



Hackmann TJ, Zhang B. Science Advances (2023).
[DOI: 10.1126/sciadv.adg8687]

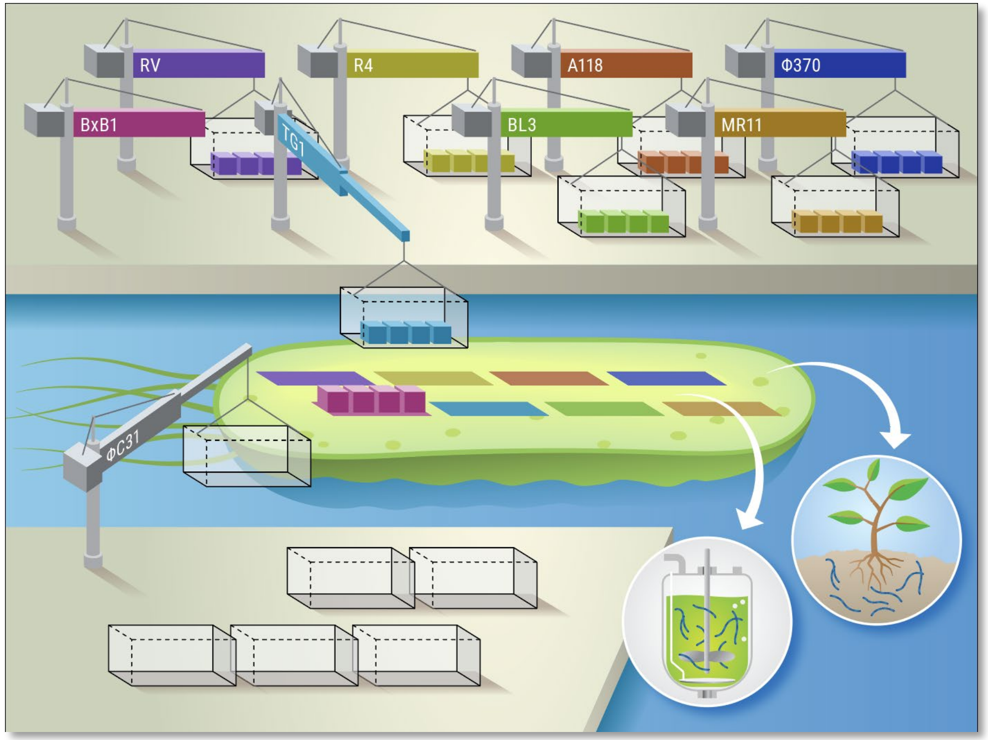
High-efficiency Genome Engineering for Non-Model Bacteria

Objective

Develop a serine recombinase-based method for rapid and stable introduction of DNA constructs in potentially any bacterial species.

Approach

- Serine recombinase-Assisted Genome engineering (SAGE) leverages serine recombinases that do not require host proteins, allowing its use in virtually in any bacterial species.
- Base strain containing 10 recombinase attachment sequences was built and ten different recombinases were used to iteratively integrate up to ten constructs in non-model bacteria.



Result/Impacts

- Applied to five taxonomically diverse bacterial hosts with traits related to plant rhizosphere colonization, plant biomass productivity, and industrial bioproduction.
- Provided transformation efficiency equivalent to or better than standard plasmid transformation for each host.
- Used to introduce a library of taxonomically diverse promoters that showed consistent behaviors across multiple environmental growth conditions.

Pacific Northwest NATIONAL LABORATORY

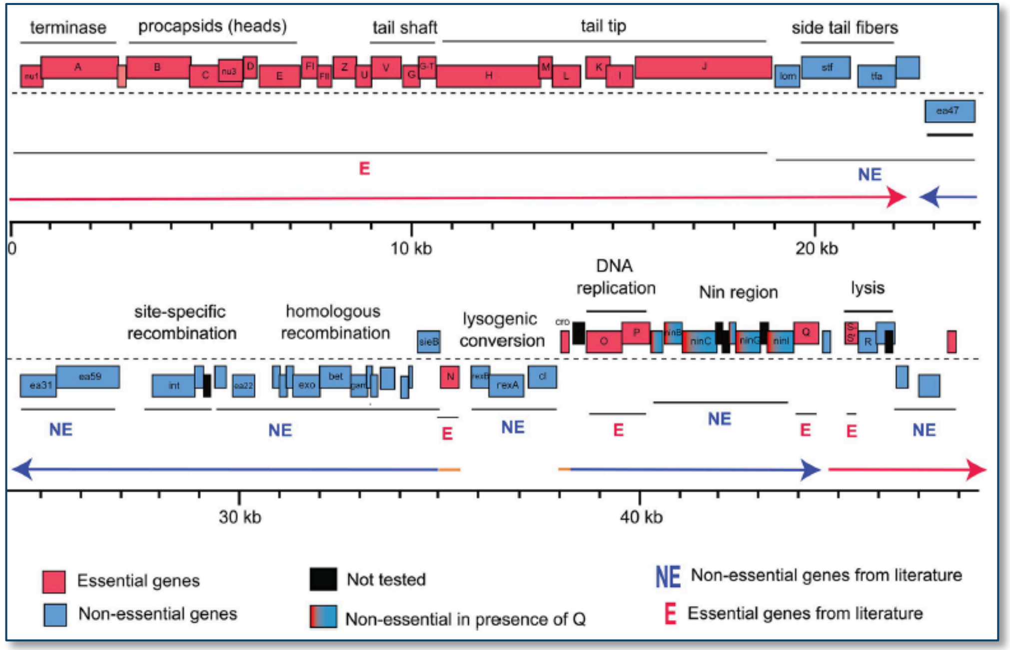
Biosystems Design

Elmore et al. Science Advances (2023) [DOI: 10.1126/sciadv.ade1285]

Systematic and scalable genome-wide essentiality mapping to identify nonessential genes in phages

Objective

Develop a systematic gene essentiality mapping method that is scalable to new phage–host combinations that facilitate the identification of nonessential genes.



Approach

- Develop an arrayed genome-wide CRISPR interference (CRISPRi) assay to map gene essentiality landscape in phage
- Map the canonical coliphages λ and P1
- Identify locations in these phage genomes where insertion of an exogenous "payload" is less likely to disrupt critical function

Result/Impacts

- CRISPRi was an overall effective tool to inhibit gene function phage.
- Data are consistent with known assignments of gene essentiality in both phages.
- Uncovered a polar effect of CRISPRi in phages, suggesting transcripts should be mapped before gene function essentiality can be defined in less studied phage

ENIGMA

BERKELEY LAB

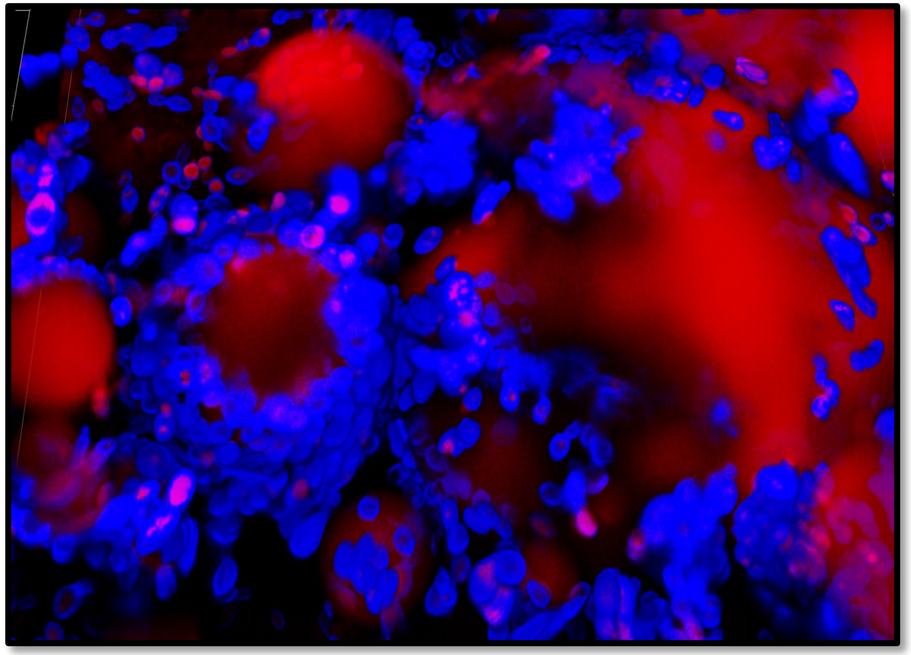
LBNL ENIGMA

Piya et. al. PLoS Biol (2023) [DOI: 10.1371/journal.pbio.3002416]

Yeast Use Plastic Waste Oils to Make High-Value Chemicals

Objective

- Determine how *Yarrowia lipolytica* metabolically responds to growth on chemically depolymerized plastic (DP) oil comprising of a complex mixture of saturated, unsaturated, even, and odd hydrocarbons.
- Establish *Y. lipolytica* as a promising host for upcycling polymer waste.



Approach

- Grew *Y. lipolytica* on DP and alternate substrates.
- GC/MS to monitor substrate degradation.
- Proteomics via LC-MS/MS to study protein allocation.

Result/Impacts

- *Y. lipolytica* shifts its protein production toward energy and lipid metabolism to grow on hydrocarbons from DP.
- The strain can produce high-value chemicals, including organic acids and lipids from DP.
- Genetic modifications will likely be needed for robust growth and upcycling.
- Discovering how *Y. lipolytica* activates its metabolism to utilize depolymerized plastics oil could establish it as a promising host for the upcycling of plastic wastes.

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Walker et. al. mSystems (2023) [DOI: 10.1128/msystems.00741-23]

Hybrid chemical-biological approach can upcycle mixed plastic waste with reduced cost and carbon footprint

JBEI Joint BioEnergy Institute
ABPDU ADVANCED BIOFUELS PROCESS DEMONSTRATION UNIT

Objective

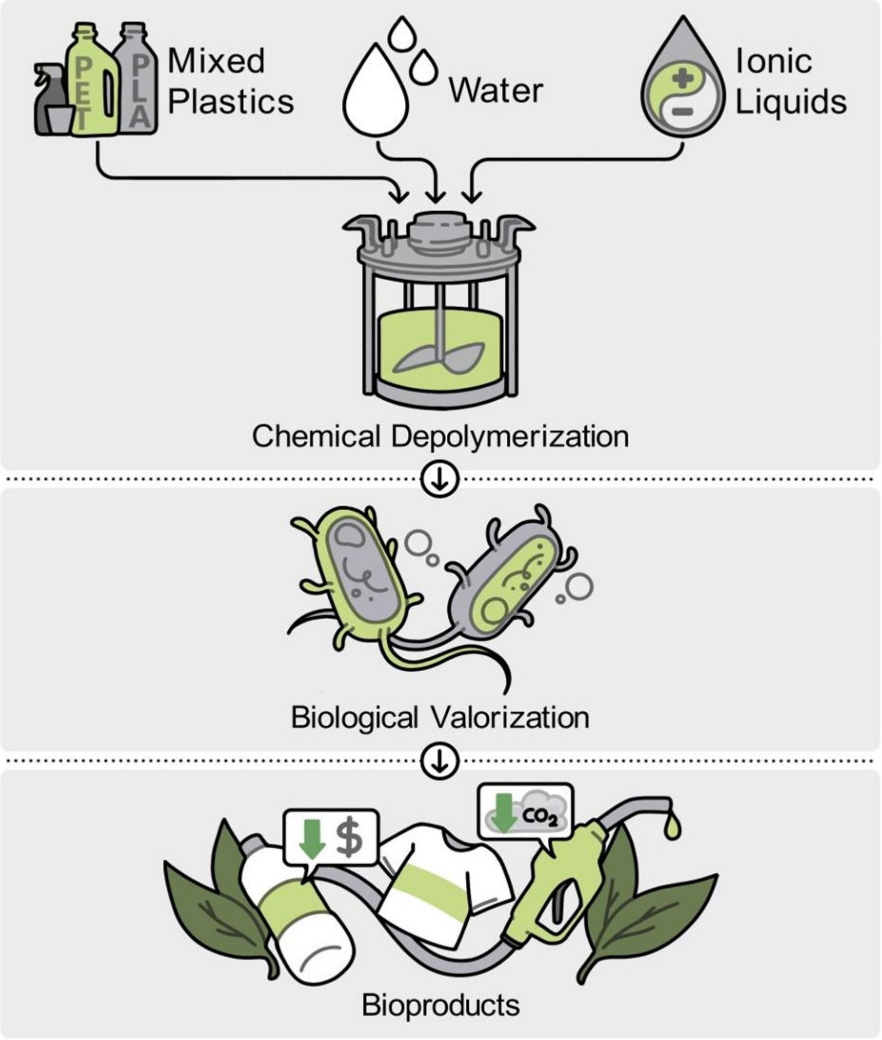
- Mixture of PLA and PET plastics poses a cross-contamination threat in existing recycling facilities.
- Study aims to upcycle mixed PLA/PET without extra separation.

Approach

- Depolymerize mixed plastics into monomers using bio-derived IL.
- Convert depolymerized stream via biological upgrading.
- Evaluate production cost and environment impact via TEA and LCA.

Result/Impacts

- Over 95% of mixed PET/PLA depolymerized into the monomers.
- Depolymerized mixed PET/PLA can serve as the sole carbon source for *Pseudomonas putida*, producing biodegradable PHA.
- Optimal production cost and carbon footprint are reduced by 62% and 29% compared to convectional commercial PHAs.
- Demonstrated a hybrid pathway to upcycle mixed plastics with reduced cost and carbon footprint.



Dou C., et al. One Earth. (2023) [DOI: 10.1016/j.oneear.2023.10.015]

High resolution spatial metabolomics and proteomics imaging of a complex microenvironment

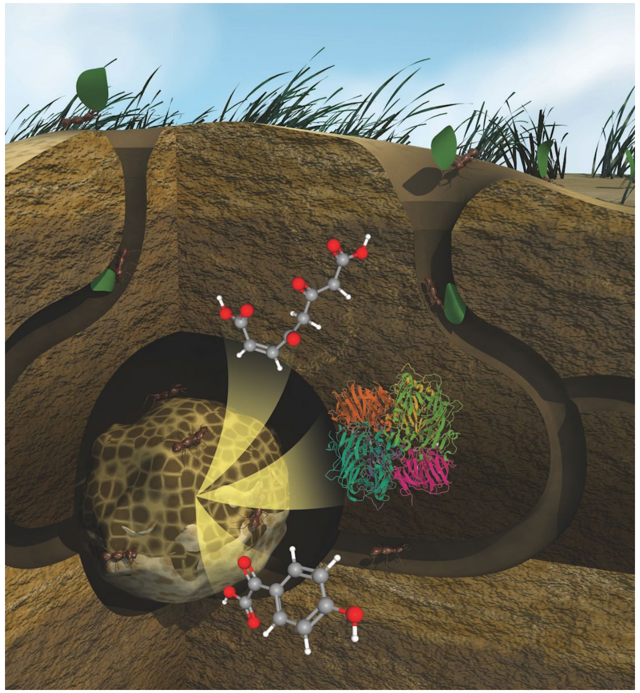
Pacific Northwest NATIONAL LABORATORY

Objective

- Combination imaging and omics technologies to achieve a mechanistic understanding of a lignocellulose-degrading microbiome.

Approach

- Combined mass spectrometry and microfluidics technologies to develop a microscale imaging approach called metabolome-informed proteome imaging (MIPI).
- Analyzed adjacent 12-µm-thick sections leafcutter ants' fungal gardens to map leaf tissue degradation *in situ* by colocalizing metabolites and proteins.
- Used sequence analysis to identify the microorganisms involved in lignocellulose degradation



Veličković M., et al. Nature Chemical Biology (2024)
[DOI: doi.org/10.1038/s41589-023-01536-7]

Result/Impacts

- Uncovered chemically and morphologically unique microhabitats with specific lignocellulose degradation metabolites and taxon-specific enzymes
- Elucidated molecular mechanisms of plant biomass degradation pathways via integrated of metabolome and proteome data
- Demonstrated MIPI has potential to map metabolic activity across heterogeneous samples with pathway-level resolution.

Early Career

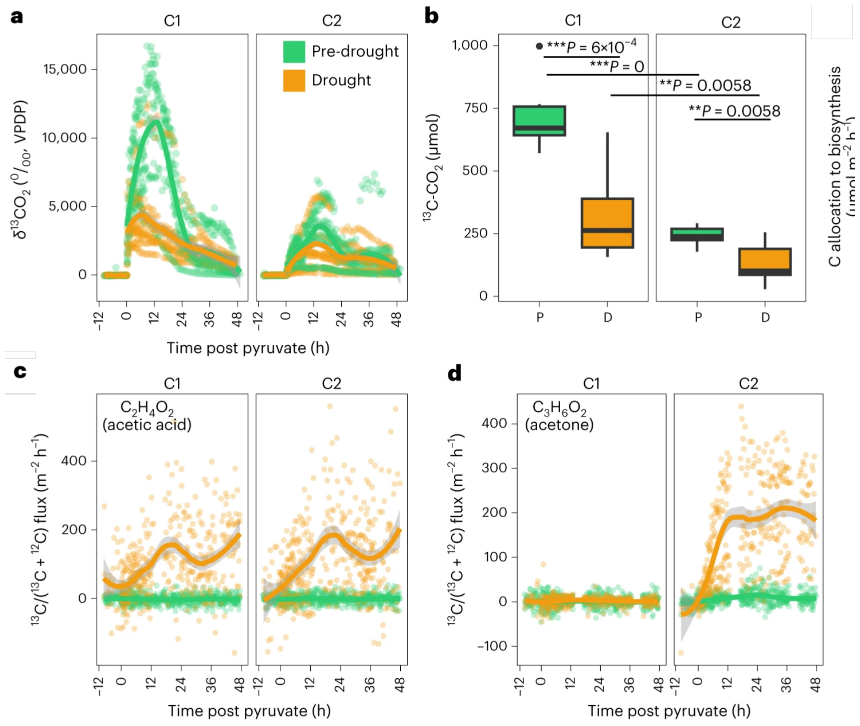
Drought re-routes soil microbial carbon metabolism towards emission of volatile metabolites in an artificial tropical rainforest.

Objective

- Understand C flow and storage in soil systems
- Study the role of drought in controlling the emissions of carbon dioxide and volatile organic compounds from soils

Approach

- Conducted a ‘ecosystem-scale’ drought experiment in Biosphere 2
- Tracked ^{13}C from position-specific ^{13}C -pyruvate into CO2 and VOCs via isotope analysis and proton-transfer-reaction time-of-flight mass spectrometry (PTR–TOF)
- Metagenomics, metatranscriptomics, metabolomics (NMR/FTICR)



Honeker, LK, et al. Nature Microbiology (2023).
[DOI: 10.1038/s41564-023-01432-9]

Result/Impacts

- During drought stress, microbial activity allocates greater amounts of C to VOCs vs cellular biomass.
- VOCs can escape into the atmosphere before being utilized by microbes.
- Dryer climate could therefore lead to enhanced carbon loss / decreased C stabilization in some soils

The University of Arizona
College of Agriculture, Life & Environmental Sciences

C cycling

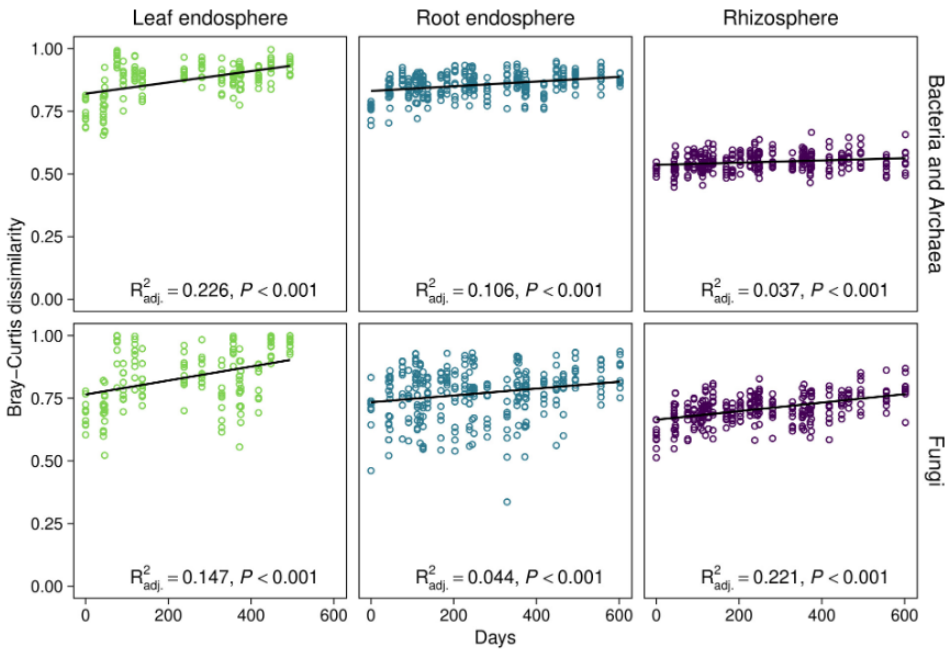
Above and belowground poplar microbiomes shift seasonally and across years

Objective

- Microbiomes are important to plant health and growth, but we lack a good understanding of microbiome temporal dynamics in plants
- Study seeks to understand if tree microbiomes change seasonally and from year to year are important to consider in plant microbiome studies.

Approach

- A common garden and clonally propagated poplar plants were used to assess temporal variation in plant microbiome composition (10 genotypes
- Conducted amplicon-based community analysis of leaf, root, and rhizophore samples collected in 3-month intervals over a 2-year period.



Argiroff, WA, et al. mSystems (2024)
[DOI:10.1128/msystems.00886-23]

UTSA The University of Texas at San Antonio™ | The University of Tennessee Knoxville | Oak Ridge National Laboratory

Result/Impacts

- Bacterial, archaeal, and fungal communities differed among seasons
- Longer-term changes in microbial composition were observed, as host trees developed across consecutive years
- Time and maturity should be considered to understand plant-microbe interactions in relation to environmental change

ORNL Plant Microbe Interfaces

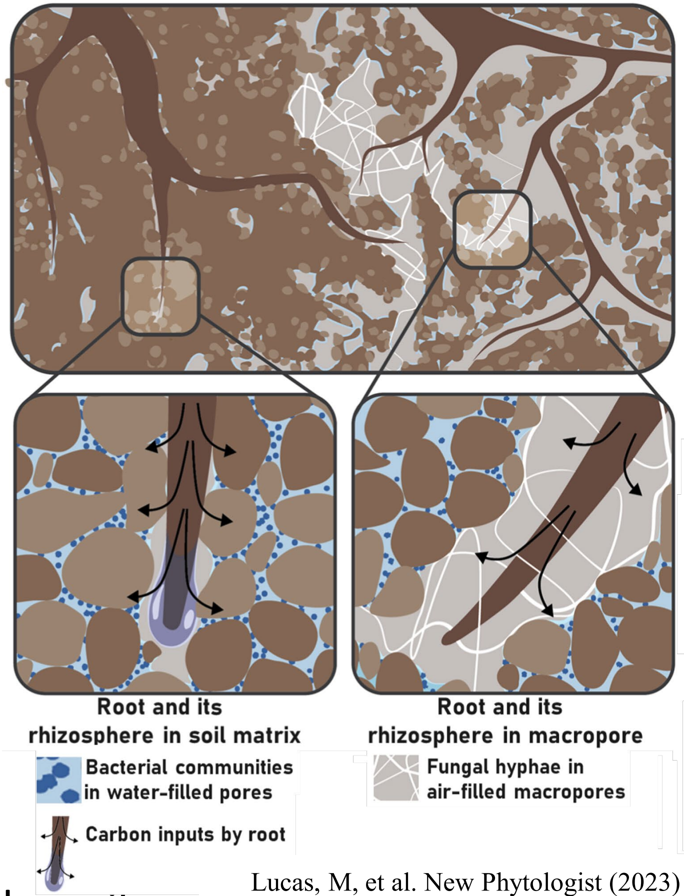
Effect of Soil Structure on Root Growth and Carbon Storage

Objective

- Understand the role of pore structure in driving root growth and below ground C input
- Determine the influence of root-soil contact on belowground plant C allocations and on the fate of plant-derived C in the soil.

Approach

- Grew Black-eyed Susan and Switchgrass on soils of prairie and switchgrass origin with contrasting pore structure.
- Combined X-ray computed micro-tomography (µCT) with ^{14}C plant labelling to identify root–soil contact



Lucas, M, et al. New Phytologist (2023) [DOI:10.1111/nph.19159]

Result/Impacts

- Soil structure can play a pivotal role in determining root growth and varies by plant
- Soil structure impacts how long the carbon transported from plants will remain in the soil.
- Root-soil contact influences the amount of C released into the root's surroundings, the microbial processing of the plant-derived C, and the spatial distribution patterns of C
- Soil presents an important opportunity to remove carbon dioxide from the atmosphere and store it underground.

Thank you

https://science.osti.gov/ber

https://www.energy.gov/science/ber/biological-and-environmental-research