The United States Department of Energy's Role in Research and Innovation for a Future Bio-economy

Sharlene Weatherwax, Ph.D.
Associate Director of Science
Biological and Environmental Research

August 15, 2011

The mission of the Department of Energy is to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

Goal 1: Catalyze the timely, material, and efficient transformation of the nation's energy system and secure U.S. leadership in clean energy technologies.

Goal 2: Maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.

Goal 3: Enhance nuclear security through defense, nonproliferation, and environmental efforts.

Goal 4: Establish an operational and adaptable framework that combines the best wisdom of all Department stakeholders to maximize mission success.

The Department's mission and strategic goals reflect the President's directives for clean energy, science, and national security.

Secretary
Steven Chu

Deputy Secretary
Daniel B. Poneman

Advanced Research Projects Agency – Energy

Under Secretary for Nuclear Security/Administrator for National Nuclear Security Administration

- Defense Nuclear Nonproliferation
- Defense Programs
- Naval Reactors
- Counter-terrorism
- Defense Nuclear Security
- Emergency Operations

Under Secretary for Science

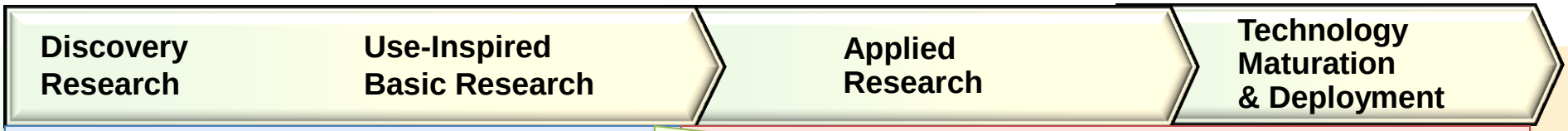
Office of Science

- Basic Energy Sciences
- High Energy Physics
- Advanced Scientific Computing Research
- Nuclear Physics
- Biological & Environmental Research
- Fusion Energy Sciences
- SBIR/STTR
- Workforce Develop. for Teachers & Scientists

Under Secretary

- Energy Efficiency & Renewable Energy
- Environmental Management
- Fossil Energy
- Legacy Management
- Nuclear Energy
- Electricity Delivery & Energy Reliability

R&D Continuum for Biofuels



Office of Science | ARPA-E | Applied Programs

BER:

- Systems biology towards understanding the principles underlying the structural and functional design of living systems
- Predictive capability to model and engineer optimized plants, microorganisms and enzymes

BES:

- Rational catalyst design and chemical transformation control
- Structure-activity relationships of inorganic, organic, and hybrid catalytic materials in solution or solids

BER:

- Genetic properties, molecular and regulatory mechanisms and resulting functional potential of microbes & plants for novel approaches to new biofuels
- Mining for natural environments for new biological catalysts.
- Characterization of microbial soil communities

BES:

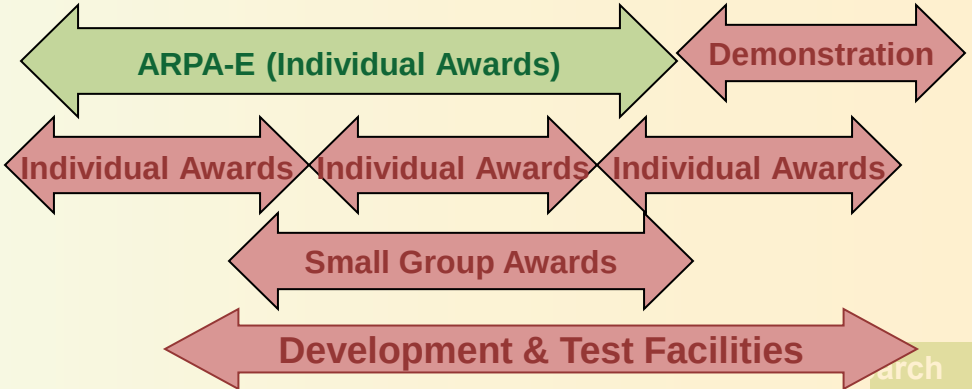
- Biochemical and biophysical principles determining assembly and architecture of biopolymers and protein complexes
- Mechanisms of biological energy transduction, bioinspired solar energy conversion
- Synthesis of robust, functional catalysts that mimic biological processes
- Solar conversion into oils and biofuels in plant and algal systems

ARPA-E

- Non-photosynthetic electrofuels – using microbial use of electric currents (from solar PV) to convert CO_2 & H_2O to fuels; engineering of H_2-using microbes to convert CO_2 liquid fuels and other hydrocarbons
- Production of isobutanol from seaweed

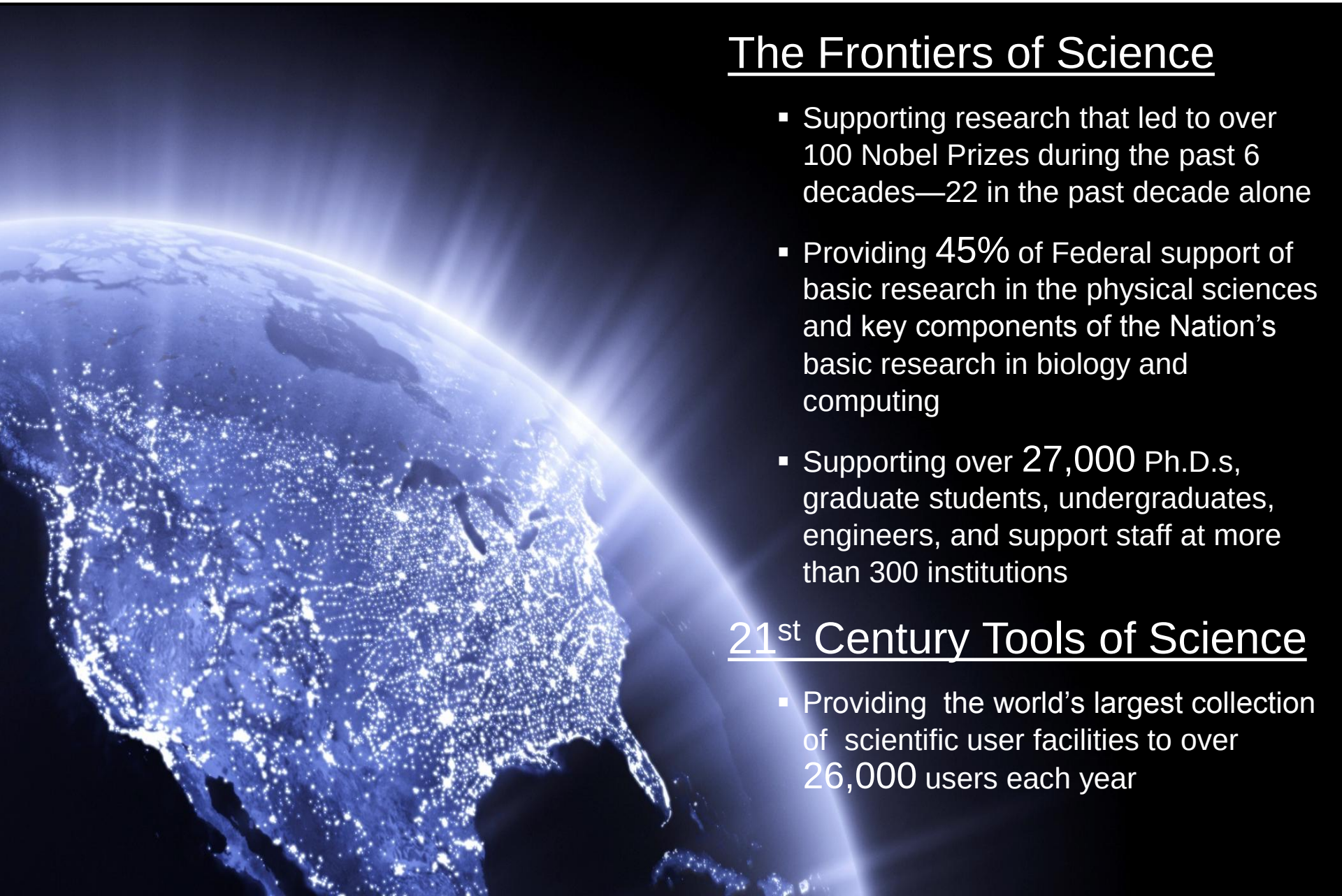
EERE:

- Validate and demonstrate biorefinery technologies at pilot through commercial scale; integrated biorefineries employing combinations of feedstocks and conversion technologies, main focus is biofuels, but side products (chemicals, heat, power) allowed
- Sustainable feedstock production; cellulosic bioenergy crop selection and inventory – updating the "Billion Ton Study," replicated field trials
- New technologies for sustainable commercialization of algal biofuel
- Process improvement of industrial enzymes and microbial biofuel fermentation; performers take strains to a commercial scale and have a business strategy to market the organism/process.
- Development and testing of biofuels and fuel mixes for performance, emissions, engine longevity, also combined with different vehicle technologies



Office of Science

Science to Meet the Nation's Challenges Today and into the 21st Century



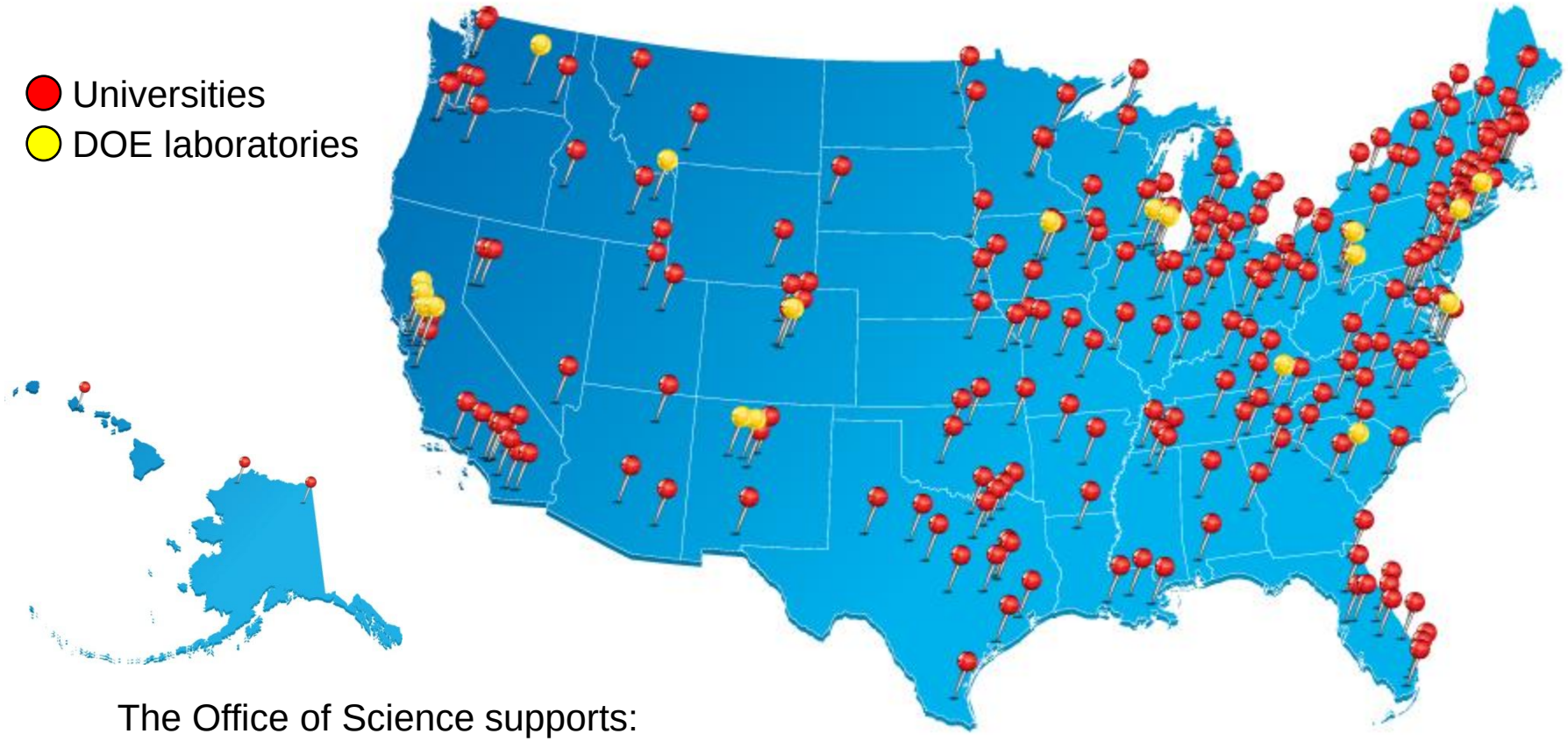
The Frontiers of Science

- Supporting research that led to over 100 Nobel Prizes during the past 6 decades—22 in the past decade alone
- Providing 45% of Federal support of basic research in the physical sciences and key components of the Nation's basic research in biology and computing
- Supporting over 27,000 Ph.D.s, graduate students, undergraduates, engineers, and support staff at more than 300 institutions

21st Century Tools of Science

- Providing the world's largest collection of scientific user facilities to over 26,000 users each year

SC Supports Research at More than 300 Institutions Across the U.S.

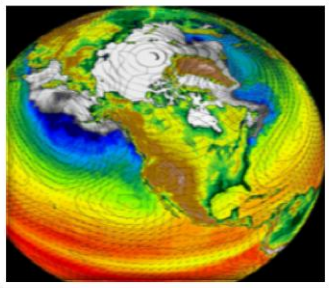


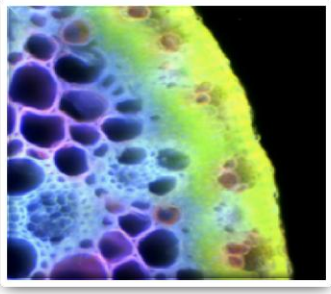
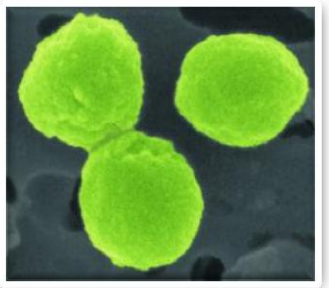
The Office of Science supports:

- **27,000** Ph.D.s, graduate students, undergraduates, engineers, and technicians
- **26,000** users of open-access user facilities
- **300** academic institutions
- **17** DOE laboratories

Biological and Environmental Research Mission

- To understand complex biological, climatic, and environmental systems across spatial and temporal scales.
- BER provides the foundational science to:
  - Support the development of biofuels as major, secure, and sustainable national energy resources
  - Understand the potential effects of greenhouse gas emissions on Earth's climate and biosphere and the implications of these emissions for our energy future
  - Predict the fate and transport of contaminants in the subsurface environment at DOE sites
  - Develop new tools to explore the interface of biological and physical sciences



Advancing Energy Technologies through Bioenergy Research Centers

Single focus, multi-disciplinary, team-based science

BioEnergy Science Center (Oak Ridge National Lab)

- Strategic focus on overcoming biomass "recalcitrance" as route to cost-effective cellulosic biofuels
- Goal of "Consolidated Bioprocessing" – one-microbe or microbial community approach going from plants to fuel

Great Lakes Bioenergy Research Center (University of Wisconsin, Michigan State University)

- Goal of re-engineering plants to produce more starches and oils
- Using HTP technologies to optimize chem/bio process for biomass deconstruction
- Major research thrust on sustainability of biofuels

Joint BioEnergy Institute (Lawrence Berkeley National Lab)

- Experimenting with new pretreatment process using room temperature ionic liquids
- Beyond cellulosic ethanol: re-engineering *E.coli* and yeast to produce hydrocarbons – goal of "green" gasoline, diesel, jet fuel

The DOE Bioenergy Research Centers--accomplishments

Feedstocks

- Genetically modified switchgrass to yield 30% increased ethanol using 3- to 4-fold less enzyme for processing, significantly lowering of the cost of biofuel production
- Identified a plant gene involved in synthesis of an oil with 30% less viscosity than available vegetable oils, with potential for simpler production of biodiesel in nonfood crops

Deconstruction

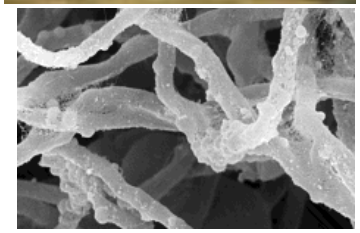
- Developed new pretreatment technology using ionic liquids, that completely dissolves biomass and enables downstream yield of fermentable sugars 10 fold faster than current commercial approaches.
- Identified novel enzymes from natural environments such as leaf cutter ant gardens or green compost, improving the ability to turn biomass into usable sugars

Fuel Synthesis

- Identified, tested, and re-engineered metabolic pathways for microbial production of advanced, drop-in biofuels
- Developed multi-tasking microbes that can break down plant fibers to sugars and ferment them to ethanol in a single step. This consolidated bioprocessing significantly reduces the cost and time for biofuel production.

Joint Genome Institute (JGI): A DOE USER FACILITY

- Using high throughput tools, technologies and comparative analysis, the JGI serves as a discovery platform to understand the organization and function of complex genomes for bioenergy, carbon cycle, and bioremediation.
- Genome and metagenome expression and sequencing of microbes, plants, and other complex systems, such as microbial communities or the rhizosphere.
- Genome annotation, functional analysis and verification of genome-scale biological system models. Systems-level integration and validation of genomic data from multiple sequencing and functional analyses.
- Sequencing more than 18 Terabases per year (more than 3000 human genome equivalents)



Tackling big genomics challenges for DOE

DOE Joint Genome Institute

Sorghum genome sequenced

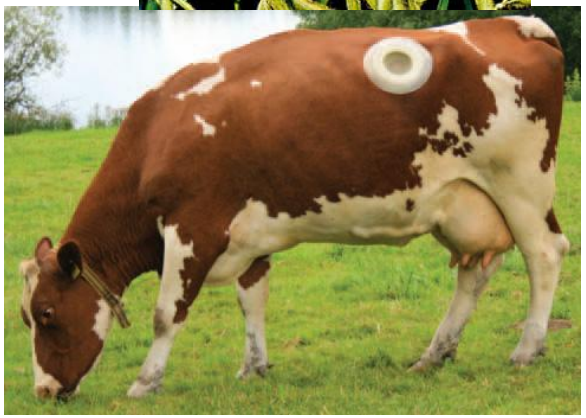
- Provides a key reference for next-generation cellulosic biofuel crops and sugar production.
- Key traits include efficient C4 photosynthesis and ability to grow on marginal land under drought conditions

Soybean genome sequenced

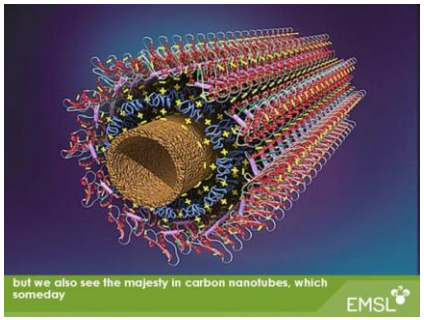
- Globally important agricultural crop, providing protein and oil for foods.
- Provides a key reference for more than 20,000 legume species, accelerating soybean trait discovery for enhanced soil nitrogen content and production of biodiesel fuel.

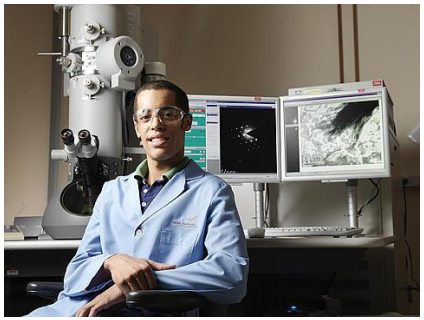
"Mining" cows for new enzymes to degrade biomass

- Sequenced 268 Gb of DNA from microbes in rumen of cow feeding on switch grass
- Identified 27,755 *candidate* genes for carbohydrate-degrading enzymes—potential new sources of industrial enzymes able to break down cellulose-rich feedstocks.



Environmental Molecular Sciences Laboratory (EMSL)





- **EMSL's mission as a Scientific User Facility**

  "…provide integrated experimental and computational resources for discovery and technological innovation in the environmental molecular sciences to support the needs of DOE and the nation."

- EMSL **Science Themes** provide scientific focus for user research:
  - Biological Interactions and Dynamics
  - Geochemistry/Biogeochemistry and Subsurface Science
  - Science of Interfacial Phenomena

- Instrumentation includes: Nuclear magnetic resonance and mass spectrometers, molecular/microscopy imaging capabilities; nano- & molecular-level characterization instruments.

- Collaboration with industry led to new catalyst that reduced diesel fuel emissions and increased fuel efficiency.

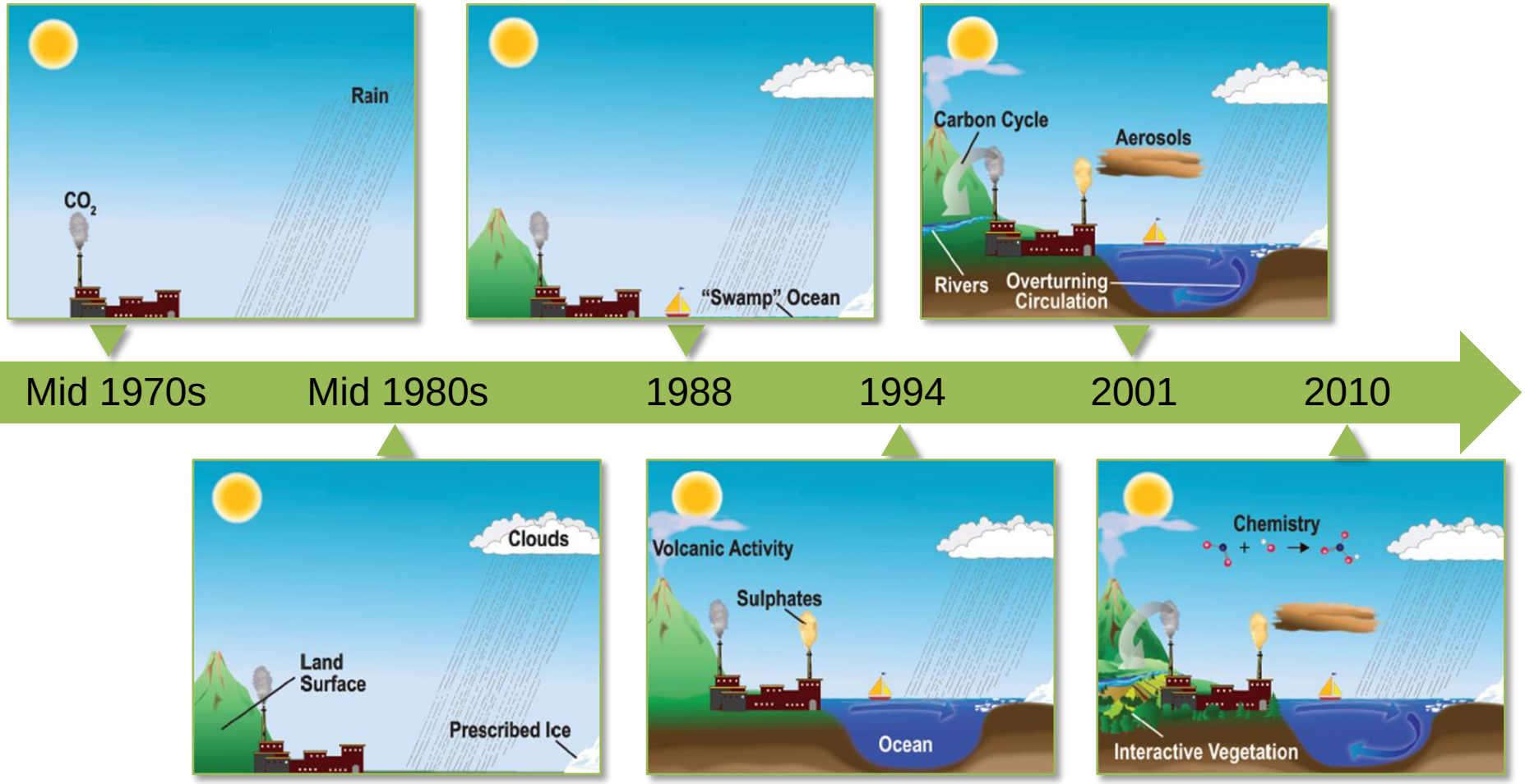
Why DOE?
The Energy-Climate Nexus

Greenhouse gases are emitted during energy production…
and climate change will impact energy production

DOE seeks to:

- Understand the effects of GHG emissions on Earth's climate and the biosphere
- Provide world-leading capabilities in climate modeling and process research on clouds and aerosols, and the carbon cycle
- Provide unique, world-leading capabilities in cloud and aerosol observations and large scale ecological experiments
- Build foundational science to support effective energy and environmental decision making

Climate models have increased in complexity

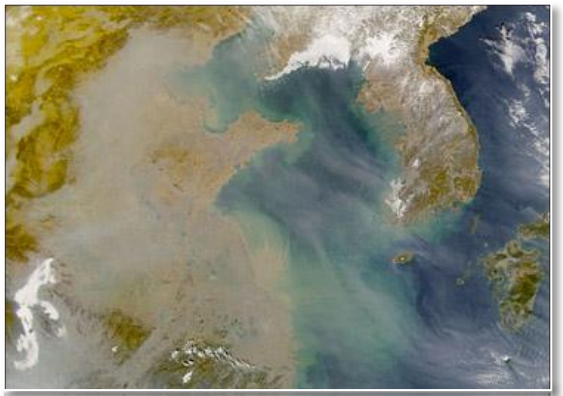


What are the major knowledge gaps in climate models?

Representation of **clouds** in climate models

Direct and indirect effects of **aerosols** on climate

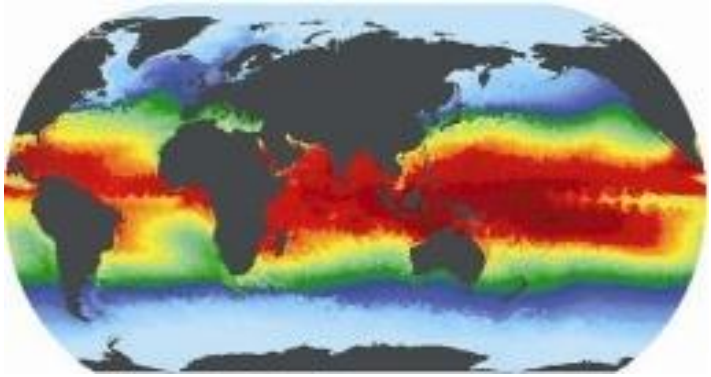
Interactions of the **carbon cycle** and climate



Why are climate models important?

- Decision makers, planners, and citizens need predictive tools
- Climate effects are myriad, interconnected, and complex
  - Sea level rise
  - Frequency and severity of severe weather
  - Prevalence of drought and flooding, etc.
- Models can dynamically synthesize climate theory and data
- Models are constantly improving
- Goal is ever more reliable and predictive models at both global and regional scales

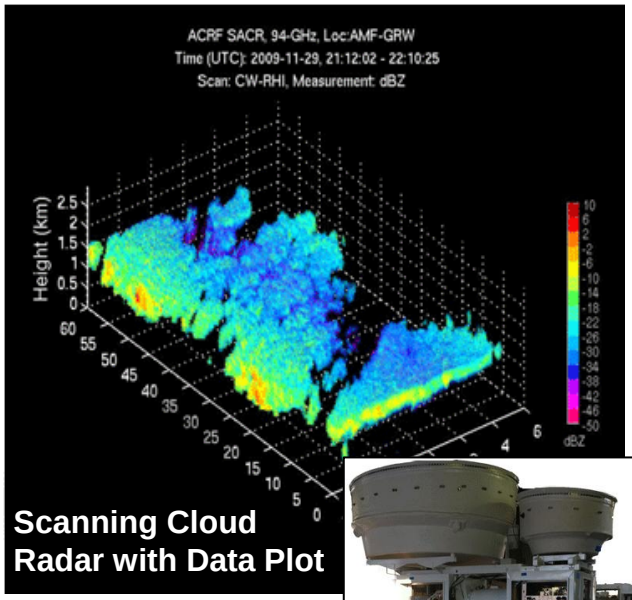
NERSC's Supercomputer Franklin



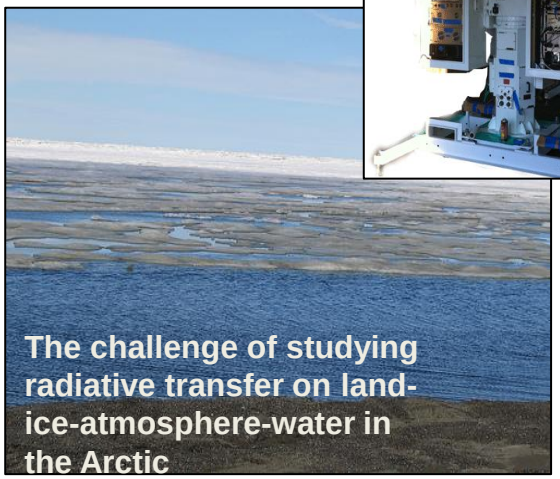
Tackling Major Climate Uncertainties

Atmospheric Radiation Measurement (ARM) Climate Research Facility

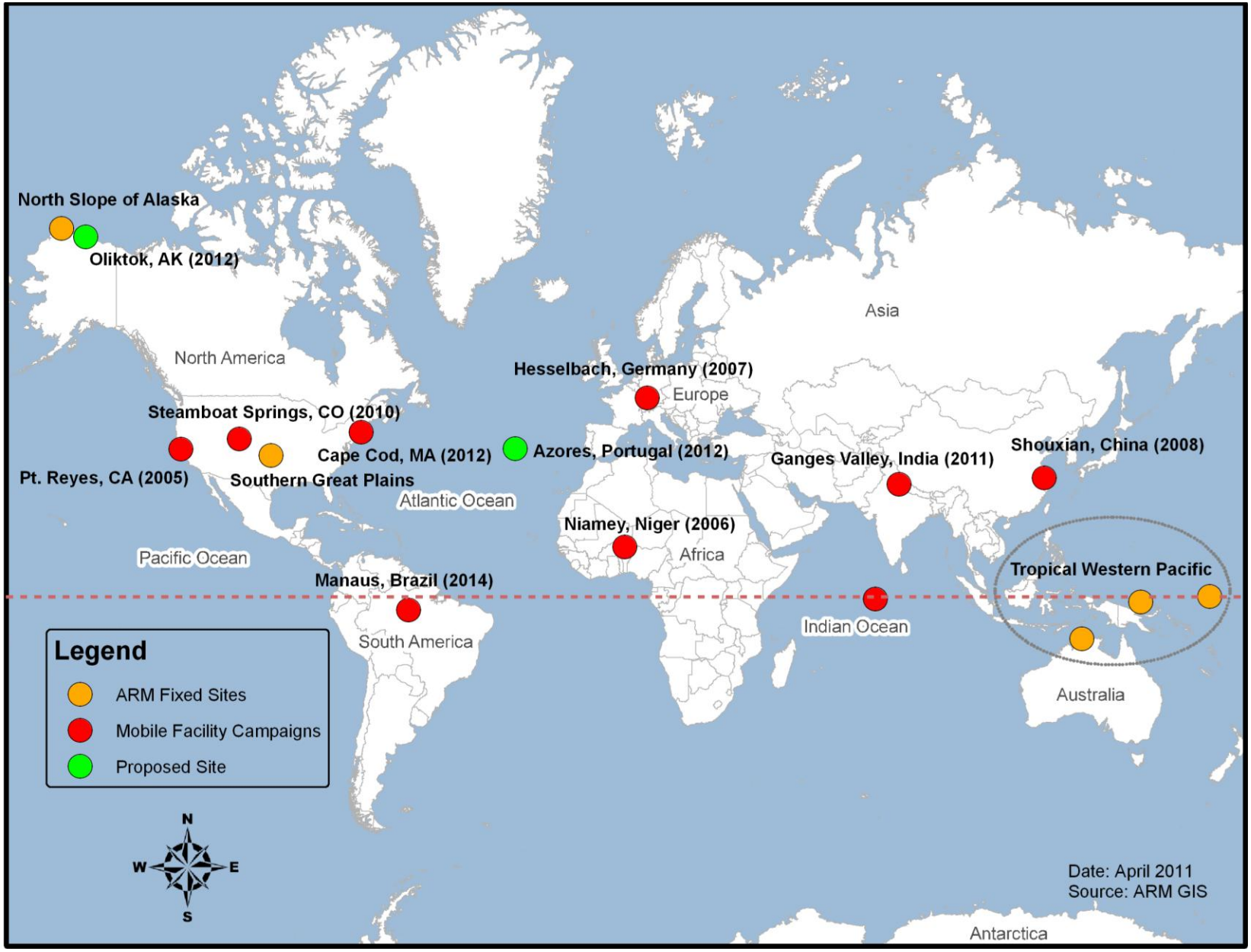
- Provides the world's most comprehensive 24/7 observational capabilities for obtaining atmospheric data for climate change research.
- Data transformed understanding of aerosol-cloud interactions. Built most advanced parameterizations of atmospheric radiative transfer.
- Facility operates highly instrumented ground stations worldwide studying cloud formation, aerosol processes and their influence on radiative transfer.
- In FY12 will deploy new suite of measurement capabilities to regions of high scientific interest, e.g., the Azores (marine clouds) and Alaska (Arctic clouds & aerosols over land, sea, and ice).



Scanning Cloud Radar with Data Plot

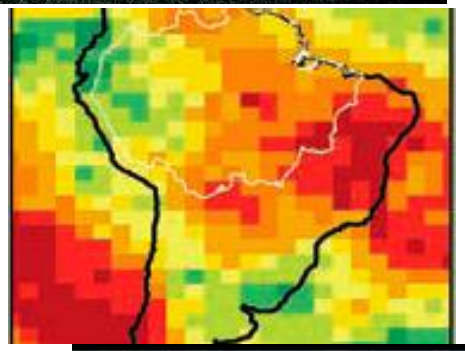

The challenge of studying radiative transfer on land-ice-atmosphere-water in the Arctic

ARM Climate Research Facility



Observations and Modeling of the Green Ocean Amazon

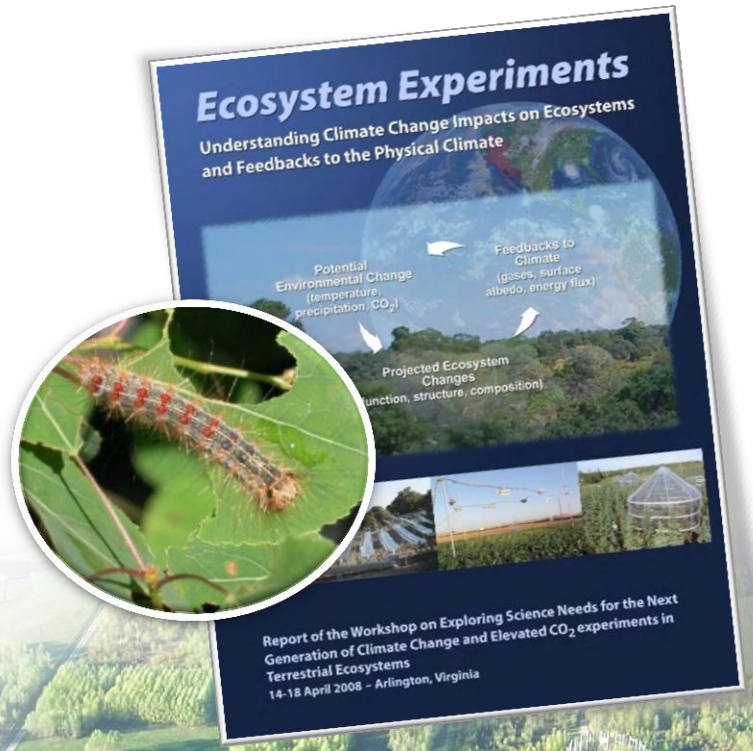
- The Amazon Basin is one of the primary heat engines of the Southern Hemisphere but is currently not well simulated by earth system models.
- In 2014, BER will conduct an integrated experiment, GreenOceanAmazon2014, to observe, analyze, and model the coupled biosphere-atmosphere system.
- The goal is to improve understanding of cloud-aerosol-precipitation interactions including the role of biological material directly released from rainforest biota.
- BER is building collaborations with Brazilian and other agency and international partners
- **http://www.arm.gov/campaigns/aaf2014amazon**




Map
Satellite
Hybrid
Custom
ATTO Tower
FLUXNET- BR Ma1
FLUXNET- BR Ma2
Potential Site
Manuas
ARM Site
Ponta Pelada
Manacapuru
20 mi
50 km
Google
Imagery ©2011 TerraMetrics - Terms of e

Long-term, ecosystem-scale experiments

- Hallmark of DOE science: Long-term, ecosystem-scale experiments manipulating temperature, precipitation, and CO_2 levels
- Predict vulnerability of terrestrial ecological systems to projected changes in climate and atmospheric composition
- Determine the role of soil microbial processes and communities in the ecosystem changes and feedbacks
- Determine the feedbacks from ecosystems to the atmosphere and climate
- Reduce critical uncertainties, and improve representation of fundamental processes within ecological models
- **Proposed next-generation ecosystem experiments: Arctic and tropics**



FY2012: Science for Innovation and Clean Energy in Biological and Environmental Research

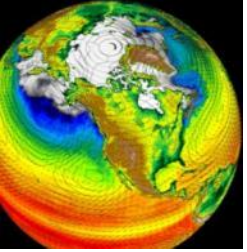
Employing biotechnology, advanced measurement technologies, computation, modeling and simulation in pursuit of disruptive technologies: applications of 21st century science to long-standing barriers in energy technologies.

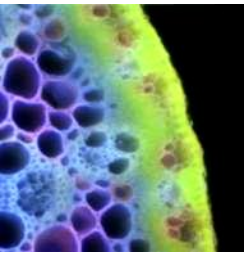
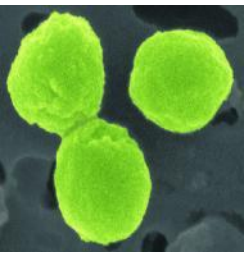
- ***Biosystems by design*** combining the development of new molecular toolkits for understanding natural systems with testbeds for the design and construction of improved biological components or new biohybrid systems and processes for improved biofuels and bioproducts.

- ***Computational tools*** to develop a systems biology knowledgebase that integrates and makes accessible diverse data types and data sets for development into models that accurately describe and predict the behavior of complex biological systems.

- ***3D measurements of clouds and aerosols*** over land, sea and ice in the Arctic to better understand these major uncertainties in the climate system in a region that is a bell weather for global climate change.

- ***Cross discipline ecosystem experiments*** in the Arctic tundra that leverage capabilities in long-term ecosystem research including warming, carbon cycle dynamics, biogeochemistry and microbial genomics.



Systems science to meet DOE mission needs in bioenergy, climate and the environment.

http://science.energy.gov/ber

Thank you!

Sharlene Weatherwax
Sharlene.Weatherwax@science.doe.gov