US-China Biofuels Cooperation

Study Tour for the China NEA

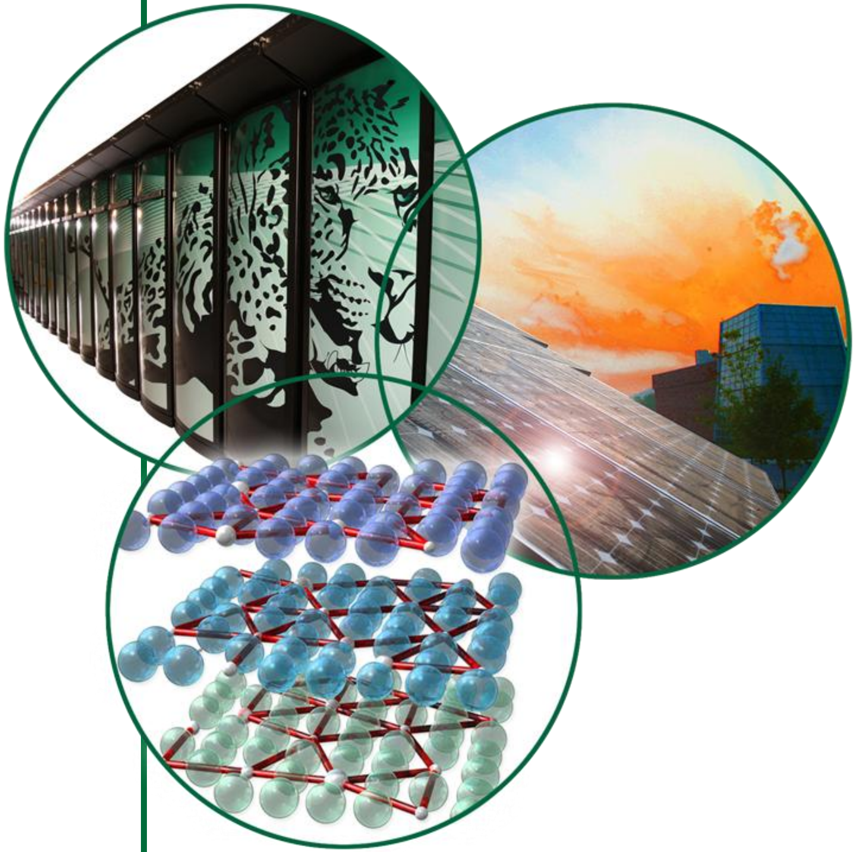
Tennessee • December 6, 2010

WIRELESS CODE HIL866

Oak Ridge National Laboratory:
Science and Technology for the Energy Challenge

Robin Graham
Groupleader
Renewable Energy Systems
Environmental Sciences Division

December 6, 2010



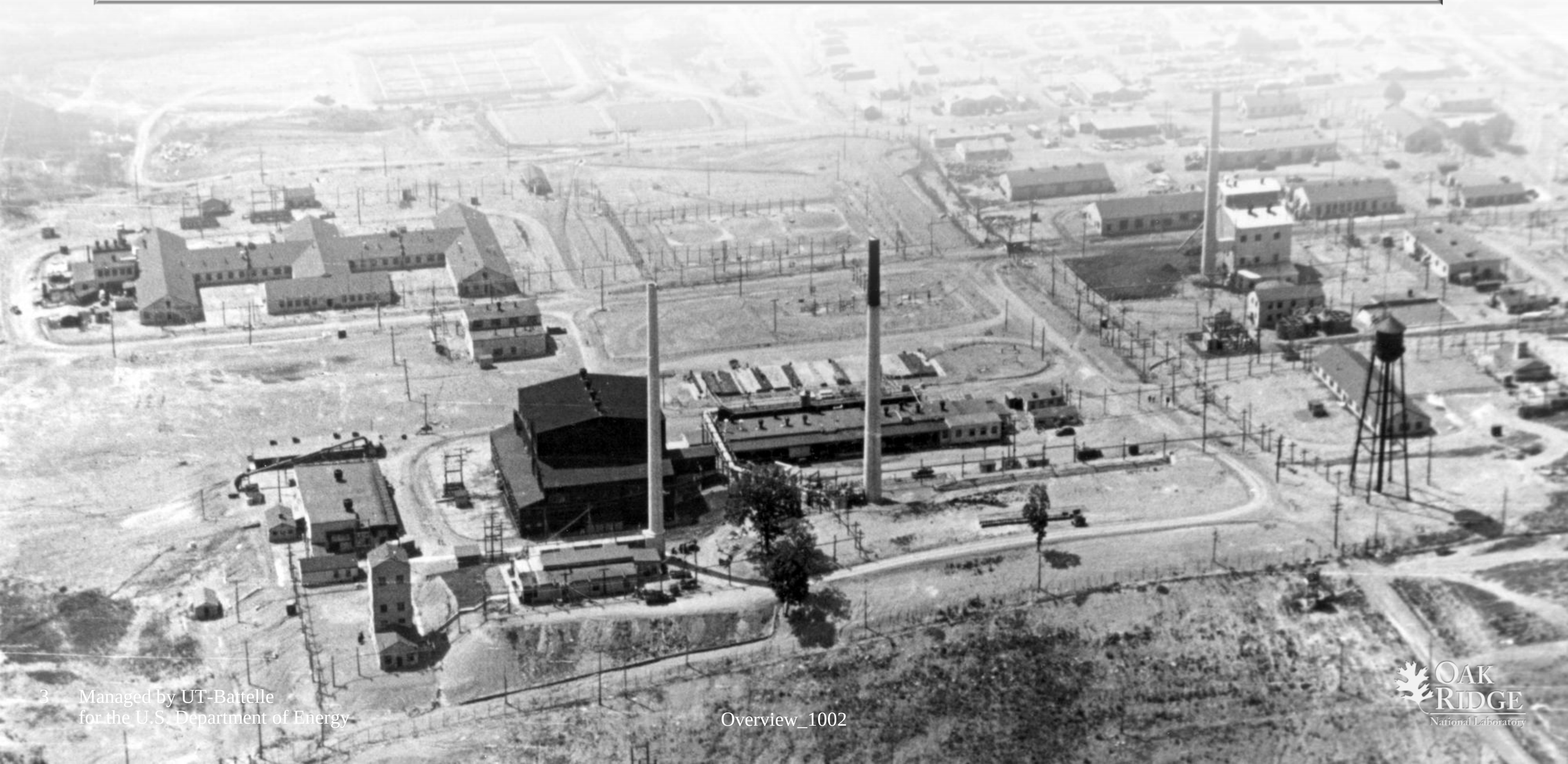
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Oak Ridge National Laboratory evolved from the Manhattan Project

ORNL in 1943

The Clinton Pile was the world's first continuously operated nuclear reactor



Today, ORNL is DOE's largest science and energy laboratory

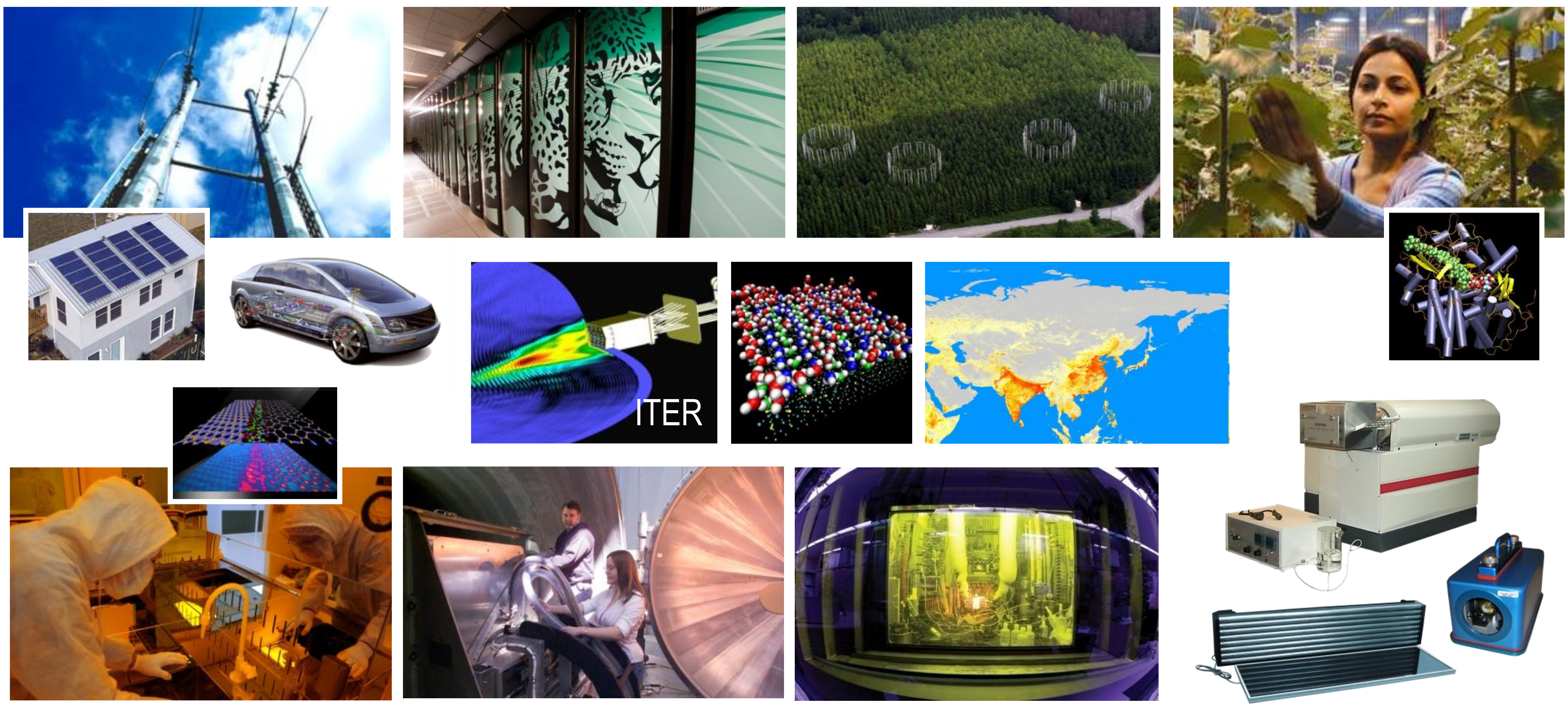
- $1.65B budget
- 4,500 employees
- 4,000 research guests annually
- $500 million invested in modernization

- Nation's largest concentration of open source materials research
- World's most intense pulsed neutron source and a world-class research reactor

- World's most powerful open scientific computing facility
- Nation's most diverse energy portfolio
- Managing the billion-dollar U.S. ITER project

Delivering science and technology:
We lead major R&D programs for DOE and other customers

Energy technologies | Ultrascale computing | Climate | Bioenergy



Materials at the nanoscale | Neutron sciences | Nuclear energy | National security

Translating science and technology into sustainable energy solutions

Generation

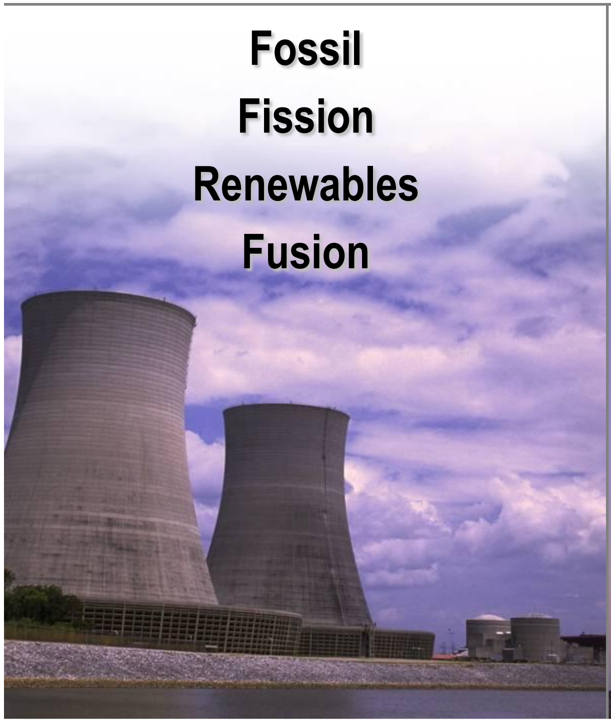
- Fossil
- Fission
- Renewables
- Fusion

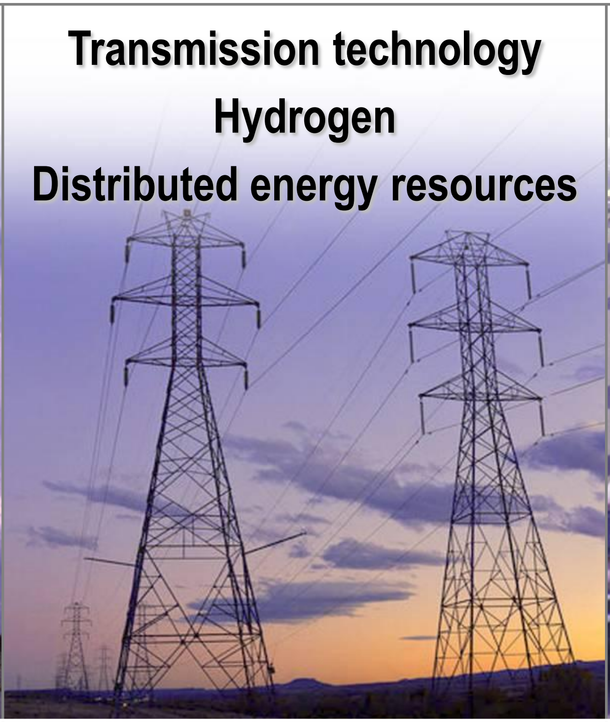
Distribution

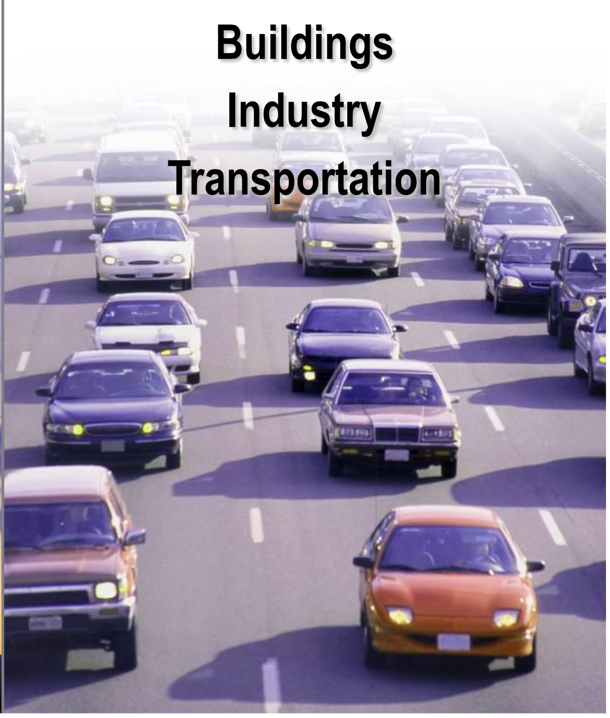
- Transmission technology
- Hydrogen
- Distributed energy resources

Consumption

- Buildings
- Industry
- Transportation







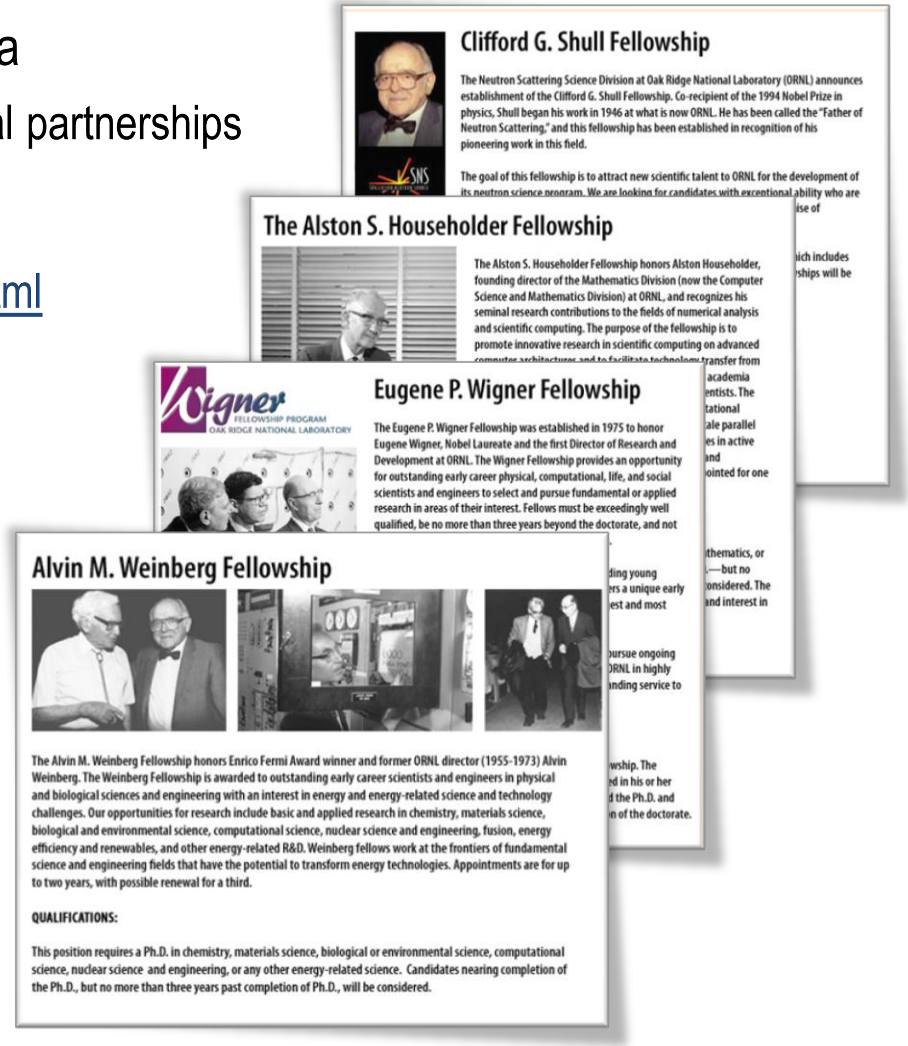
Strong university partnerships are critical to ORNL's success

Major projects	Collaborative research	Joint hiring	Joint institutes	Outreach
• BioEnergy Science Center • NSF Track 2 computer • 4 SNS instruments led by university consortia • Energy Frontier Research Centers	• Projects with 200+ universities • Hundreds of joint research publications	• 62 joint faculty members with 8 universities	• Heavy ion research • Neutron sciences • Biological sciences • Computational sciences	• Mentor/protégé agreements with HBCUs • Distance education with Morehouse College • DOE SERCh poster competition

UT · Duke University · Virginia Tech · NC State University · University of Virginia · Georgia Tech · Vanderbilt · Florida State University · ORAU

A variety of robust programs support these partnerships

- Collaborative research across ORNL's agenda
  - From bench-level collaborations to multinational partnerships
- Distinctive scientific user facilities
  - http://www.ornl.gov/ornlhome/user_facilities.shtml
- Research and educational opportunities for faculty, students, and recent graduates
  - jobs.ornl.gov



Clifford G. Shull Fellowship

The Neutron Scattering Science Division at Oak Ridge National Laboratory (ORNL) announces establishment of the Clifford G. Shull Fellowship. Co-recipient of the 1994 Nobel Prize in physics, Shull began his work in 1946 at what is now ORNL. He has been called the "Father of Neutron Scattering," and this fellowship has been established in recognition of his pioneering work in this field.

The goal of this fellowship is to attract new scientific talent to ORNL for the development of its neutron science program. We are looking for candidates with exceptional ability who are

The Alston S. Householder Fellowship

The Alston S. Householder Fellowship honors Alston Householder, founding director of the Mathematics Division (now the Computer Science and Mathematics Division) at ORNL, and recognizes his seminal research contributions to the fields of numerical analysis and scientific computing. The purpose of the fellowship is to promote innovative research in scientific computing on advanced

Eugene P. Wigner Fellowship

Wigner FELLOWSHIP PROGRAM OAK RIDGE NATIONAL LABORATORY

The Eugene P. Wigner Fellowship was established in 1975 to honor Eugene Wigner, Nobel Laureate and the first Director of Research and Development at ORNL. The Wigner Fellowship provides an opportunity for outstanding early career physical, computational, life, and social scientists and engineers to select and pursue fundamental or applied research in areas of their interest. Fellows must be exceedingly well qualified, be no more than three years beyond the doctorate, and not

Alvin M. Weinberg Fellowship

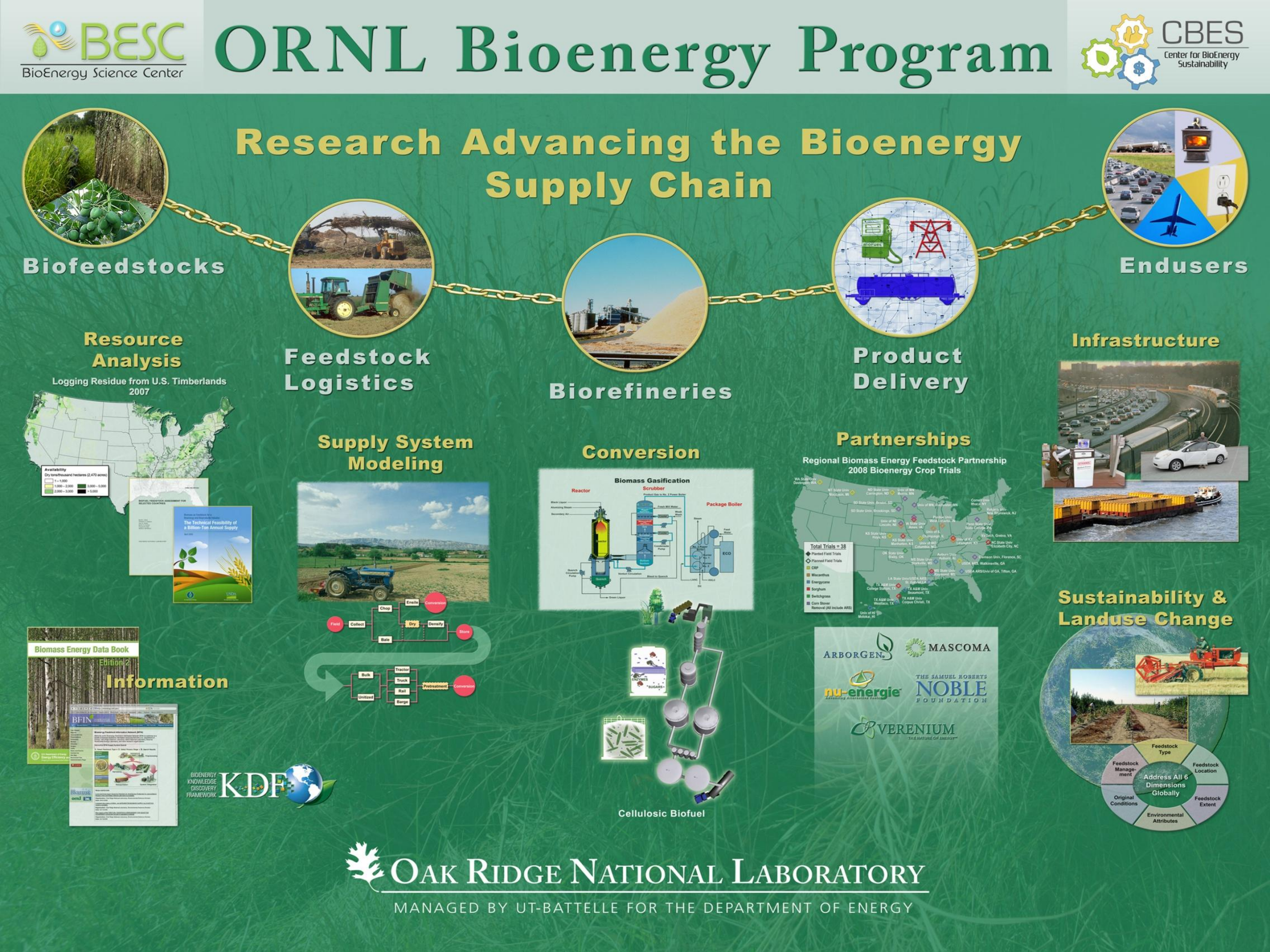
The Alvin M. Weinberg Fellowship honors Enrico Fermi Award winner and former ORNL director (1955-1973) Alvin Weinberg. The Weinberg Fellowship is awarded to outstanding early career scientists and engineers in physical and biological sciences and engineering with an interest in energy and energy-related science and technology challenges. Our opportunities for research include basic and applied research in chemistry, materials science, biological and environmental science, computational science, nuclear science and engineering, fusion, energy efficiency and renewables, and other energy-related R&D. Weinberg fellows work at the frontiers of fundamental science and engineering fields that have the potential to transform energy technologies. Appointments are for up to two years, with possible renewal for a third.

QUALIFICATIONS:

This position requires a Ph.D. in chemistry, materials science, biological or environmental science, computational science, nuclear science and engineering, or any other energy-related science. Candidates nearing completion of the Ph.D., but no more than three years past completion of Ph.D., will be considered.

ORNL is an international laboratory

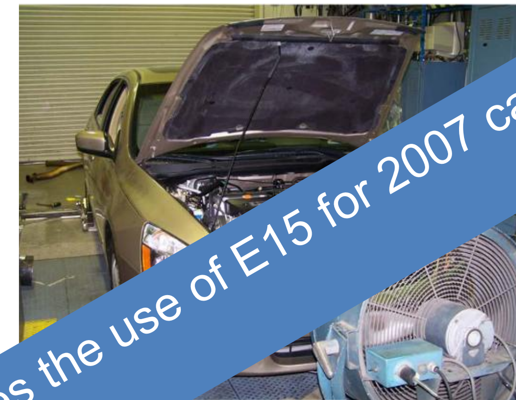
- Our research is enriched by ~150 international collaborations
  - In 2009, we hosted more than 6,000 visitors from 112 other nations
- Our staff annually make ~1,000 trips to other nations
- About 35% of our research staff are citizens of other nations, representing some 80 countries
- About 25% of papers by ORNL authors have a coauthor from another nation


BESC
BioEnergy Science Center
ORNL Bioenergy Program
CBES
Center for BioEnergy Sustainability
Research Advancing the Bioenergy Supply Chain
Biofeedstocks
Feedstock Logistics
Biorefineries
Product Delivery
Endusers
Resource Analysis
Logging Residue from U.S. Timberlands 2007
Feedstock Logistics
Supply System Modeling
Field
Collect
Chop
Ensile
Conversion
Dry
Densify
Store
Bale
Bulk
Truck
Rail
Barge
Tractor
Unitized
Pretreatment
Conversion
Conversion
Biomass Gasification
Reactor
Scrubber
Package Boiler
Cellulosic Biofuel
Partnerships
Regional Biomass Energy Feedstock Partnership
2008 Bioenergy Crop Trials
Total Trials = 38
ArborGen
MASCOMA
nu-energie
THE SAMUEL ROBERTS NOBLE FOUNDATION
VERENIUM
Infrastructure
Sustainability &
Landuse Change
Feedstock Type
Feedstock Location
Feedstock Extent
Environmental Attributes
Original Conditions
Feedstock Management
Address All 6 Dimensions Globally
Biomass Energy Data Book
Edition 2
Information
BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK
KDF
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL Bioenergy research impacts the nation

Energy Independence and Security Act of 2007 (EISA)

Vehicle aging and catalyst durability studies



OCT 2010 EPA approves the use of E15 for 2007 cars and newer

Oak Ridge National Laboratory:
Meeting the challenges of the 21st century

Brian Davison

The fully integrated agro-biofuel-biomaterial-biopower cycle for sustainable technologies.

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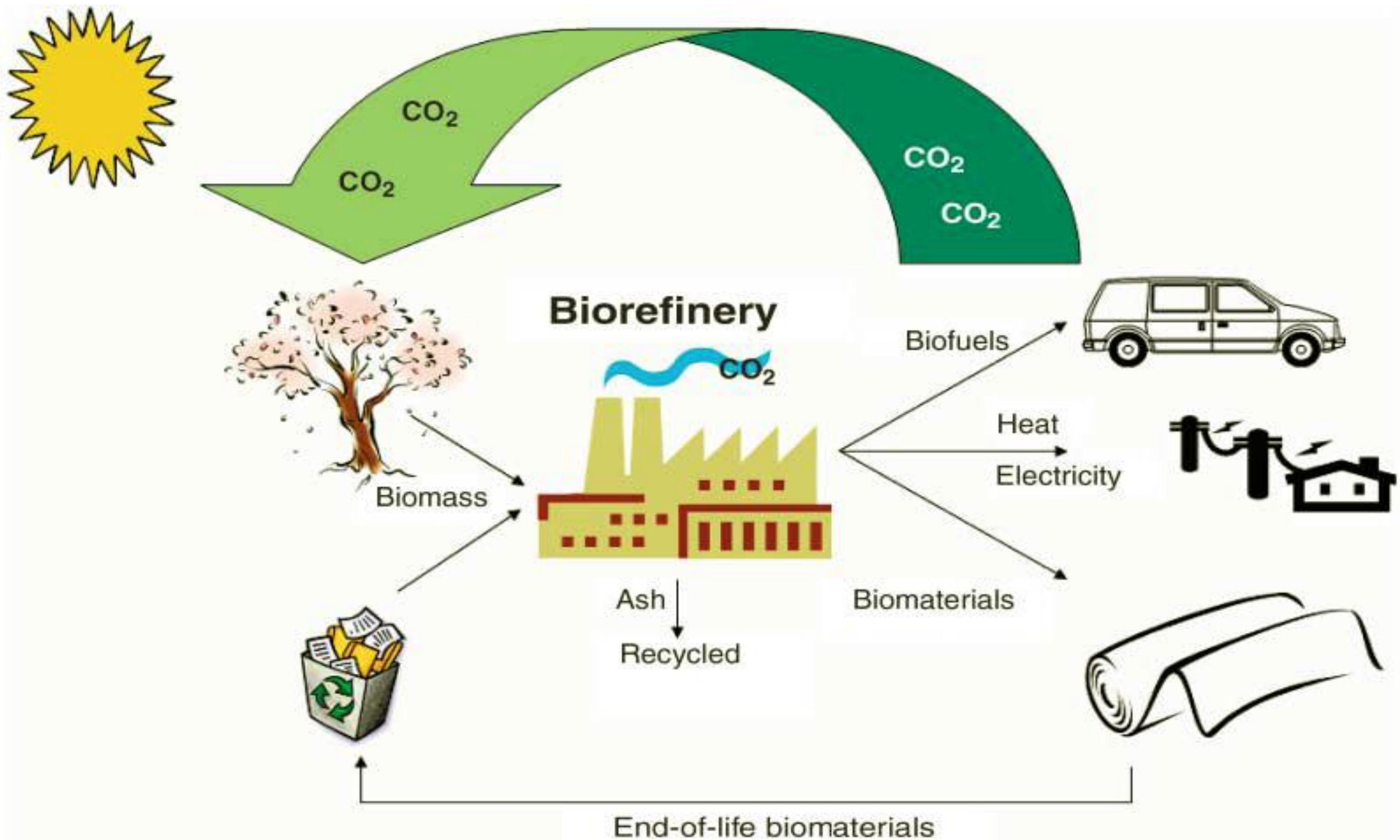

Ragauskas et al. 2006, *SCIENCE* **311**:484-489

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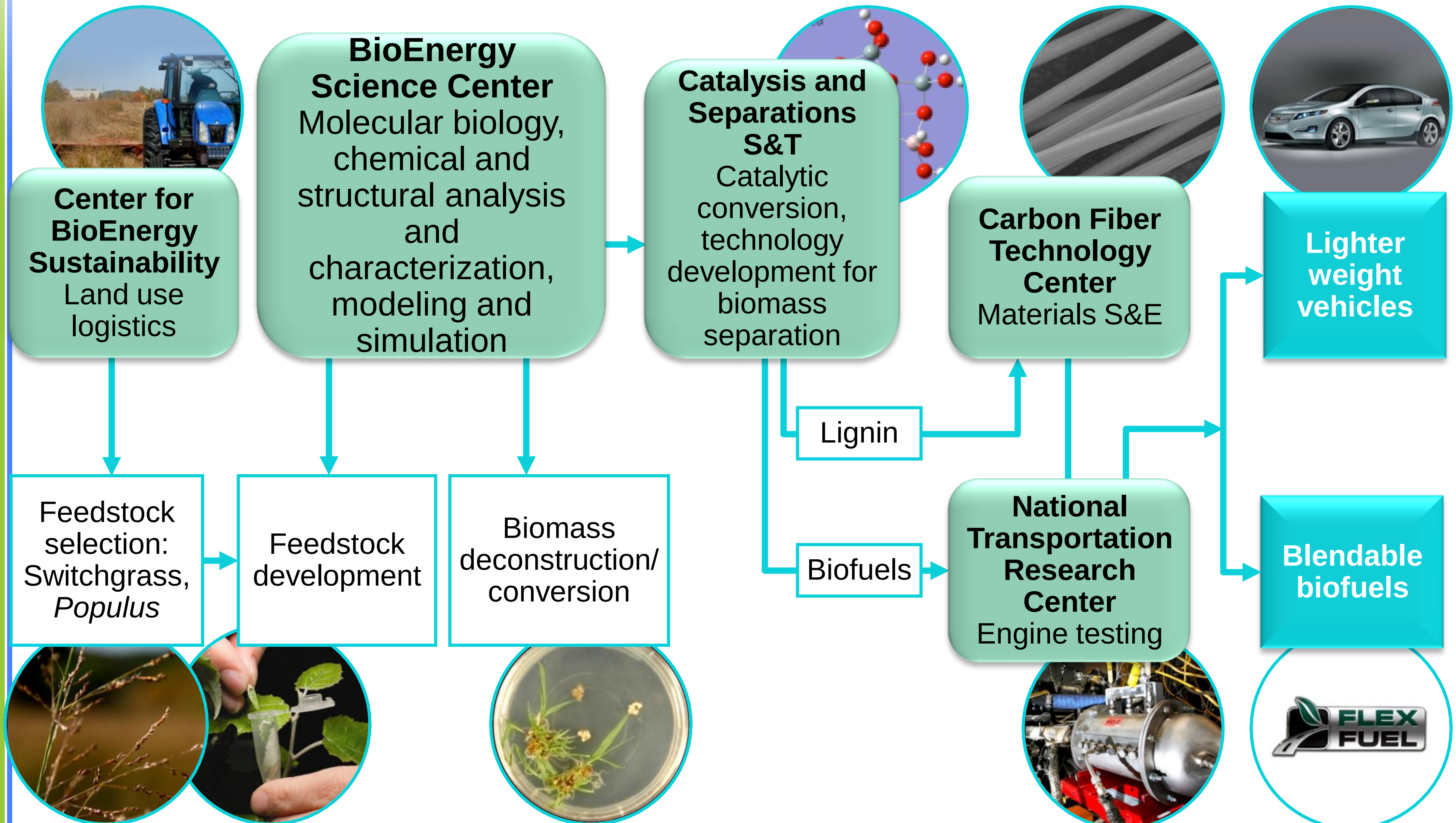
Bioscience and biotechnology for sustainable mobility



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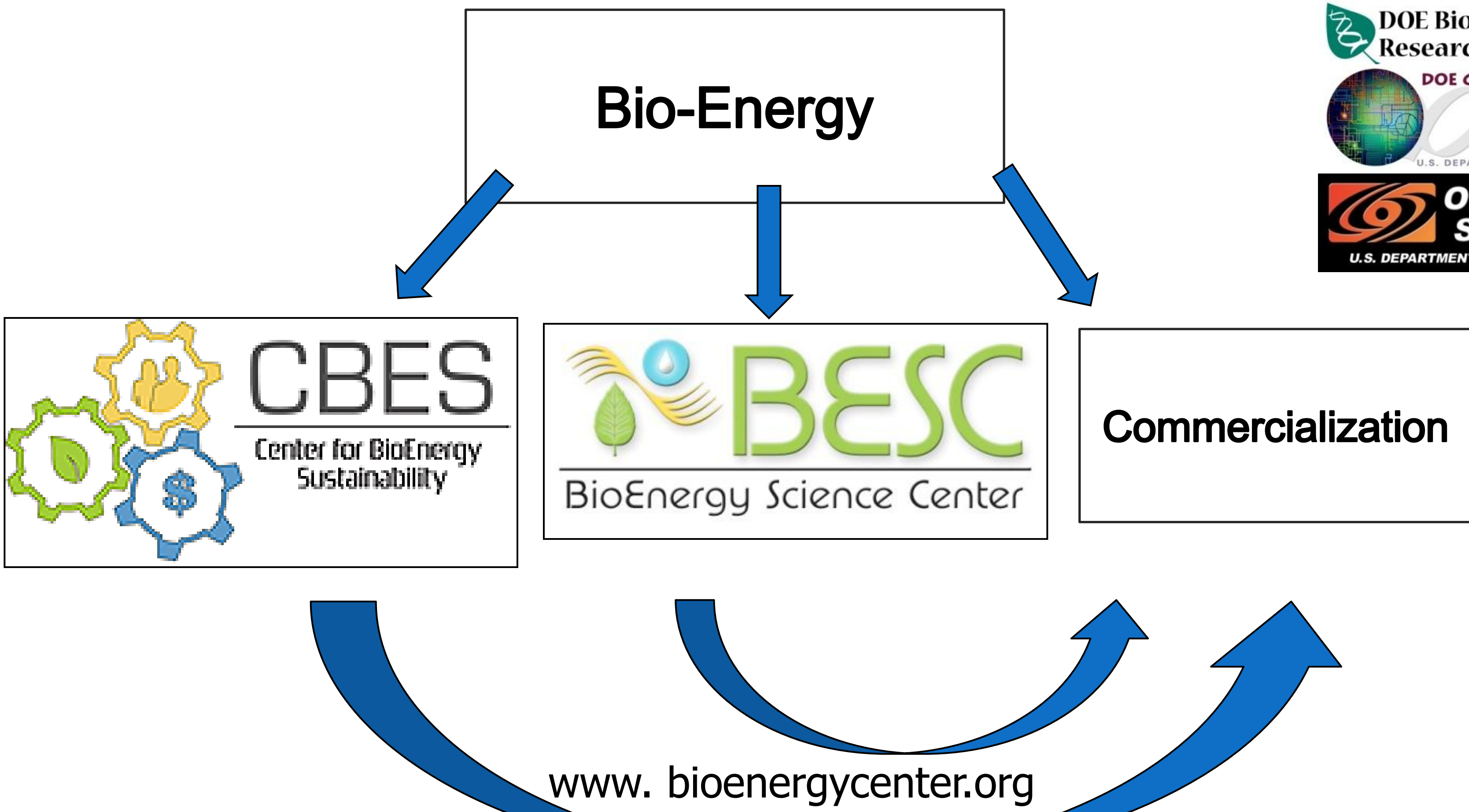
Bio-Energy and Bioproducts at ORNL



www.ornl.gov/sci/besd/cbes

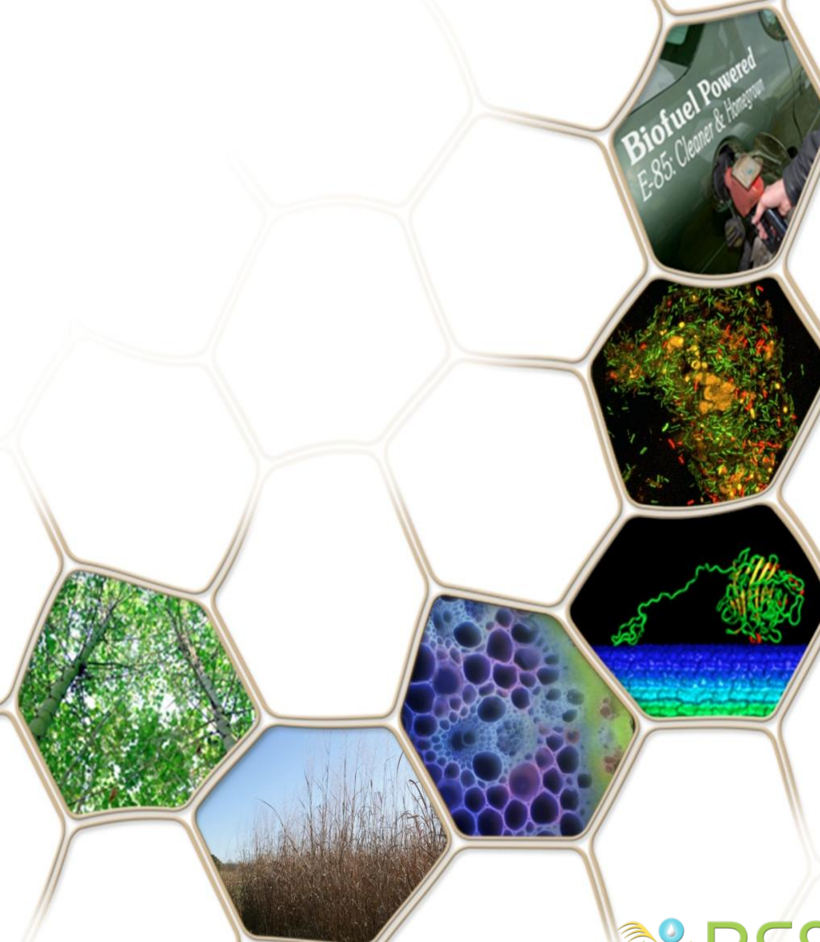
Tech. Transfer
Nat'l Transport. Res. Center
Bioproducts, etc.

Acknowledgements: slides from BESC, Robin Graham, Mark Downing, L. Russo (USDOE-OBP), etc.

BioEnergy Science Center:

An Integrated Strategy to Understand Biomass Recalcitrance

Brian H. Davison
BioEnergy Science Center



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BESC
BioEnergy Science Center

The BioEnergy Science Center

BESC: A multi-institutional DOE-funded center dedicated to understanding and modifying plant biomass recalcitrance

- Samuel Roberts Noble Foundation
- National Renewable Energy Laboratory
- Brookhaven National Laboratory
- Cornell University
- University of Minnesota
- Washington State University
- University of California–Riverside
- North Carolina State University
- Virginia Polytechnic Institute
- University of California–Los Angeles

- Oak Ridge National Laboratory
- University of Georgia
- University of Tennessee
- Dartmouth College
- West Virginia University
- Georgia Institute of Technology
- ArborGen, LLC
- Ceres, Incorporated
- Mascoma Corporation

322 People in 19 Institutions

Access to the sugars in lignocellulosic biomass is the current critical barrier

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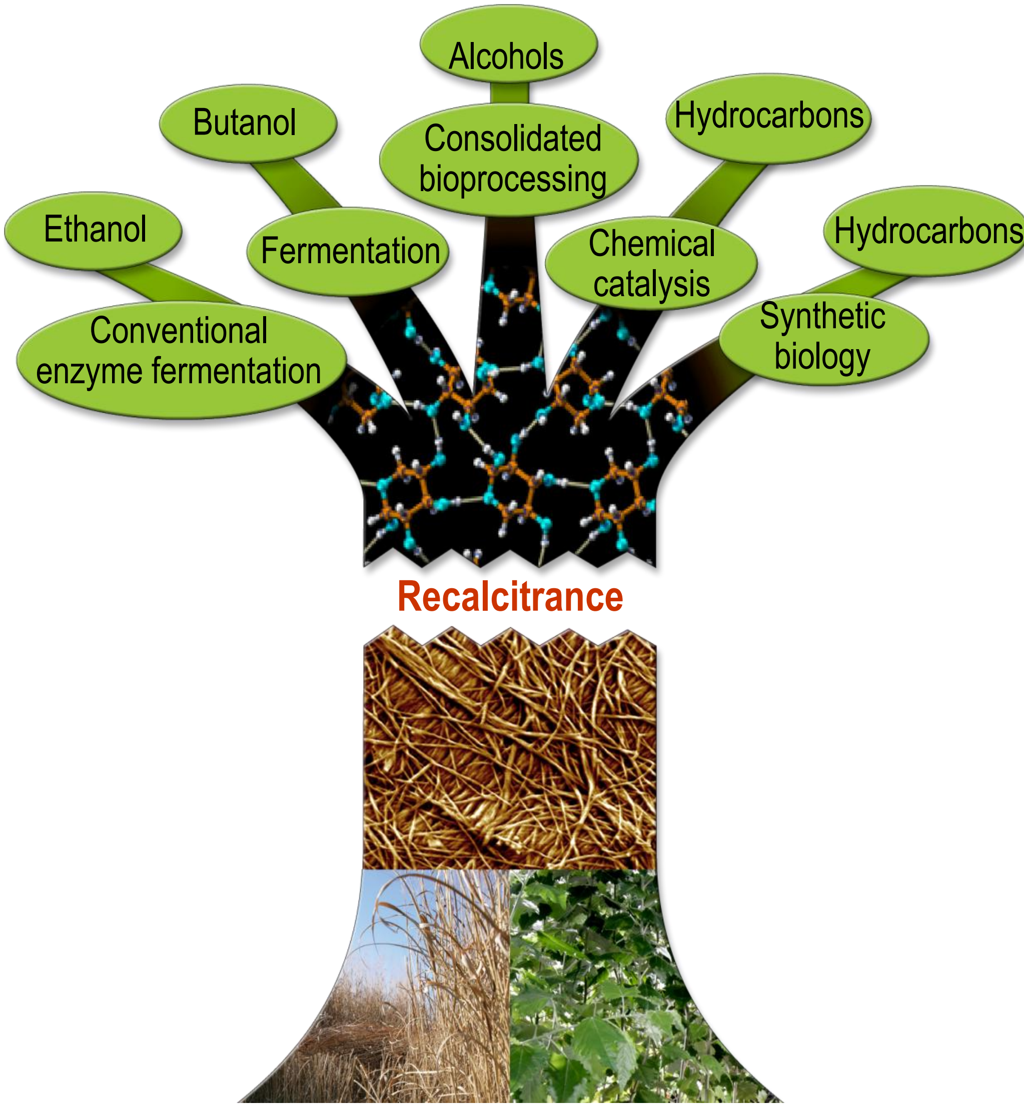

- Overcoming this barrier will cut processing costs significantly and be used in most conversion processes
- This requires an integrated, multi-disciplinary approach

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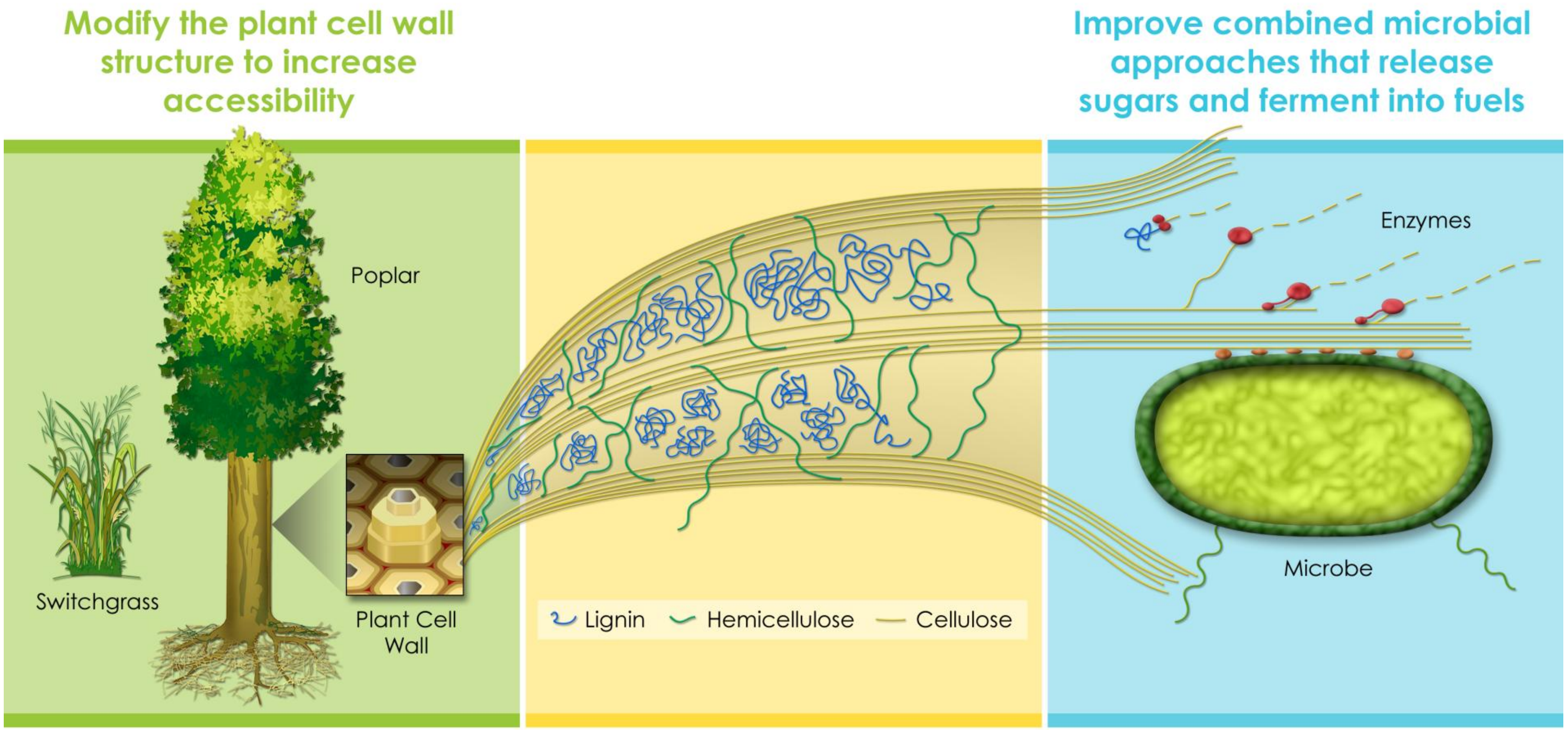
A two-pronged approach to increase the accessibility of biomass sugars



Both utilize rapid screening for relevant traits followed by detailed analysis of selected samples

Genetic block in lignin biosynthesis in switchgrass increases ethanol yields

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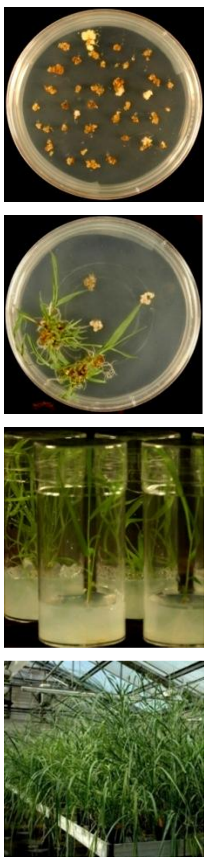
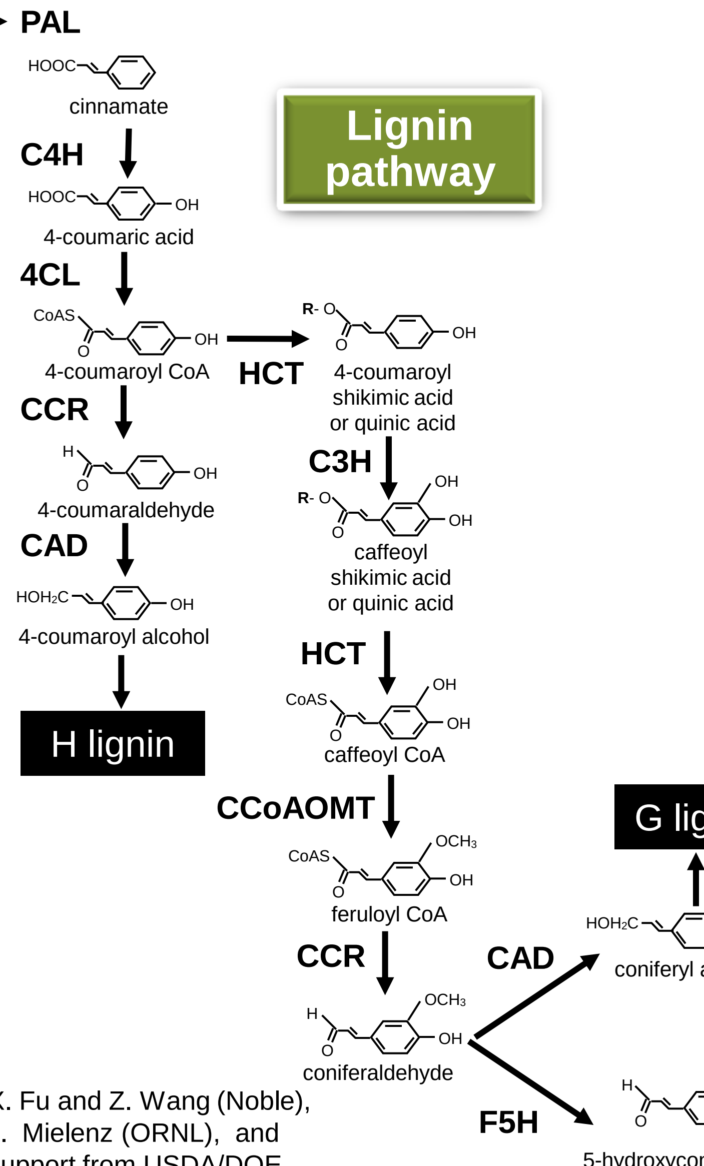
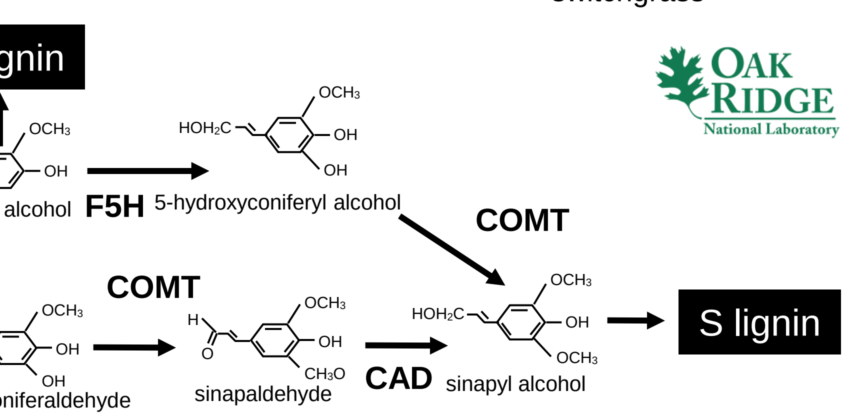
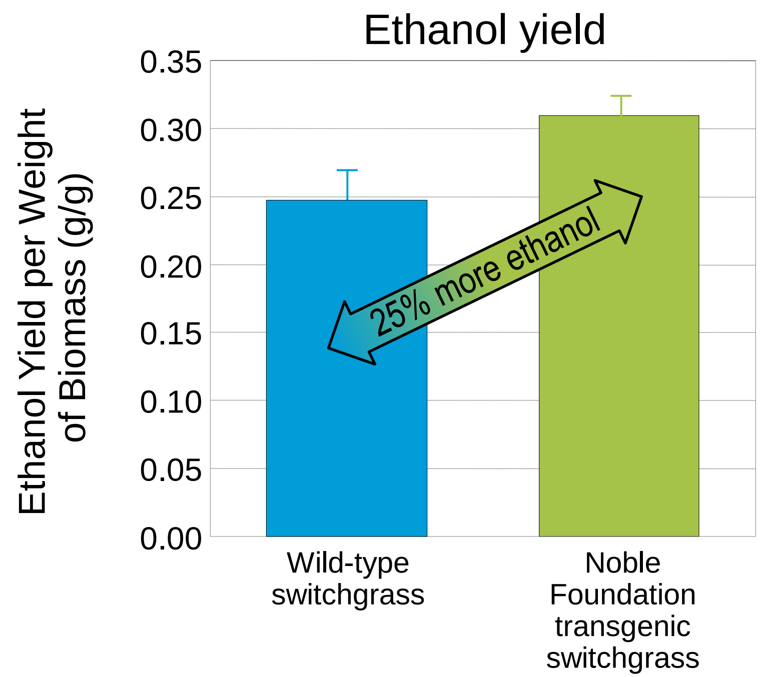
Agrobacterium-mediated transformation of switchgrass









THE SAMUEL ROBERTS NOBLE FOUNDATION

OAK RIDGE National Laboratory

X. Fu and Z. Wang (Noble), J. Mielenz (ORNL), and support from USDA/DOE

Tension Stress Study: Characterization

Spectroscopy
- MBMS
- NMR
- FTIR

- Sugar Release
- Glycome Profile

LIMS
- Sample workflow
- Barcodes

-Omics
- Transcriptomics
- Proteomics
- Metabolomics

- qRT-PCR

Imaging
- WoodCAT
- AFM
- Optical microscope

Mining Variation to Identify Key Genes in Biomass Composition and Sugar Release

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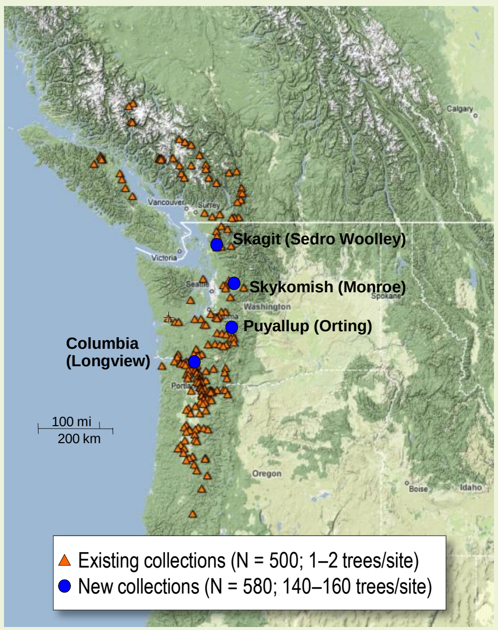
Collected ~1300 samples for *Populus* association and activation-tag study

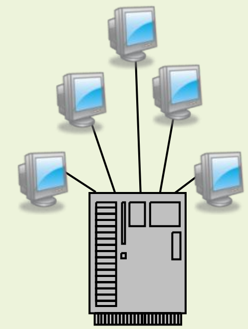


High-throughput screening pipeline

- Create genetic marker map to identify allelic variation
- Identify marker trait association

Sugar release assay

Cell wall biosynthesis database



Establish common gardens for association and activation-tag populations with thousands of plants

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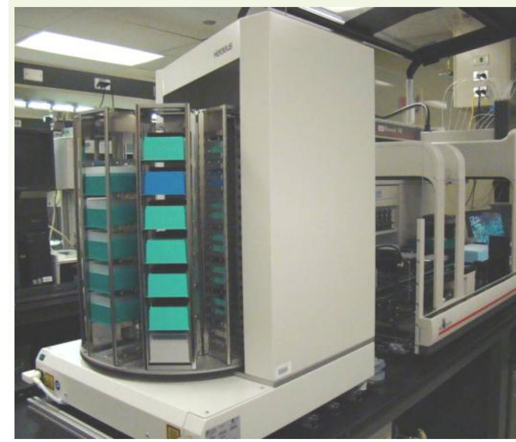
High-Throughput Characterization Pipeline for the Recalcitrance Phenotype

Screening thousands of samples

Composition analytical pyrolysis, IR, confirmed by wet chemistry

Pre-treatment new method with dilute acid and steam

Enzyme digestibility sugar release with enzyme cocktail



Detailed chemical and structural analyses of specific samples

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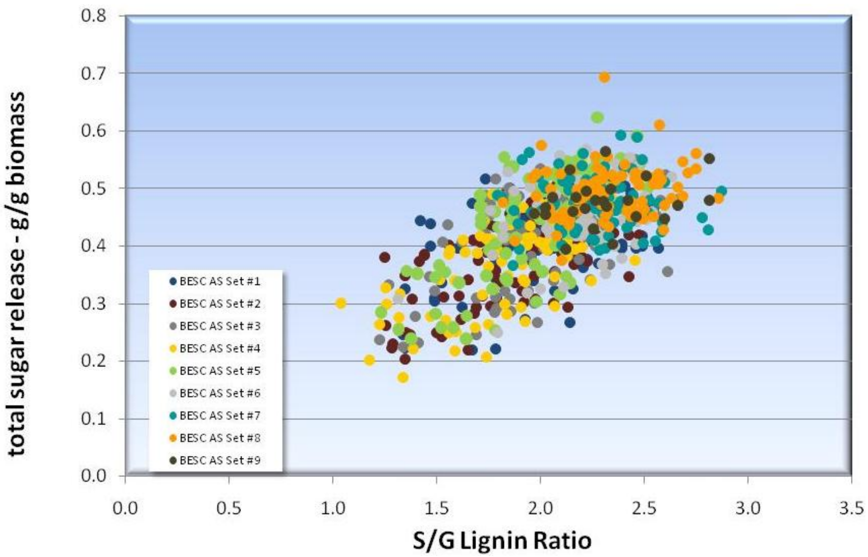
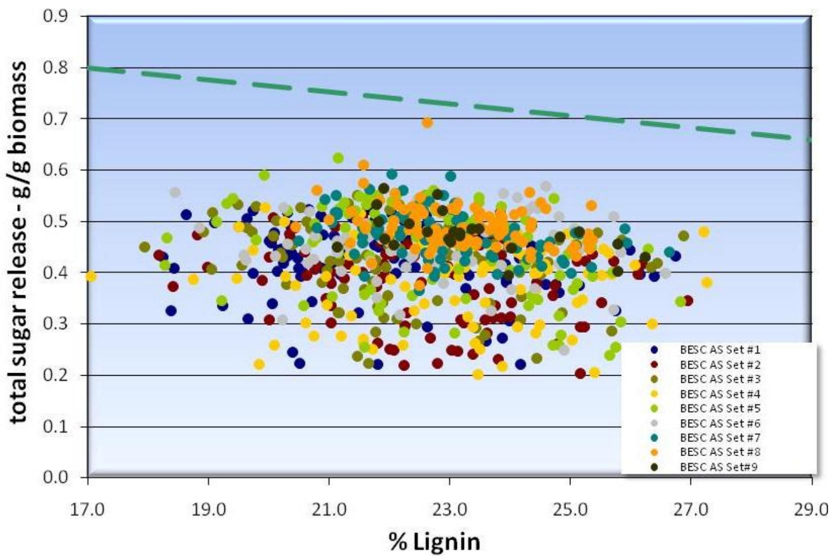
High-Throughput Screening to Analyze Natural *Populus* Trees

- Screening of 1200 natural *Populus* trees shows high natural variability in composition and digestibility
- Hot water as pretreatment only
- Sugar release varies from 25% to >90% of theoretical value





Environmental vs Genetic?

The High-Throughput Pretreatment and Hydrolysis (HTPH) System has Analyzed >10,000 Samples in FY2010 for Composition and Digestibility

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Unique BESC samples submitted and analyzed by HTP pipelines (not including replicates).

	CRCC	ORNL	UCR	Noble	U. Tennessee	Total
Analytical Pyrolysis	138	795	11	140	5248	6332
Recalcitrance	112	807		147	5248	6314

Samples from Industrial, International, and external collaborations.

	ArborGen	Purdue	U. Copenhagen	Edenspace	Total
Analytical Pyrolysis	640	3000			3640
Recalcitrance	24	731	1100	120	1975

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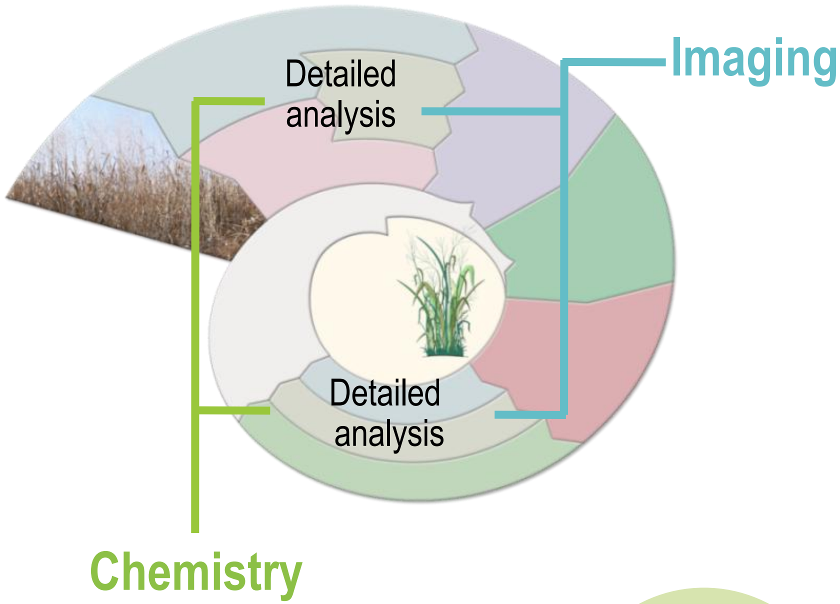
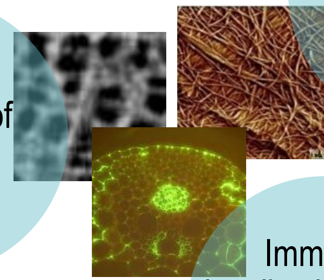
Detailed Analysis of Specific Samples Inform Cell-wall Chemistry and Structure



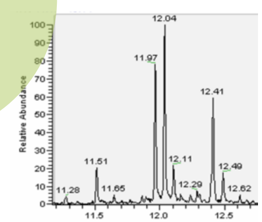
MSAFM: IR spectra of localized cell walls

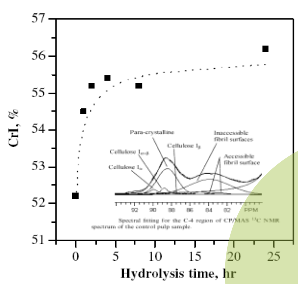


AFM of switchgrass showing cellulose microfibrils

Immuno-localization using wall antibodies on switchgrass

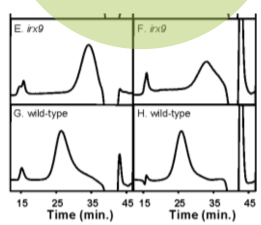
Mass spectrometry for key metabolites



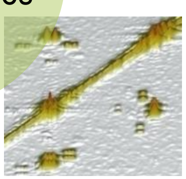


NMR for cellulose crystallinity

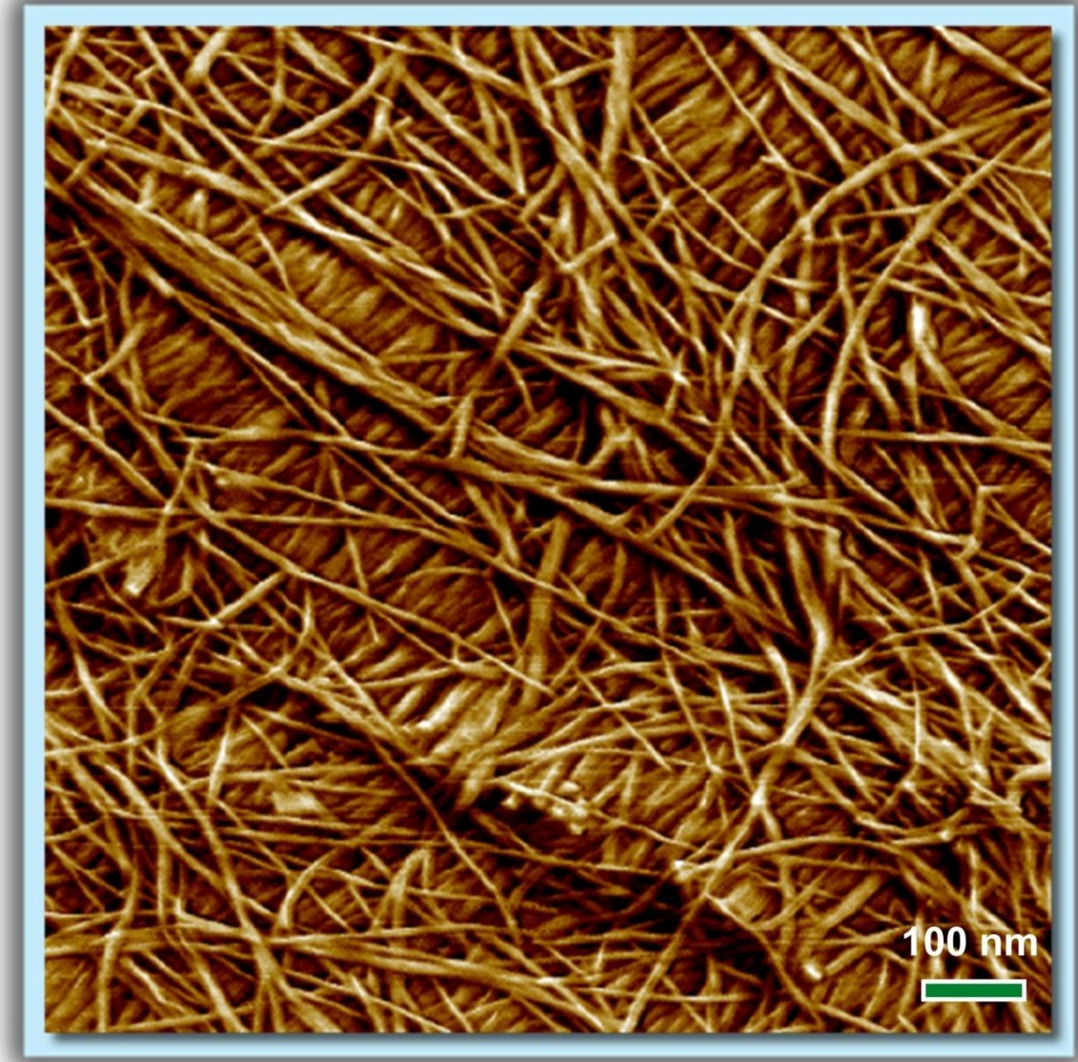
Fractionation and chromatography



2D [1]H-NMR sees altered bonds in polysaccharides and lignin in biomass



Switchgrass – Atomic Force Microscopy (AFM)



Crystalline cellulose microfibrils

NREL, Ding, et al, unpublished results

Enzymatic and microbial hydrolysis

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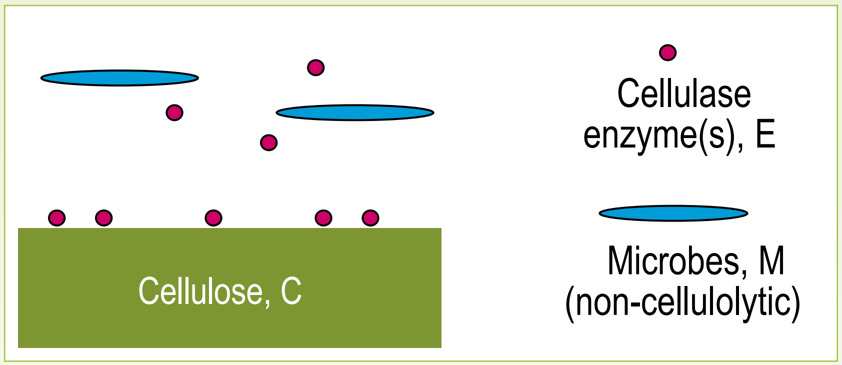
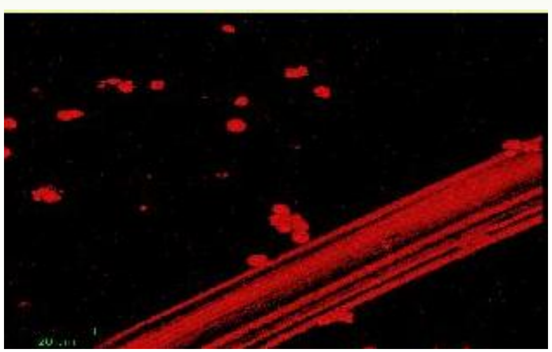
A fundamentally different relationship between microbes and cellulose

Enzymatic hydrolysis (classical approach)

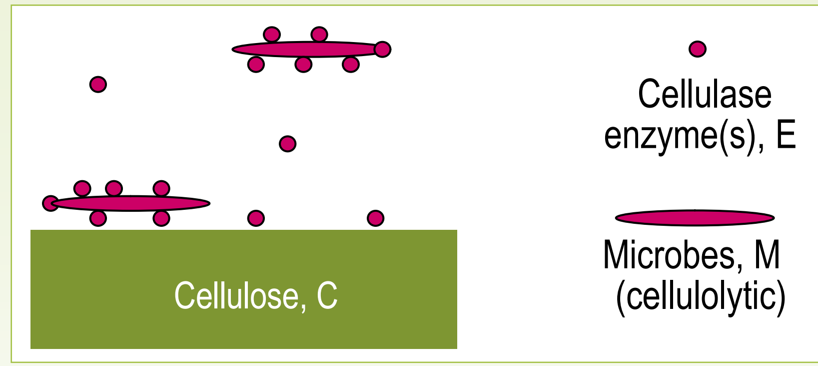


- Hydrolysis mediated by CE complexes
- Enzymes (several) both bound and free
- Cells may or may not be present

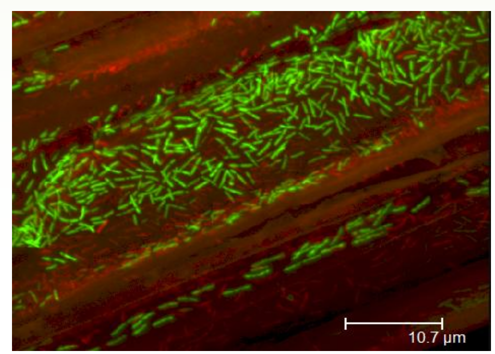


Yeast, enzymes with biomass (Dumitrache and Wolfaardt)

Microbial hydrolysis (CBP)



- Hydrolysis mediated mainly by CEM complexes
- Enzymes both bound and free
- Cells both bound and free



C. thermocellum on poplar (Morrell-Falvey and Raman, ORNL)

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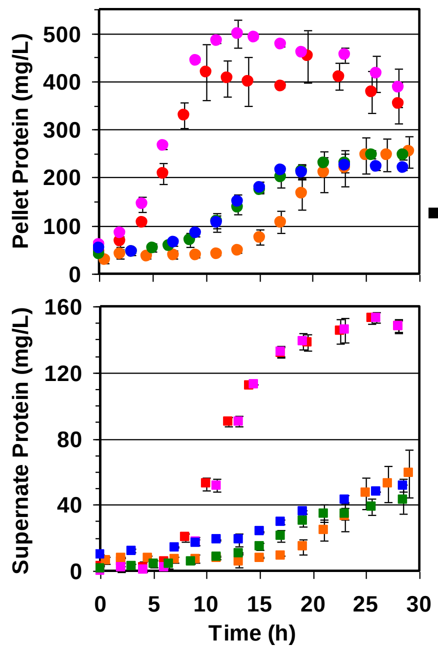
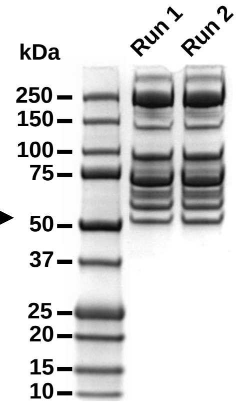
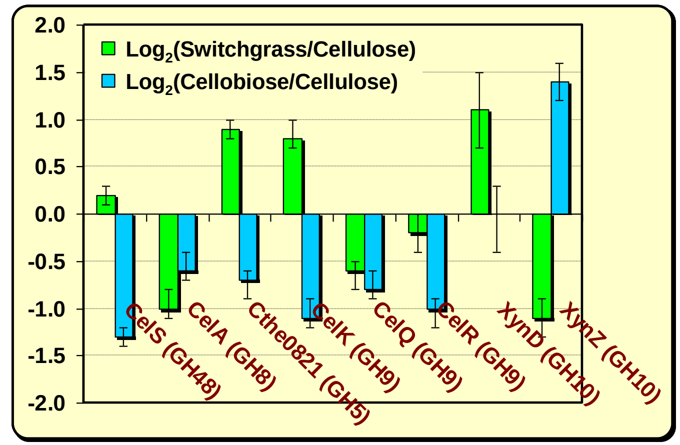
Cellulosome Changes in *C. thermocellum* on Different Biomass Substrates

Fermentation **Affinity Purification** **Shot-gun LC-MS/MS Identification**





Metabolic Labeling Quantitation



- Pretreated Switchgrass
- Cellobiose
- Amorphous Cellulose
- Avicel - ^{14}N
- Avicel - ^{15}N
- Avicel-Pectin
- Avicel-Xylan
- Avicel-Pectin-Xylan

- ***C. thermocellum*** **alters its cellulosome catalytic composition depending upon the growth substrate**
- **We identified and experimentally verified 16 “new” cellulosome components**
- **Insights aid in constructing designer cellulosomes with tailored enzyme composition for industrial ethanol production**

Citation: “Raman B, *et al*. (2009) Impact of Pretreated Switchgrass and Biomass Carbohydrates on *Clostridium thermocellum* ATCC 27405 Cellulosome Composition: A Quantitative Proteomic Analysis. PLoS ONE 4(4): e5271. doi:10.1371/journal.pone.0005271”

BioEnergy Science Center

Biodiversity Access for New Biocatalysts

- Hypothesis: Will higher temperature anaerobic microbes be more effective?
- State-of-the-art cultivation techniques to isolate novel high-temperature microbes with powerful lignocellulolytic enzymes
  - Collect samples from thermal biotopes
  - Establish primary enrichment cultures at relevant temperatures and conditions

Sampling at Yellowstone National Park October 2007 and July 2008

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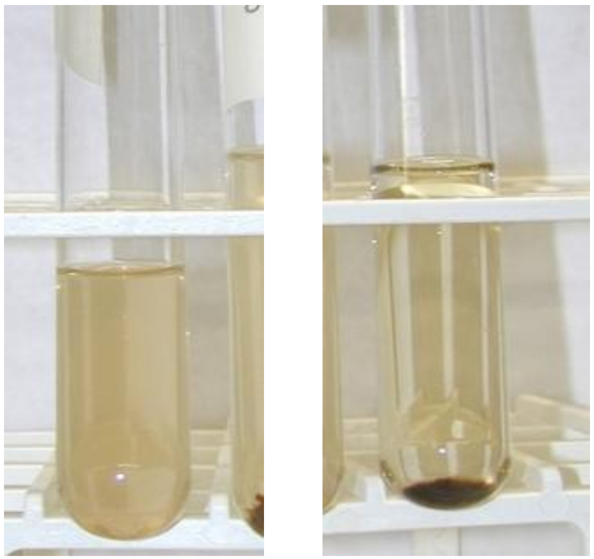
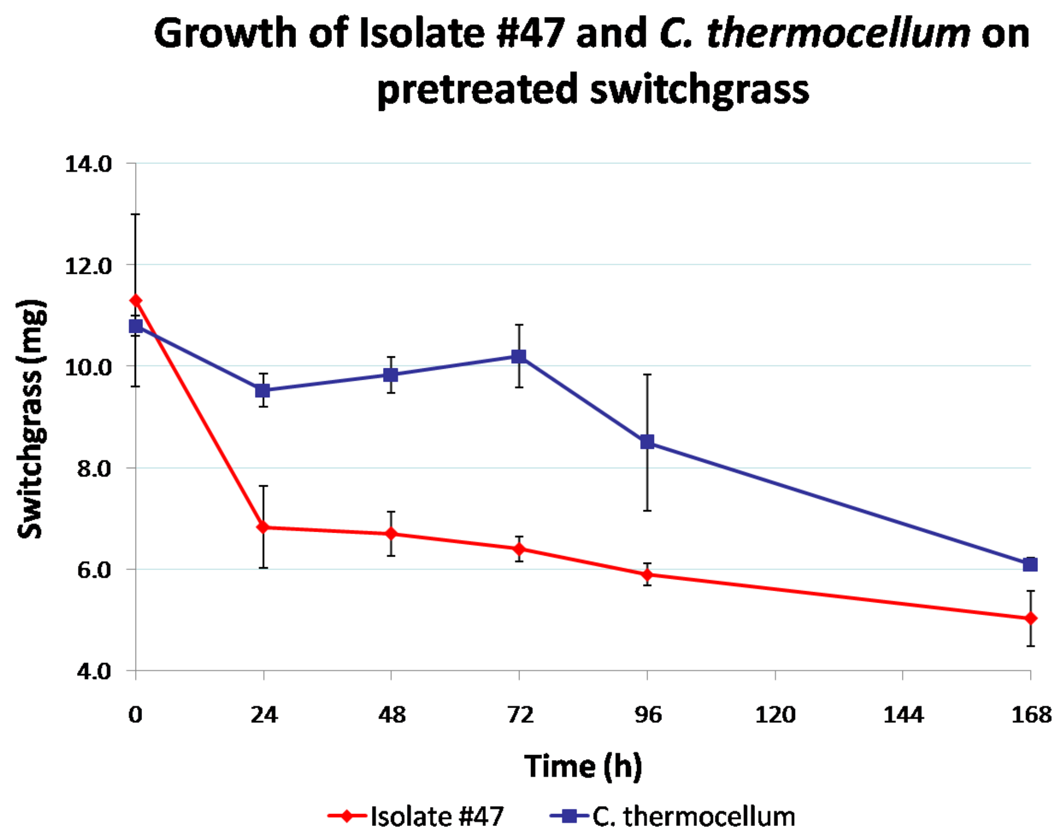
New Isolates Show Enhanced Biomass Hydrolysis Rates



Isolate #47 Control



Preliminary results show visual disappearance of pretreated switchgrass solids during growth at 78˚C relative to a benchmark organism

Elkins et al. - ORNL

OB#47 submitted as Caldicellulosiruptor sp.

CBP organism development yeast

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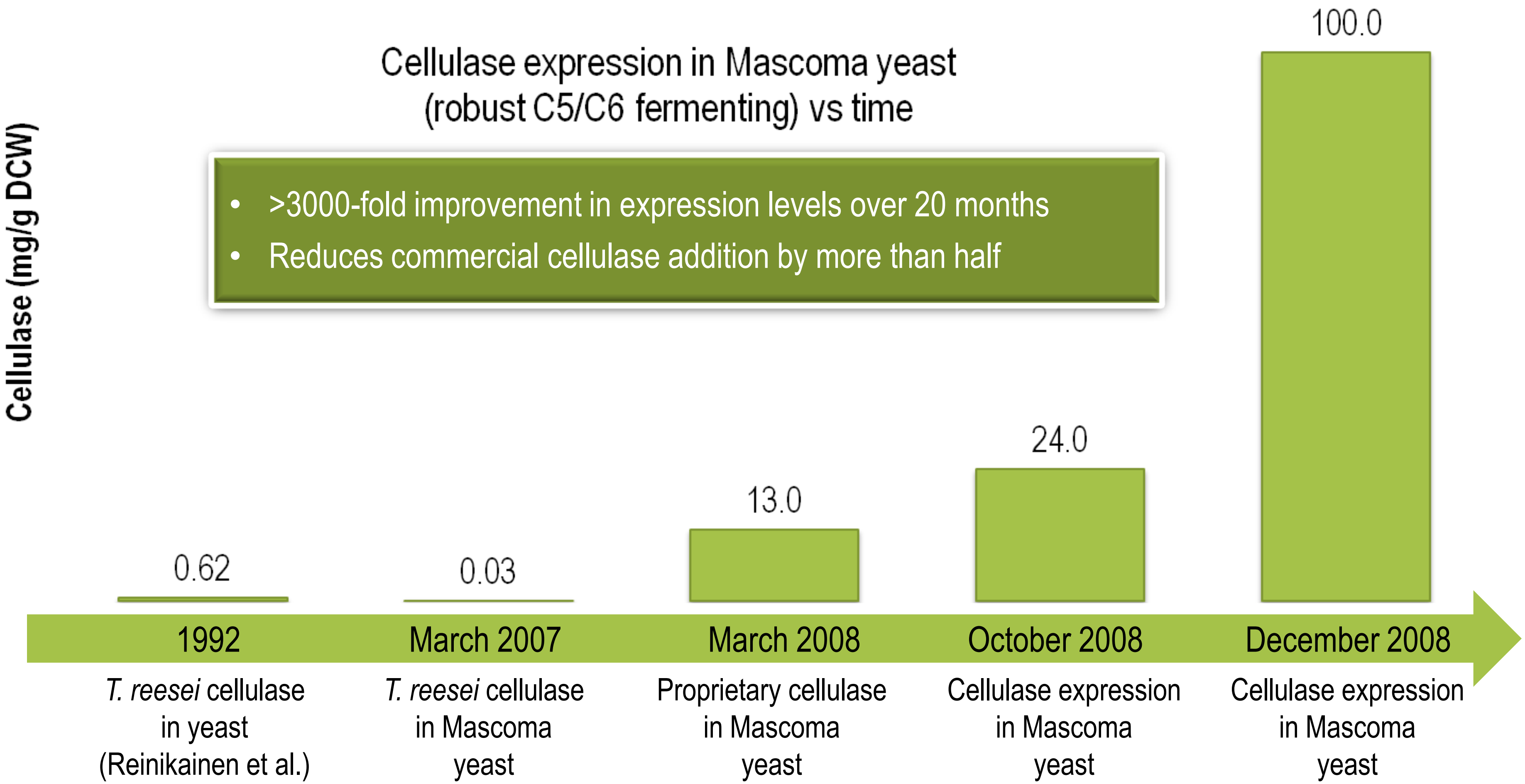

- >3000-fold improvement in expression levels over 20 months
- Reduces commercial cellulase addition by more than half

MASCOMA

BESC BioEnergy Science Center

A Paradigm for Strain Improvement Breaks Down Barriers for Biofuel Production

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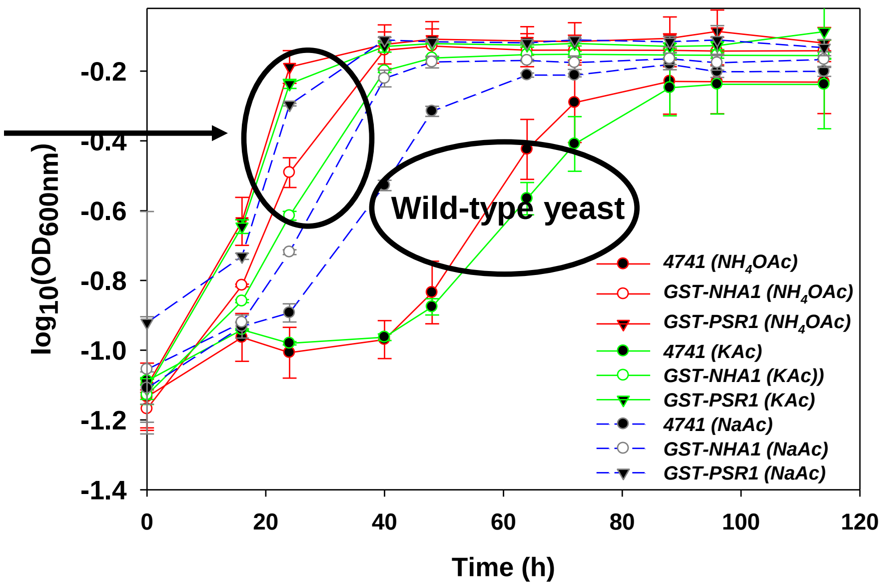
Improved strains

Different acetate salts (pH 5.5)



Contact: Steven Brown, brownsd@ornl.gov

This work is sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory.

The BioEnergy Science Center is a U.S. Department of Energy Bioenergy Research Center supported by the Office of Biological and Environmental Research in the DOE Office of Science.

Problem/Summary: **A core challenge in converting cellulosic material to biofuels such as ethanol and butanol is the recalcitrance of biomass to breakdown. Severe biomass pretreatments are required to release the sugars. These processes also generate a range of inhibitory chemicals such as acetate and can increase biofuel costs.**

One approach to overcome inhibition utilizes inhibitor-tolerant microorganisms for efficient fermentation of lignocellulosic material to biofuels. Their utility is considered an industrial requirement.

Technology Application: **This invention relates to microorganisms that display enhanced resistance to acetate as a result of increased expression of an antiporter gene, and are therefore advantageous for use in fermentation of biomass materials to produce biofuels such as ethanol.**

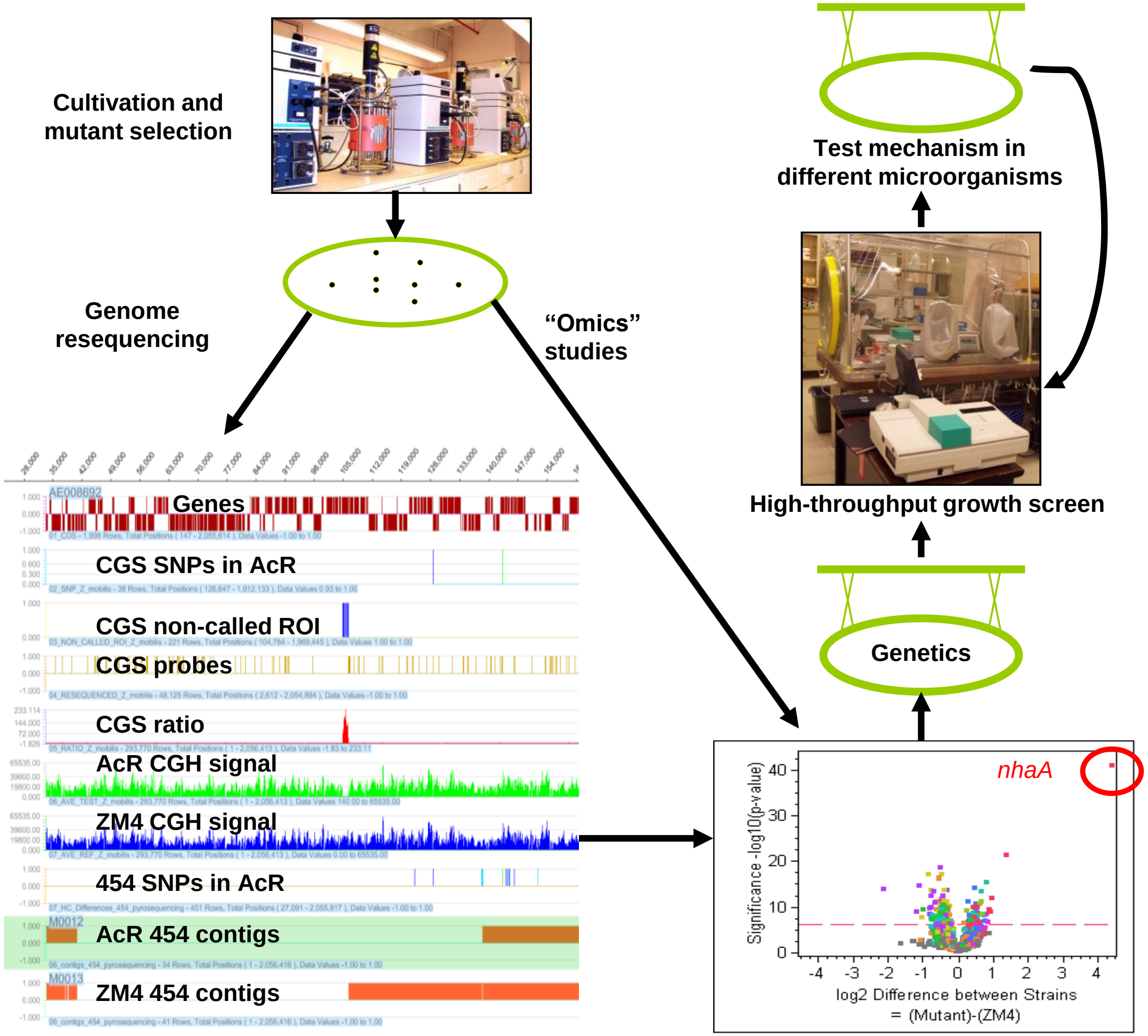
BESC BioEnergy Science Center

Yang, S. *et al*. A paradigm for strain improvement identifies sodium acetate tolerance loci in *Zymomonas mobilis* and *Saccharomyces cerevisiae.* PNAS. 2010 *in press*

Patent Application US 61/173,649

Exclusive and non-exclusive licenses available

A Paradigm for Strain Improvement Breaks Down Barriers for Biofuel Production



Contact: Steven Brown, brownsd@ornl.gov

- The application of classical and systems biology tools is a paradigm for industrial strain improvement.
- Identification and overexpression of Na^+/H^+ antiporter genes confers enhanced tolerance to acetate salts.

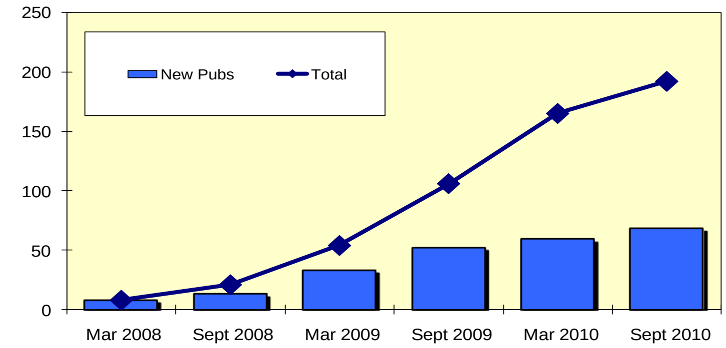
Patent Status: Patent Application US 61/173,649

Licensing Status: Exclusive and non-exclusive licenses available

BESC BioEnergy Science Center

Yang, S. *et al*. A paradigm for strain improvement identifies sodium acetate tolerance loci in *Zymomonas mobilis* and *Saccharomyces cerevisiae.* PNAS. 2010 *in press*

Translating Discoveries to the Scientific Community



- 198 scientific publications (Sep. 2010)
  - ~33% of publications include external collaborators at non-BESC Institutions
- BESC publications have already been cited 600+ times in peer-reviewed journals
- Several publications in top-tier journals
  - *Nature Biotechnology*, 2008, Lynd *et al*., How biotech can transform biofuels
  - *PNAS*, 2008, Shaw *et al*., Metabolic engineering of a thermophilic bacterium to produce ethanol at high yield
  - *Nature Nanotechnology*, 2010, Tetard *et al*., New modes of subsurface atomic force microscopy through nanomechanical coupling
- 25 inventions disclosed (under evaluation by BESC Commercialization Council)

Access to the sugars in lignocellulosic biomass is the current critical barrier

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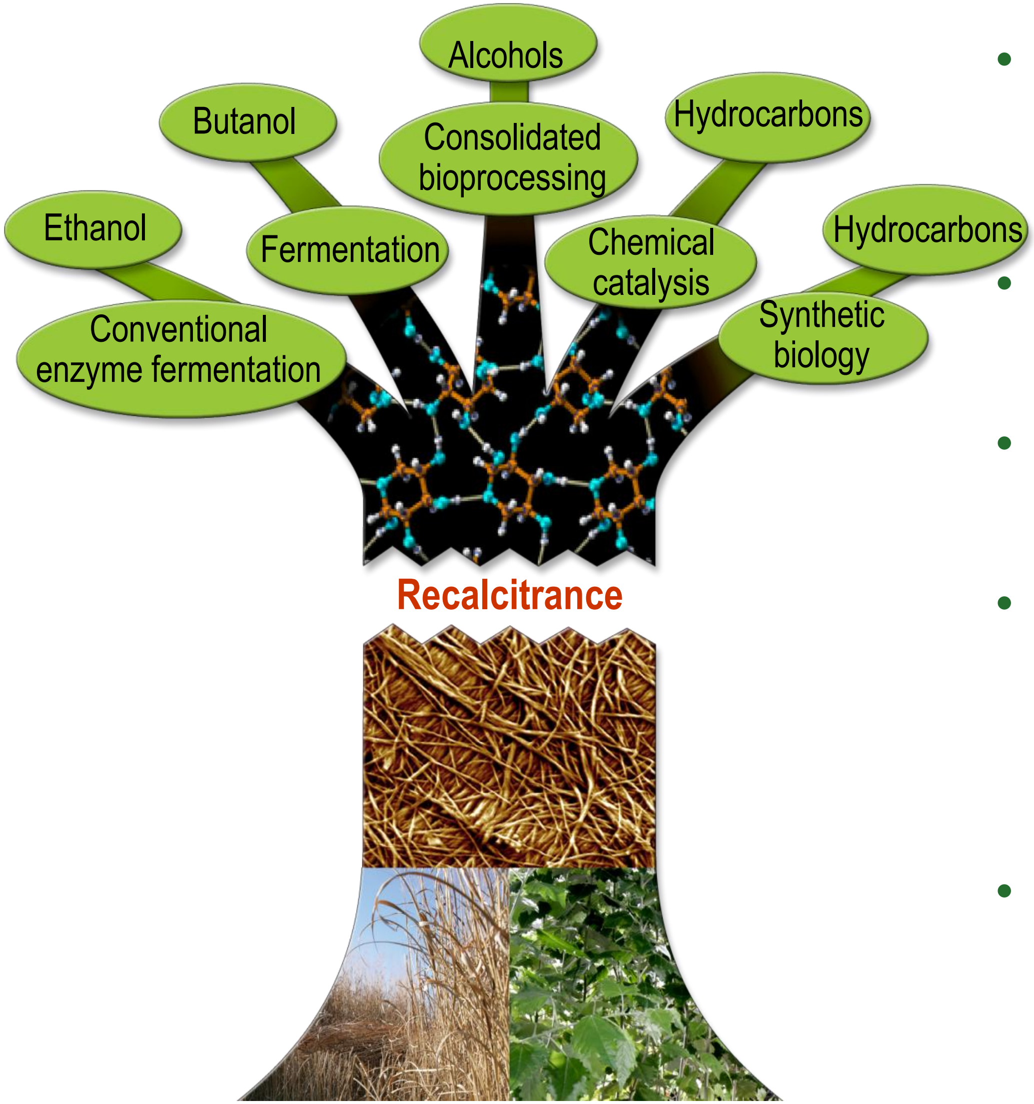

- Feedstock screening research uses enzyme and fermentation into ethanol
- Conversion research focuses on CBP
- Impacts are beyond ethanol into other fuels and products
- Preliminary results on butanol production from a modified CBP microbe (UCLA and ORNL)
- Plans to provide modified lignins to carbon fiber research

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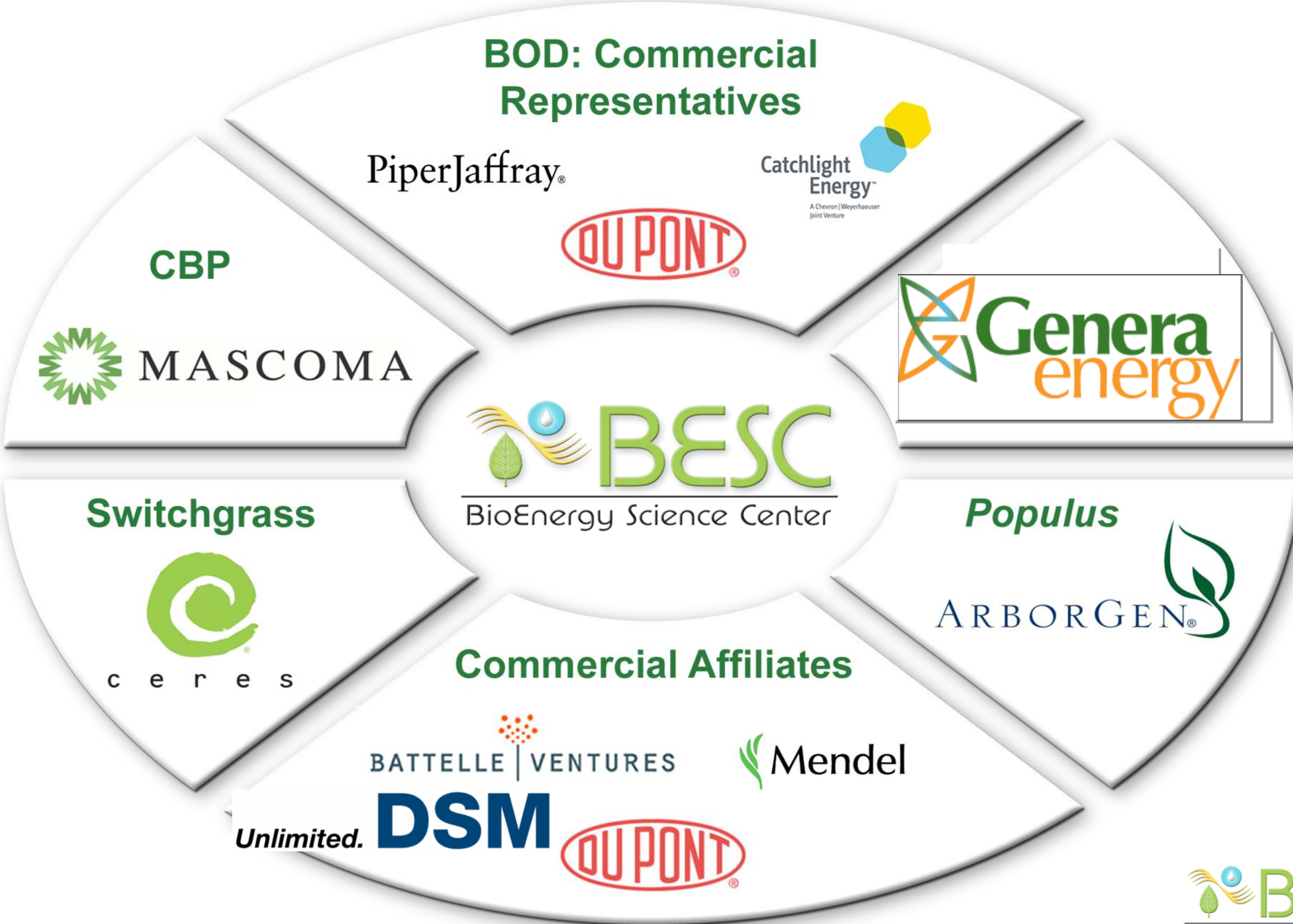
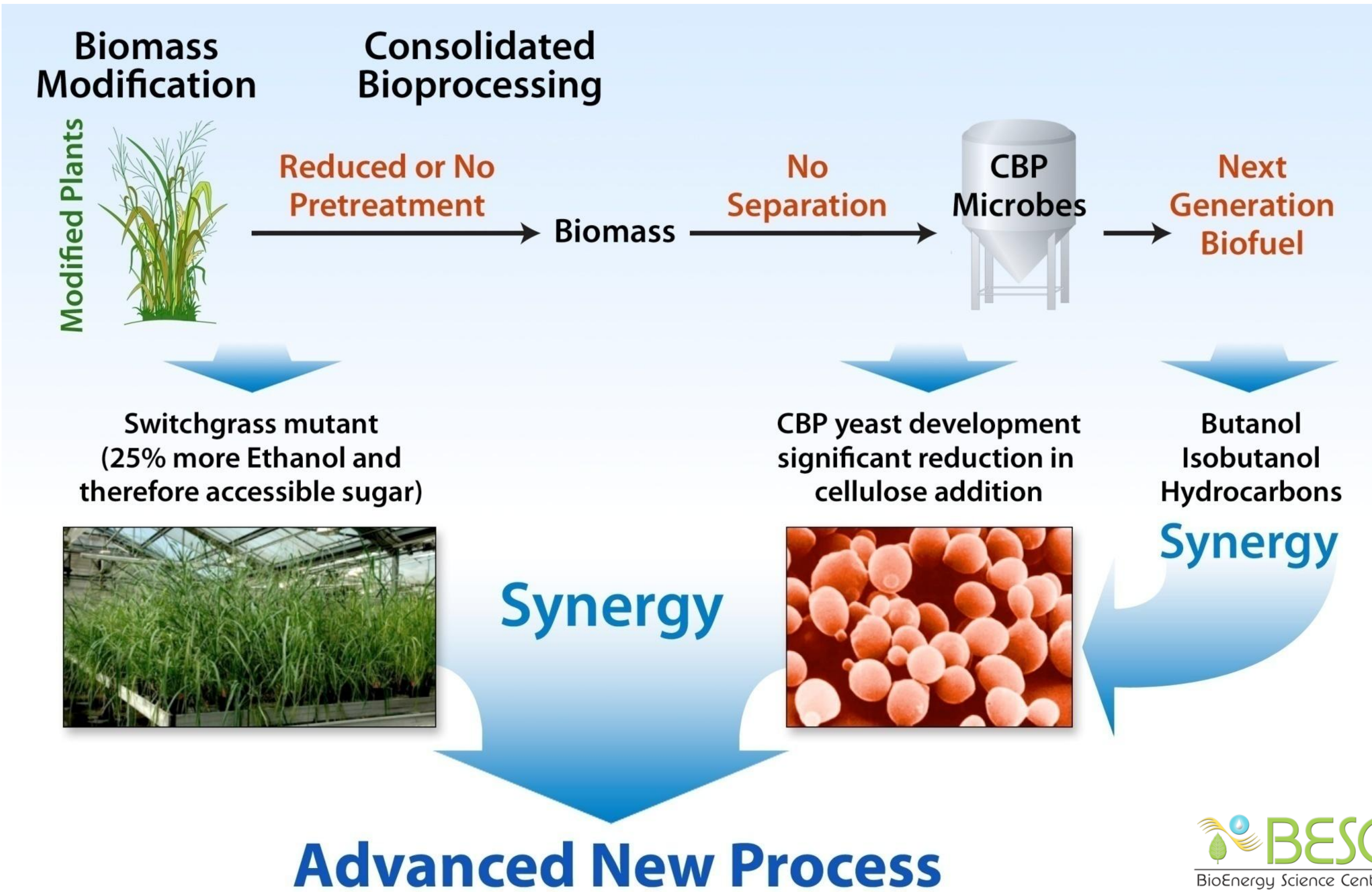
Industrial partners facilitate strategic commercialization



Partnerships Expedite to Technology Transfer of Science moving into Applications

- BESC is generating 1000's of plant samples
- BESC is developing and utilizing improved genetic tools for CBP thermophiles
- BESC has access to several pilot facilities
  - Tennessee Biofuels Initiative pilot refinery in Vonore, TN with UT, Genera, and DuPont-Danisco
  - Mascoma biorefinery pilots in upstate NY and upper MI
  - Biofeedstock field trials via Arborgen, Ceres, Noble, and others
- A switchgrass field trial (a BESC transgene in BLADE) is scheduled at Ceres next spring
- Separately, ORNL is providing Systems Biology support to applied efforts at Mascoma under EERE funding
  - Resequencing improved cellulolytic yeast strains under the 10% biorefinery project
  - Transcriptomic and metabolomic analysis of improved T. sacch. Under the ethanologen project

BESC Will Revolutionize How Biomass is Processed and Converted



BioEnergy Science Center

Confidential

Thank you

SCIENCE RETREAT JUNE 2010

DOE Bioenergy Research Centers

DOE GENOMICS:GTL SYSTEMS BIOLOGY FOR ENERGY AND ENVIRONMENT

OFFICE OF SCIENCE U.S. DEPARTMENT OF ENERGY

Office of Science U.S. DEPARTMENT OF ENERGY

BESC is a U.S. Department of Energy Bioenergy Research Center supported by the Office of Biological and Environmental Research in the DOE Office of Science

U.S. DEPARTMENT OF ENERGY

BESC BioEnergy Science Center

Bioenergy Sustainability and Land Use Research

Keith Kline, Gbadebo Oladosu, Virginia Dale, and others
Oak Ridge National Laboratory

For the China National Energy Agency U.S. Biofuels Study Tour

6 December, 2010

CBES
Center for BioEnergy Sustainability

Visit the websites:

CBES: http://www.ornl.gov/sci/besd/cbes
CCSI: http://climatechangescience.ornl.gov

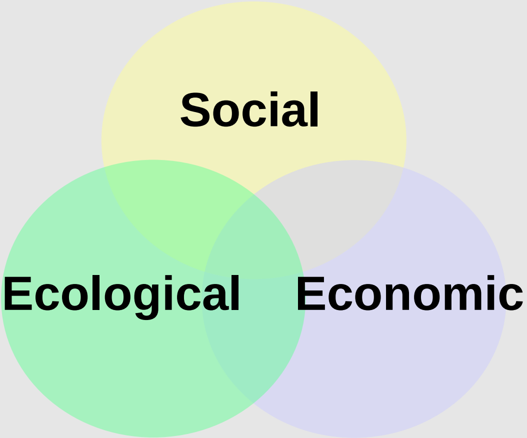
Climate Change SCIENCE INSTITUTE

OAK RIDGE National Laboratory

Key points

- Sustainability is contextual, relative (more/less) and process based
- Sustainability implications of biofuel choices are complex

- Opportunities to design systems to optimize socioeconomic and ecologic benefits of bioenergy merit attention
- Scales matter
- You can only manage what you can measure
- Assessment involves a suite of measures:



Overview of talk: Examples of research and implementation related to sustainability and land use

- The Global Sustainable Bioenergy Project (GSB)
- Developing and testing indicators and metrics for sustainability of feedstock production
  - International Standards Organization (ISO) PC 248 "sustainable bioenergy criteria"
  - See CBES Forum (October 2010) - GBEP, RSB, CSBP and other standard and certification initiatives (www.ornl.gov/sci/besd/cbes)
- Modeling and Analysis
  - Economic models, GTAP
  - Historical data and decomposition analysis
- Publications and communications
  - CBES publication list (Science, Ecological Society of America etc.)
  - CARB www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
  - IPCC – Bioenergy Chapter in Special Report on Renewables (in prep)

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Exploring feasibility of global sustainable bioenergy

The Global Sustainable Bioenergy Project "GSB" initiated (June, 2009)

- Joint statement in *Issues in Science and Technology* letter supporting ORNL paper, "Biofuels Done Right"
- 2010 – web sites launched; five conventions held

Test a working hypothesis:

It is possible to reconcile large-scale bioenergy production ($\geq$ 25% of global mobility or equivalent) with:

- feeding humanity
- meeting other needs from managed lands
- preserving wildlife habitat and environmental quality

For more information and full presentations see:

http://engineering.dartmouth.edu/gsbproject/index.html

GSB

Oak Ridge National Laboratory

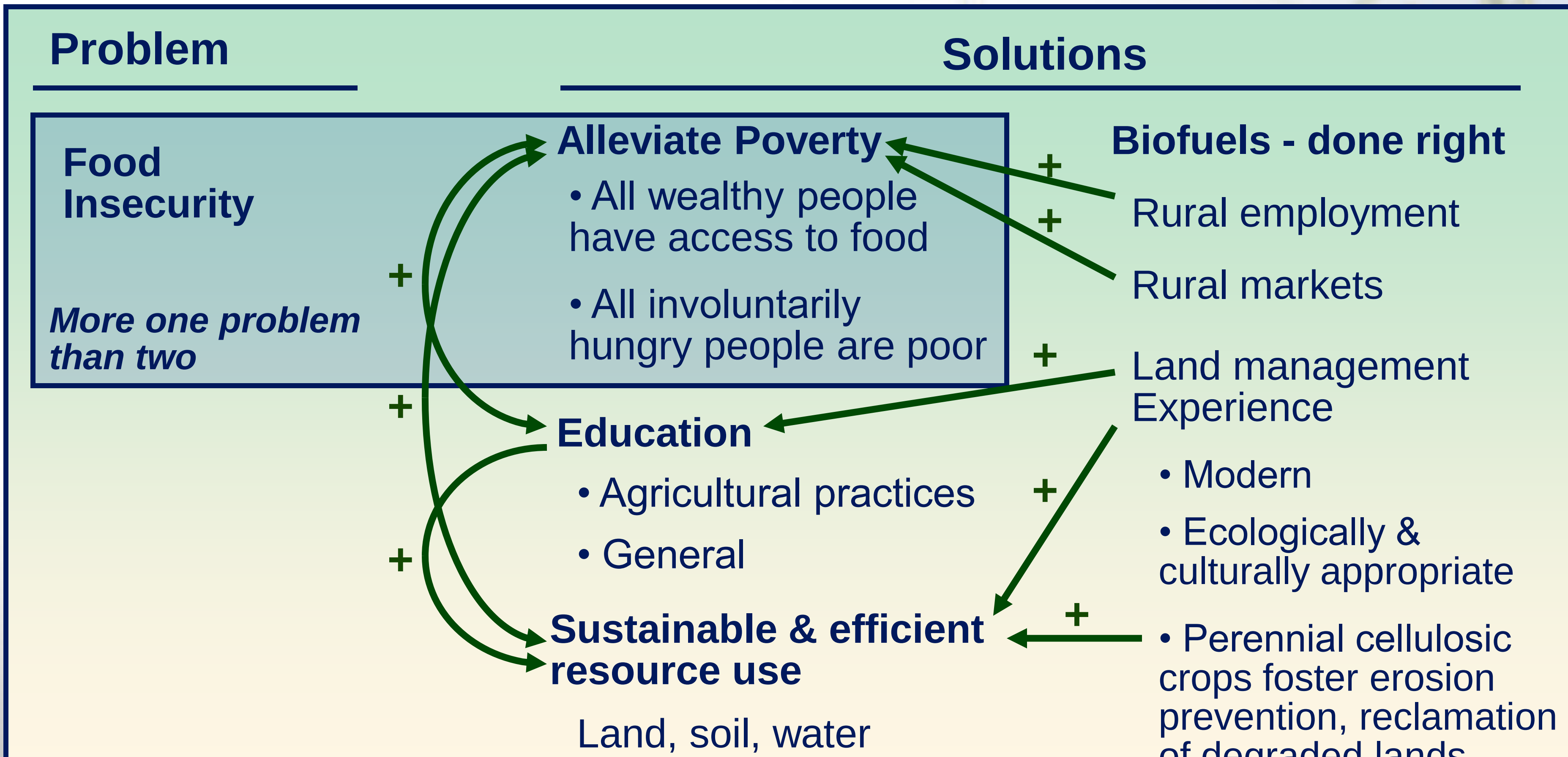
Feeding Humanity: Bioenergy, Food Security and Poverty

Rather than a threat, could development of biofuels be part of the solution?

Problem	Solutions
Food Insecurity	**Alleviate Poverty** • All wealthy people have access to food • All hungry people are poor

Feeding Humanity: Bioenergy, Food Security and Poverty

Rather than a threat, could development of biofuels be part of the solution?



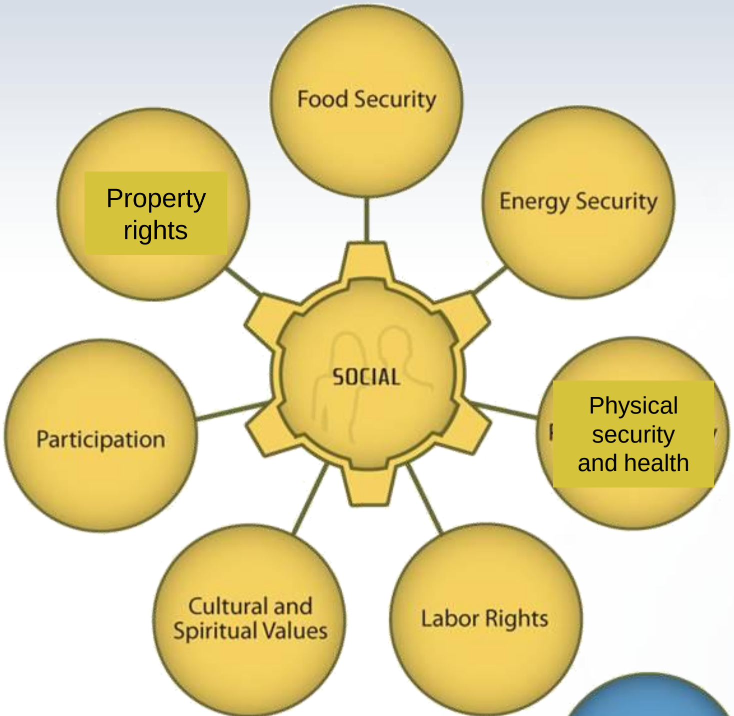
Source: GSB presentation *http://engineering.dartmouth.edu/gsbproject/index.html*

Next steps – opportunities for collaborations:

- **GSB Project** – Contact Lee Lynd or other project participants Lee.R.Lynd@Dartmouth.edu
- **Land availability**: previously disturbed and underutilized land, land reclamation; regional and national estimates of available marginal areas and yields – Contact Keith Kline klinekl@ornl.gov
- **Double crops** – field based experiments and estimates of larger scale effects and importance. Contact Tom Richard, Penn State University tlr20@engr.psu.edu
- **Water and ecosystem effects:** evaluate bioenergy crops at watershed scale (eco-system services with minimum measurements for water and soils).

Big systemic challenges – paths to a more sustainable world – require big systemic solutions and cooperation in many small steps to get there. All participation is welcome!

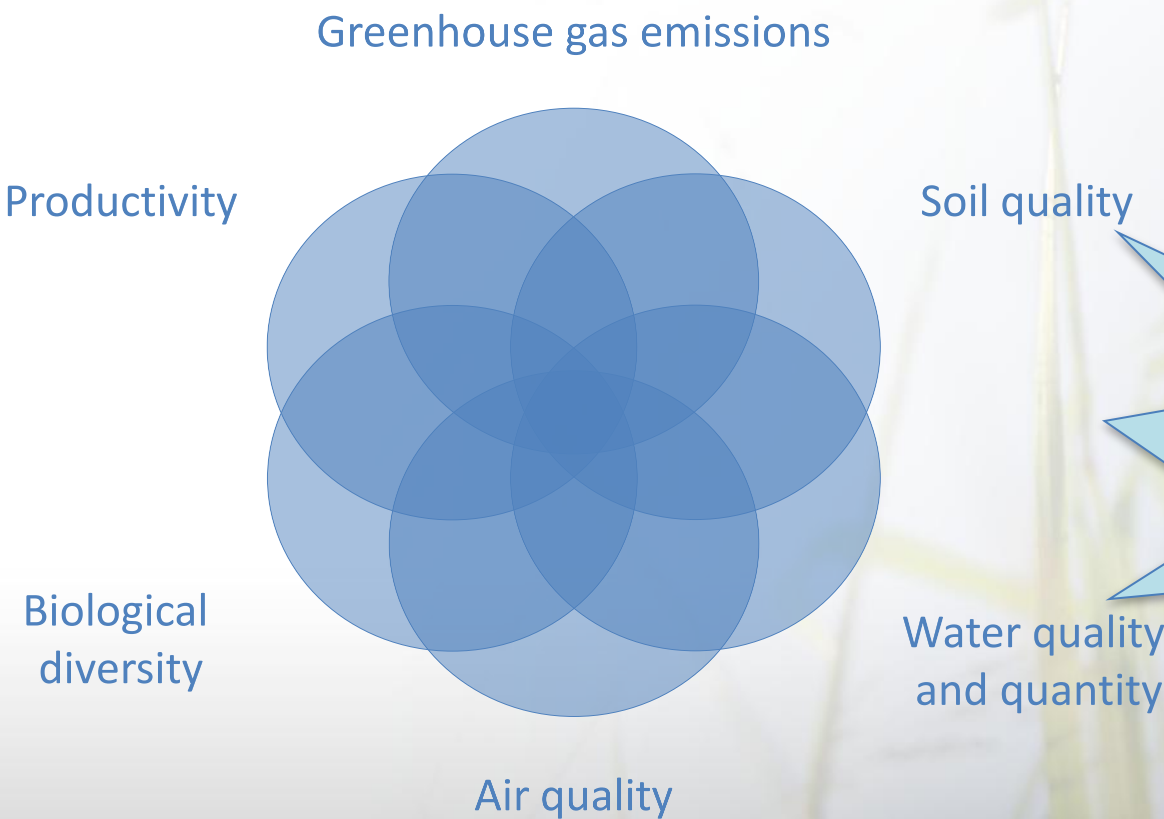
Components of Sustainability



Sustainability is the capacity of an activity to continue while maintaining options for future generations.

For more information see:
http://www.ornl.gov/sci/besd/cbes

Environmental Indicators of Bioenergy Feedstock Sustainability



Cross-cutting issues: Land-use change, Ecosystem services, GMOs

For more information see:
http://www.ornl.gov/sci/besd/cbes

[Based on McBride, Dale, Baskaran, Downing, Eaton, Efromyson, Garten, Kline, Jager, Mulholland, Parish, Schweizer, Storey. In review. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators*]

Example: Productivity

Indicator

Aboveground net primary productivity ($gC/m^2/yr$)

- Management-related variables particularly important
- Important to track trends over time relative to other indicators (soil, water, etc.)

Managing land to improve soil qualities improves productivity and food security while supporting local adaptation to climate change and mitigation strategies (Lal, 2010 and others: see food-fuel references)

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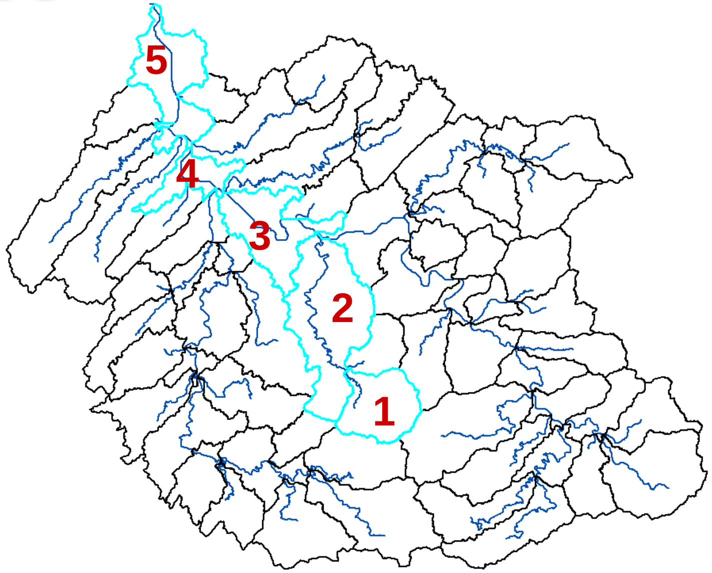
Ecosystem services

- Indicators of social and economic sustainability are connected to indicators of environmental sustainability through the concept of ecosystem services.
- Ecosystems provide people with provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005).
- Bioenergy can enhance or degrade each type of service – depending on how implemented.

Sources: MEA 2005, CBES 2009.

Agricultural Landscape - watershed approach to bioenergy assessment

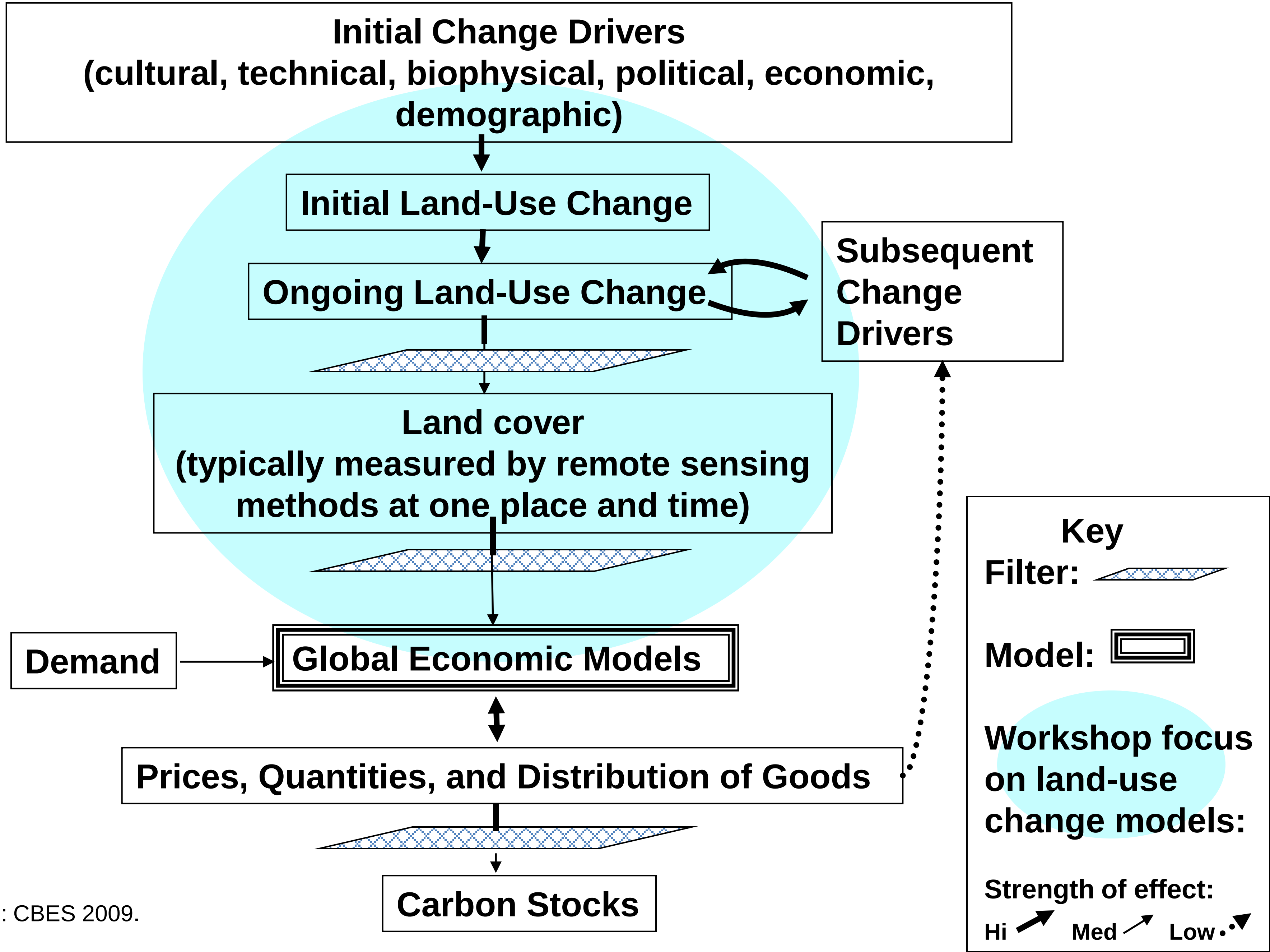
- A systems-based approach
  - Captures cause and effects
  - Includes feedbacks
  - Allows options to be considered
- Landscape design
  - Quantifies desired conditions for biofuel feedstock
  - Integrates spatial aspects of environmental & socioeconomic constraints
- Spatial optimization
  - Quantifies potential sustainability of bioenergy options
  - Operates at multiple scales



Land-Use Change (LUC) underlies many biofuel concerns

- “Conventional wisdom”
- Regulatory initiatives
  - California (CARB)
  - NESCAUM (Northeast US)
  - EPA and EISA RFS2 requirement
- Certification initiatives (ISO PC248)

2009 LUC & BIOENERGY WORKSHOP



Source: CBES 2009.

Interactions among bioenergy, agriculture, climate change, deforestation (REDD) are complex

Addressing deforestation in developing nations involves support for:

- Sustainable rural livelihoods – improve prices for products (increase security, land practices that reduce fire)
- Improved land tenure
- Inventory & protect key conservation areas
- Improved governance, local participation & capacity, enforcement
- LU plans & management

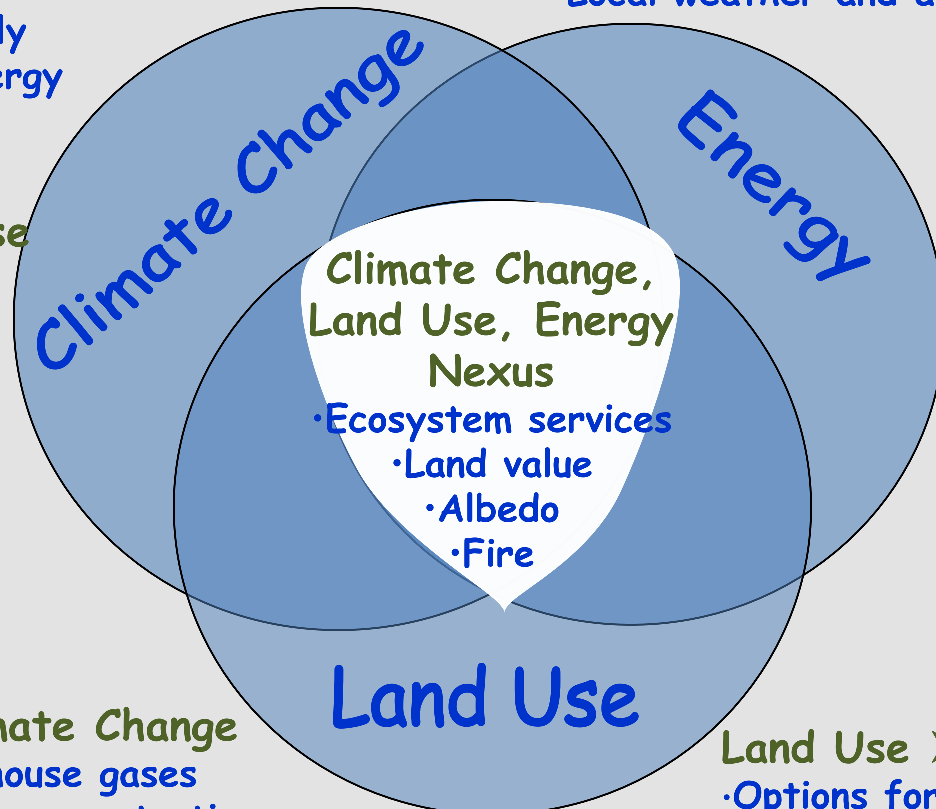
Source: USAID – FAA Sec. 118/119 Reports 2000-2008

Need to Address Linkages

Climate Change ➢ Energy
- Energy Options
- Intensity of use
- Distribution of supply and demand for energy

Energy ➢ Climate Change
- Greenhouse gas emissions and carbon sequestration
- Local weather and air quality

Climate Change ➢ Land Use
- Productivity
- Suitability for life forms and management practices
- Distribution of land uses
- Human settlement patterns



Energy ➢ Land Use
- Energy extraction, production and distribution footprint
- Infrastructure and settlement plans

Land Use ➢ Climate Change
- Release of greenhouse gases
- Amount of carbon sequestration
- Weather changes
- Vulnerability to climate change

Land Use ➢ Energy
- Options for energy extraction, infrastructure, and production
- Efficiency of energy production
- Demand for energy

For more information see: http://www.ornl.gov/sci/besd/cbes

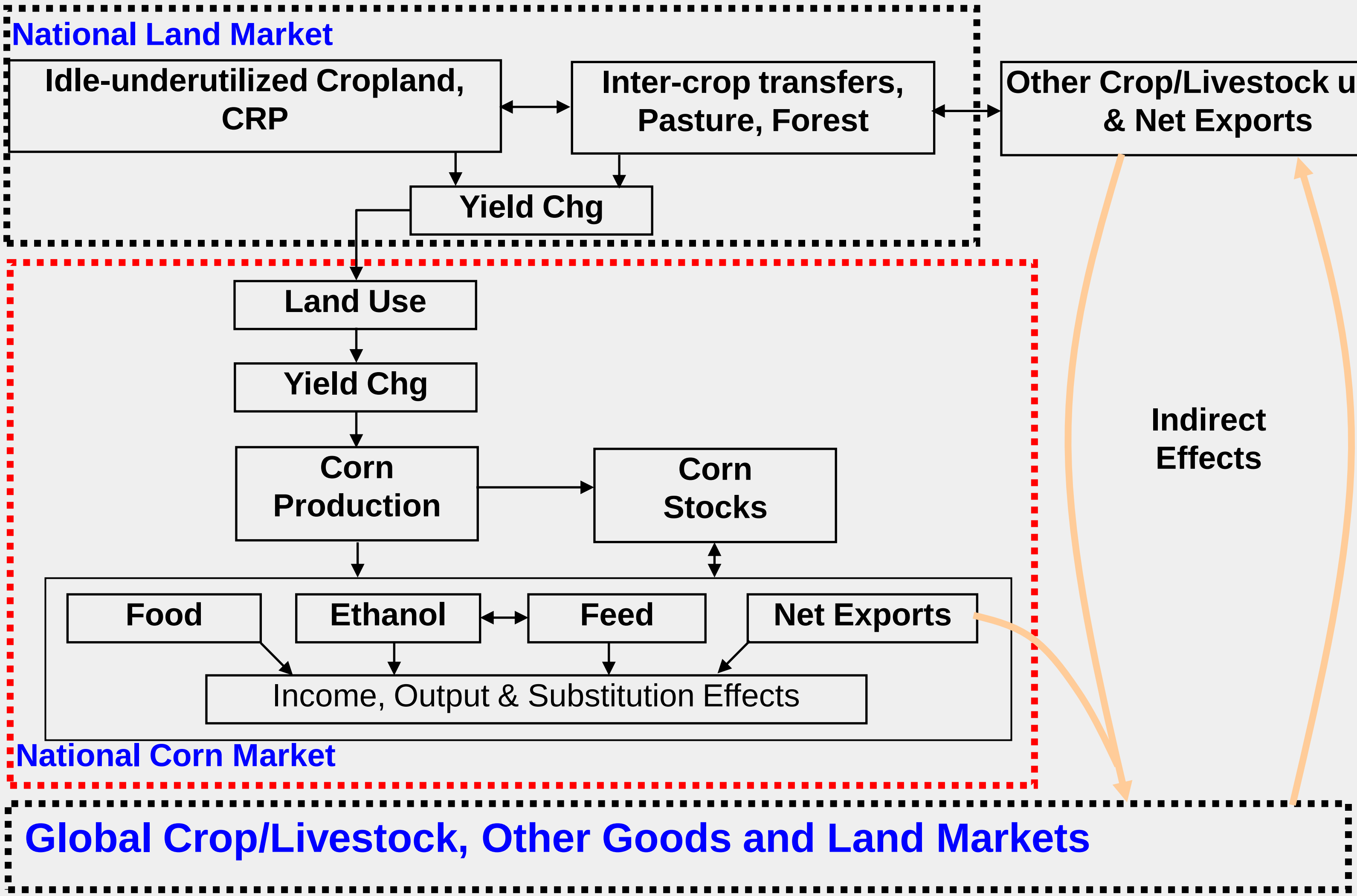
[Based on Dale, Efroymson and Kline, In review. The land use – climate energy nexus. *Landscape Ecology*.]

Of Models and Science

"models … are simplified views of the world that help us think about a complex issue, but not true representations of the complexity itself."

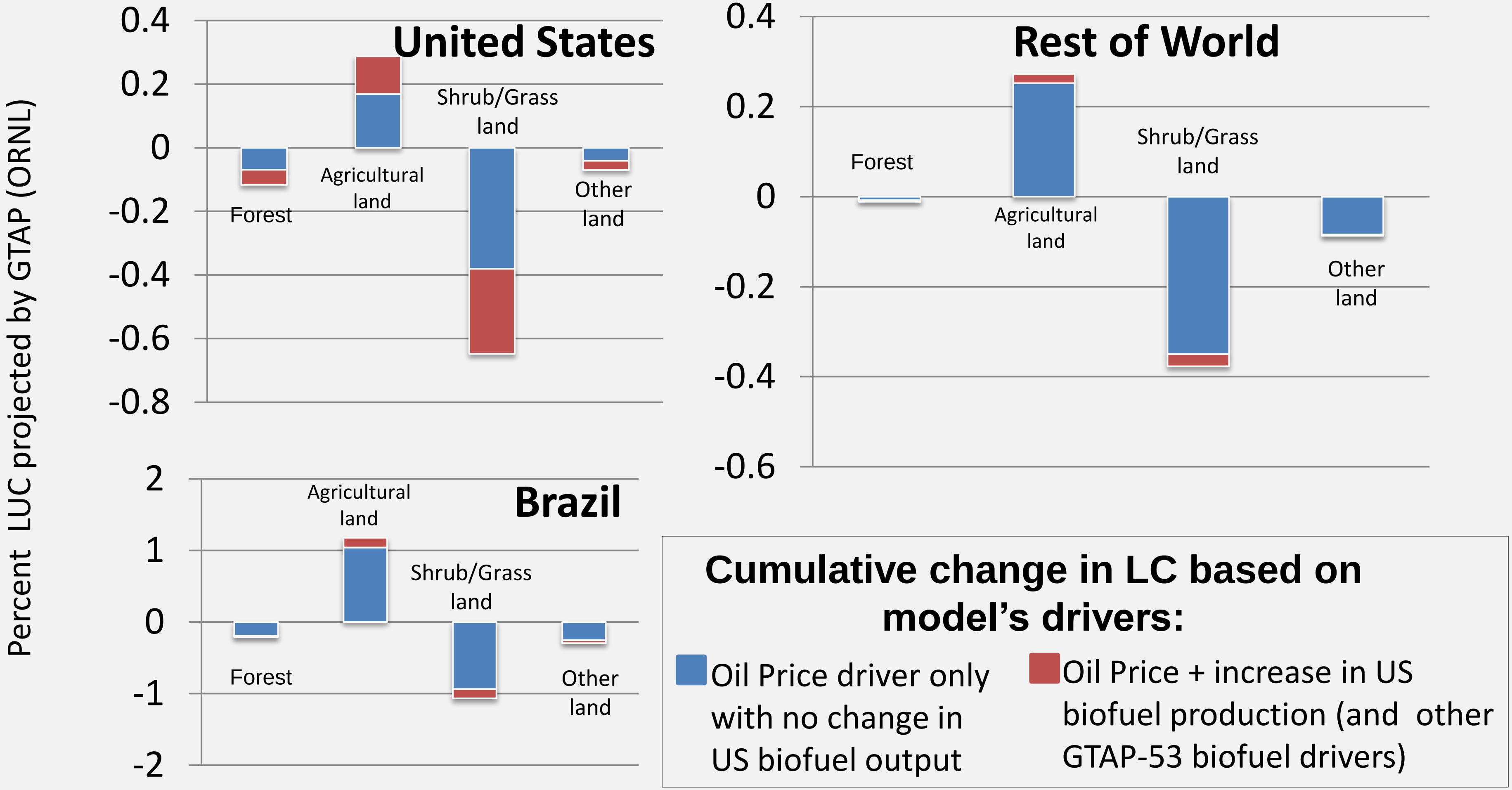
-Claude Diebolt, Research Director of Economics, Universite de Strasbourg [quoted in *The Economist*, Aug 6, 2009]

Computational General Equilibrium Models such as GTAP are needed to estimate effects of multi-market interactions



- **ILUC cannot be observed; it is estimated by modeling**

Example of GTAP model uncertainty for LUC due to structure, assumptions and initial conditions



- **LUC due to oil price driver alone ~90% of total change**
- **Most LUC associated with US biofuels occurs in the US**

Ref: IAEE 2010, Proceedings; Oladosu and Kline

Of Models and Science

"Science is the pursuit of knowledge and understanding of the natural and social world following <u>a *systematic methodology based on evidence*</u>."

-Britain's Science Council http://www.sciencecouncil.org/

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Decomposition Analysis of U.S. Corn Use for Ethanol Production from 2001-2008

California Air Resources Board (CARB)
Low Carbon Fuel Standard Expert
Workgroup Meeting
Sacramento, CA
October 14-15, 2010

'Debo Oladosu and Keith Kline
October 6, 2010

See: http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm

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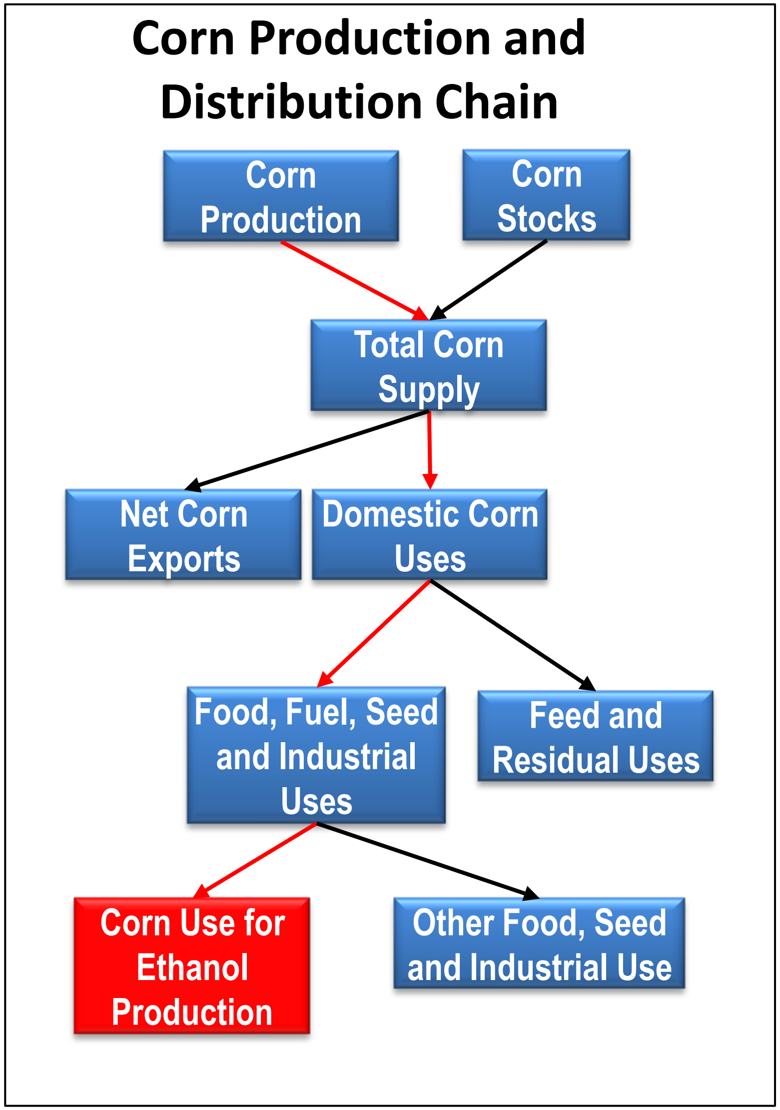
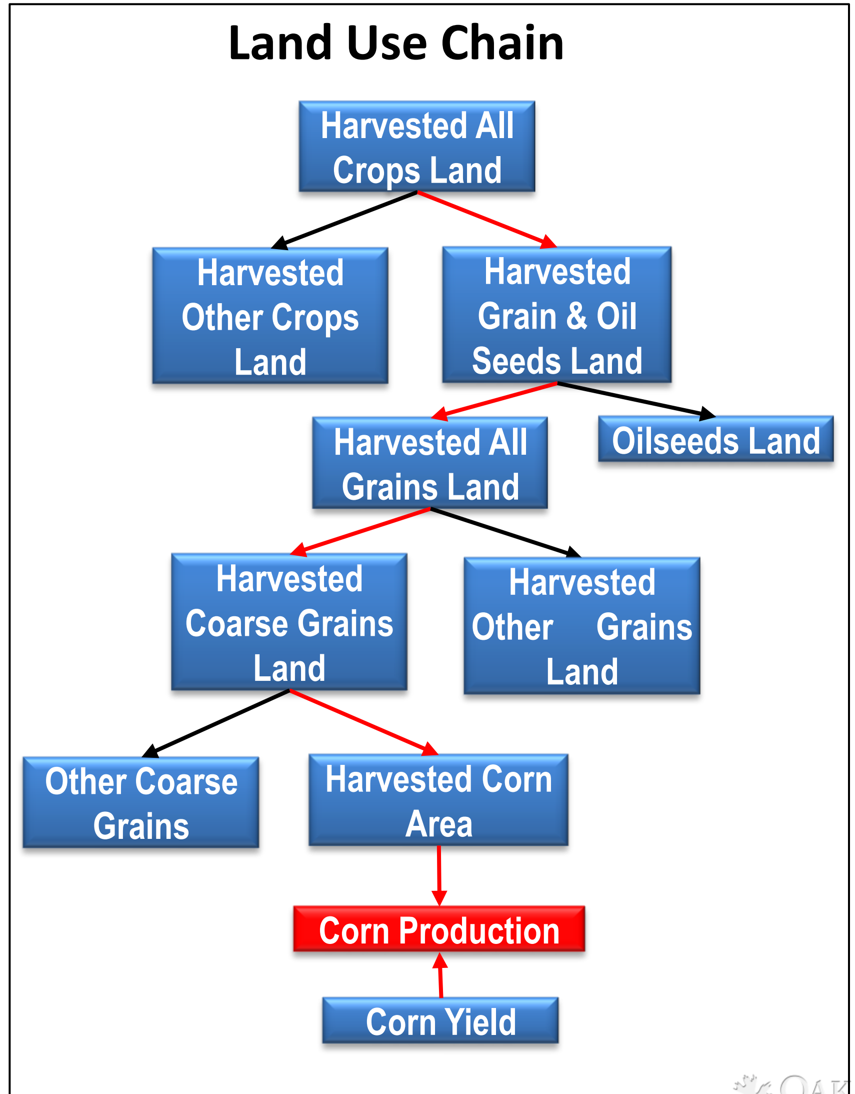
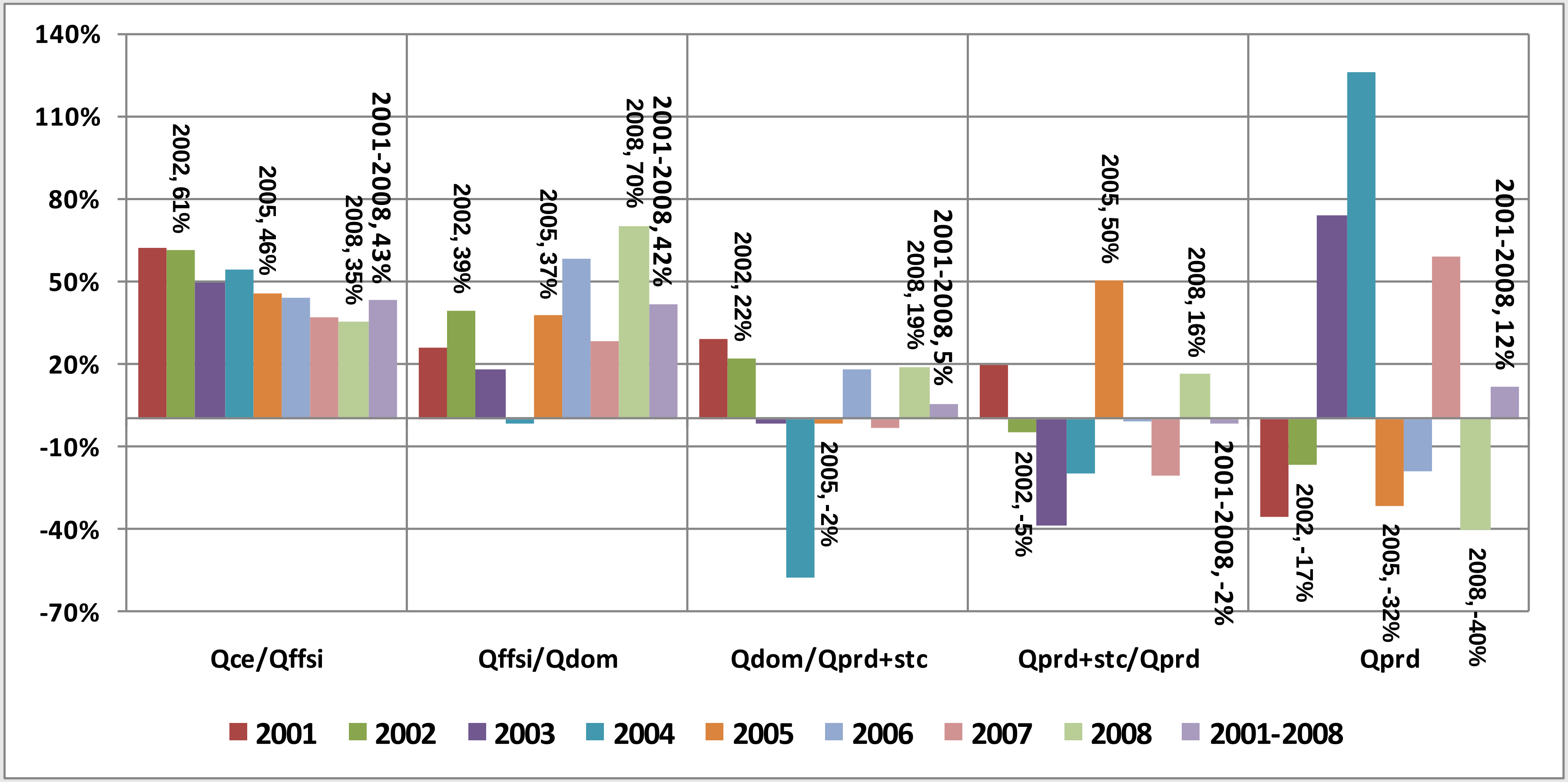
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Decomposition Analysis of Empirical Corn Use for Ethanol Data with LMDI I: Linkages in the Chain



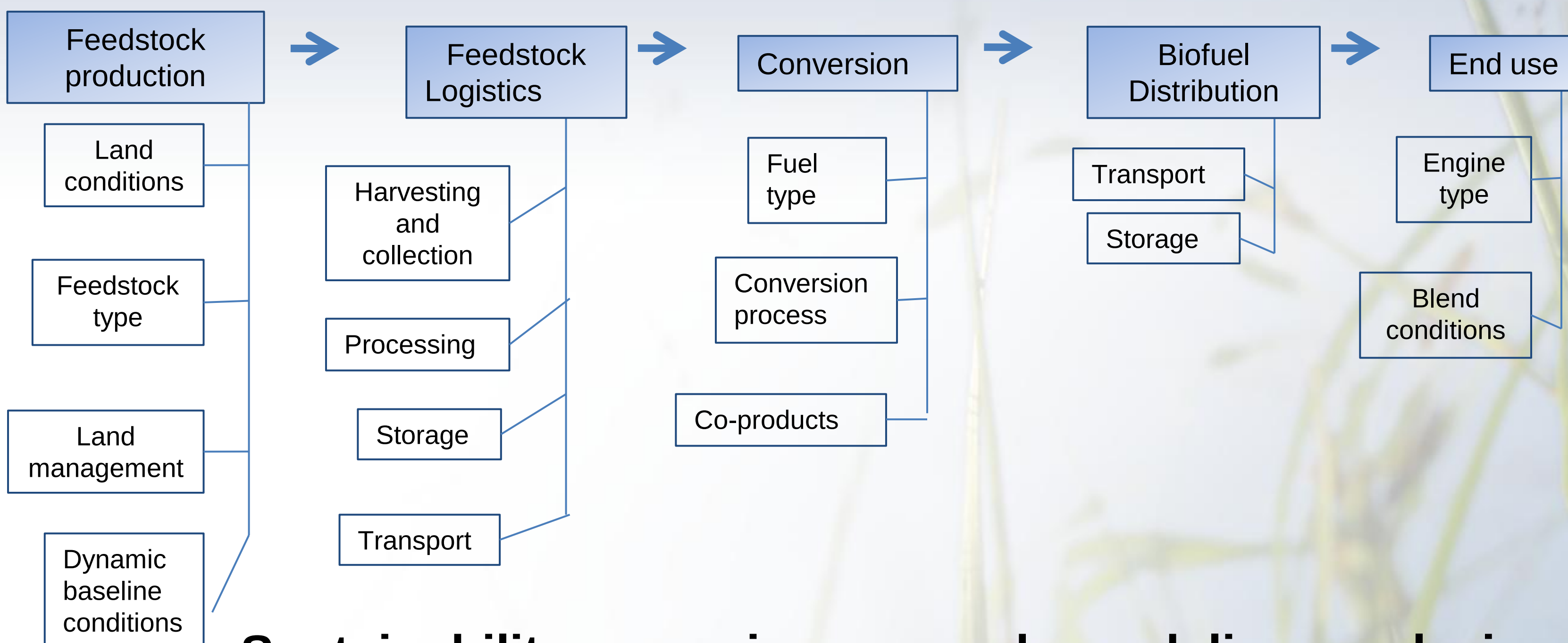


Decomposition Results of Corn Use for Ethanol: Domestic Adjustments Account for Most Change



- Contribution across all years, 2001-2008
  - Domestic Reallocation: 85%; Production: 12%;
    Domestic Corn Use Share: 5%; Corn Stock Withdrawals: -2%;

Sustainability Issues are Important Across Supply Chains



Sustainability – ongoing research, modeling, analysis

- **Context of indicator choices**
- **Scale of analysis and environmental effects (linkages, up/down)**
- **Baseline dynamics**
- **Comparative analysis of bioenergy pathways (ISO, GBEP, RSB, CSBP and others)**
- **Ecosystem services**
- **Communicating about bioenergy sustainability**
- **Enabling implementation**

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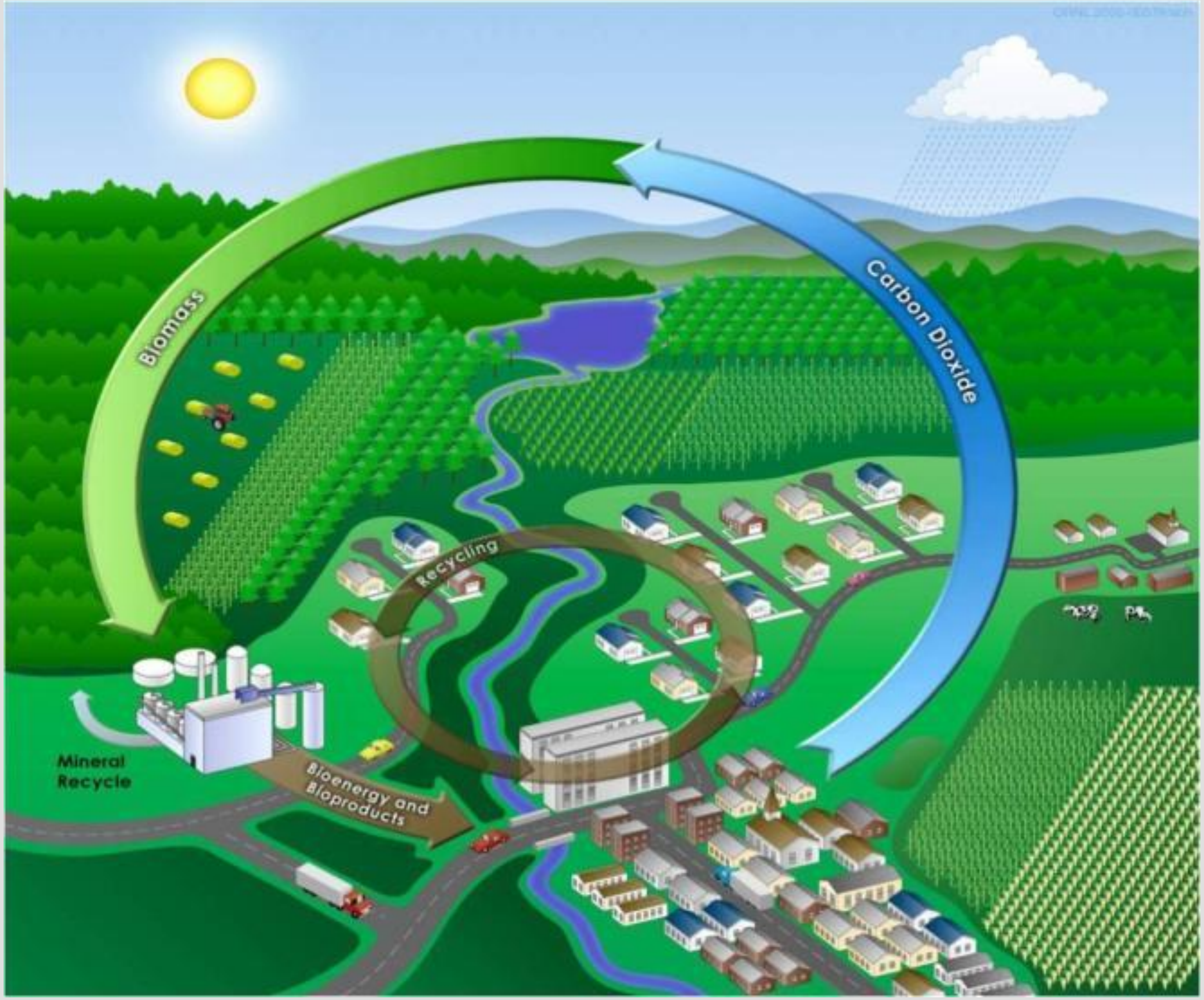
Considering sustainability within the system as an opportunity to design landscapes that add value



Thank you!

Acknowledgements

The Center for Bioenergy Sustainability (CBES) and related research at Oak Ridge National Laboratory (ORNL) are supported by the U.S. Department of Energy (DOE) under the Office of the Biomass Program and by U-T Battelle, LLC using the Lab-Directed R&D fund.

The views in this presentation are those of the authors and not necessarily those of ORNL, DOE or any other institution.

Center for Bioenergy Sustainability http://www.ornl.gov/sci/besd/cbes

ORNL bioenergy: http://bioenergy.ornl.gov/

Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.

The GSB is supported by multiple individuals and institutions. See http://engineering.dartmouth.edu/gsbproject/index.html

Contact information: Keith L Kline klinekl@ornl.gov, Gbadebo Oladosu oladosuga@ornl.gov, Virginia Dale dalevh@ornl.gov

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- Presentations and reports on LUC issues are available on the CARB Expert Work Group web site: http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
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Links to Information Resources

- DOE Biomass and Biofuels Program: www.eere.energy.gov/biomass/
- DOE Office of Science, Bioenergy Research Centers: http://genomicsgtl.energy.gov/centers/
- Alternative Fuels Data Center - http://www.eere.energy.gov/afdc/fuels/ethanol.html
- Bioenergy Feedstock Information Network: http://bioenergy.ornl.gov/
- Biomass R&D Initiative: www.biomass.govtools.us
- ORNL Center for Bioenergy Sustainability: http://www.ornl.gov/sci/besd/cbes

US-China Biofuels Cooperation

MORNING BREAK

Oak Ridge National Laboratory

Bioenergy Resource Analysis at ORNL

Bob Perlack, **Laurence Eaton,**
Craig Brandt, Matt Langholtz,
Anthony Turhollow, Mark Downing,
Robin Graham

US Biofuels Study Tour for the China NEA

Knoxville, Tennessee

December 6, 2010

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Overview

1. Introduction
2. Research objectives
3. The Billion Ton Repoprt, resource assessment methods, capabilities
4. Conclusions

Research team

- Interdisciplinary team of economists, ecologists, agricultural engineers, and agronomists
- Collaborate across DOE laboratories, federal agencies (e.g. USDA), academia, and private industry

Resource Assessment at ORNL

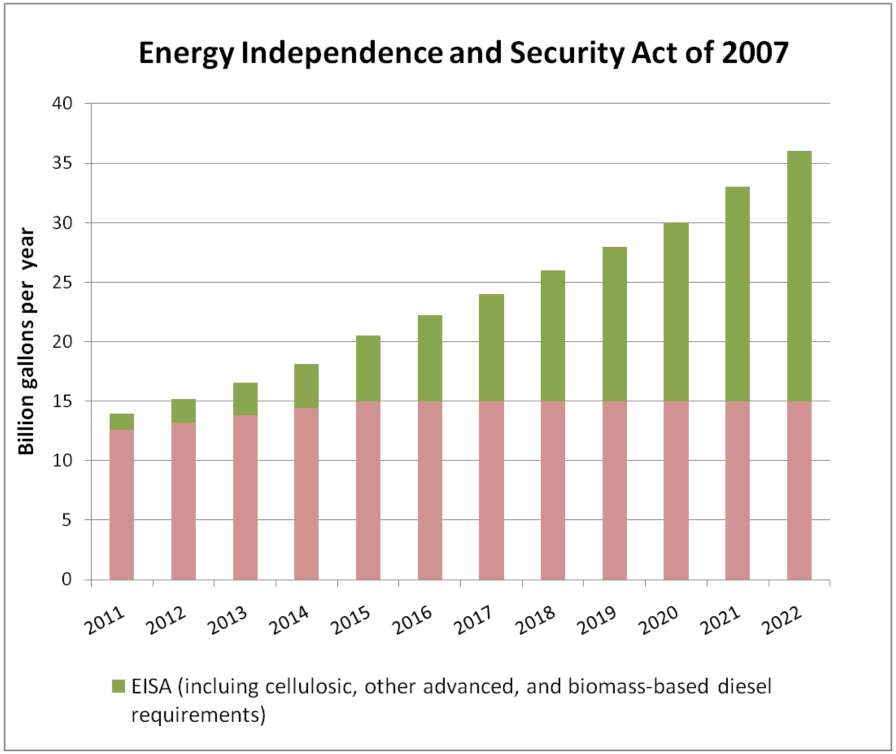
- Identify supplies of potential current and future cellulosic bioenergy feedstocks at target prices
- Integrate "state-of-the-art" sustainability science parameters into production scenarios
- Estimate supplies that minimize disturbance to current production systems (e.g. food and livestock)
- Assess conditions under which energy mandates (e.g. biopower, EISA) can be met

Resource Assessment (cont'd)

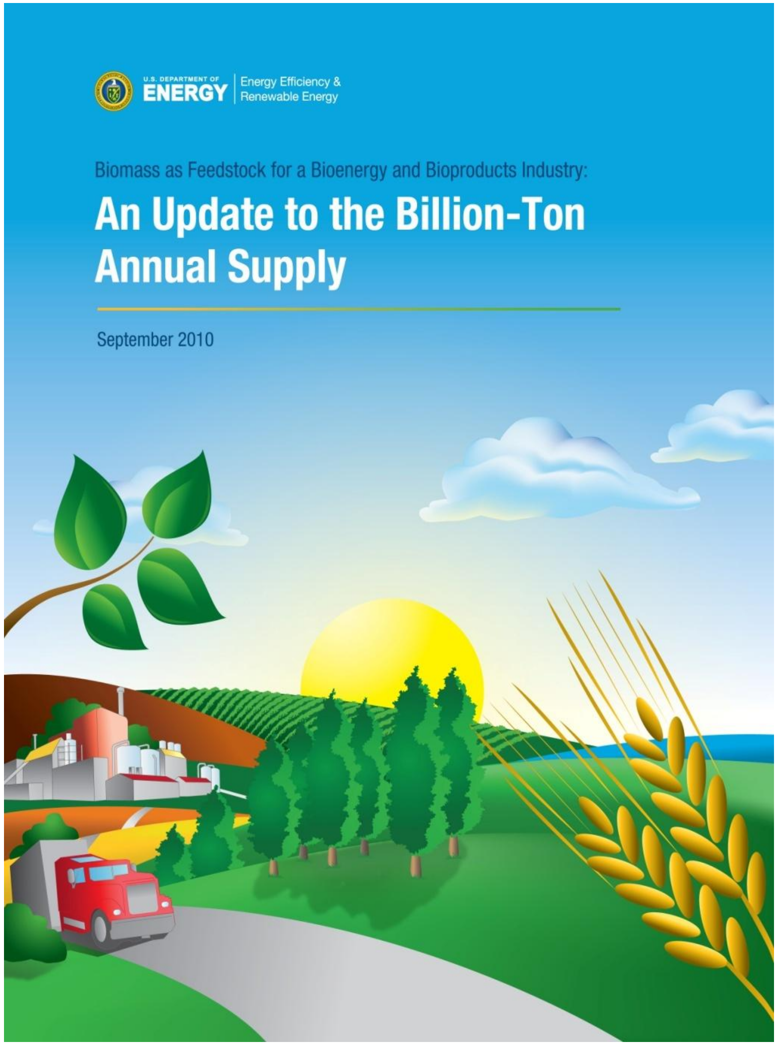
- Address potential biomass resource availability at target prices and high spatial resolution
- Provide the data and analysis transparent and available to end users (government, NGO, academia, private sector)

Recent National Energy Policy Mandate

- EISA (2007) mandates 36 billion gallons of ethanol by 2022
  - Maximum of 15 billion gallons of corn ethanol
  - Remaining 21 billion gallons to come from cellulosic and advanced sources

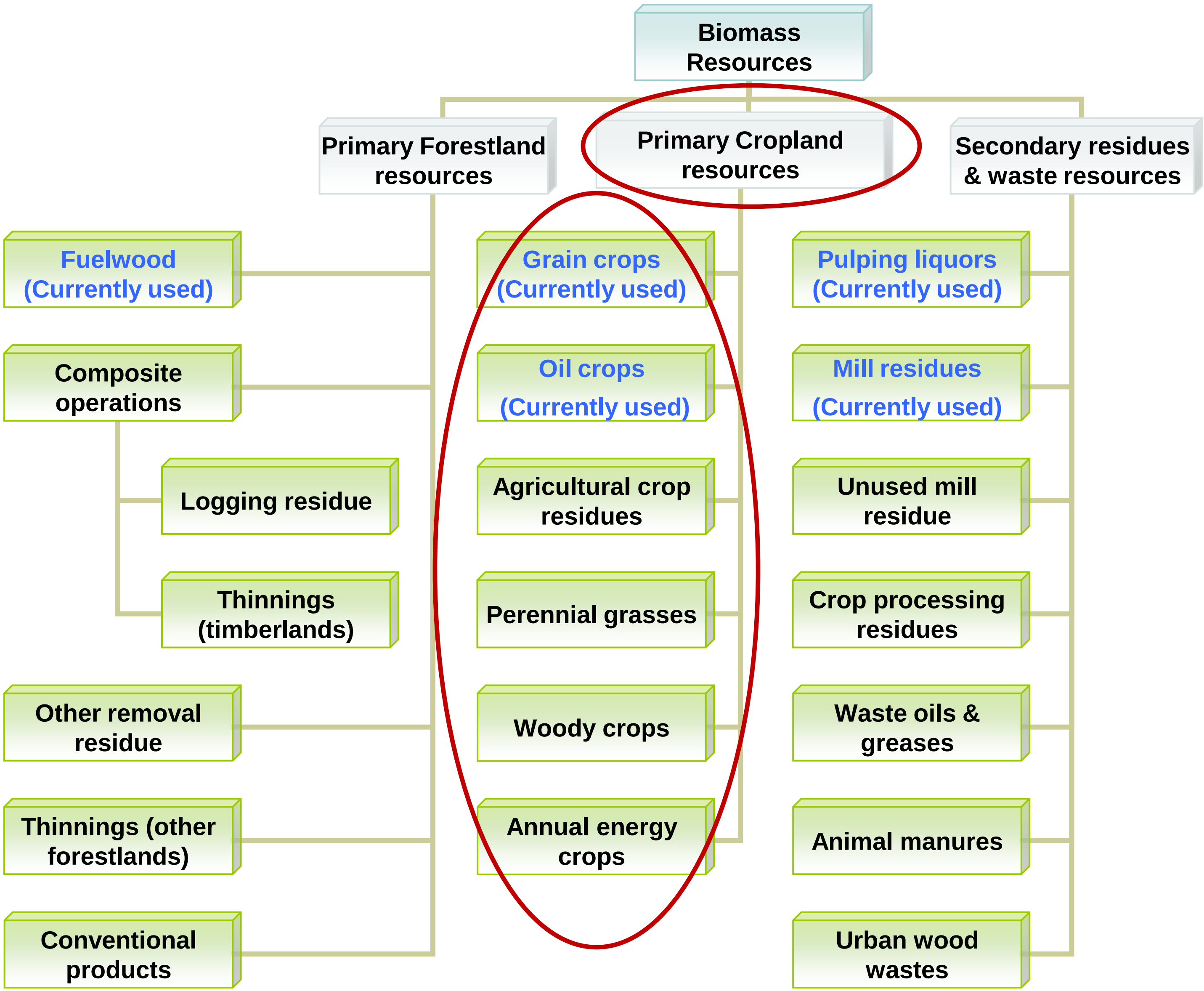


What is the Biomass Potential?



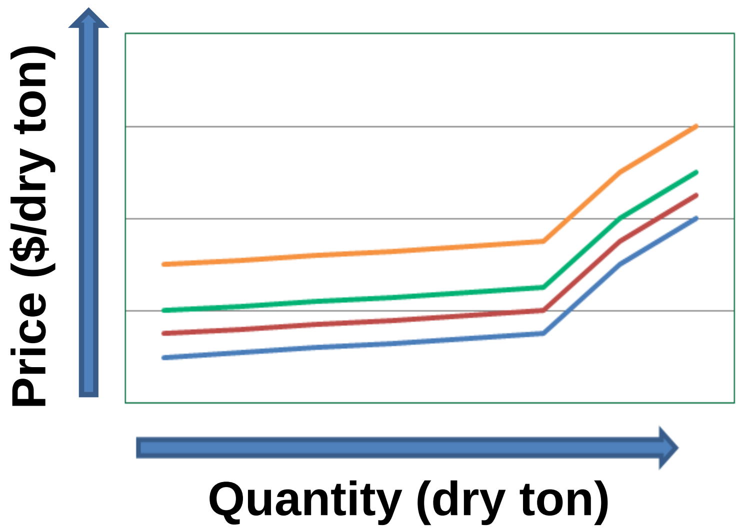
- Initially report (2005) identified between 0.6 to nearly 1 billion dry tons (~1.2 Mg) annually
- 2010 Update finds similar quantities (by 2030) depending on scenario and prices offered

Biomass Feedstocks



How Much Biomass is Available?

- feedstock; price, year, yield assumptions (scenarios); current use status; geography



Feedstocks
- Forest
- Agriculture

Selected Prices
- $10-$100 (Forest)
- $20-$80 (Agriculture)

Year
- 2010 (base)
- 2017
- 2022
- 2030

Scenarios
- Baseline
- High-yield
  - 2%, 3%, 4% annual growth

Use Status
- Currently used
- Potential

Scale
- National
- Regional
- State
- Multi-county
- County

General Approach

- Estimate economic supply curves
  - Price and quantity relationships of resources
    - Residues for annual crops
    - Dedicated energy crops
    - Forest residues and conventional wood
  - Prices cover collection and harvest costs
    - Include transportation to the farm or field gate

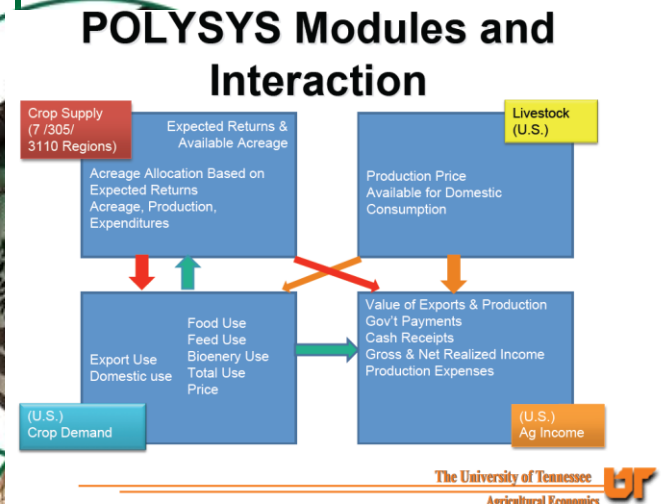
Primary Land Resource Categories

1. **Primary agriculture resources - Residues from annual crops and energy crops**
   - Economic simulations POLYSYS- Policy Analysis System Model
   - Based on USDA-NASS, USDA Census data, USDA Agricultural Baseline projections
   - Dedicated energy crops include switchgrass, energycane, energy sorghum, hybrid poplar, pine, eucalyptus,

2. **Primary forest resources – Forest logging residues, thinnings, and mill residue**
   - Use USDA-Forest Service data (FIA, TPO, RPA, …); meet RPA projections for pulp, timber, veneer
   - Resource constraints include forest residue access, recovery, and merchantability
   - Requirements for resource environmental sustainability

Economic Forecasting Model

- POLYSYS- Policy Analysis System, partial equilibrium mathematical displacement model
  - County model of the U.S. agricultural sector anchored to USDA 10-year baseline projection & extended to 2030
  - 8 major crops (corn, soybeans, wheat, sorghum, oats, barley, rice, cotton) and hay, livestock, food/feed markets
  - USDA projected demands for food, feed, industrial demand, and exports
  - Stover, straw, energy crops (perennial grass, coppice and non-coppice woody, annual)
  - Land base includes cropland (250 million acres), cropland pasture (22 million acres), hay (61 million acres), permanent pasture (118 million acres)

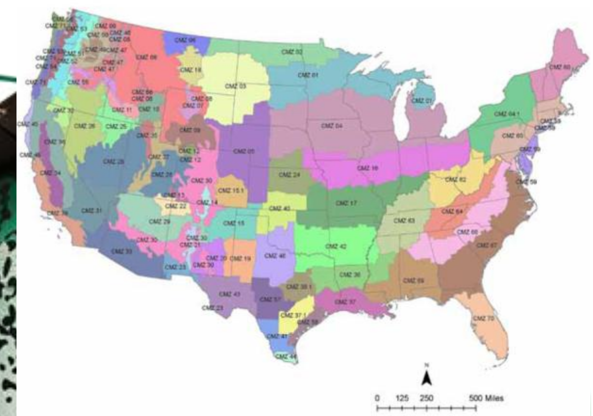


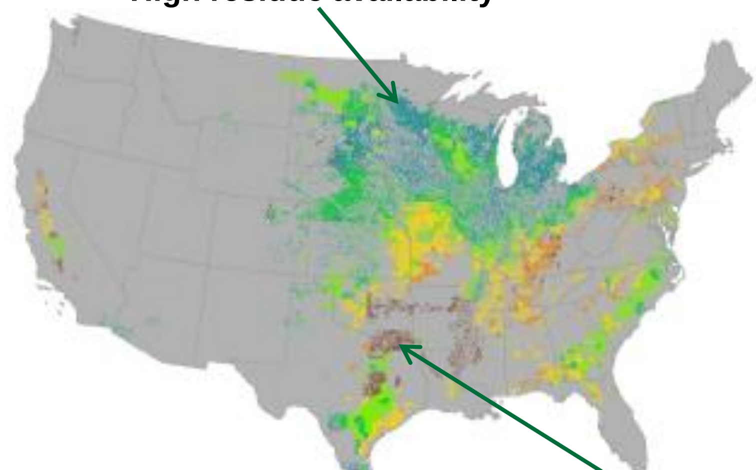
For model background: Daniel G De la Torre Ugarte,., and Darrell E. Ray. 2000. "Biomass and Bioenergy Applications of the POLYSYS Modeling Framework," *Biomass and Bioenergy* 4(3):1-18.

Agricultural Crop Residues

- **Residue retention coefficients estimated using RUSLE2, WEPS, and SCI models for erosion and soil carbon**
  - **Separate coefficients for reduced till and no-till**
  - **No residue removal under conventional till**

NRCS Crop Management Zones

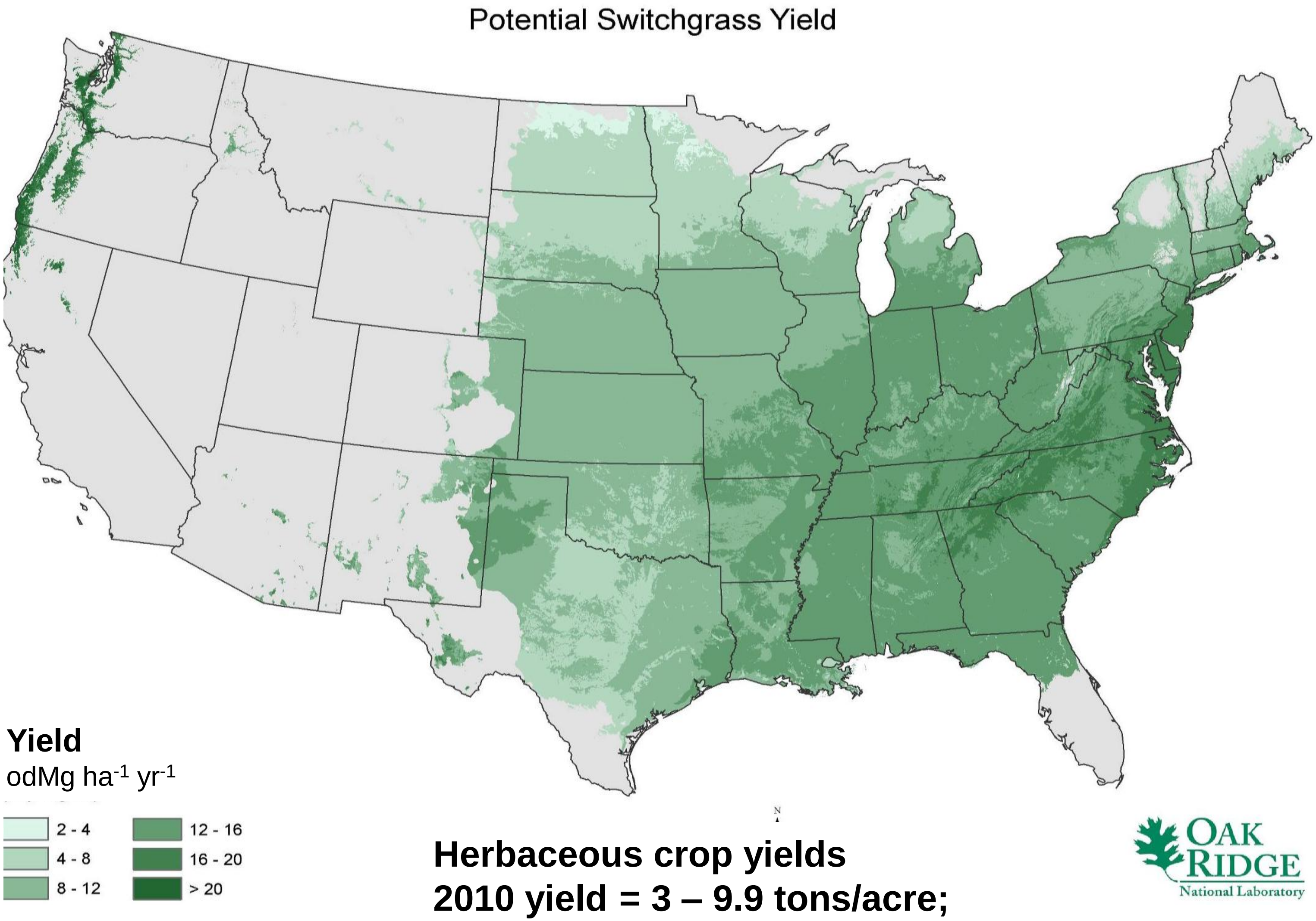




Dedicated Energy Crops: Sustainability

- **Energy crops allowed on non irrigated land**
- **Minimal tillage, fertilizer and herbicide applications**
- **Used BMPs for establishment, cultivation, and harvesting**
- **Some intensification of pasture land required (Management Intensive Grazing) to meet lost forage when energy crops displaced pasture**

Dedicated Energy Crops: Switchgrass Yields



Herbaceous crop yields
2010 yield = 3 – 9.9 tons/acre;
2030 yield = 3.6 – 12.0 tons/acre
(baseline scenario)

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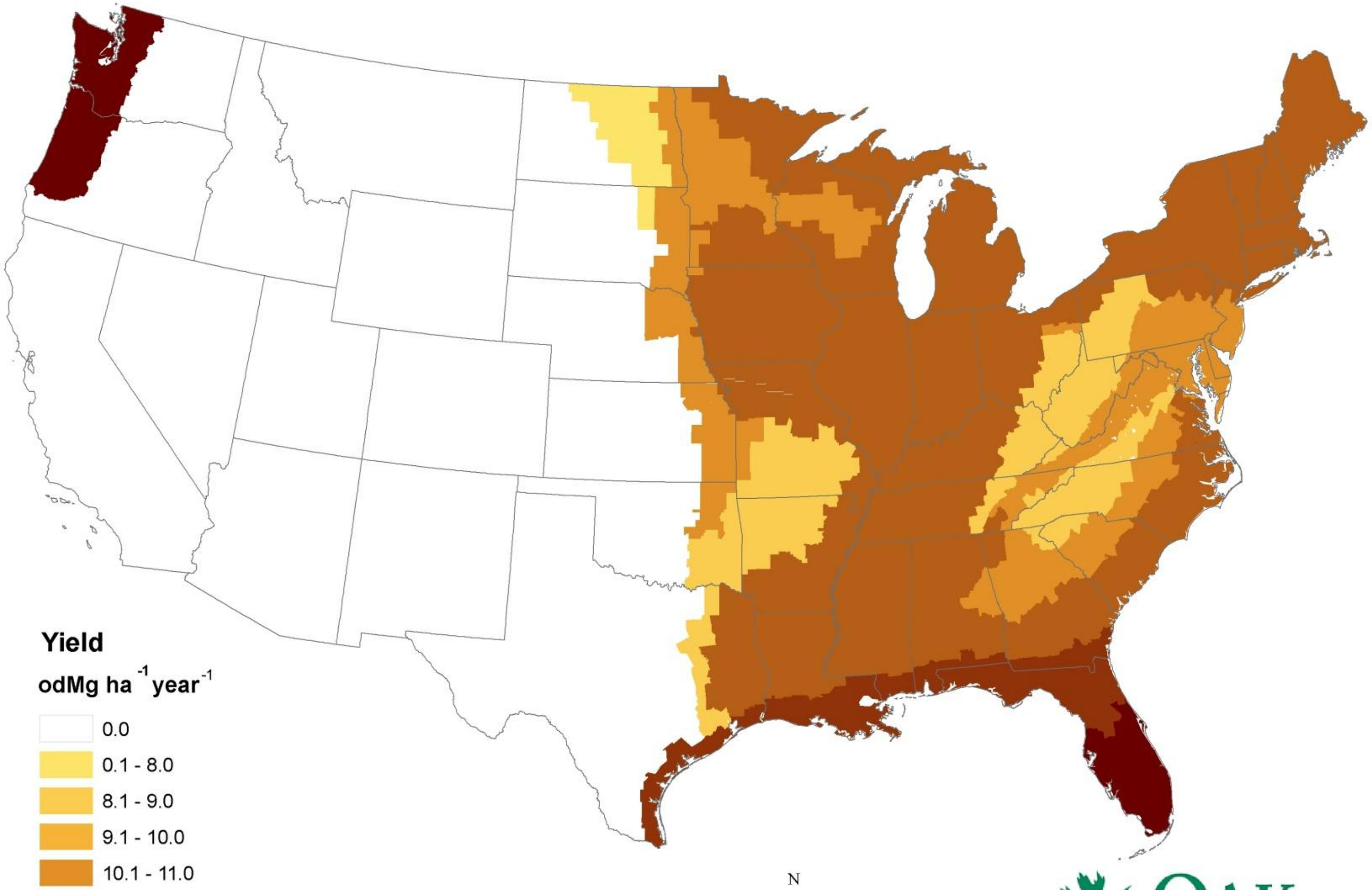
Dedicated Energy Crops: Woody Crop Yields

- **Woody crops (poplar, pine, eucalyptus, willow)**



Woody crop yields
2010 yield = 3.5 – 6;
2030 yield = 4.2 – 7.2
(baseline scenario)

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Scenarios

- **Baseline scenario assumptions**
  - **Published USDA Baseline forecast for crop yields, acres, etc.**
  - **Baseline forecast extended to 2030 based on trends in last 3-years of published forecast**
  - **Stover to grain ratio of 1:1 assumed**
  - **National corn yield average of 160 bu/ac in 2010 and assumed to increase to 201 bu/ac in 2030**

Scenarios (cont'd)

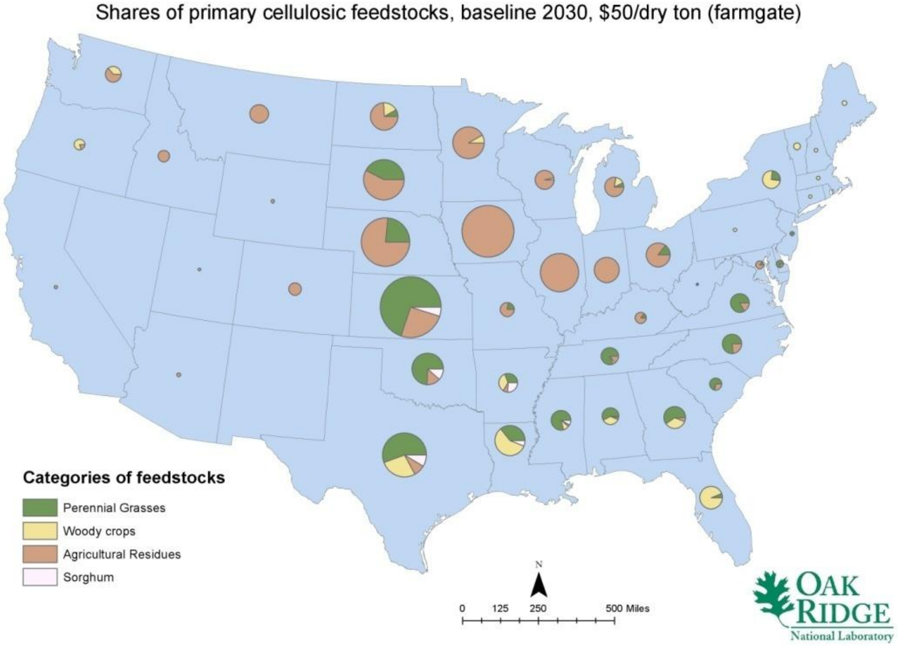
- **Baseline scenario assumptions (continued)**
  - **Assumes a mix of conventional till (CT), reduced till (RT), and no-till (NT)**
    - **For corn**
      - **2010 – 38% conventional till, 43% reduced till, 20% no-till**
      - **2030 – 34% conventional till, 43% reduced till, 23% no-till**
    - **No residue collected on conventionally tilled acres**
  - **Energy crop yields increase of 1% (learning-by-doing)**
- **High-yield scenario assumptions**
  - **National Corn yield average increases to 265 bu/acre in 2030**
  - **Higher no-till adoption allowed (greater residue removal allowed)**
  - **Energy crop yields increase at 2%, 3%, and 4% annually**
    - **Higher yields attributed to more aggressive R&D**

Scenarios (cont'd)

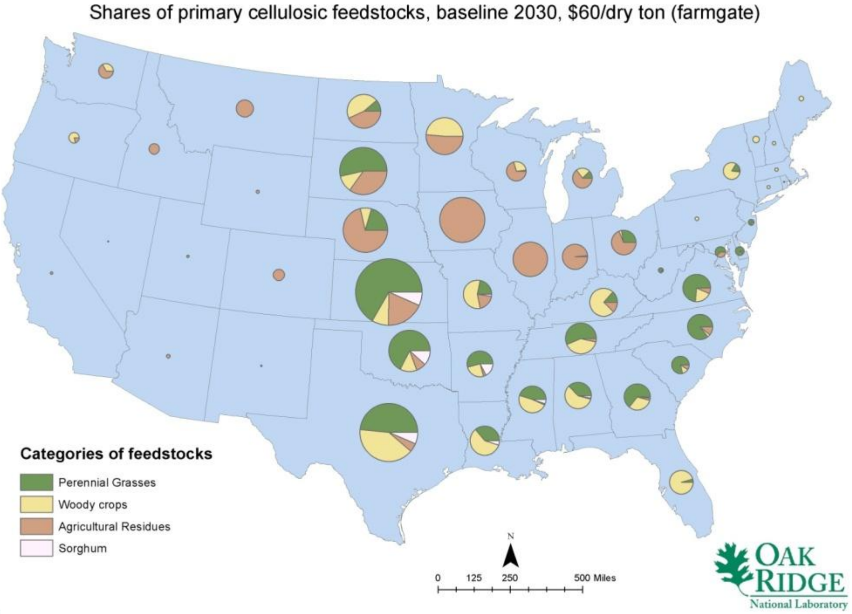
- **High-yield scenario assumptions**
  - **National Corn yield average increases to 265 bu/acre in 2030**
  - **Higher no-till adoption allowed (greater residue removal allowed)**
  - **Energy crop yields increase at 2%, 3%, and 4% annually**
    - **Higher yields attributed to more aggressive R&D**

State-level sources of agricultural feedstocks in 2030

$50/dry ton



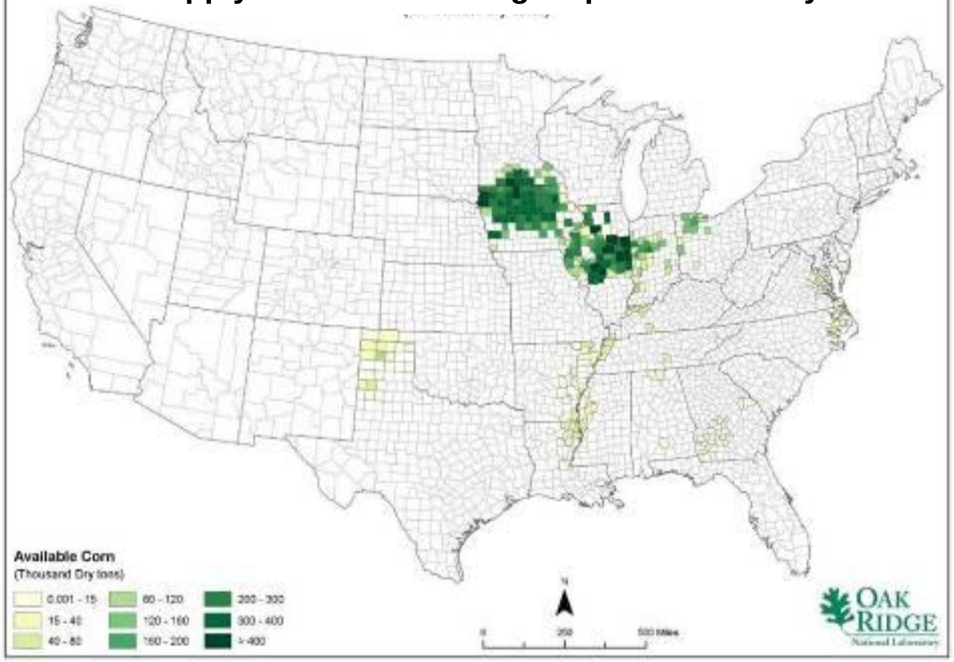
$60/dry ton



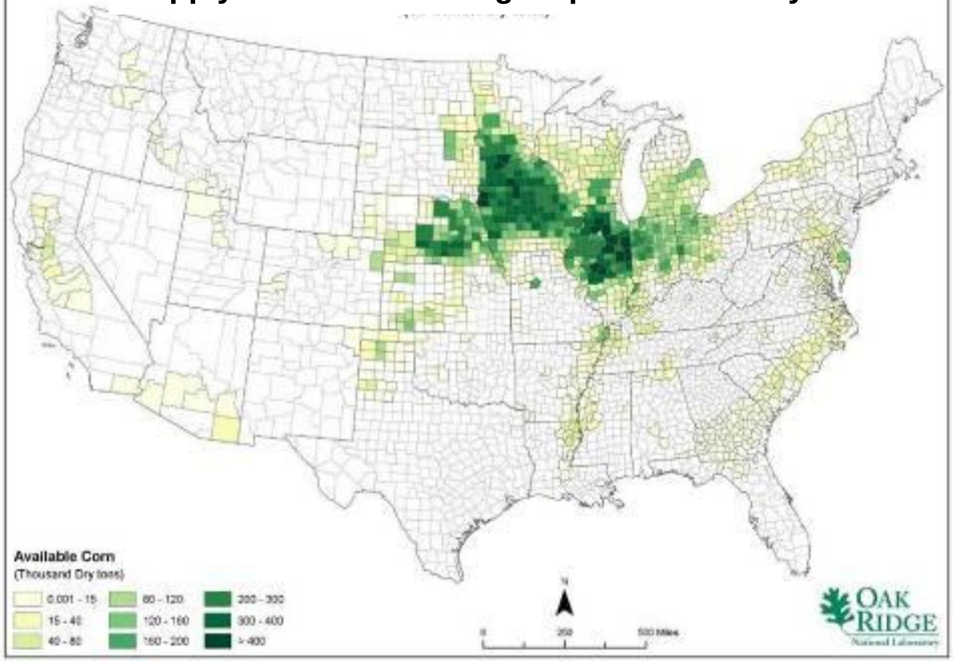
As price increases, fraction of supply that is woody crops increases

County-level Corn Stover Supply, 2030

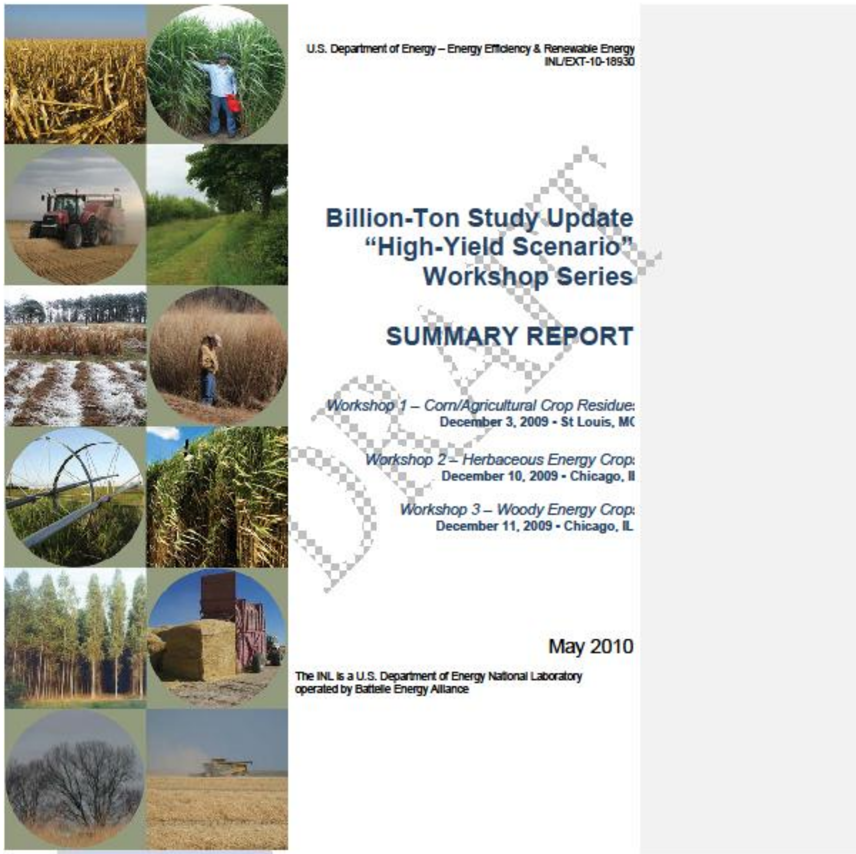
Supply of stover at farmgate price of $50/dry ton



Supply of stover at farmgate price of $60/dry ton



Other research publications (under review)


U.S. Department of Energy – Energy Efficiency & Renewable Energy
INL/EXT-10-18930

Billion-Ton Study Update
"High-Yield Scenario"
Workshop Series

SUMMARY REPORT

Workshop 1 – Corn/Agricultural Crop Residues
December 3, 2009 • St Louis, MO

Workshop 2 – Herbaceous Energy Crops
December 10, 2009 • Chicago, IL

Workshop 3 – Woody Energy Crops
December 11, 2009 • Chicago, IL

May 2010

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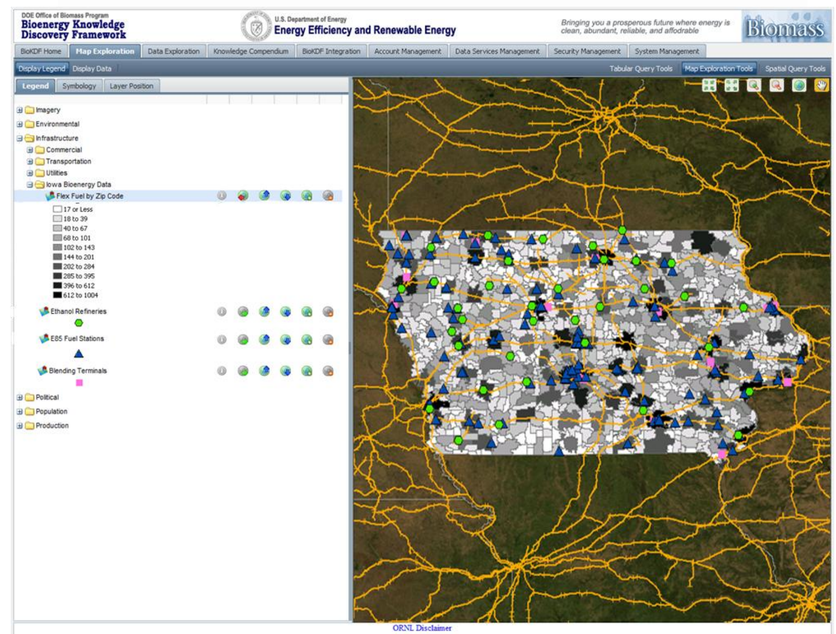

Final comments and Conclusions

1. Projections for the annual potential of biomass is estimated to exceed 1 billion dry tons on an annual basis, depending on technology assumptions, prices and land availability
2. Crop residue sustainability is important (retention, rotations, etc)
3. Resource assessment relies upon multiple sources of data and information

Thank you for your attention!

Contact:

eatonlm@ornl.gov