A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

Biomass to Liquid Fuels Biorefinery Development in the USA: An Update

IEA Bioenergy Task 39 Symposium

Cork, Ireland – September 16, 2008

James D. McMillan

NREL

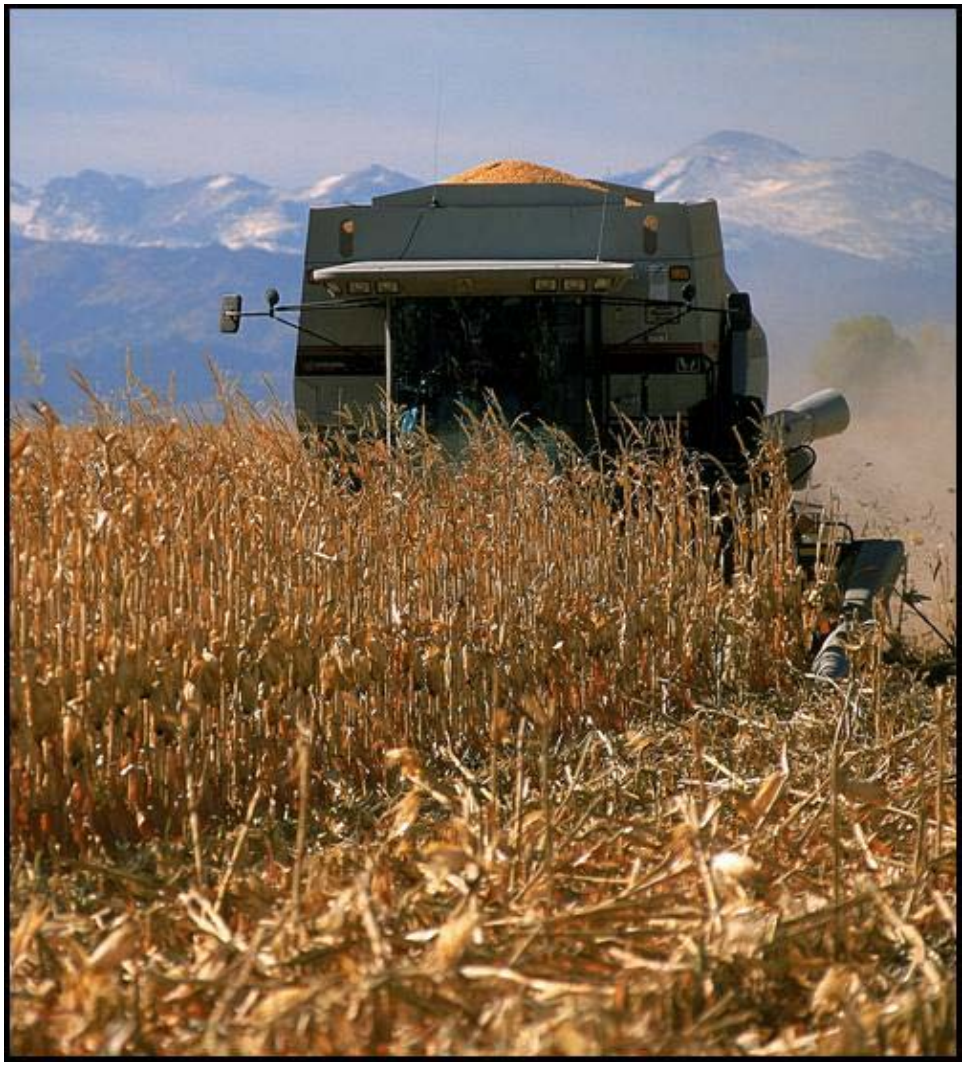
Golden, Colorado, USA

NREL is operated by Midwest Research Institute • Battelle

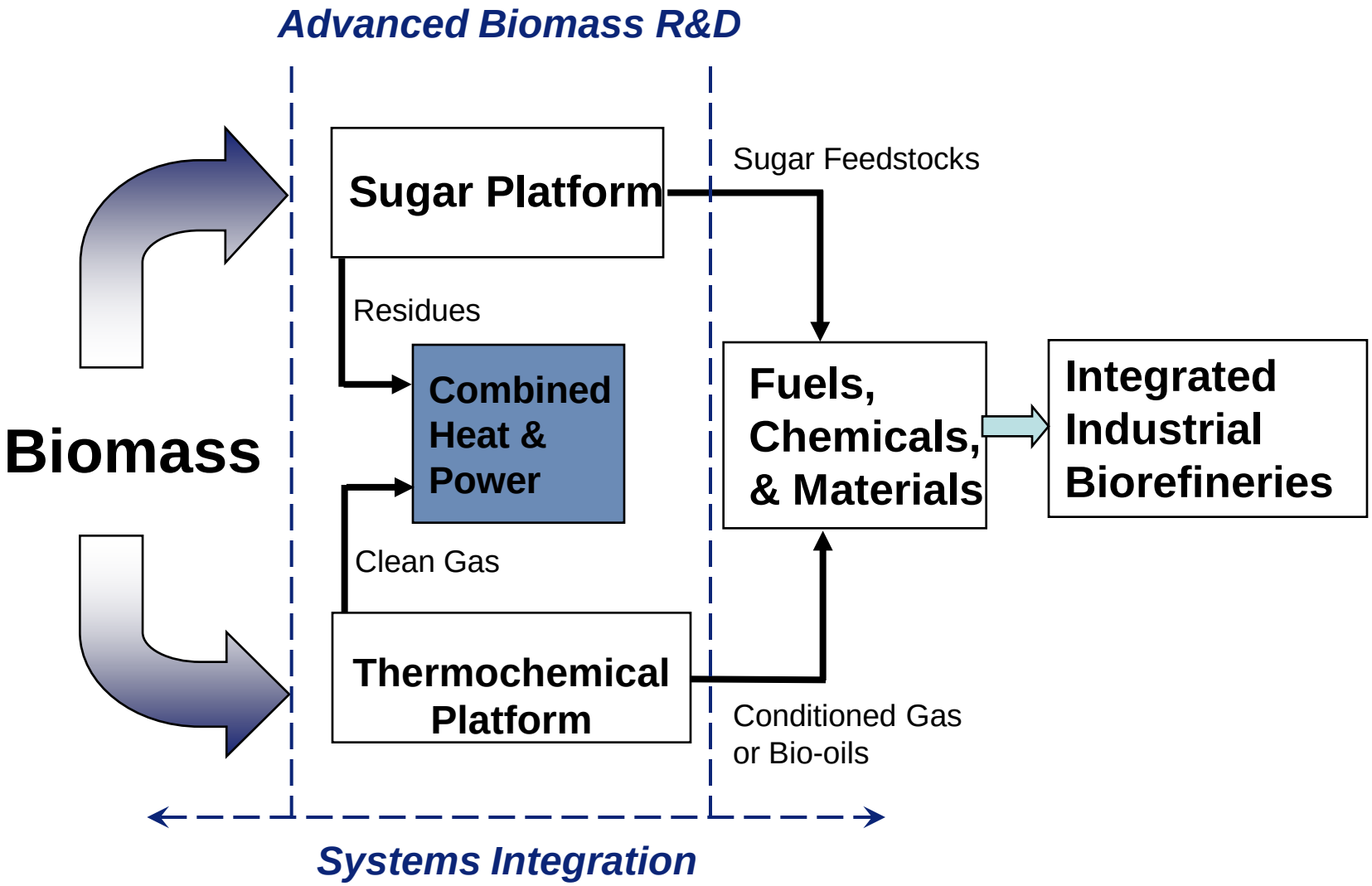
Biomass – Part of the Solution

While the growing need for sustainable electric power can be met by other renewables…

Biomass is the only renewable that can meet our demand for carbon-based liquid fuels and chemicals

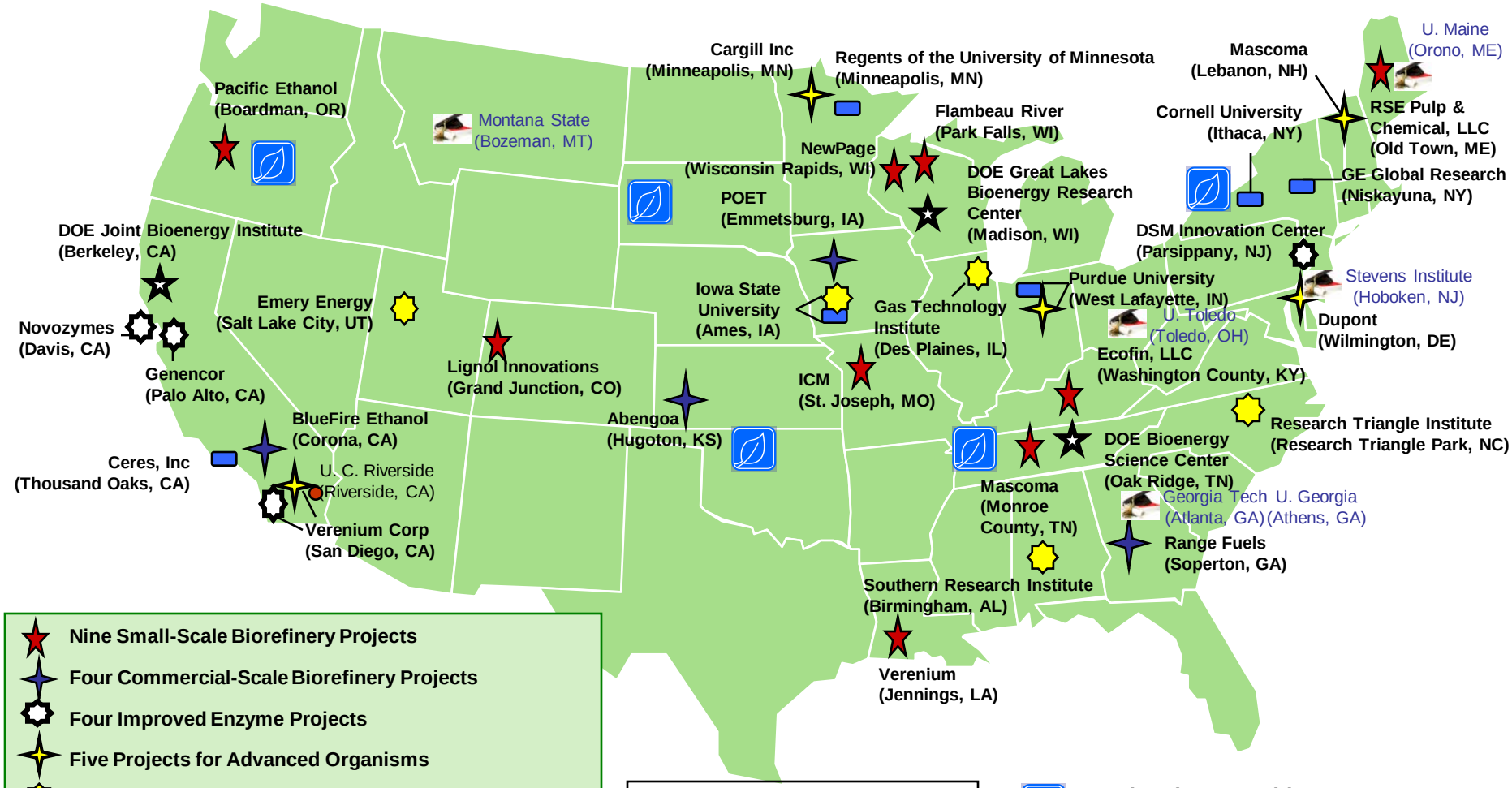


Integrated Biorefinery Conversion Platforms



Major DOE Biofuels Project Locations

Geographic, Feedstock, and Technology Diversity



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2002 Biorefinery Projects

Broin (Poet) – Scotland, SD

DuPont – Wilmington, DE

Abengoa – York, NB

Cargill – Minnetonka, MN

Regional Partnerships

South Dakota State University, Brookings, SD
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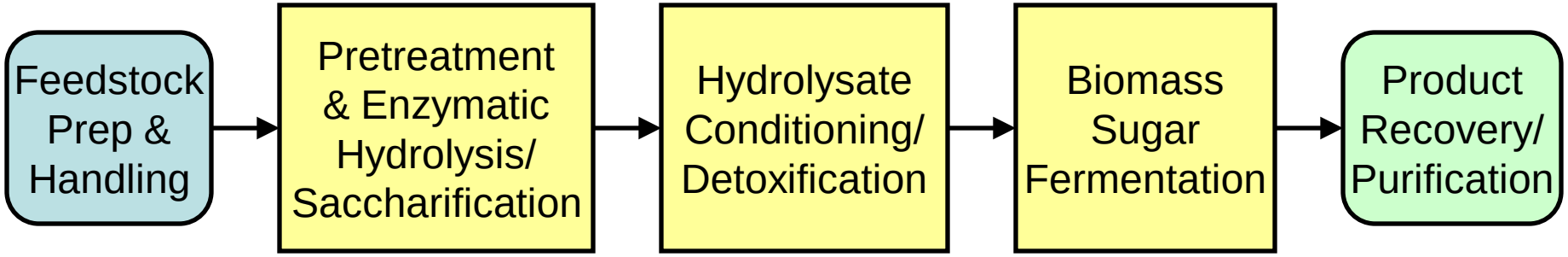
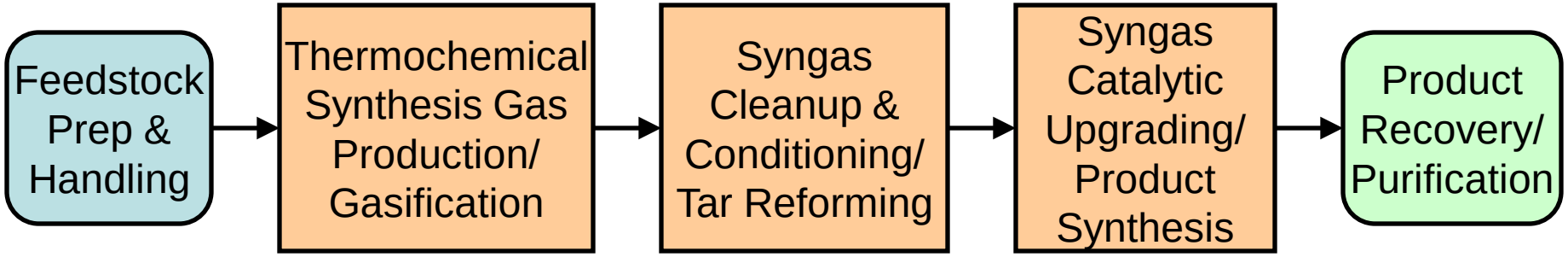
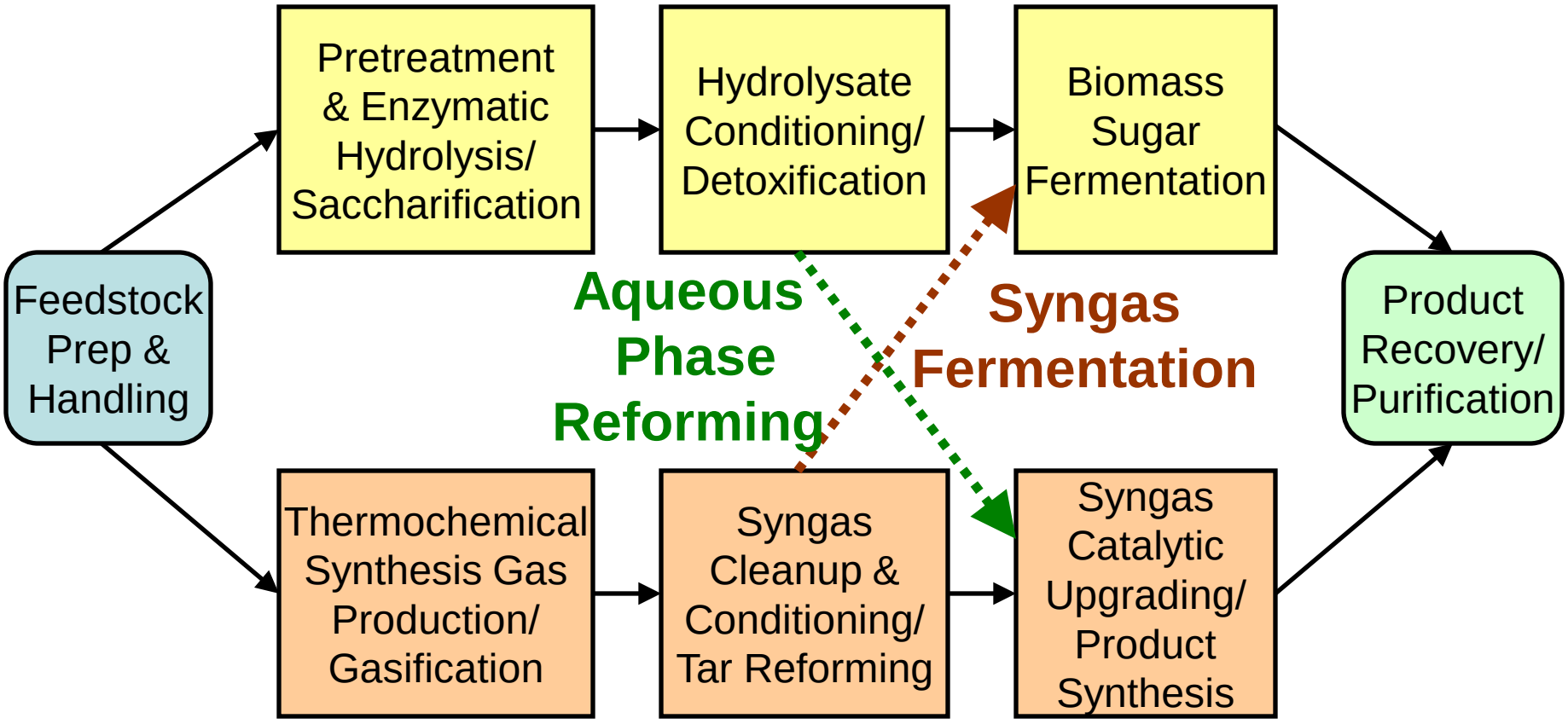
Biomass Conversion to Fuels – Major *Biochemical* Conversion Steps



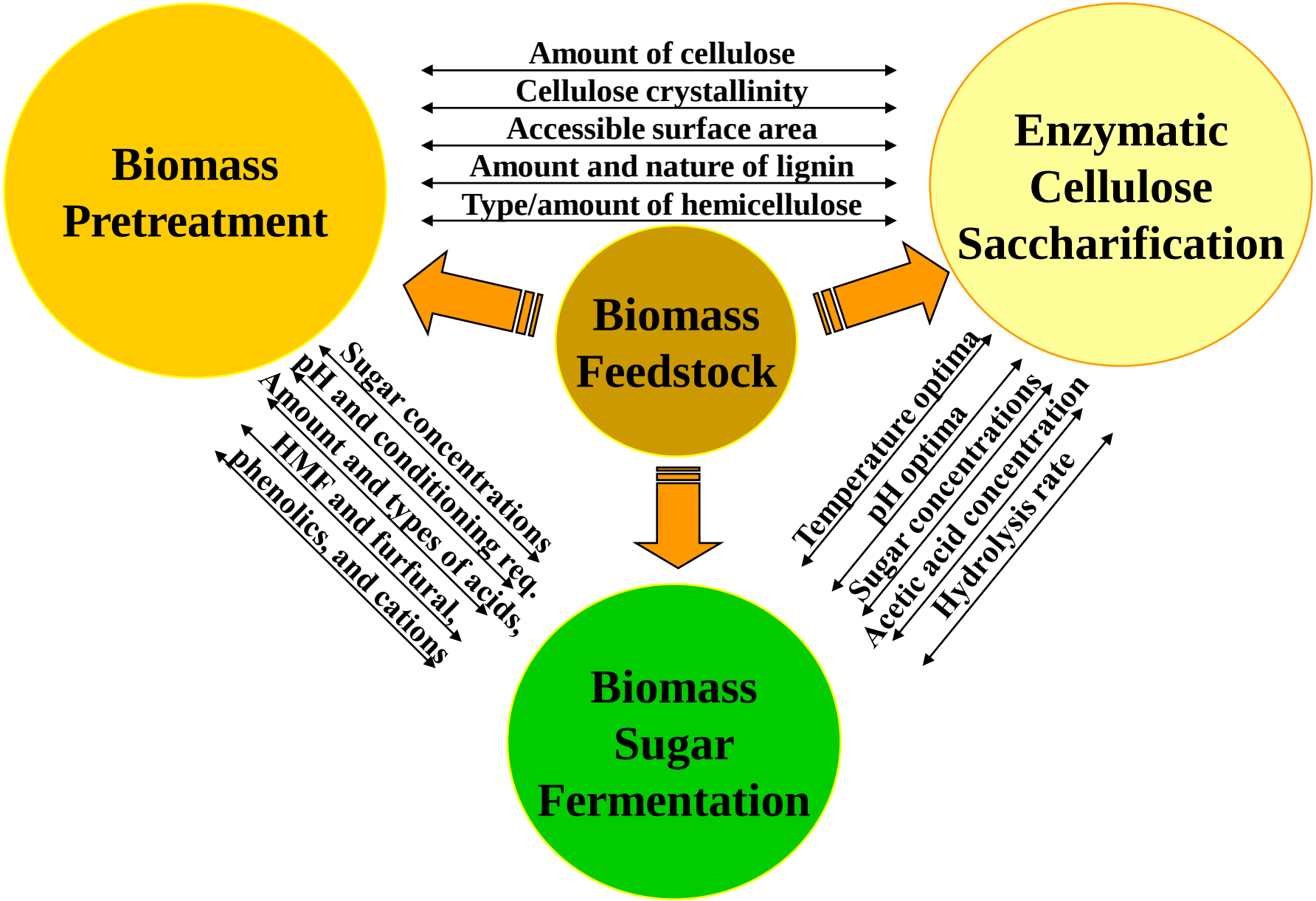
Biomass Conversion to Fuels – Major *Thermochemical* Conversion Steps



Biomass Conversion to Fuels – *Hybrid* Approaches



Integrated *Biochemical* Process – Interactions



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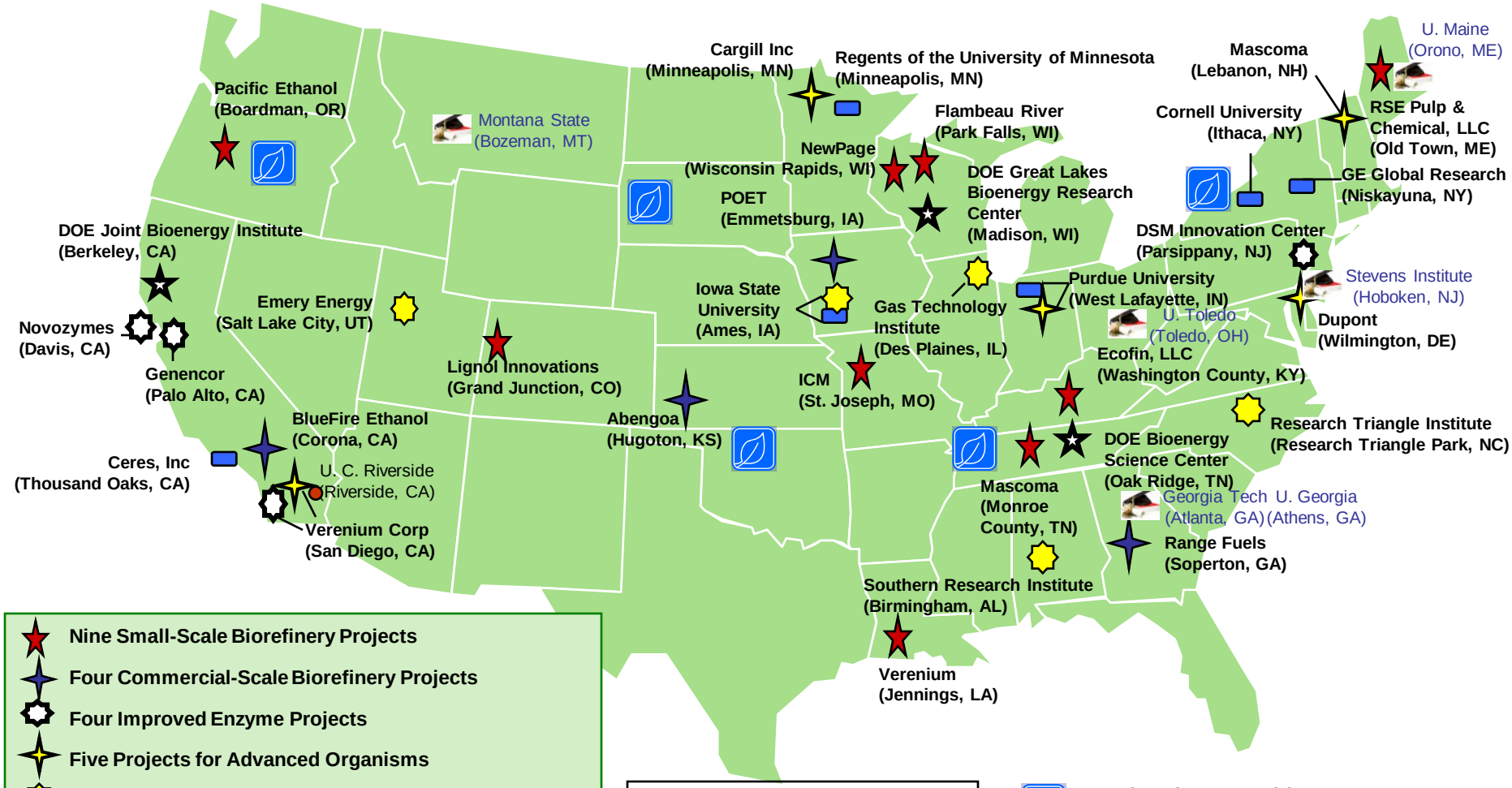
Geographic, Feedstock, and Technology Diversity



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2002 Biorefinery Projects

Objective: Advance technologies for producing fuels from cellulosic feedstocks or improve biorefinery economics through co-products (power, chemicals, materials, etc.)

Project Leader	Feed-stock type	Conv. Tech.	Status	Outcome
Abengoa	Ag. Residues	Biochem	Continue to operate and evaluate systems & unit operations.	Using this facility to develop plans for the 932 Hugoton commercial plant.
Broin (now Poet)	Ag. Residues	Biochem	Completed R&D for improved animal feed co-product. Conversion technology was not successful.	Submitted to 932 FOA for with a new process and proposed pilot plant. Will do a 932 project under new entity POET.
DuPont	Corn cobs	Biochem	Completed pilot runs at NREL and DuPont. Created LCA model & developed basic engineering data.	Partnering with Genencor (Danisco) to build an integrated pilot plant in Tennessee.
Nature Works (now Cargill)	Corn Starch and Ag. Residues	Biochem	Developed new strains for coproduction of chemicals and ethanol.	Partnered with Abengoa to evaluate strains on hydrolysates. Also, developed new acid tolerant lactic acid strain for commercial use in a starch plant.
Cargill	Corn Starch	Biochem	Partnering with Novozymes to develop biochem pathway to a new platform chemical.	Have developed new intermediates from platform chemical. Finishing biosynthesis work in 2009.

Industrial Biorefinery Development

Section 932 of Energy Policy Act of 2005 directed USDOE to conduct solicitations to demonstrate integrated processes for biofuels production

1. Minimum of 700 dry metric tons/day (t/d)
2. Must use lignocellulosic feedstock and produce ethanol or any fungible replacement for gasoline or diesel

USDOE Solicitations

- 2006 commercial scale (700 t/d) solicitation
  - Cost share 60% industry / 40% USDOE
- 2007 10% scale (70 t/d) solicitation
  - Cost share 50% industry / 50% USDOE

Four “Commercial Scale” Biorefinery Projects Moving Forward (of Six Initially Selected)

- Abengoa Bioenergy
  - up to $76 million
  - 9/30/07 - Phase 1
- ALICO, Inc.
  - up to $33 million
  - Phase 1 in negotiation
- BlueFire Ethanol
  - up to $40 million
  - 9/30/07 - Phase 1
- Iogen Biorefinery
  - up to $80 million
  - Phase 1 in negotiation
- Poet
  - up to $80 million
  - 9/30/07 - Phase 1
- Range Fuels
  - up to $76 million
  - 11/03/07 - Phase 2

ALICO, Inc.

Using an innovative syngas fermentation process

Production:

- 7 million gallons/year from first unit; second unit at 13.9 million gallons/year, 6,255 kW power plus ammonia and hydrogen (produced based on market requirements including their own use of ammonia as fertilizer).

Technology & Feedstocks:

- Gasification of wood or agricultural residues and fermentation of syngas to ethanol with ammonia and electricity as co-products
- 770 tons/day of yard, wood, crop residue (citrus peel), and eventually energy cane

BlueFire Ethanol, Inc.

Biological fermentation process not using enzymes

Production:

- 19 million gallons ethanol/year in the unit in which USDOE will be participating.

Technology & Feedstocks:

- Concentrated acid processing of 700 tons/day of *sorted green waste and wood waste from landfills* followed by fermentation of sugars to ethanol.
- Based on smaller scale pilot plant experience in Japan.

Iogen Biorefinery Partners, LLC

Enzyme producer will demonstrate a *biochemical process* with the flexibility to process a wide range of agricultural residues

Production:

- 18 million gallons/year in the first plant, 250 million gallons/year in future plants
- Cellulosic ethanol & co-products in first plant; future plants to be primarily cellulosic ethanol

Technology & Feedstocks:

- Agricultural residues: wheat straw, barley straw, corn stover, switchgrass and rice straw
- Tested the overall process at demonstration semi-works plant scale

Poet LLC

Integrating **an innovative corn processing waste to ethanol** ***biochemical process*** **into an** ***existing dry corn mill*** **infrastructure**

Production:

- 125 million gallons/year of ethanol, of which roughly 25 percent will be from lignocellulosics.
- Ethanol from lignocellulosic stream and ethanol, chemicals and animal feed from the dry-grind operation.

Technology & Feedstocks:

- Processing 842 tons/day of corn fiber and corn stover (cobs and stalks)
- Based on Broin/DuPont/Novozymes/NREL CRADA

Range Fuels, Inc.

Use of a novel two stage gasifier followed by catalytic conversion of the syngas to mixed alcohols

Production:

- 20 million gal/yr ethanol, 8 million gal/yr methanol in first module
- 100 million gal/yr ethanol, 40 million gal/yr methanol at commercial scale

Technology & Feedstock:

- Pyrolysis followed by reforming of pyrolysis vapors to synthesis gas.
- Syngas catalytically converted to mixed alcohols.
- Unmerchantable timber as feedstock, 500 tons/day first module, 2500 tons/day commercial scale.

Abengoa Bioenergy

Demonstrating ***biochemical and thermochemical*** conversion

Production:

- 11.4 million gallons/year and sufficient energy to power the operation and sell excess energy to a co-located dry-grind ethanol production plant.
- Both ethanol and syngas production, with long term strategy of using the syngas for ethanol and chemicals production.

Technology & Feedstocks:

- Thermochemical (gasification) and biochemical processing of 700 tons/day of corn stover, wheat straw, milo (sorghum) stubble, switchgrass, and other opportunity feedstocks.

“Commercial Scale” Biorefinery Projects

DOE cost-shared under EPACT Section 932

DOE investments in cellulosic biofuels to accelerate commercialization and help create a biofuels market based on non-food feedstocks.

Project Leader	Feed-stock type	Conversion Technology	Location	Status
Bluefire	Sorted MSW	Biochemical – Concentrated Acid Hydrolysis	Mecca, CA	Anticipate an Award 2 for construction in FY09 after NEPA work is completed
Poet	Corn Cob Corn Fiber	Biochemical	Emmetsburg, IA	NEPA EA ready for public comment. Currently negotiating for an Award 2.
Range Fuels	Woody Waste	Gasification + Mixed Alcohol synthesis	Soperton, GA	Award 2 issued, engineering and construction in progress.
Abengoa	Agricultural Residue	Biochemical and Thermochemical	Hugoton, KS	NEPA EIS process initiated. Award 2 anticipated in FY09.

“Demonstration Scale” Biorefinery Projects

Selected for DOE funding in FY08; Under Negotiation

Project Leader	Feedstock Type	Conversion Tech.	Location
Ecofin	Corn Cobs, Corn Fiber	Biochemical – Enzymes by Solid State Ferm.	Washington County, KY
ICM	Switchgrass, Forage Sorghum, Stover	Biochemical	St. Joseph, MO
Lignol Innovations	Woody Biomass	Biochemical – Organosolv	Grand Junction, CO
Mascoma	Switchgrass – Woody Biomass	Biochemical – Thermophile	Upper Peninsula, MI
NewPage	Woody Biomass - Mill Residues	Thermochemical – FT Liquids	Wisconsin Rapids, WI
Pacific Ethanol	Wheat straw, Stover, Poplar Residuals	Biochemical – BioGasol Process	Boardman, OR
RSE	Woody Biomass – Mill Residues	Biochemical – Pentose Extraction	Old Town, ME
Verenium Biofuels Corp.	Energy Cane and Bagasse	Biochemical	Jennings, LA
Flambeau River Biofuels	Forest Residues and Wood Waste	Thermochem – FT Liquids	Park Falls, WI

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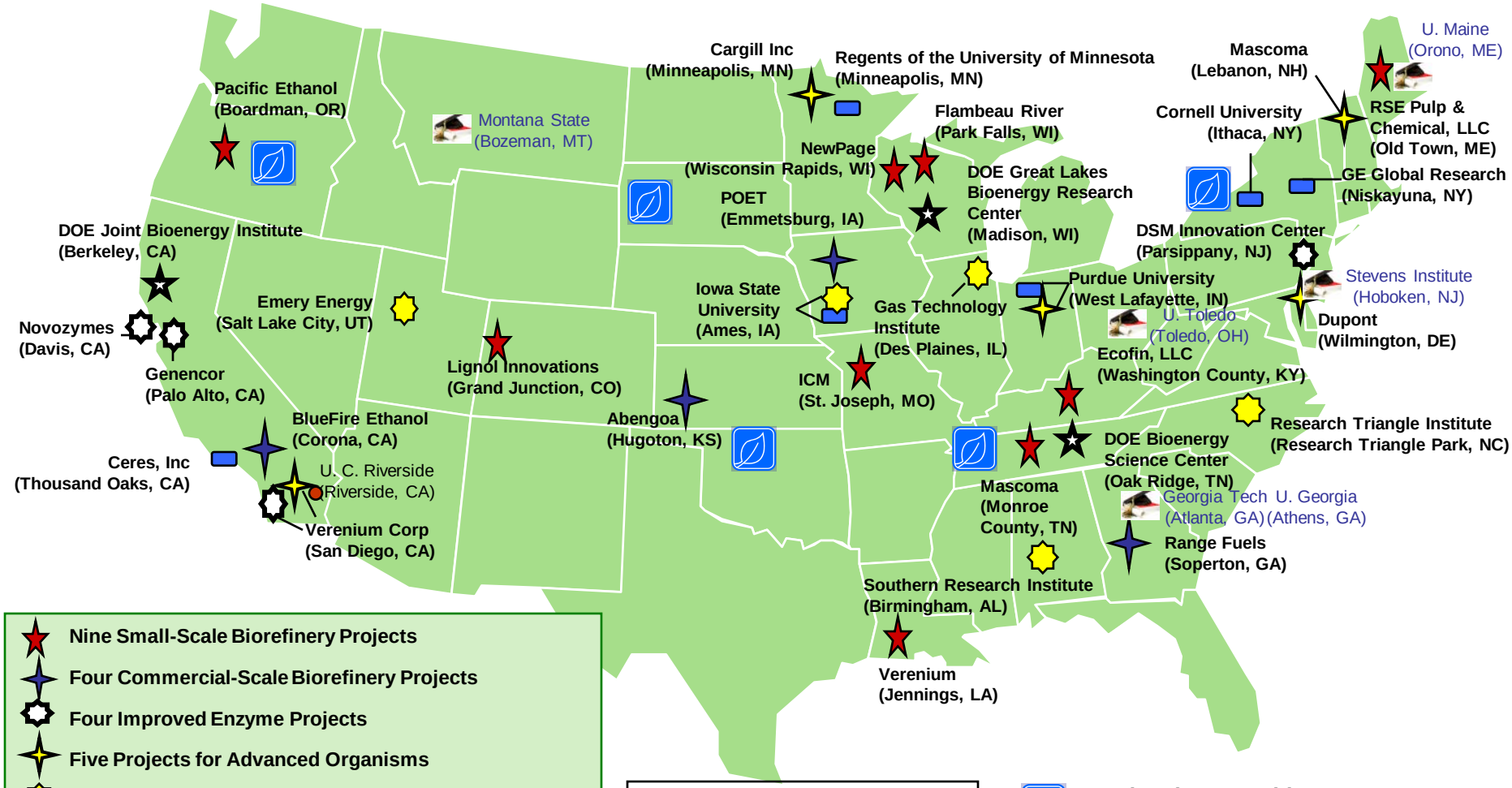

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Conclusions

Broad Project Selection Achieves USDOE Goals

- Diversity of primary conversion technologies
  - Saccharification with concentrated acids and by pretreatment followed by enzymatic hydrolysis
  - Pretreatment with or without an organic solvent
  - Enzymes produced by submerged culture or solid state cultivation
  - Thermochemical syngas production by pyrolysis/gasification
- Diversity of process integration scenarios/approaches
  - Biochem-thermochem (gasification of lignin rich residues)
  - Biological ethanol production by mesophilic and thermophilic microorganisms
  - Syngas fermentation
  - Syngas mixed alcohols catalytic synthesis
  - Syngas Fischer-Tropsch catalytic synthesis

Conclusions, cont'd.

Achieving USDOE Biorefinery Demonstration Goals

- Diversity of feedstocks
  - **Ag residues**: Corn stover, wheat & barley straw, corn fiber, etc.
  - **Woody biomass**: Poplar residues, unmerchantable timber and wood wastes, mill residues
  - **Collected/sorted municipal solid waste** and other wastes: Sorted green waste and wood wastes from landfills, wood and vegetative waste (citrus peels)
  - **Energy and other crops**: Switchgrass, sweet sorghum

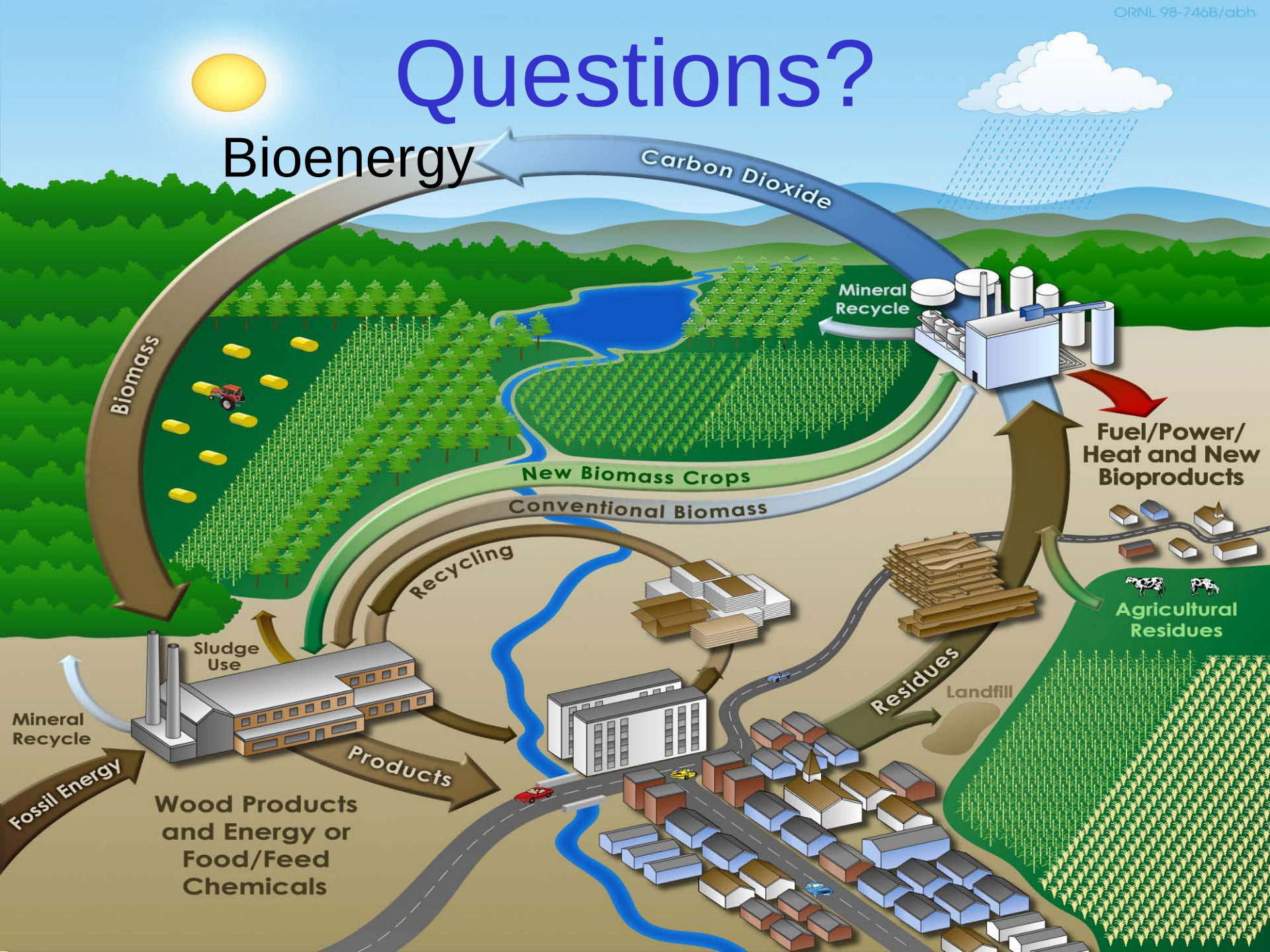
- Integration with current bio- and petro- refineries
  - Dry mill ethanol plants
  - Petroleum refinery
  - Pulp and paper mills

Additional Information

- EERE Biomass Program
  - http://www.eere.energy.gov/biomass/
- NREL Biomass Research
  - http://www.nrel.gov/biomass/
- USDOE-USDA Biomass R&D Initiative
  - http://www.brdisolutions.com/

Questions?

Bioenergy



Acknowledgments

- Funding
  - USDOE EERE Office of the Biomass Program, Washington DC
- Status of Solicitations
  - Gene Petersen and John Scahill, USDOE Golden Field Office, Golden, Colorado