Renewable Energy: A Significant Contributor?

Achieving the Goal of 30% Transportation Fuels from Biomass by 2030

10th Annual Green Chemistry & Engineering Conference

June 29, 2006

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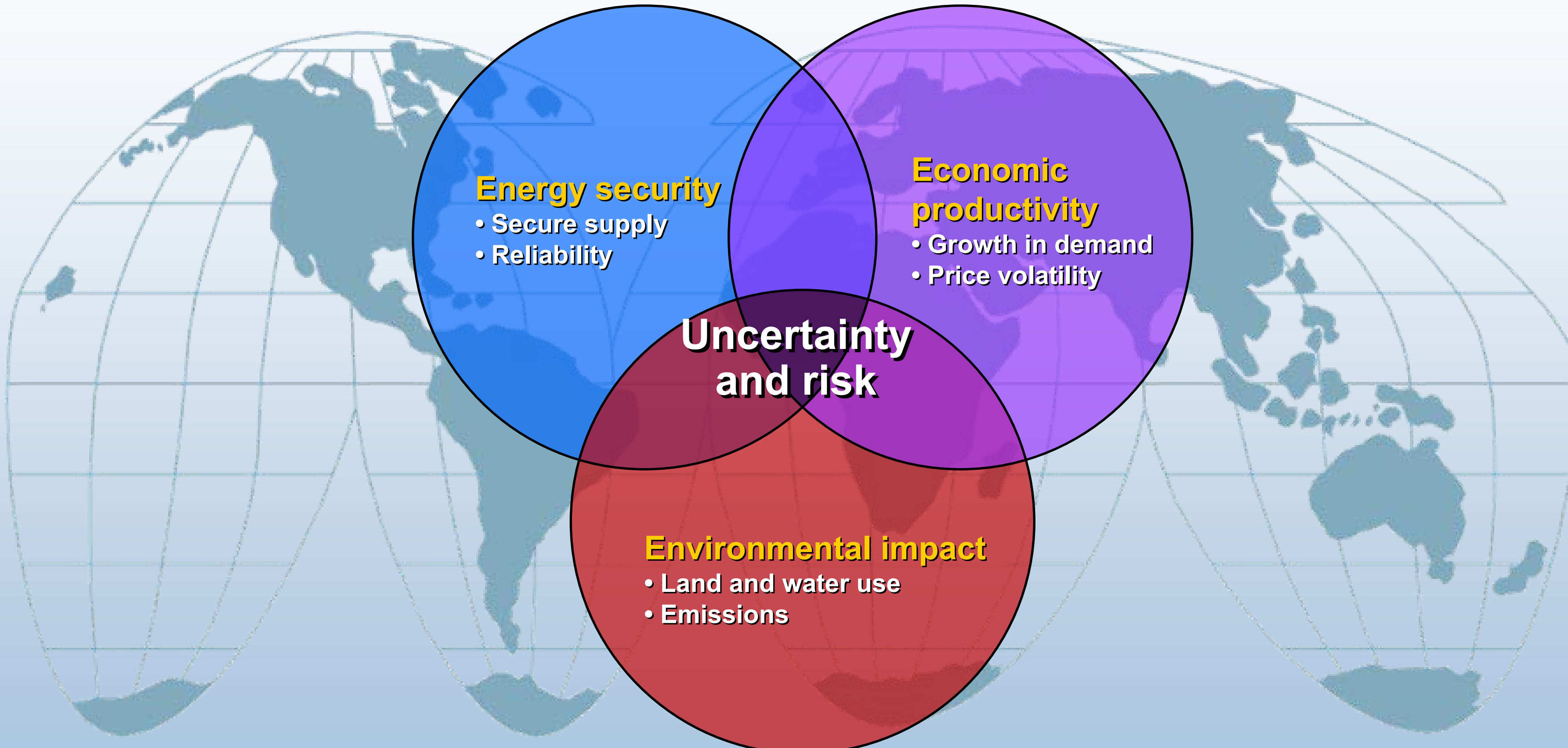
Director, National Renewable Energy Laboratory

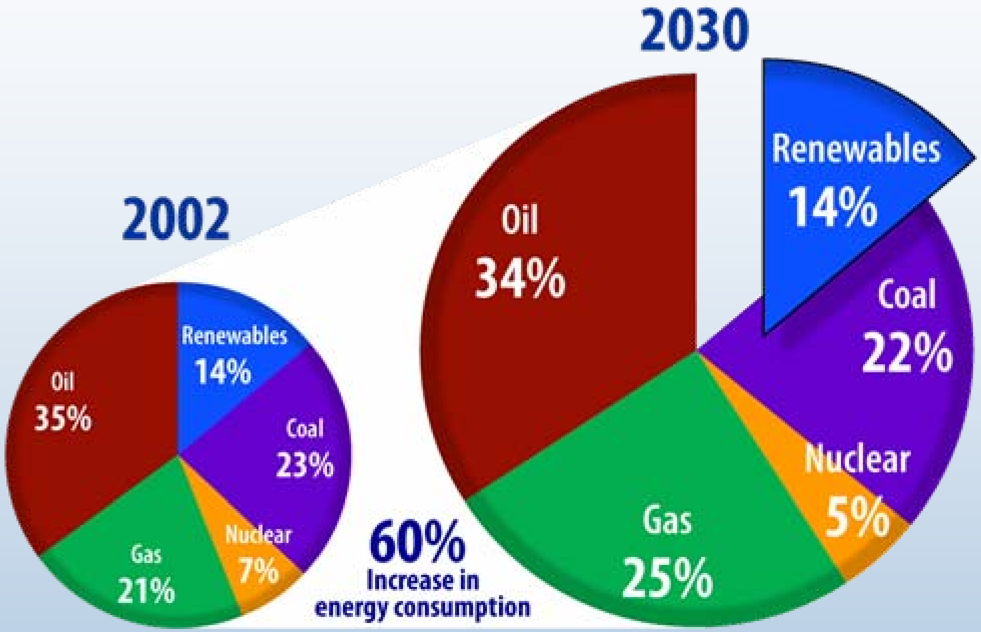
NREL/PR-100-40773

Energy Solutions are Enormously Challenging

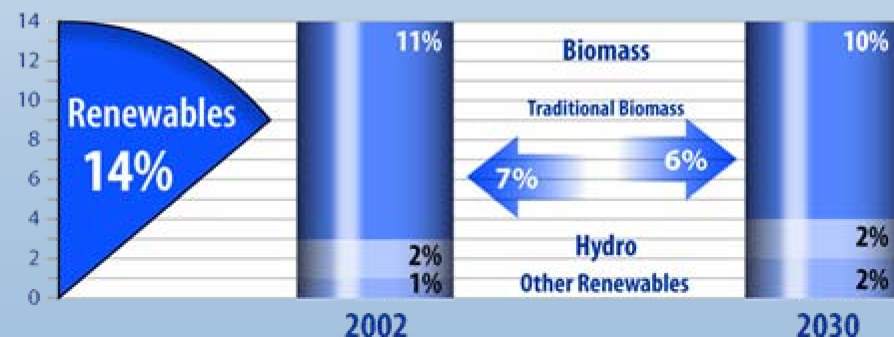


We need a balanced portfolio of options

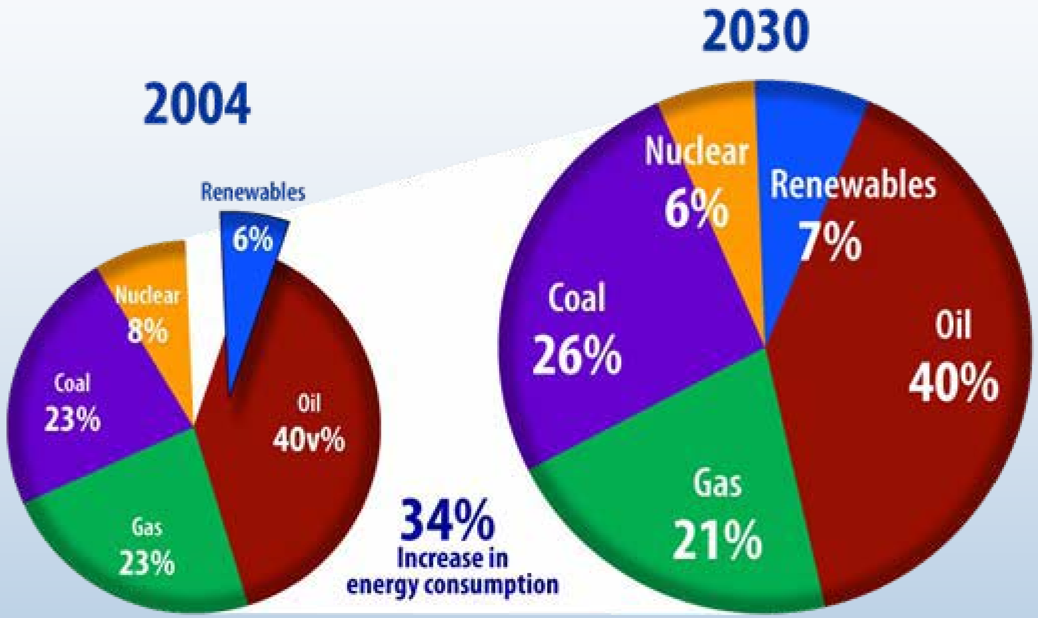
World Energy Supply and the Role of Renewable Energy



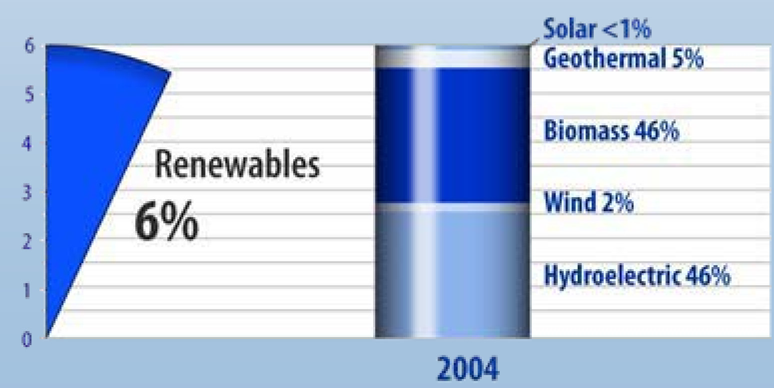
Source: OECD/IEA, 2004



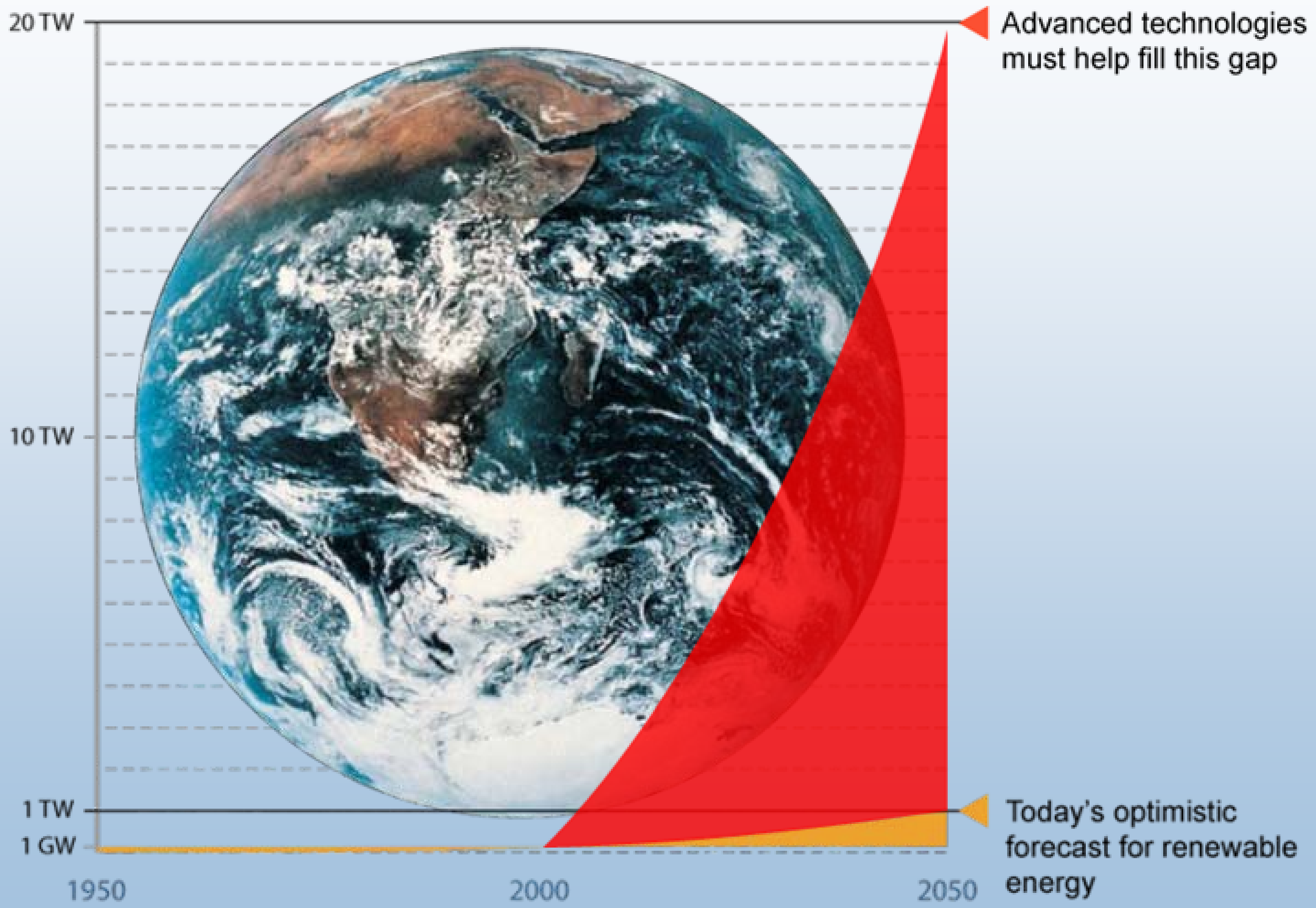
U.S. Energy Consumption and the Role of Renewable Energy



Source: Energy Information Administration, *Annual Energy Outlook 2006,* Table D4



Magnitude of Challenge Requires Global Action and a Change in Trajectory



Technology-based Solutions:

There is no single nor simple answer

- Energy efficiency
- Renewable energy
- Non-polluting transportation fuels
- Separation and capture of CO_2 from fossil fuels
- Next generation of nuclear fission and fusion technology
- Transition to smart, resilient, distributed energy systems coupled with pollution-free energy carriers, e.g. hydrogen and electricity

Energy Efficiency & Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal

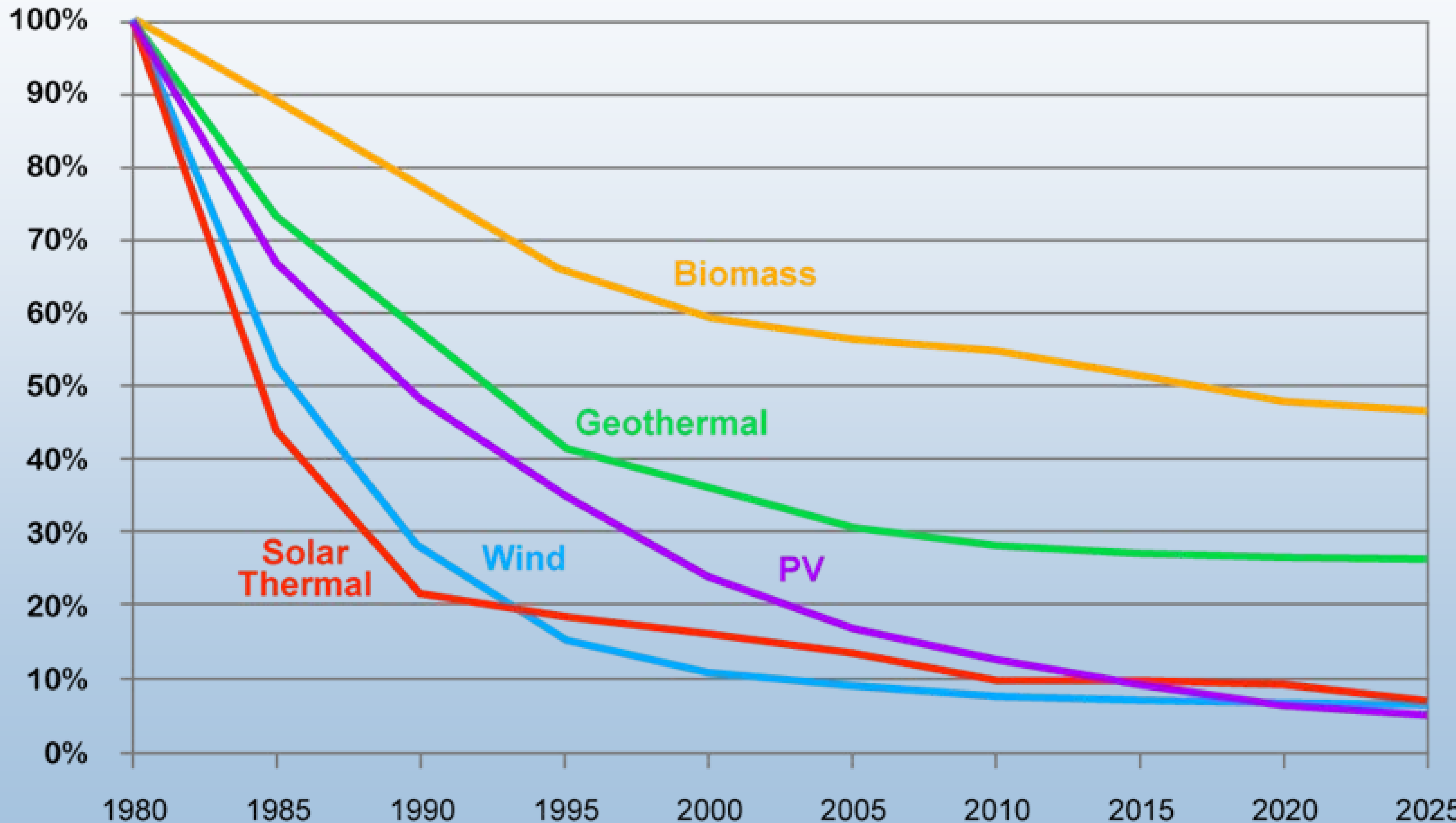
Energy Delivery & Storage

- Electricity Transmission & Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science

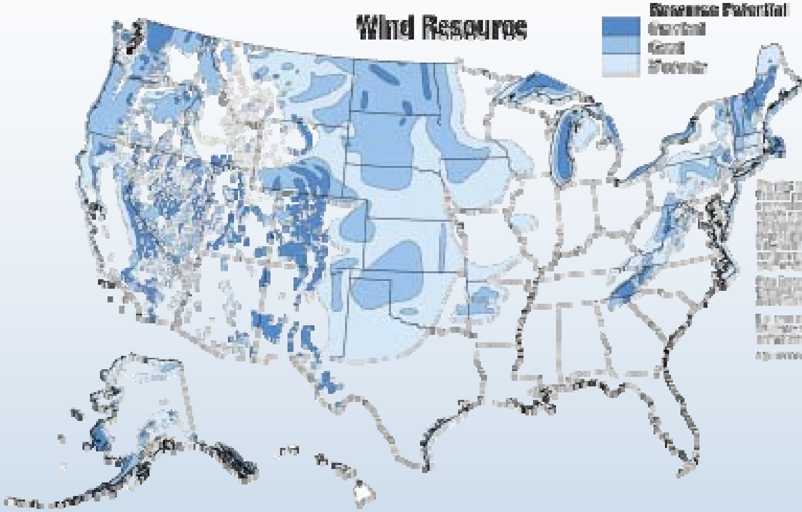
Renewable Energy Electricity Generation Costs as Percentage of 1980 Levels:

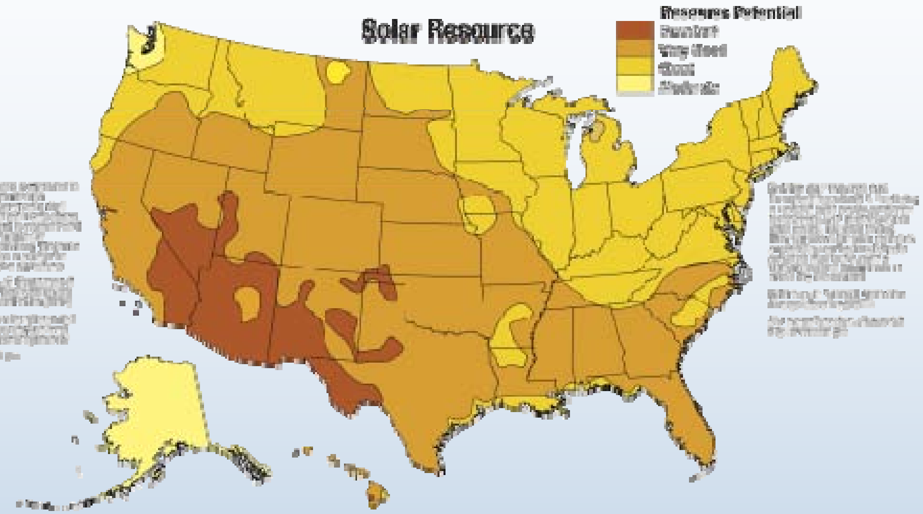
Historical and Projected

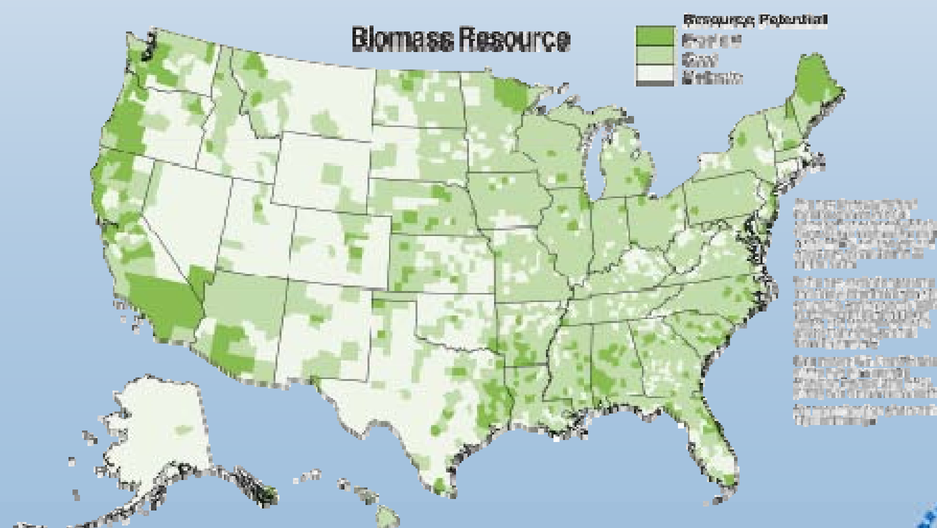


Source: NREL 2005, 2002

National Resources

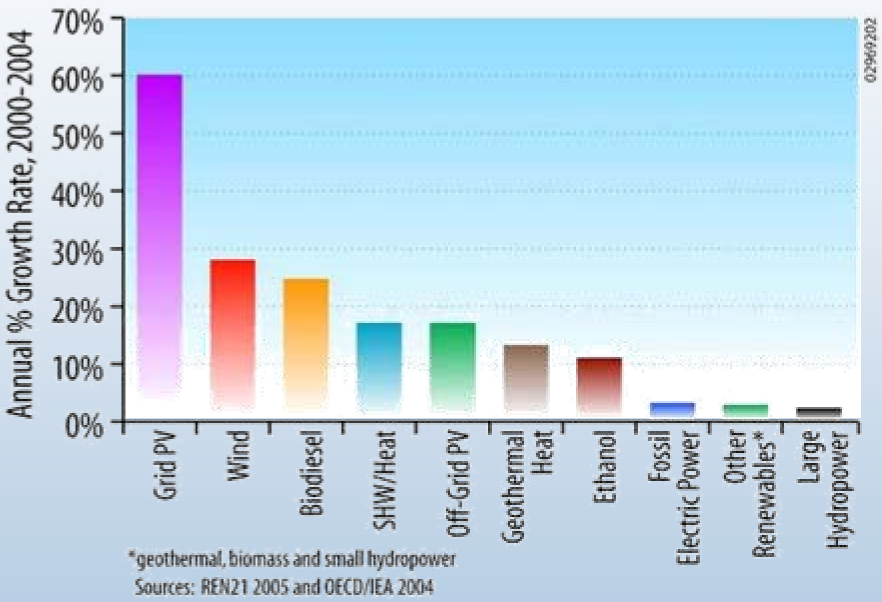




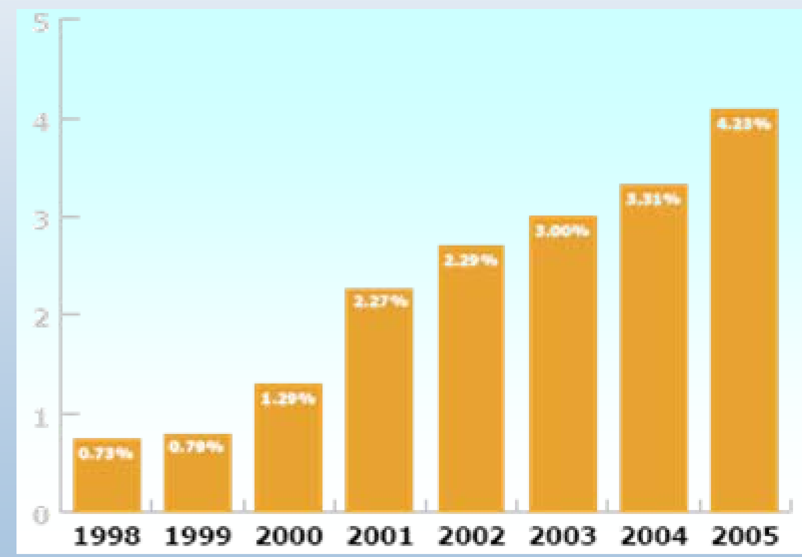


Renewable Energy is Growing

Renewable Energy Annual Growth Rates



Energy-Tech Investments as a Percent of Total U.S. Venture Capital



Source: Nth Power LLC

Wind & Solar are each $10B+ industries and there is over a $1B clean energy venture capital market

Wind

Today's Status in U.S.:

- 9,200 MW installed as of Dec 2005
- Cost 6-9¢/kWh at good wind sites with no PTC

U.S. DOE Cost Goals:

- 3.6¢/kWh, onshore at low wind sites by 2012
- 5¢/kWh, offshore in shallow water by 2014

Long Term Potential:

- 20% of the nation's electricity supply
- Major benefits to rural economy

NREL Research Thrusts:

- Low wind speed technology
- Advanced rotor development
- Utility grid integration

Source: U.S. Department of Energy, Wind Power Monthly January 2006

Geothermal

Today's U.S. Status:
- 2,800 MWe installed, 500 MWe new contracts
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

U.S. DOE Cost Goals:
- <5¢/kWh, for typical hydrothermal sites by 2010
- <5¢/kWh, for enhanced geothermal systems by 2040

Long Term Potential:
- 40,000 MWe installed by 2040
- Ultimate potential to supply a significant portion of domestic electricity

NREL Research Thrusts:
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

Source: NREL 2006

Biopower

Today's U.S. status:

- 2004 Capacity – 10 GWe
  - 5 GW Pulp and Paper
  - 2 GW Dedicated Biomass
  - 3 GW MSW and Landfill Gas
- 2004 Generation – 60 TWh
- Cost 8¢-10¢/kWh

Long-term potential:

- Cost 4-6¢/kWh for integrated gasification combined cycle
- 160 TWh of net electricity exported to grid from integrated 60 billion gal/yr biorefinery industry by 2030

Source: Aden,et. al, NREL/TP-510-32438

Solar

Photovoltaics and Concentrating Solar Power

U.S. Solar Status:

PV
- 450 MW
- Cost 18-23¢/kWh

CSP
- 355 MW
- Cost 12¢/kWh

Potential:

PV
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP
- 8.5¢/kWh by 2010
- 6¢/kWh by 2015

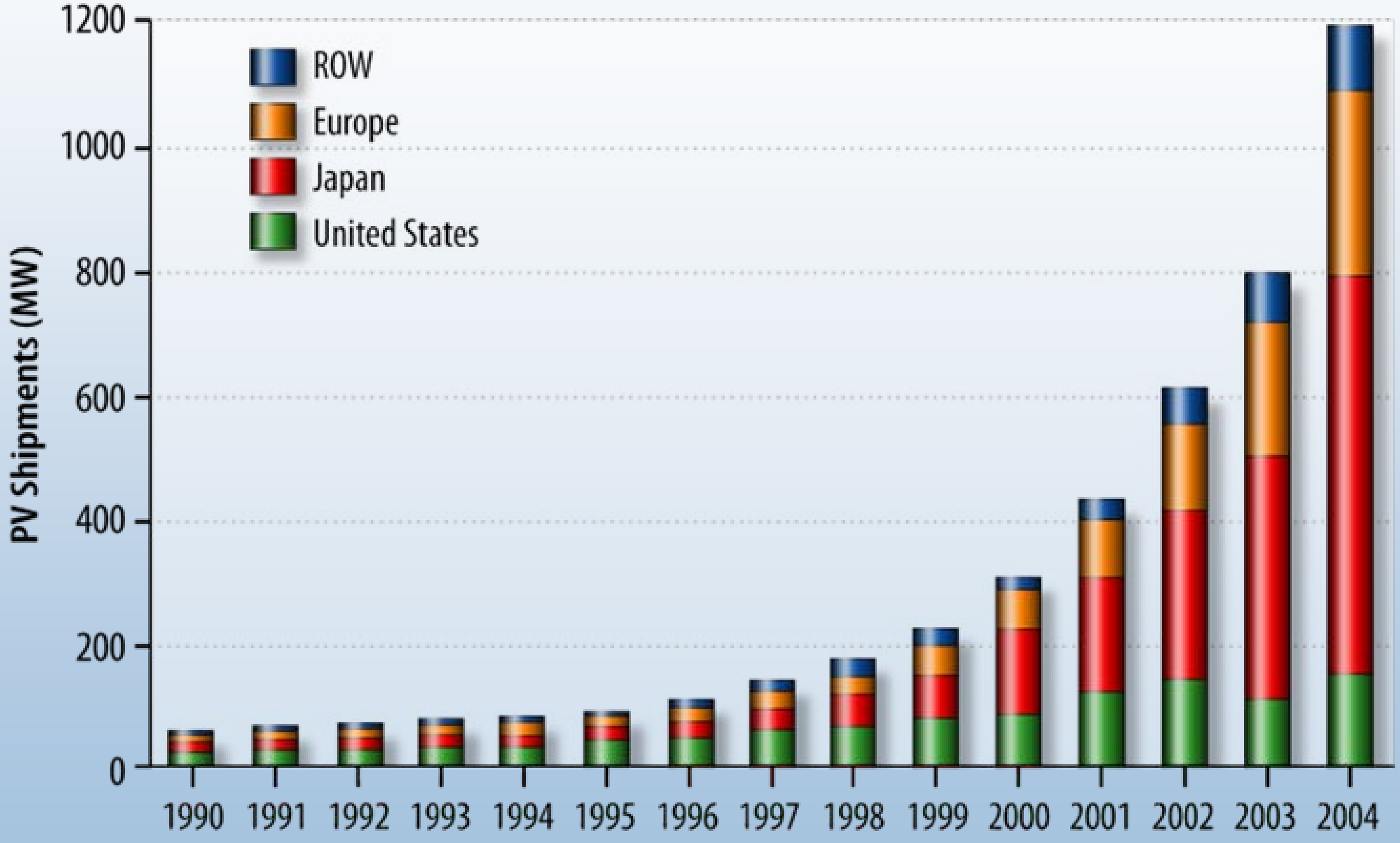
NREL Research Thrusts:

PV
- Advanced manufacturing techniques
- Higher efficiency devices
- New nanomaterials applications

CSP
- Next generation solar collectors
- High performance, high efficiency storage

Source: U.S. Department of Energy, NREL
Updated 5/15/06

Worldwide PV Shipments

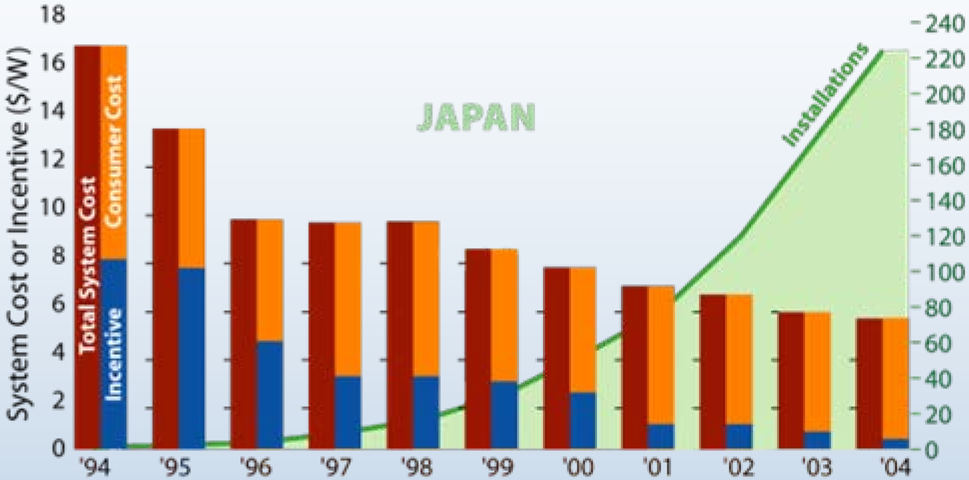


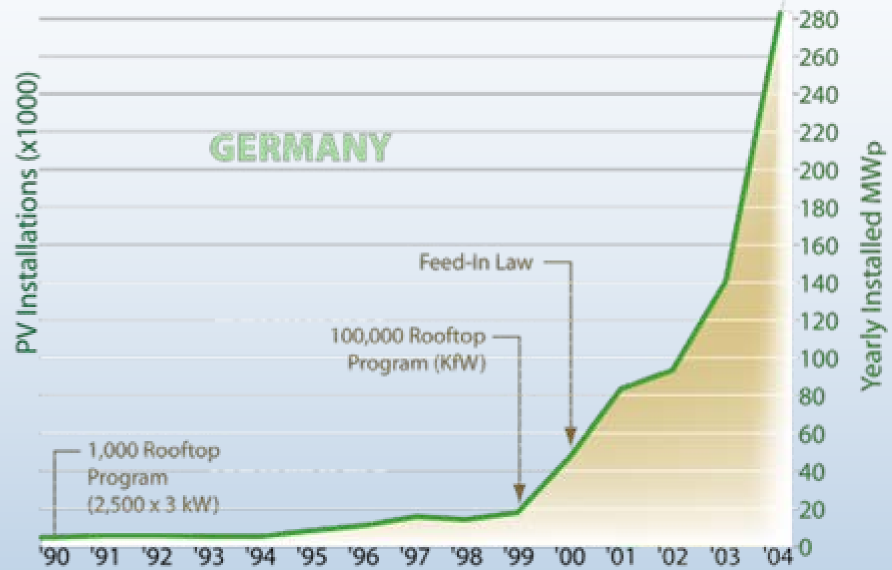
Source: Paul Maycock, PV News, February/March 2005.

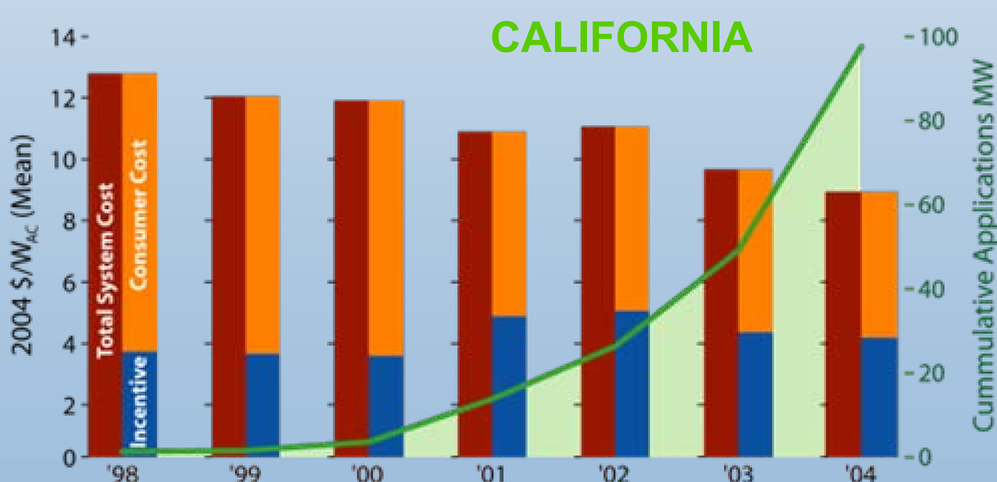
Policy

Stimulates markets

Federal, state, and local governments are the STEWARDS





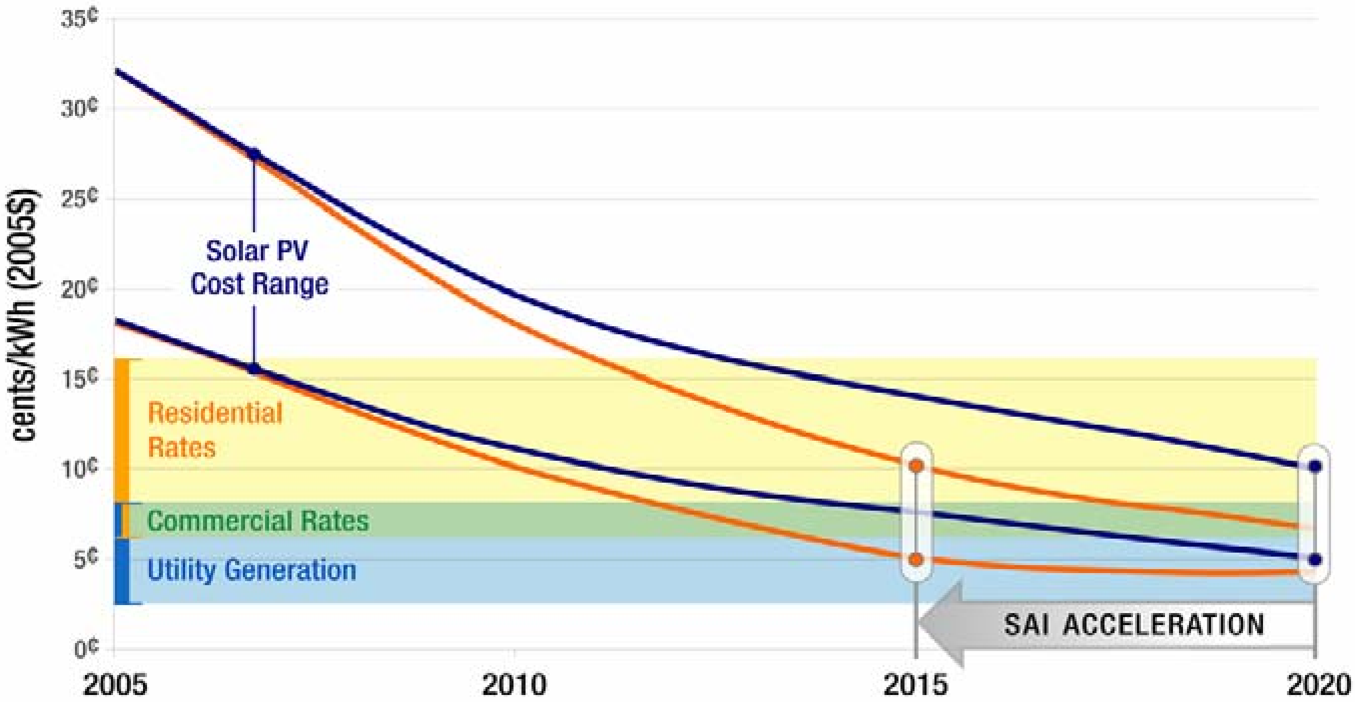


"BIG 3"
Experience
(It works . . .!)

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Solar America Initiative

Projected Cost Reductions for Solar PV



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7


Technology Investment Pathways
Basic Research Driven
Revolutionary
(10 years and beyond)
3rd Generation PV
quantum dots
nanotechnology
multi-multijunctions
thermophotonics
intermediate band
bio-inspired
Industry Driven
Technology Driven
Accelerated Evolutionary
(3 years)
Disruptive
(3–10 years)
1st & 2nd Generation PV
lower Si feedstock prices
thinner Si wafer technology
thin films
improved processing
improved performance
advanced integration
advanced packaging
2nd Generation PV
thin films
concentrators
organics
Si wafers <100 µm
Si cells beyond 25%

Hydrogen

Status

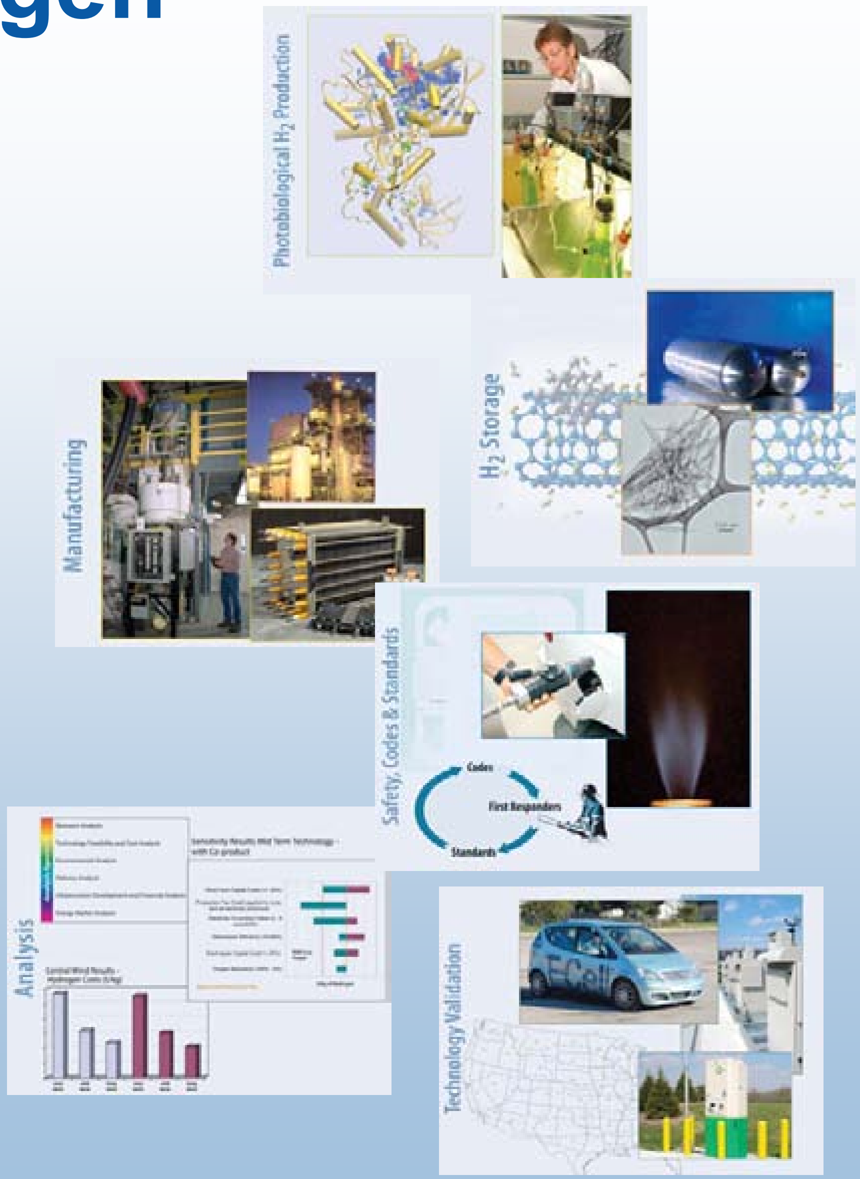
- Working with industry to develop technologies in quantities large enough, and at costs low enough, to compete with traditional energy sources.

Potential

- Commercially viable hydrogen and fuel cell systems by 2015

NREL Research Thrusts

- Hydrogen production, delivery, storage and manufacturing
- Fuel cells
- Safety, codes, and standards



Biofuels

U.S. Biofuels status

- Biodiesel – 75 million gallons (2005)
- Corn ethanol
  - 81 commercial plants
  - 3.9 billion gallons (2005)
  - Today's cost ~$1.35/gallon of gasoline equivalent (gge)
- Cellulosic ethanol
  - Projected commercial cost ~$3.00/gge

Potential

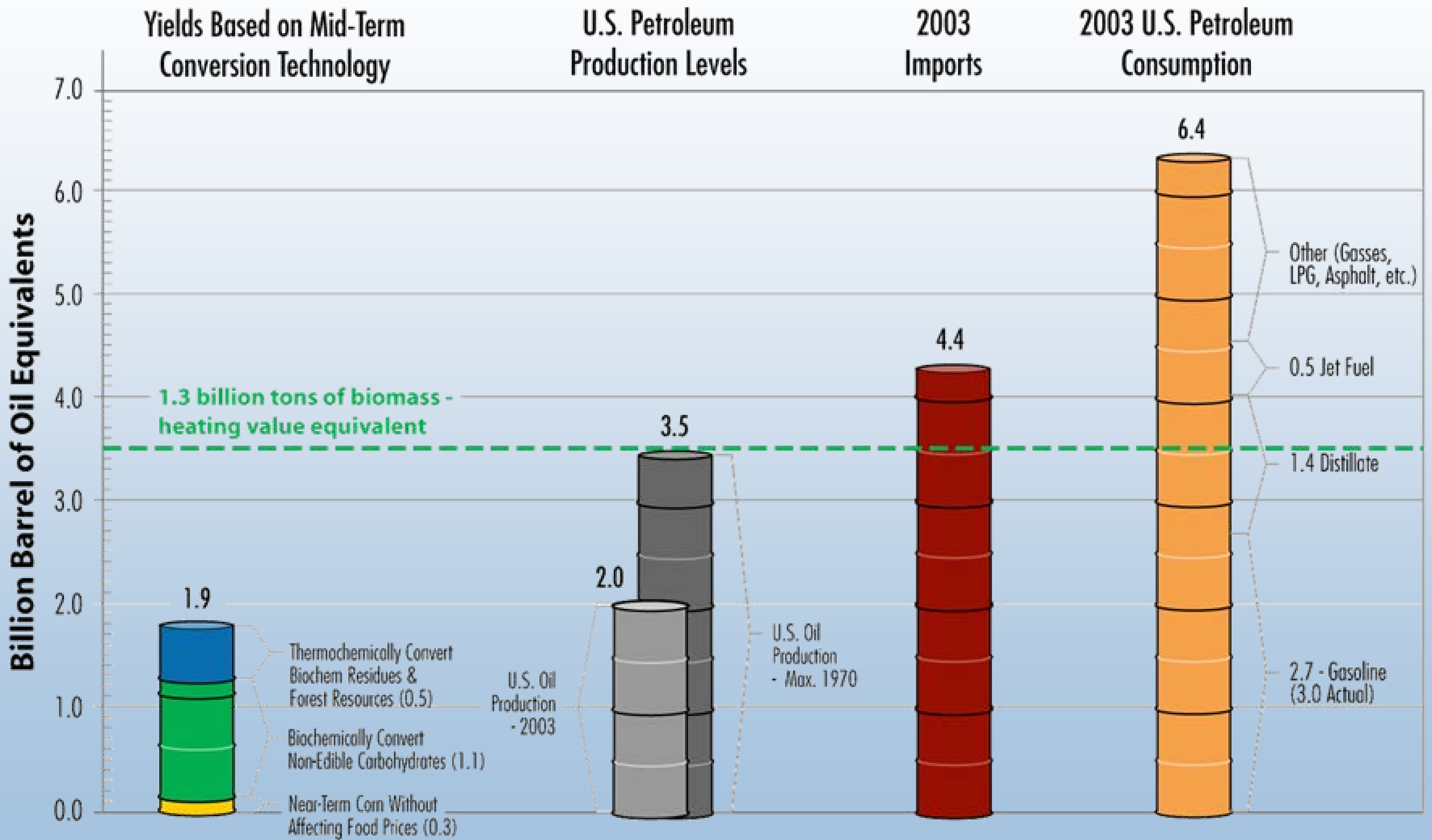
- 2012 goal – cellulosic ethanol ~$1.42/gge
- 2030 goal – all ethanol = 30% of transportation fuels

NREL Research Thrusts

- The Biorefinery
- Solutions to under-utilized waste residues
- Energy crops

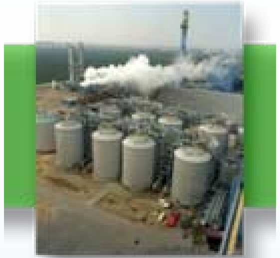
Source: U.S. Department of Energy, National Biodiesel Board, Renewable Fuels Association

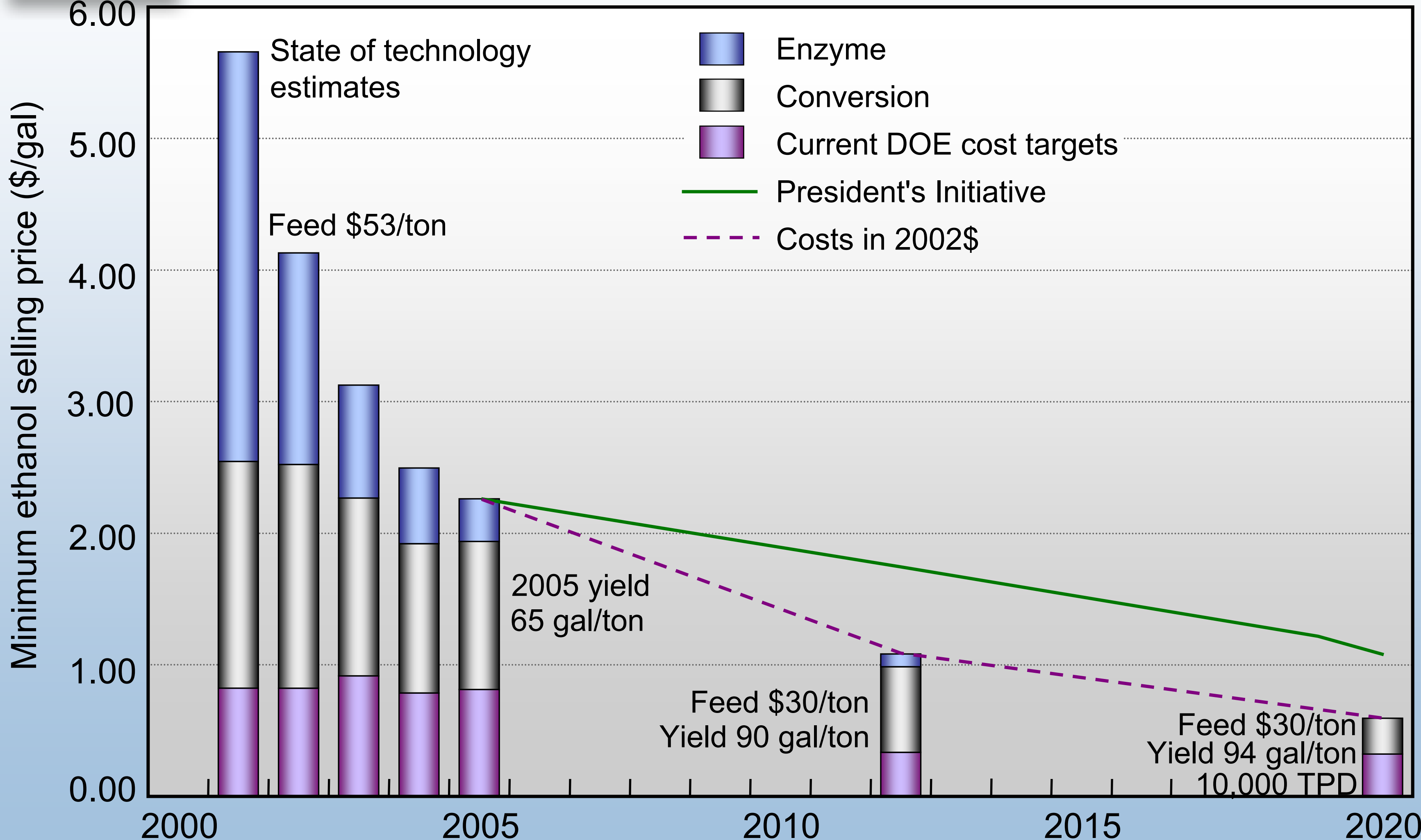
Significance of the 1.3 Billion Ton Biomass Scenario



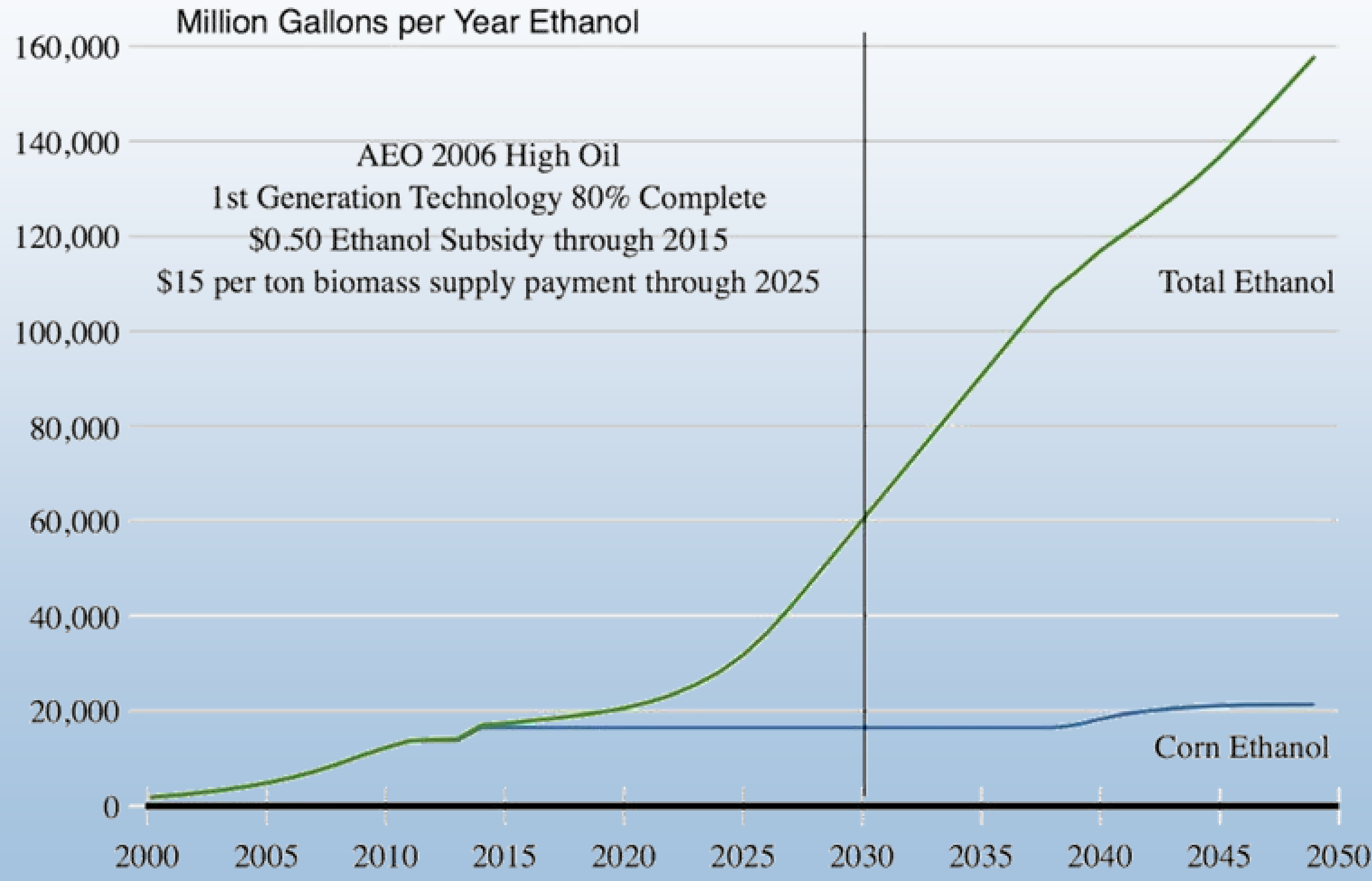
Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

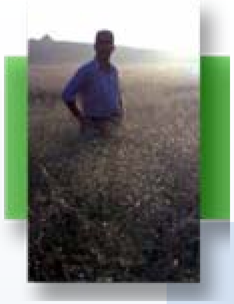
Biomass Conversion Technology
Reducing the Cost of Ethanol from Stover



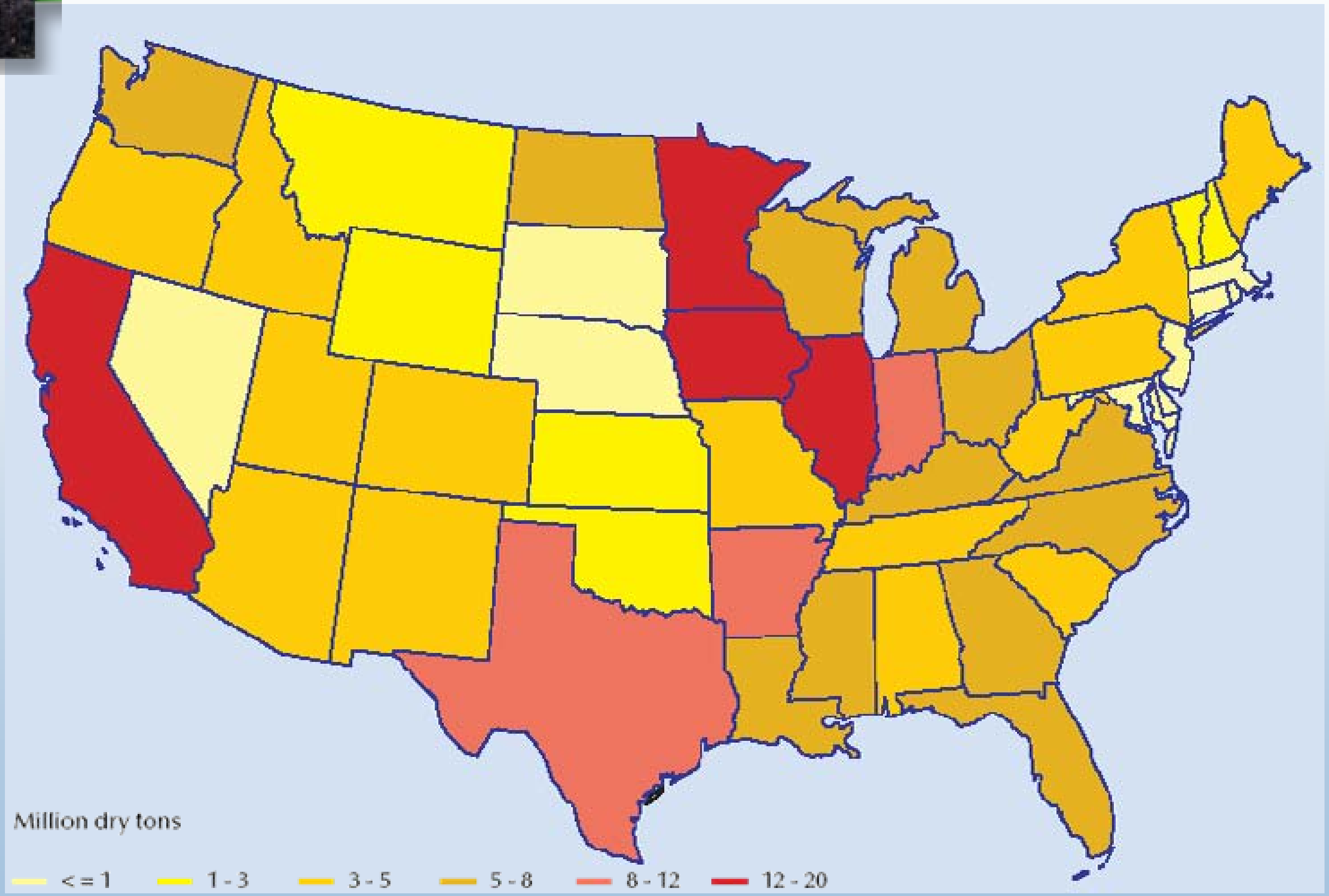


Getting to 60 Billion Gallons per Year Ethanol From Biomass





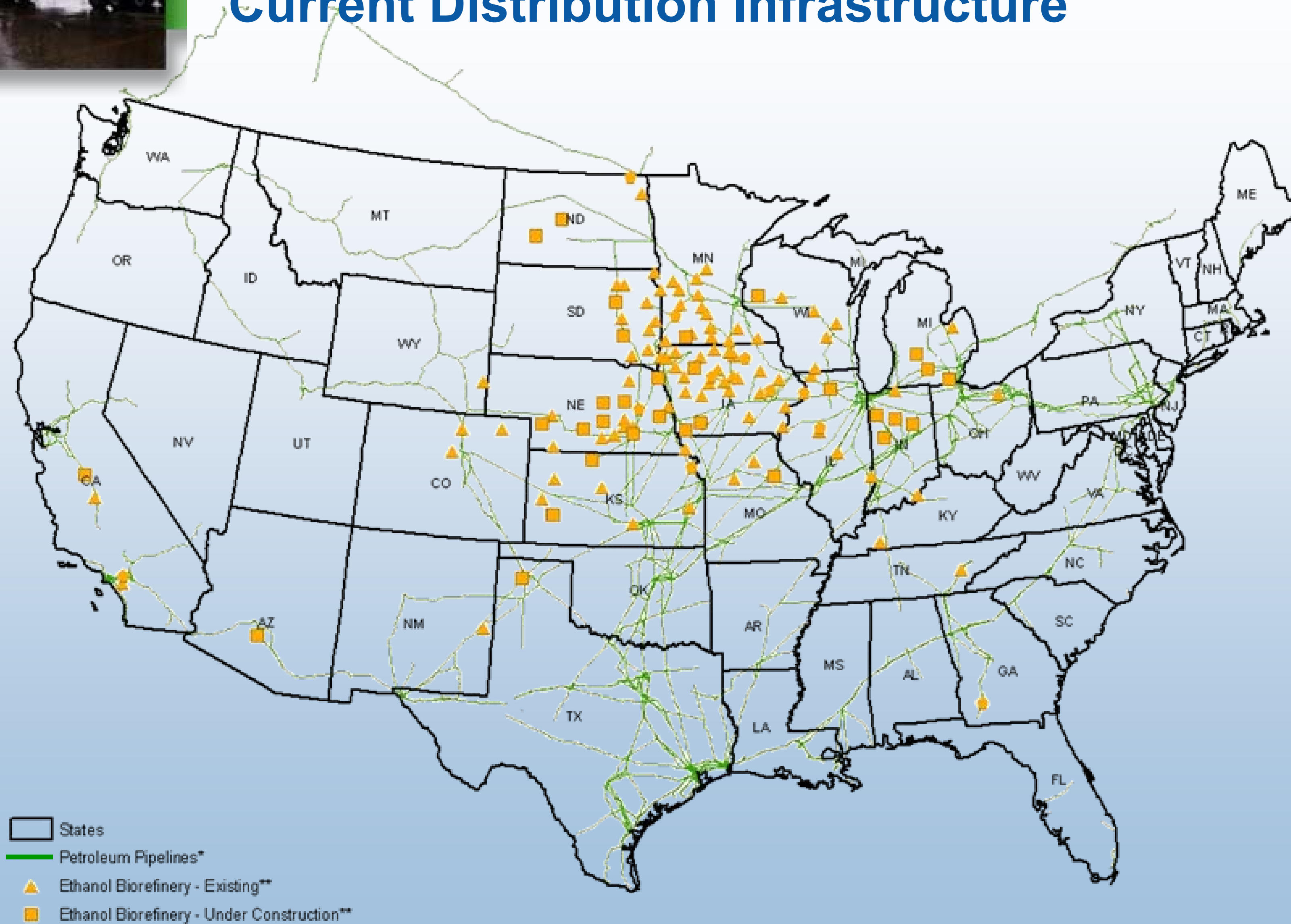
Biomass Feedstock Supply
Renewable Waste Resources



Source: National Commission on Energy Policy, *Ending the Energy Stalemate*, December 2004

Biomass Feedstock Transport

Current Distribution Infrastructure



Source: MapSearch, PennWell, Renewable Fuels Association, June 2006

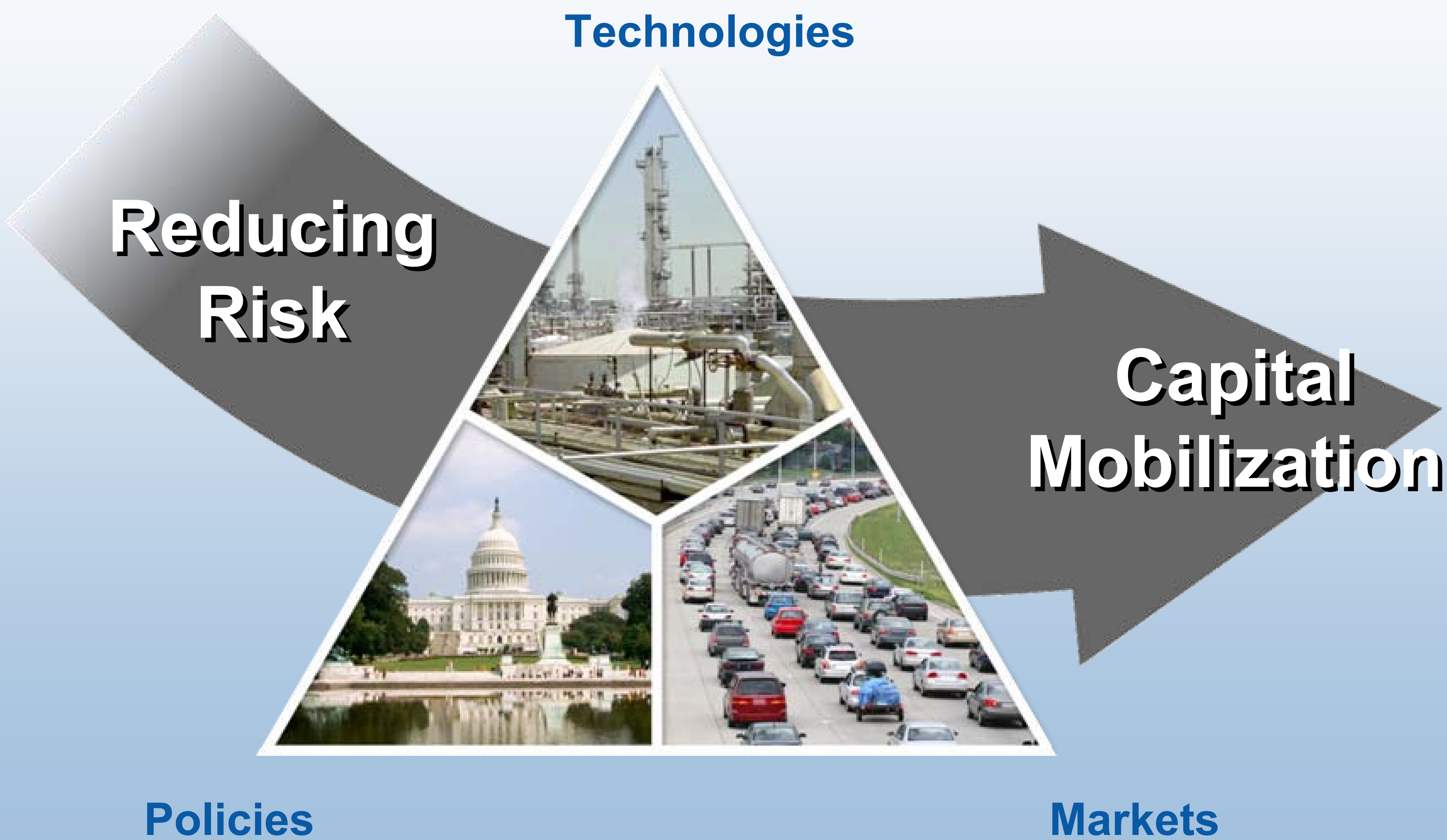
Biomass Feedstock Transport

Ethanol Distribution Infrastructure Hurdles

- Estimate that E85 pumps will be required in 50% of U.S. service stations
  - Public policy support
- E10 and E85 may enter U.S. pipeline system
  - E10 may move through product pipelines if they are modified to trap water, sediment and to keep ethanol from other products (diesel)
  - E85 dedicated pipelines will be created to connect large producing centers to large use centers
- E85 pumps may require new or modified underground tanks at retail outlets

30 x 30 Overview

Replace 30% of 2004 motor gasoline demand with ethanol by 2030 – 60 billion gallons



2005 DOE Biomass Energy Workshop

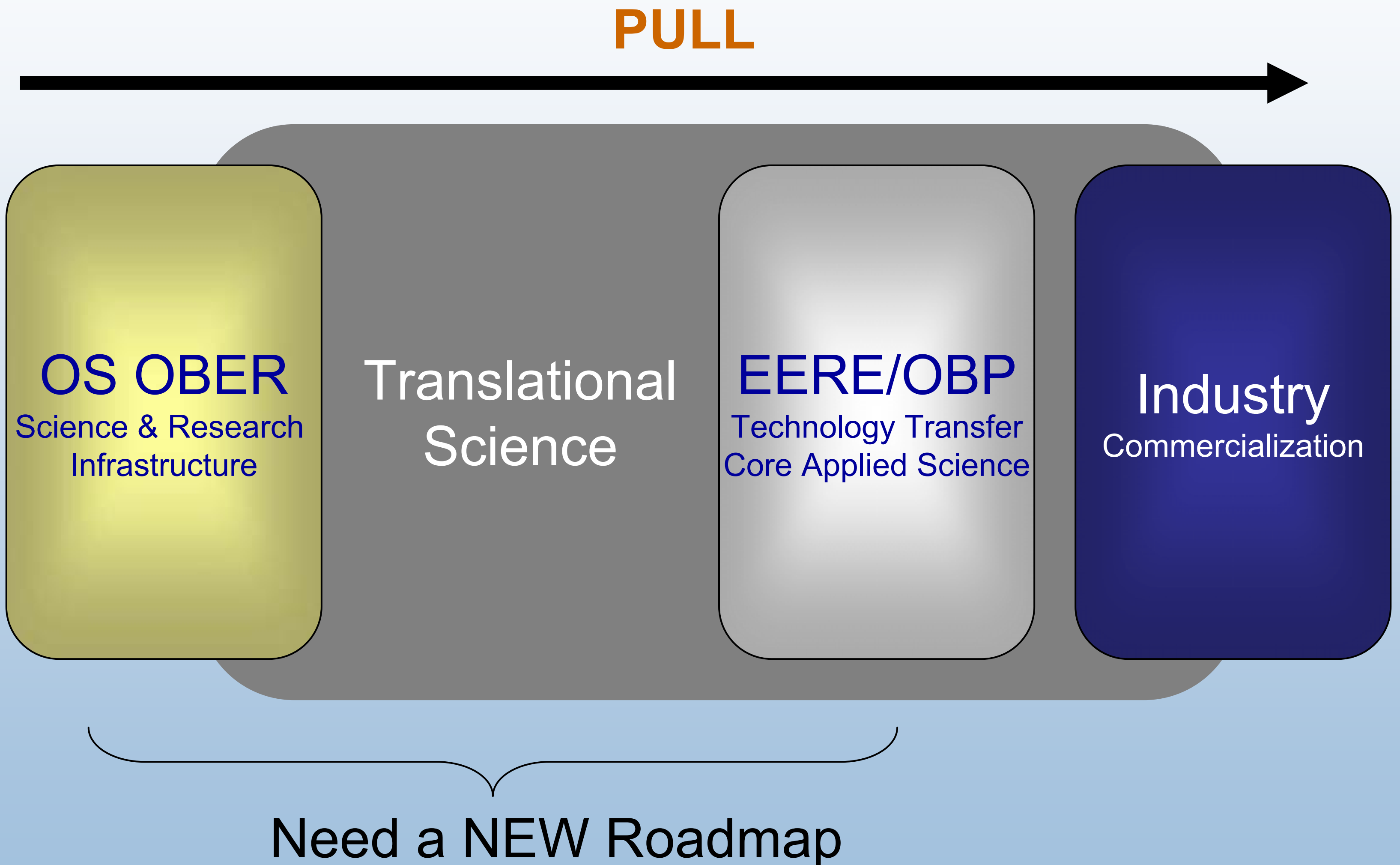
Sponsored by the DOE Office of Science OBER and Energy Efficiency and Renewable Energy OBP

Desired Outcomes

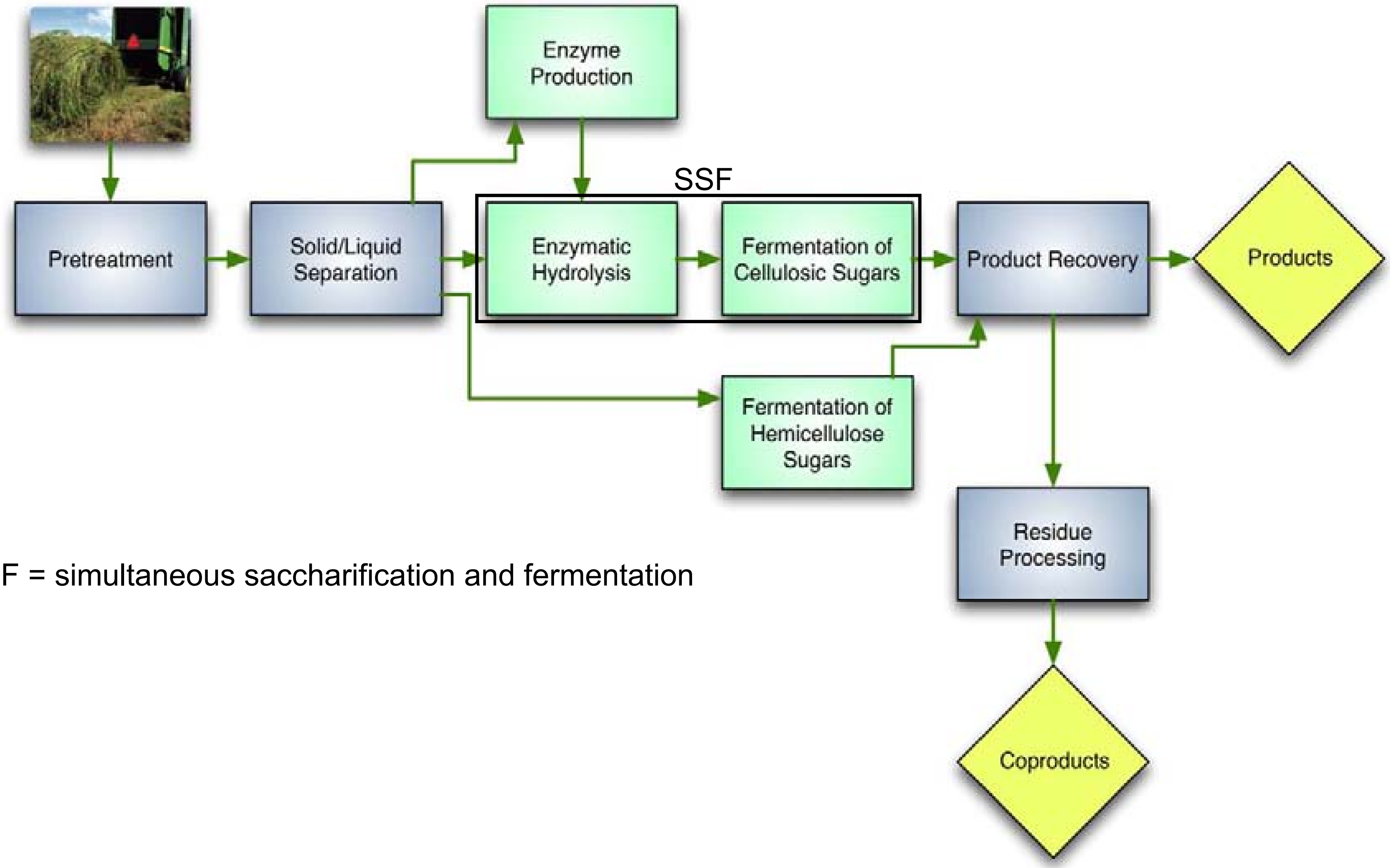
- Comprehensive summary (Roadmap) by highly respected technical authors indicating that there are numerous research topical area that must be pursued to ensure success.
- Utilize joint office collaboration to provide efficient coverage of near and mid-term science and technology, including transfer to industry.
- Employ technical coverage spanning directed science through commercialization.
- Generate key research results at level sufficiently deep to provide robust scientific conclusions.

Strategy for Joint Workshop

Define how work at the frontiers of science can enable the biorefinery industry



Biomass to Ethanol Process at a Glance



SSF = simultaneous saccharification and fermentation

DOE Office of the Biomass Program Barriers

Commercial Success Barriers

Price & Volume of Ethanol from Cellulosic Biomass

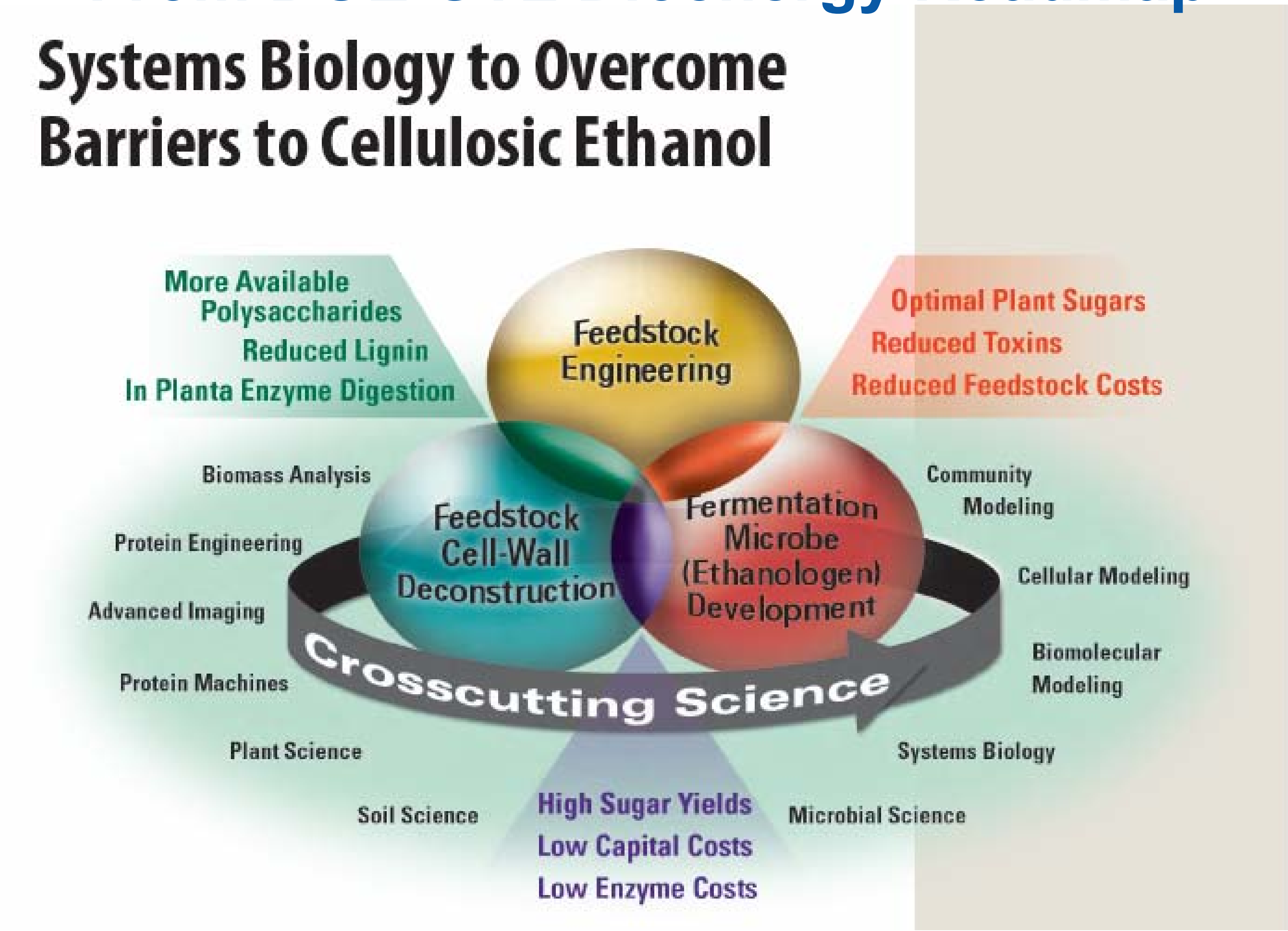
Major General Barriers

Feedstock Cost
Sugars Yield
Conversion Rate
Capital Investment

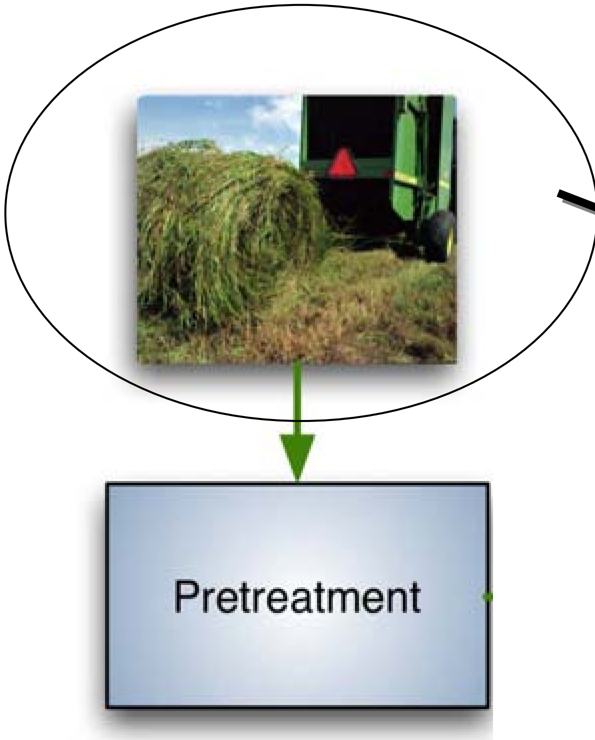
R&D Technical Barriers

Feedstock Interface
Biomass Pretreatment
Enzymatic Hydrolysis
Sugars Conversion
Process Integration

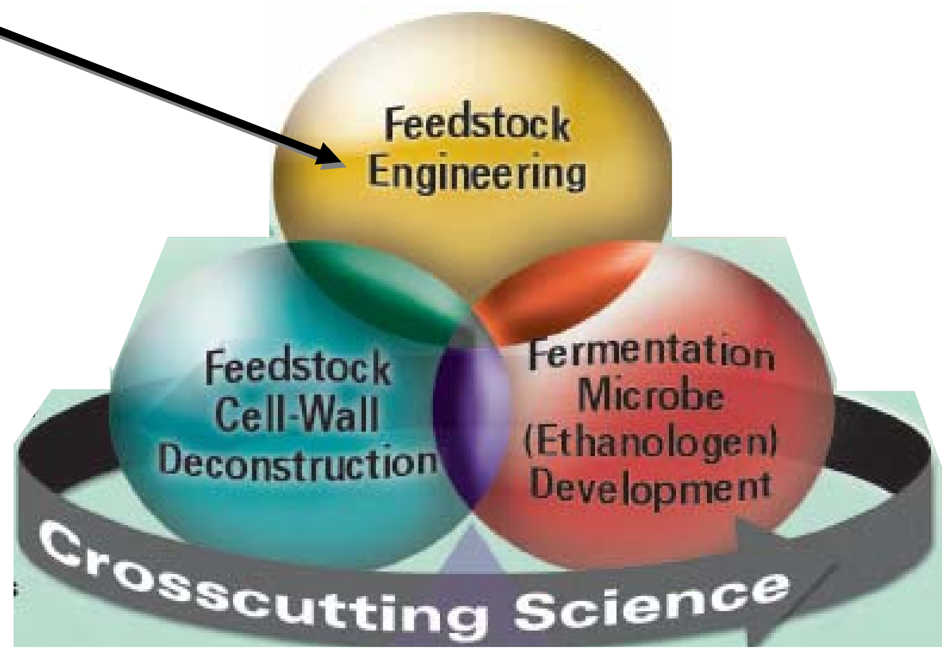
From DOE GTL Bioenergy Roadmap



Focus on Feedstock Engineering



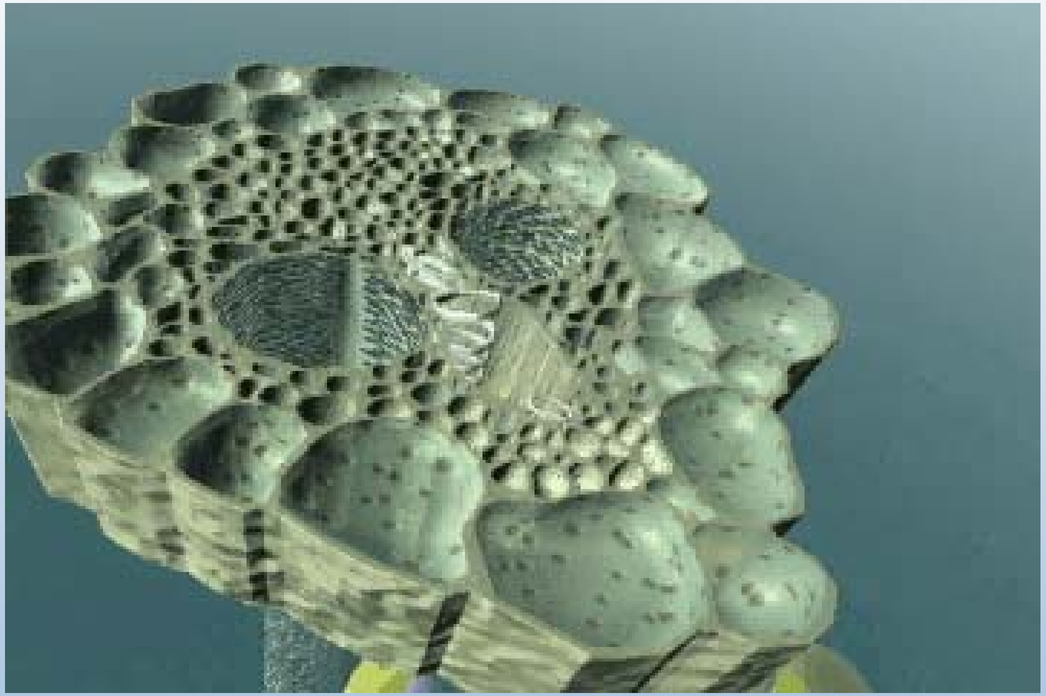
"DOE GTL Bioenergy Roadmap"



Simultaneous saccharification & Fermentation - SSF

Feedstock Engineering

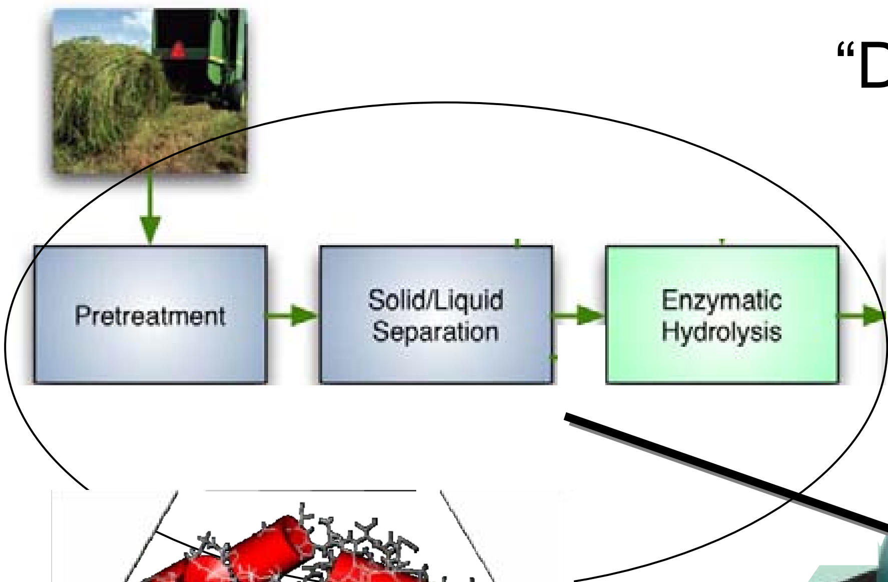
- Increase crop production (agronomics and plant engineering)
- Increase composition of desirable polysaccharides (cellulose)
- Decrease composition of undesirable polymers (lignins)

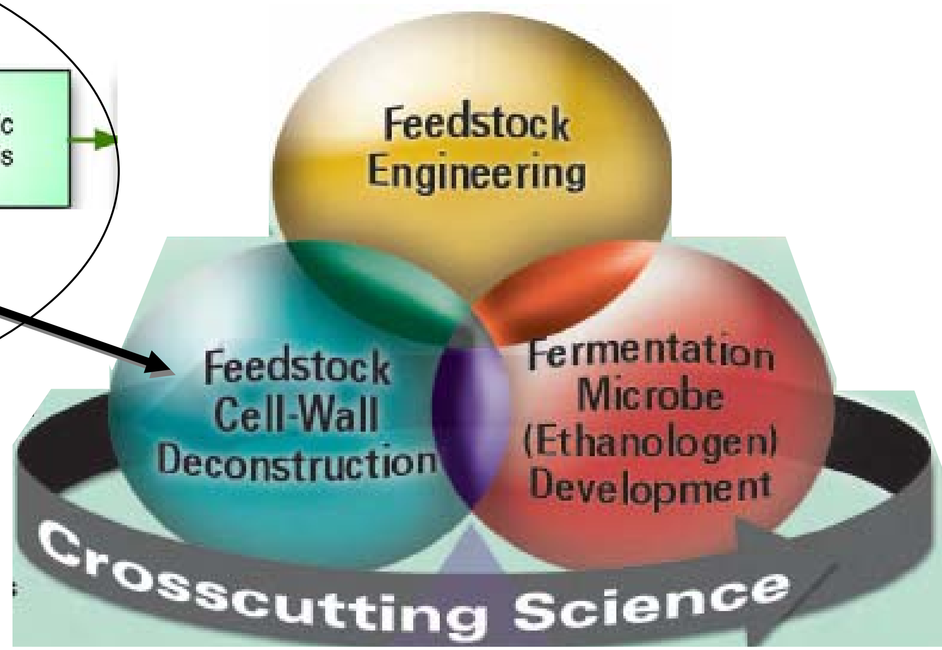


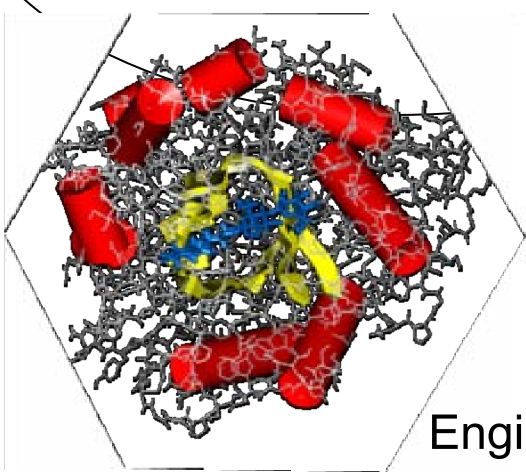
NREL "Corn Stem Tour"

Focus on Feedstock
Cell Wall Deconstruction

"DOE GTL Bioenergy Roadmap"







Engineering new enzymes at NREL

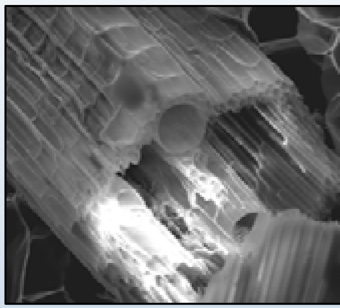
Biomass Recalcitrance

- Lignocellulosic biomass is often described as “recalcitrant”
- Plant biomass has evolved superb mechanisms for resisting assault on its structural sugars from the microbial and animal kingdoms
- These mechanisms are comprised of both chemical and structural elements:
  - the waxy barrier & dense cells forming the rind of grasses and bark of trees
  - the vascular structures (tubes) that limit liquid penetration in plant stems
  - the composite nature of the plant cell wall that restricts catalyst penetration
  - the hemicellulose coating on the microfibrils in the cell wall
  - the crystalline nature of cellulose itself
  - the inherent difficulty enzymes have acting on insoluble surfaces like cellulose

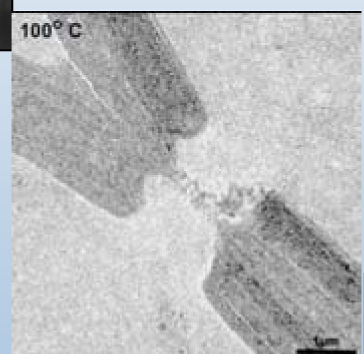
Plant Biomass Must be Studied over Wide Range of Length Scales

Tissue structure

from anatomical to molecular level

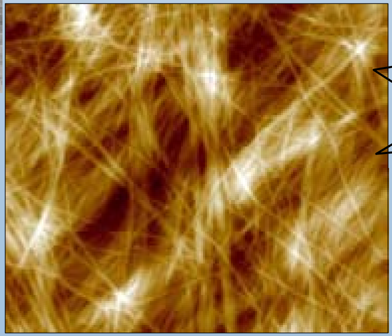


SEM



TEM

AFM

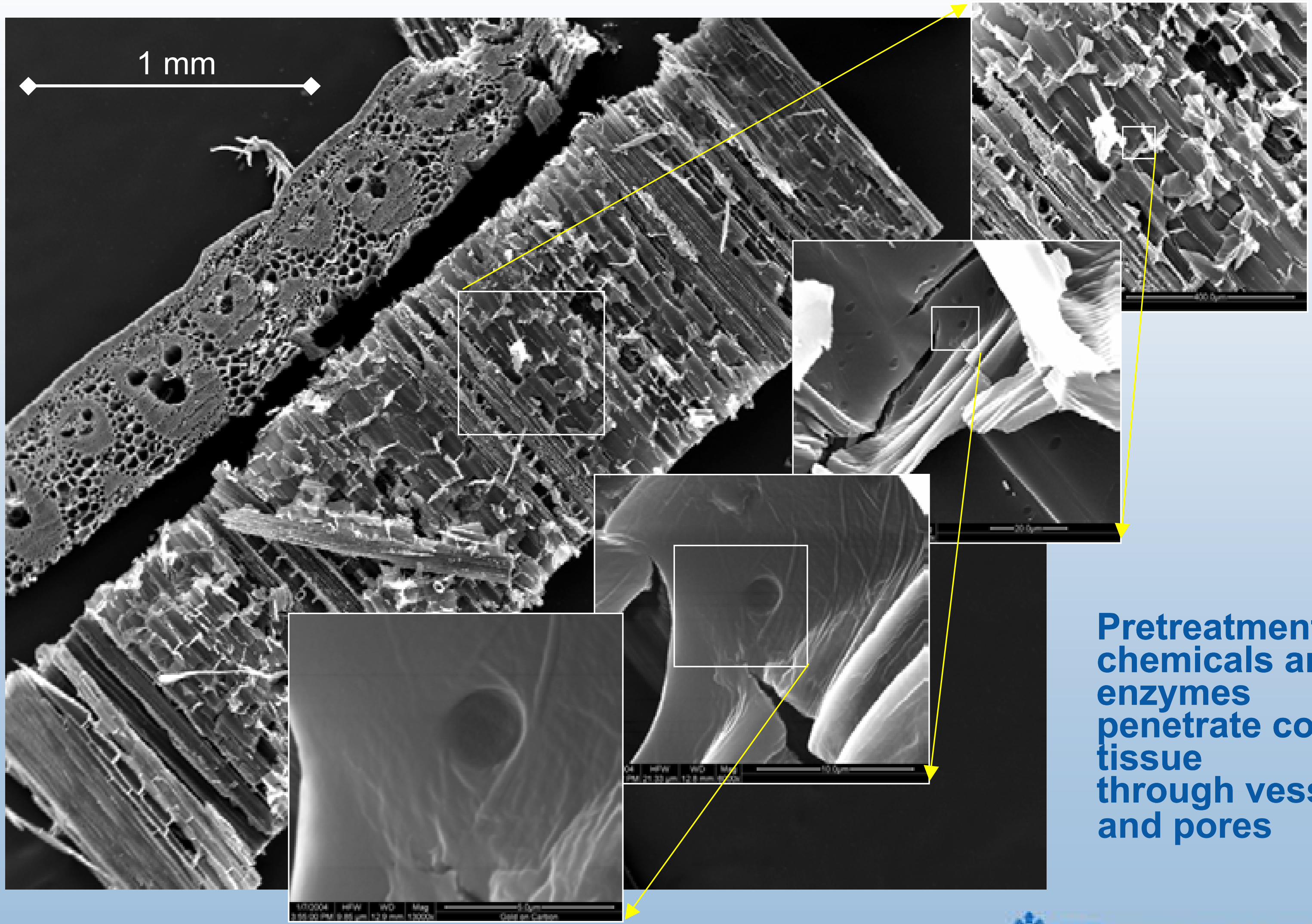


Polymer structure

From new NREL Biomass Surface Characterization Lab

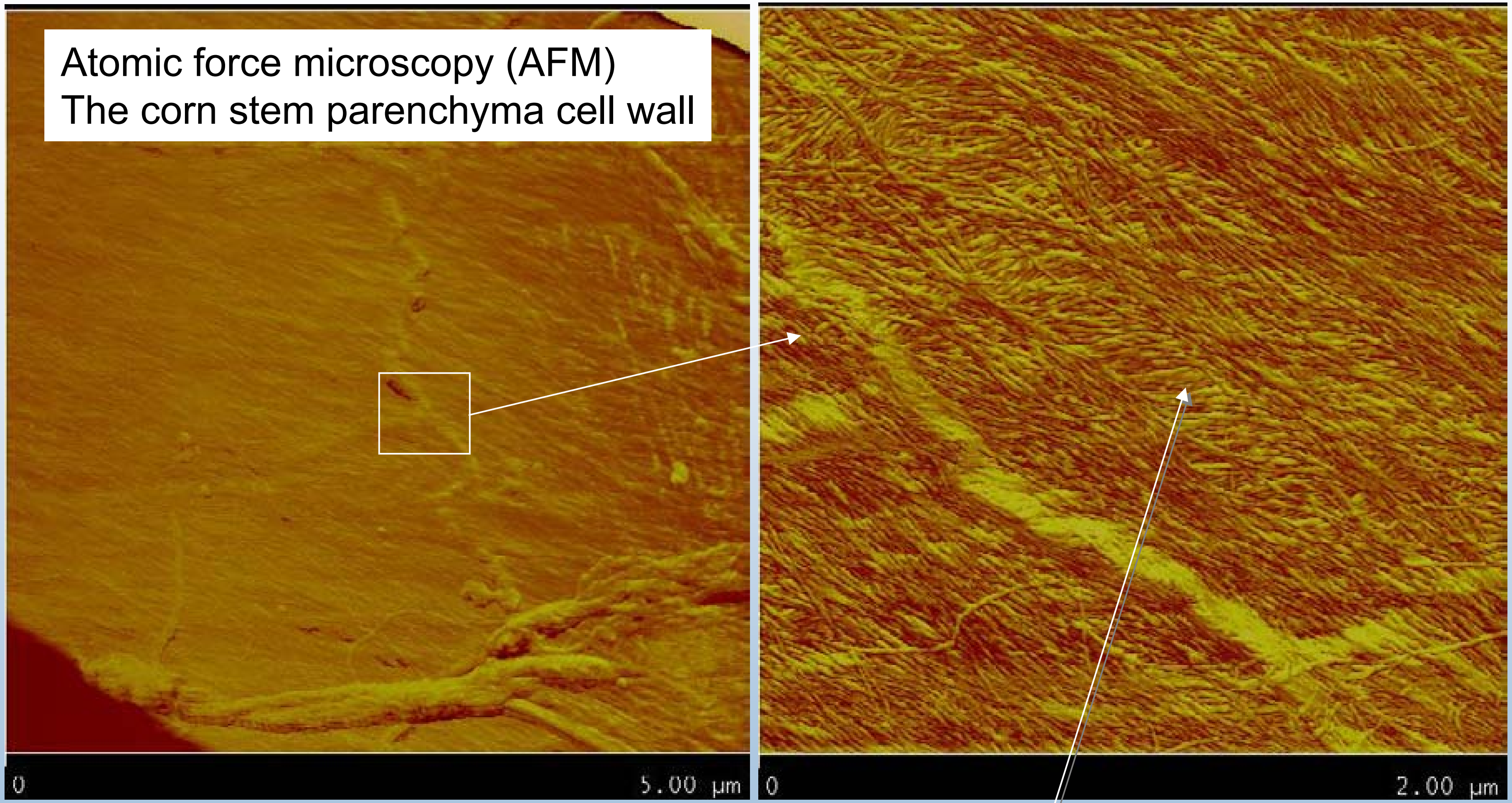
How Do Chemicals and Enzymes Penetrate Biomass?

Corn Stem Cross Sections in SEM

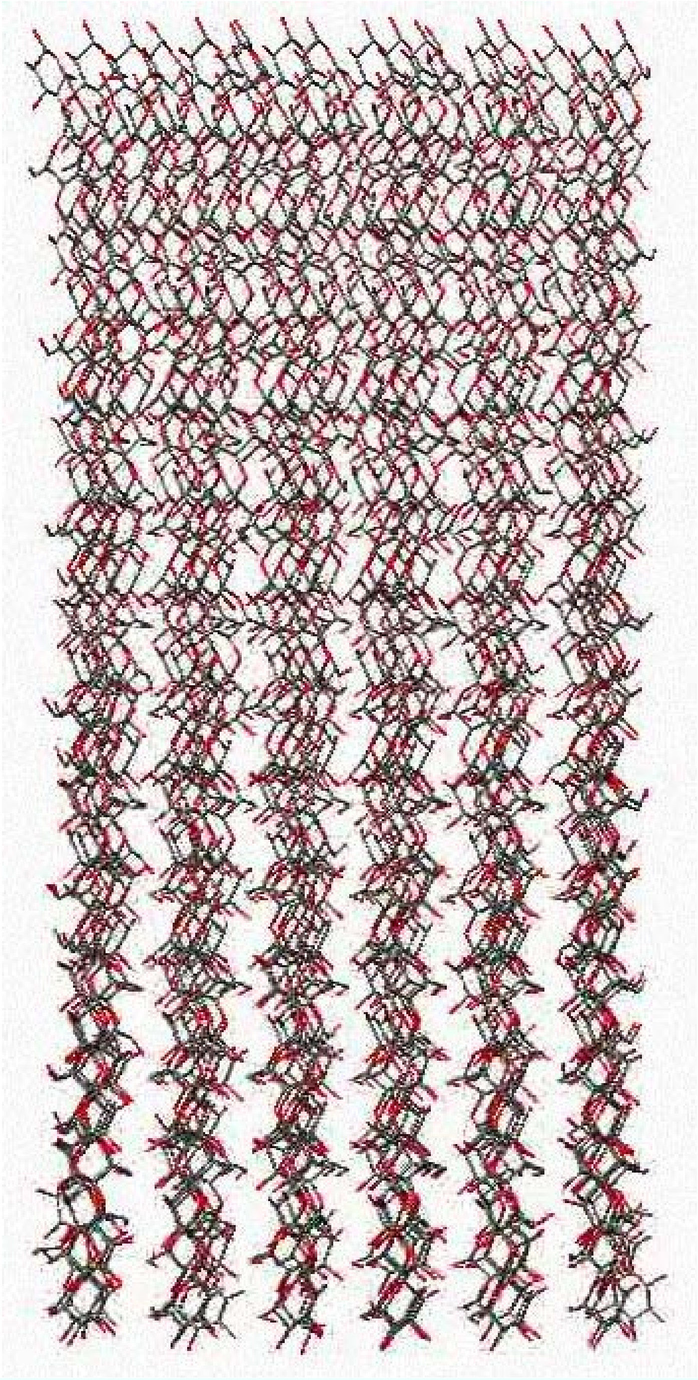


Pretreatment chemicals and enzymes penetrate corn tissue through vessels and pores

What Does the Recalcitrant Plant Cell Wall Look Like?



Close up view of plant cell wall shows matrix of tightly associated structures (microfibrils)

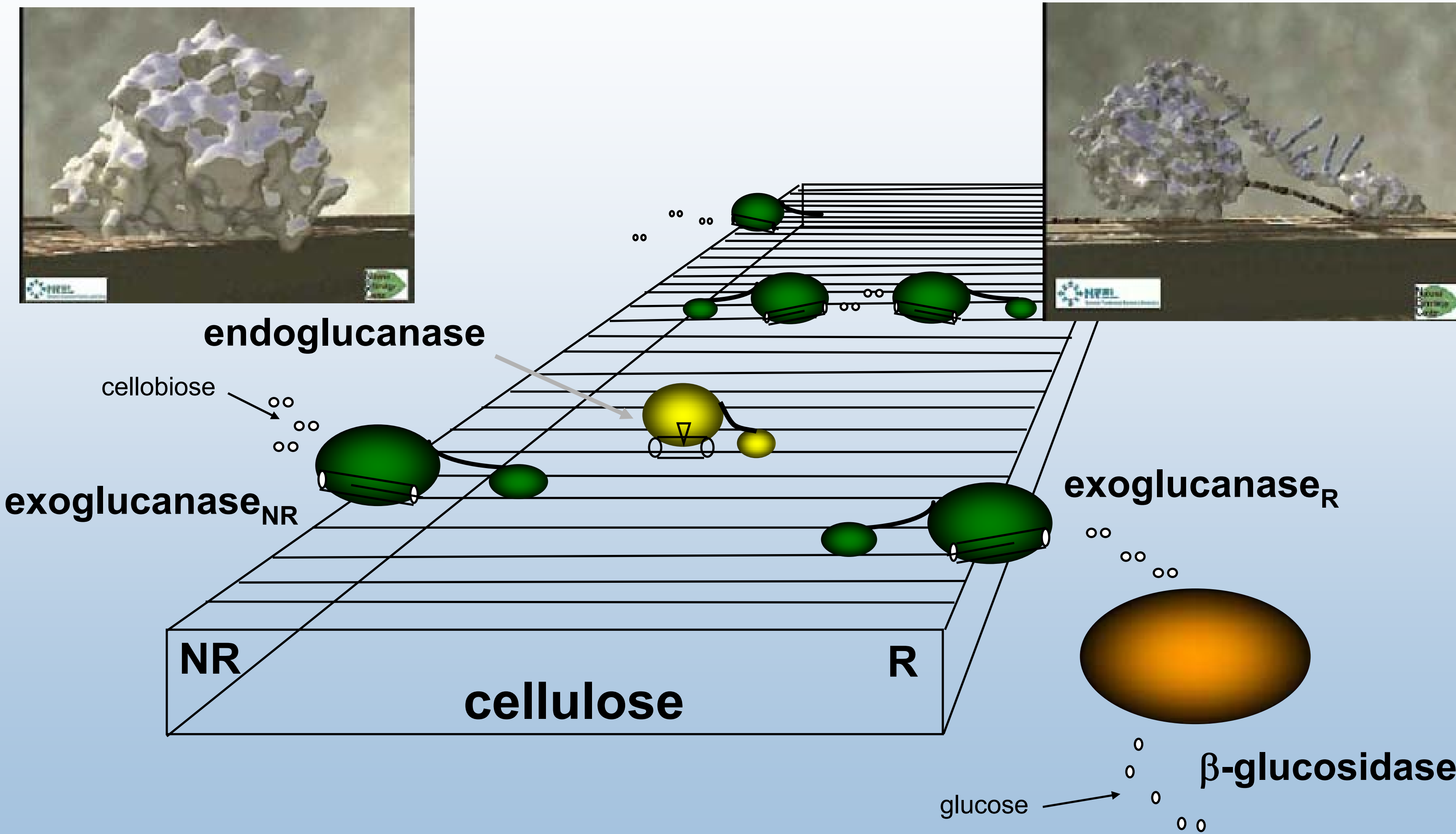


Cellulose is a Crystalline Structure that Resists Water Penetration

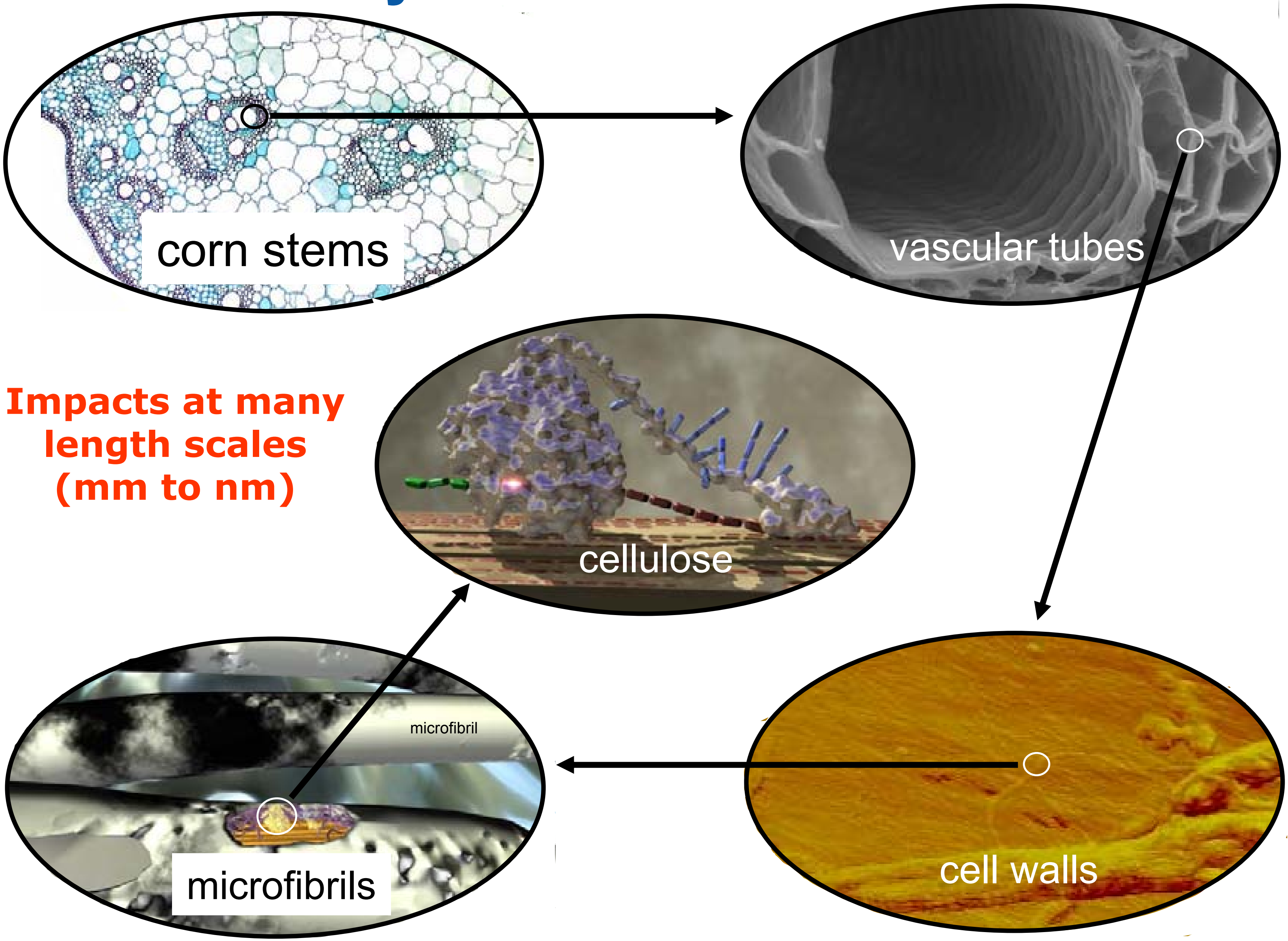
This makes disassembly very difficult

John Brady, Cornell
NREL subcontractor

Cellulases Must Function on an Insoluble Substrate

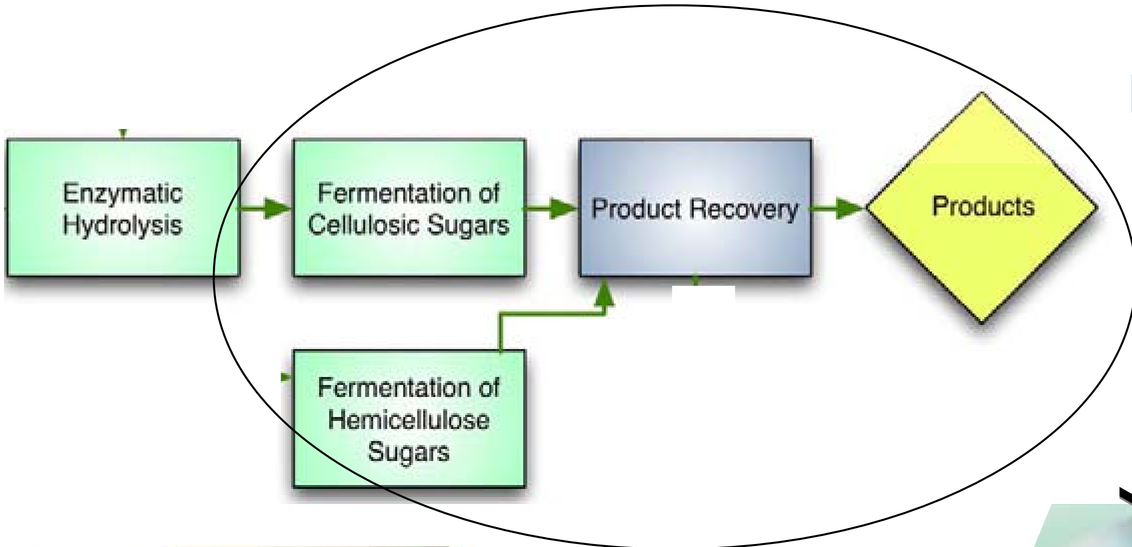


Summary: Biomass Recalcitrance

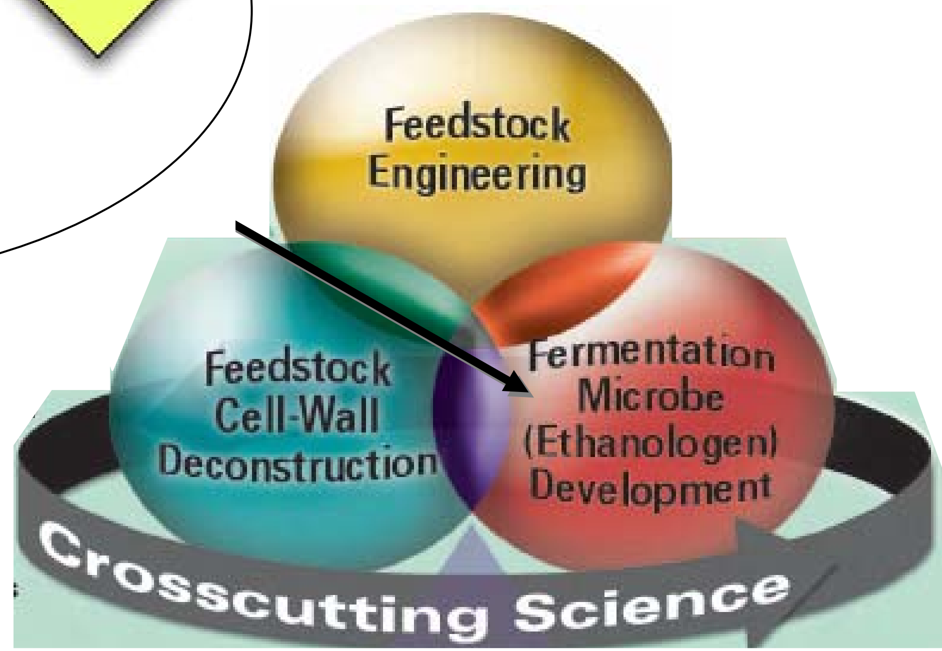


Impacts at many length scales (mm to nm)

Focus on Fermentation Microbe (Ethanologen development)



DOE GTL Bioenergy Roadmap

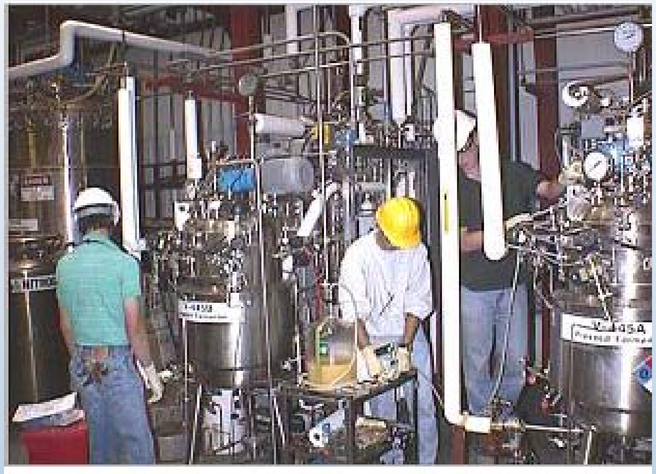


Yeast strain development at NREL

Simultaneous saccharification & Fermentation - SSF

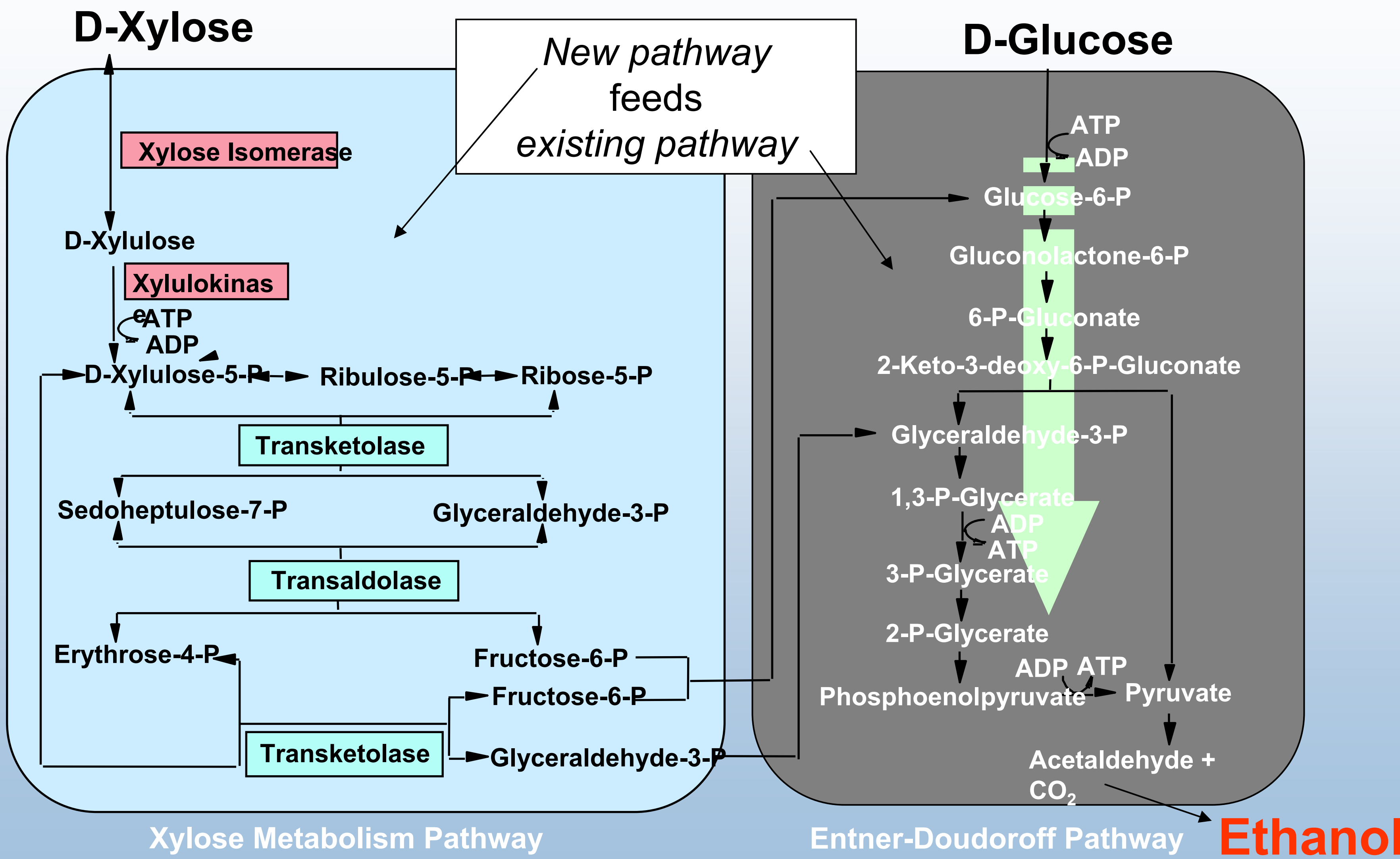
Challenges in Biomass Sugar Fermentation

- Must ferment all biomass sugars at high conversion yield
  - Glucose, xylose, arabinose, mannose, galactose (most natural yeast do not ferment xylose or arabinose)
- Must be resistant to toxic compounds present after pretreatment
  - Acids (acetate), phenols, salts, sugar degradation products
- Must be robust, able to out-compete contaminant microorganisms
- High final ethanol concentration (7% or higher)



Pilot-Scale, 5-Stage Fill and Draw Fermentation with *Z. mobilis* 31821(pZB5)

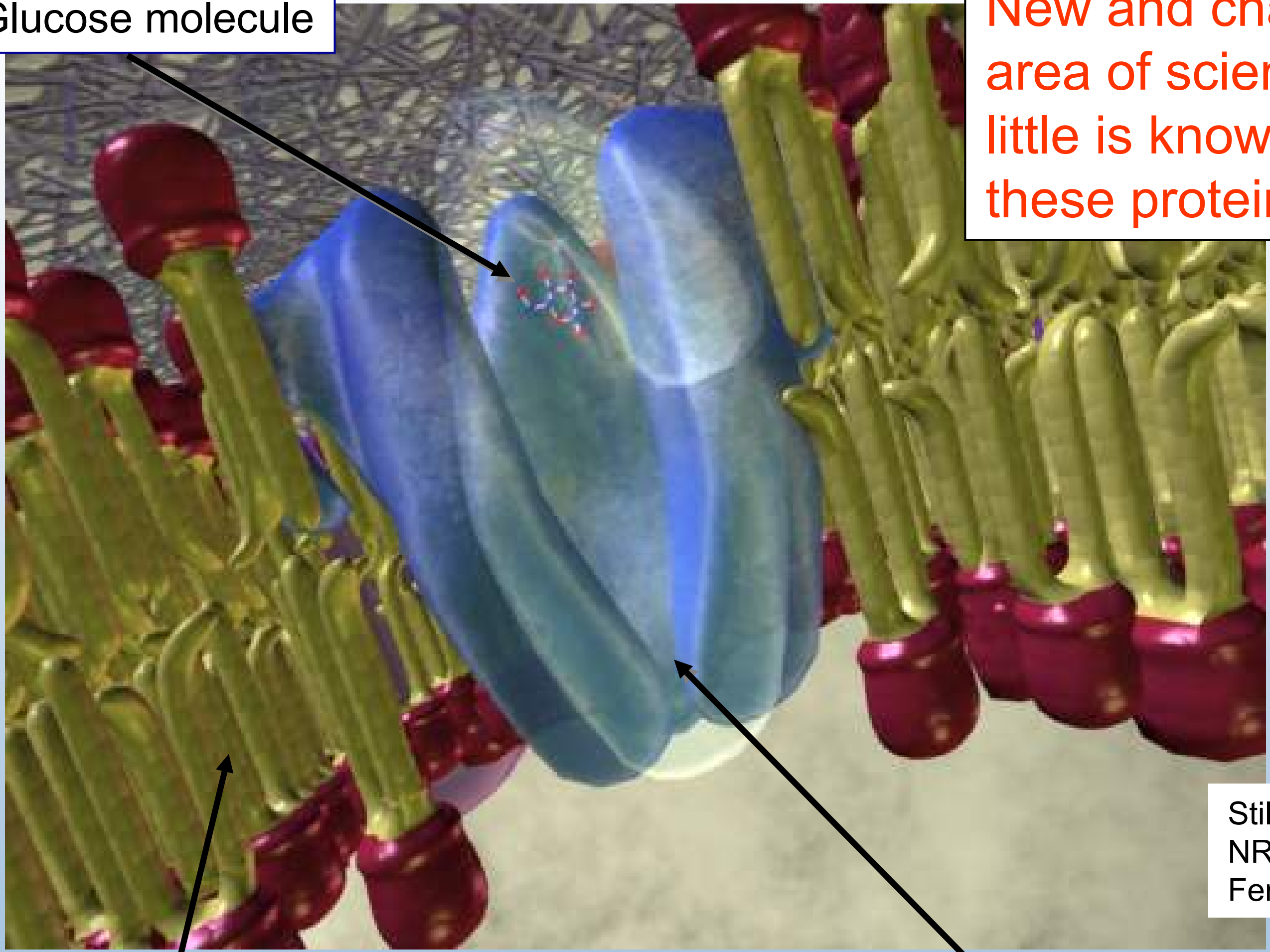
Example: Pathways Engineered for Xylose Fermentation *in Zymomonas* at NREL



Example: Sugar Transporter Proteins

Glucose molecule

New and challenging area of science. Very little is known about these proteins

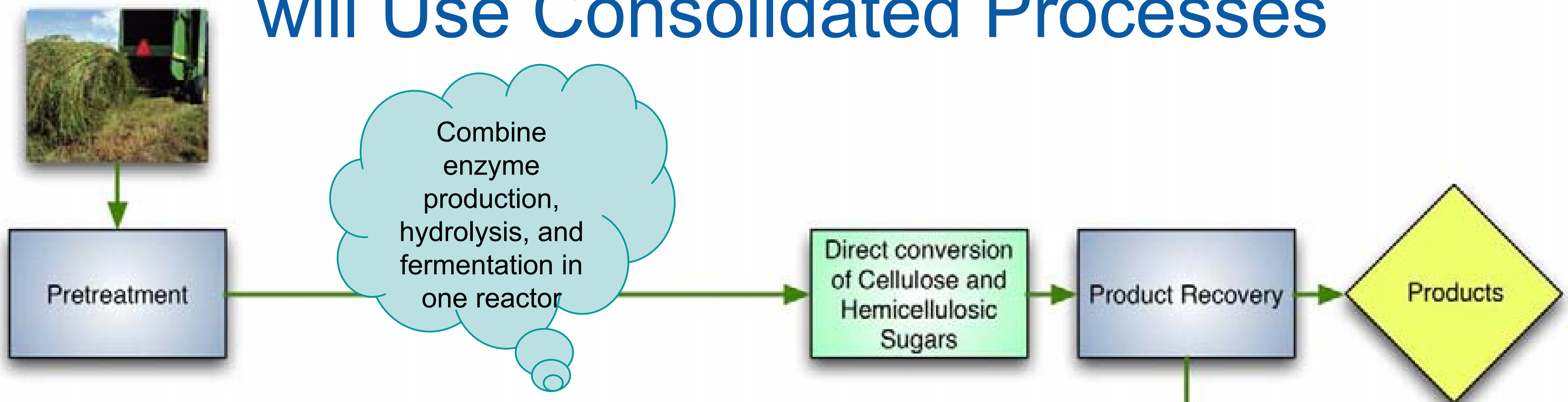


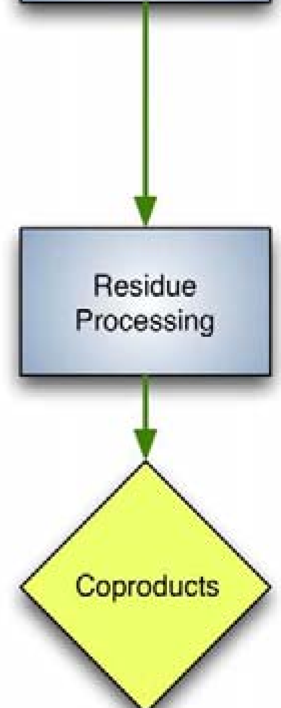
Still image taken from new NREL animation "Yeast Fermentation"

Cytoplasmic membrane of yeast cell

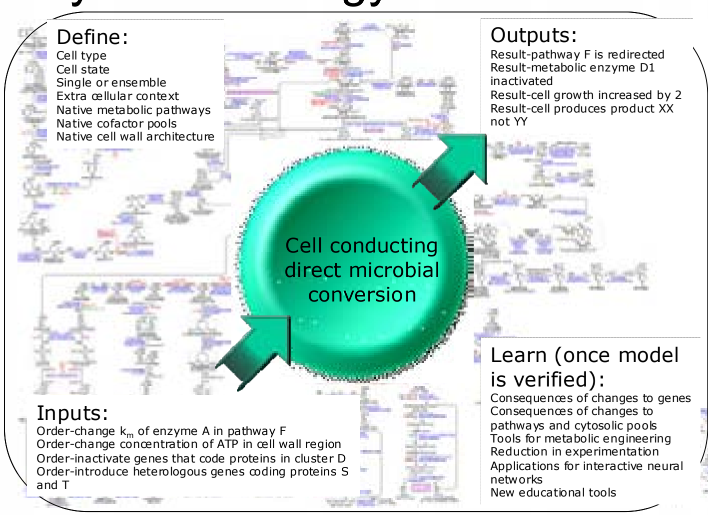
Sugar transporter protein

Next Generation Biorefineries will Use Consolidated Processes





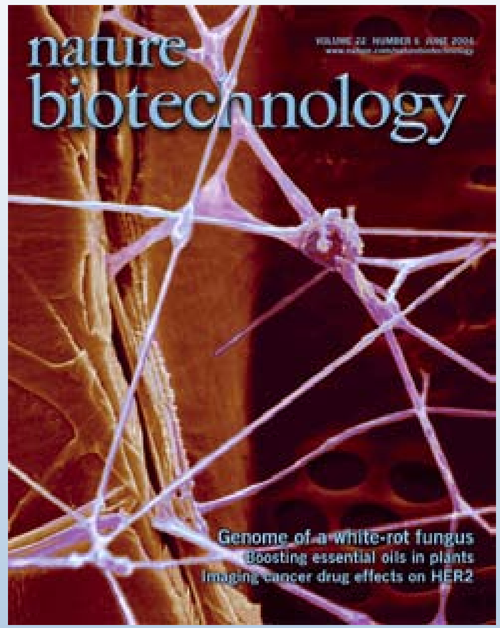
New Systems Biology Tools will be Needed



Summary and Future Outlook for Bioethanol

Challenges and Barriers:

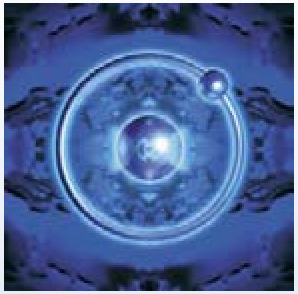
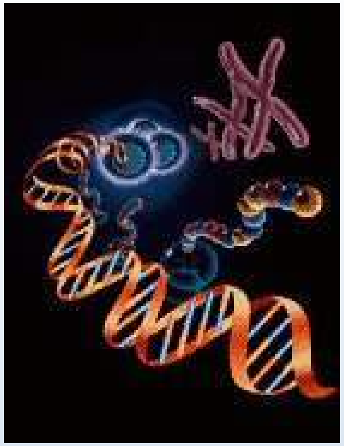
- The high cost of feedstocks
- The high capital cost of biomass pretreatment
- The high cost and loadings of cellulase enzymes
- The inability of current fermentation strains to convert ALL biomass sugars
- Overall sugar to ethanol yields far less than theoretical
- Considerable disagreement over “readiness” of the industry for commercialization



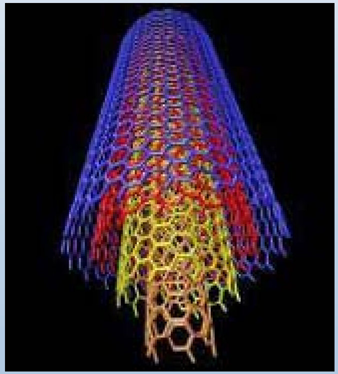
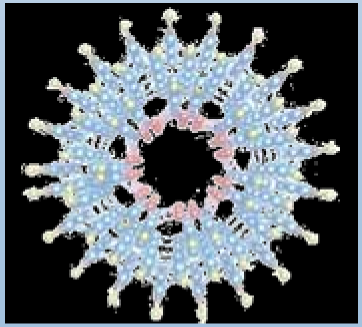
We Need a Deeper Understanding of:

- The genetic controls of plant composition and ultrastructure
- The resistance of lignocellulosic biomass to deconstruction.
- The structure and function of cellulases and other plant cell wall depolymerizing enzymes.
- The cellular controls for multi-sugar transport and ethanol fermentation.
- The cell’s mechanisms for toxicity response
- And many more……..

Energy Science and Technology: Enabling the Future

- Supercomputing
- Genomics
- Nanoscience
- Green Chemistry
- Informatics
- Cellulosic and biofuels applications
- Hydrogen

Nano/Bio/Info


The ultimate test of the human conscience may be the willingness to do something today for future generations whose words of thanks will not be heard.
-Senator Gaylord Nelson, founder of Earth Day


The U.S. Department of Energy's
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