Biofuel Technologies in the United States

F. Blaine Metting
Pacific Northwest National Laboratory

18 January 2007

RITE International Symposium

Technologies for Mitigating Global Warming

Presentation Outline

1. U.S. Biofuels Goals
2. Current Bioethanol Technologies
3. Future Technologies – U.S. Research & Development Programs

President Bush's Biofuels Initiative

Ethanol target - $0.28/liter by 2012 (= $30/bbl oil with government subsidy

= $55/bbl oil without subsidy)

1980 – 1 million liters of fuel ethanol in the U.S.

2005 – 16 billion liters

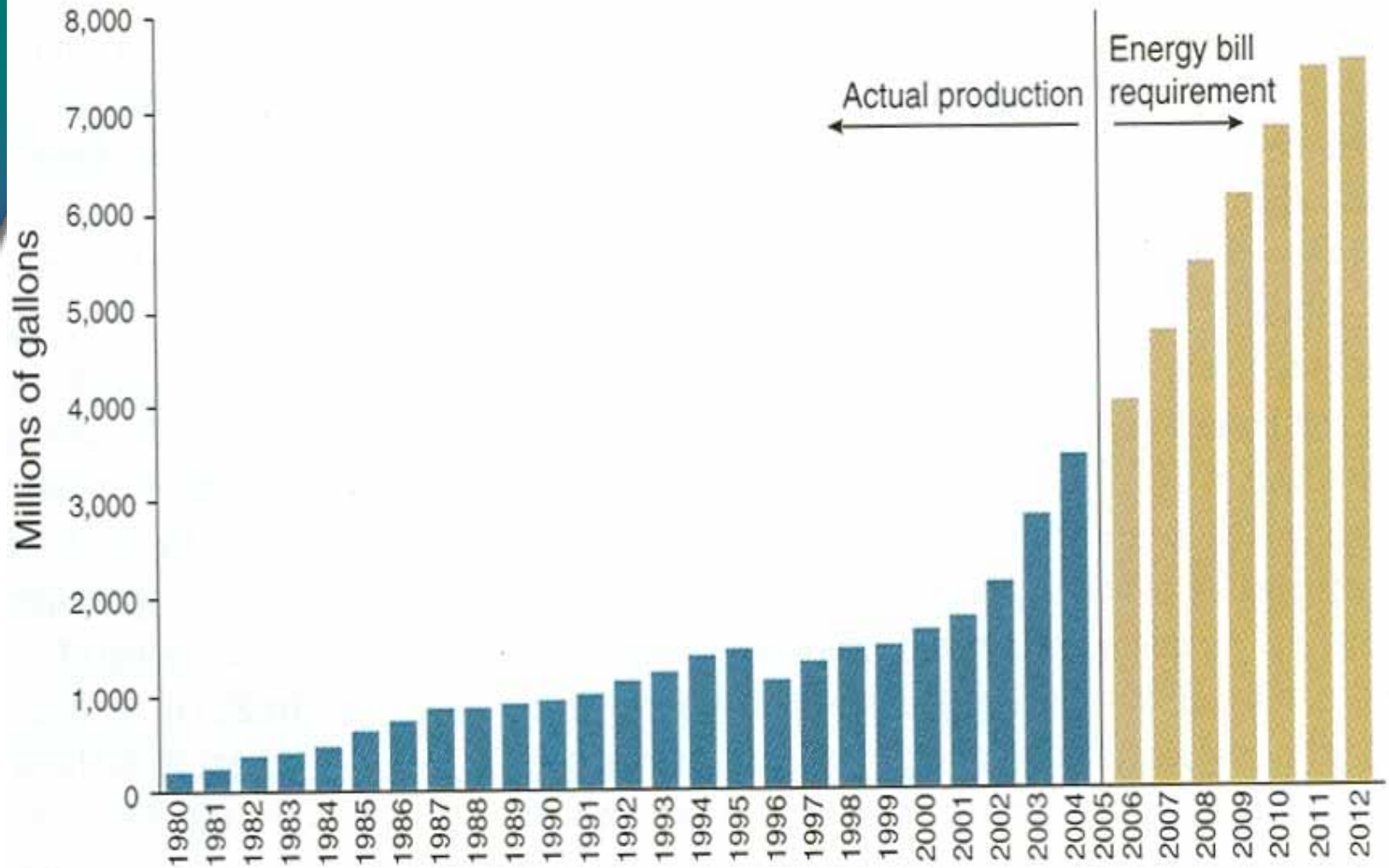
2014 Goal – 70 billion liters

30 X 30 Goal – 240+ billion liters by 2030

There are 102 grain ethanol facilities in the U.S. today

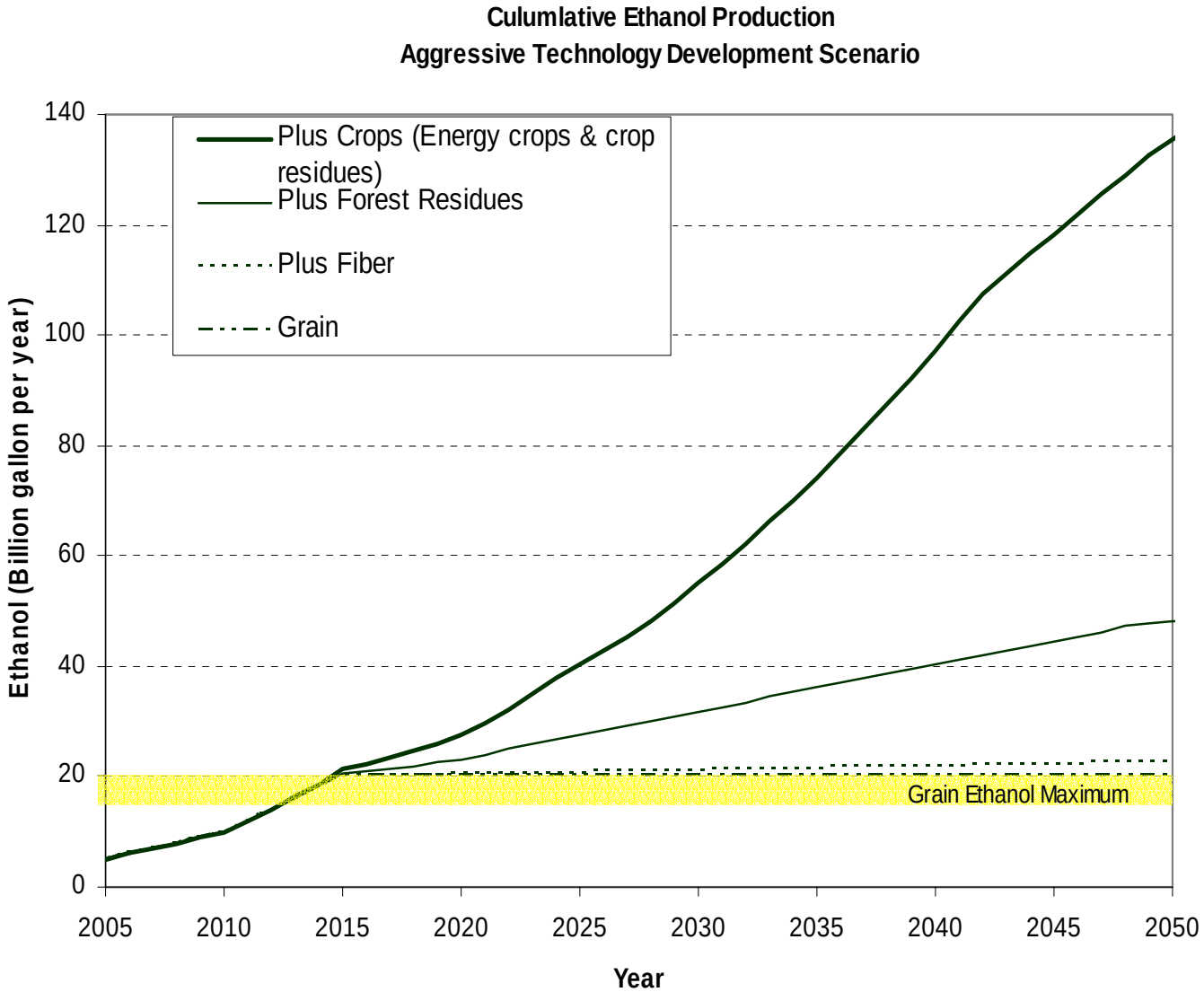
43 new facilities are under construction

7 facilities are being expanded



US production of ethanol. Source: Renewable Fuels Association.

(gallons X 3.79 = liters)


Culumlative Ethanol Production
Aggressive Technology Development Scenario
Plus Crops (Energy crops & crop residues)
Plus Forest Residues
Plus Fiber
Grain
Grain Ethanol Maximum
Ethanol (Billion gallon per year)
Year
0
20
40
60
80
100
120
140
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050

Dedicated Biomass Crops for Lignocellulosic Biofuels

Panicum **(switchgrass)**

Populus **(poplar)**

Lignocellulose Ethanol Today

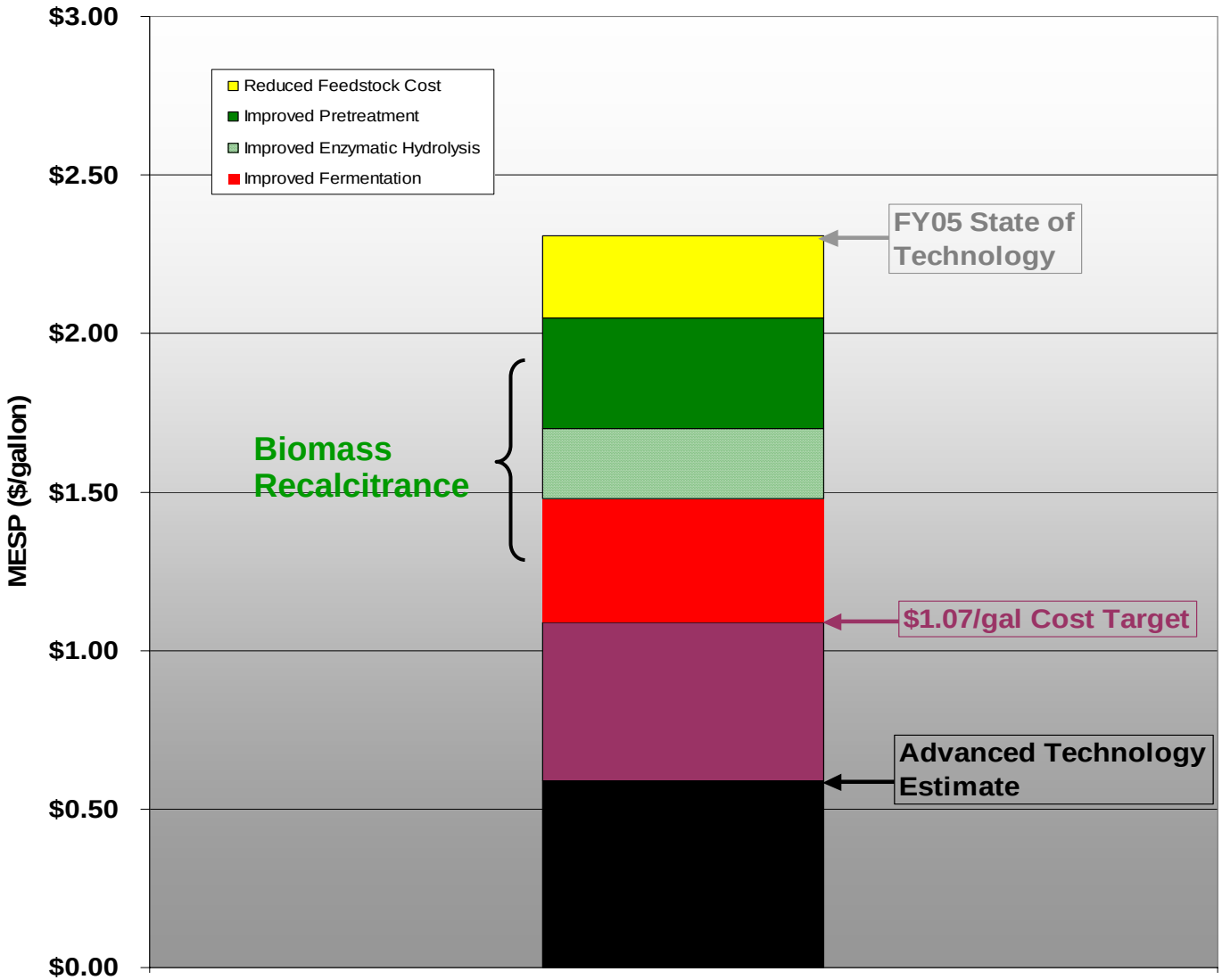
Private Companies Claim to have Proprietary Technology

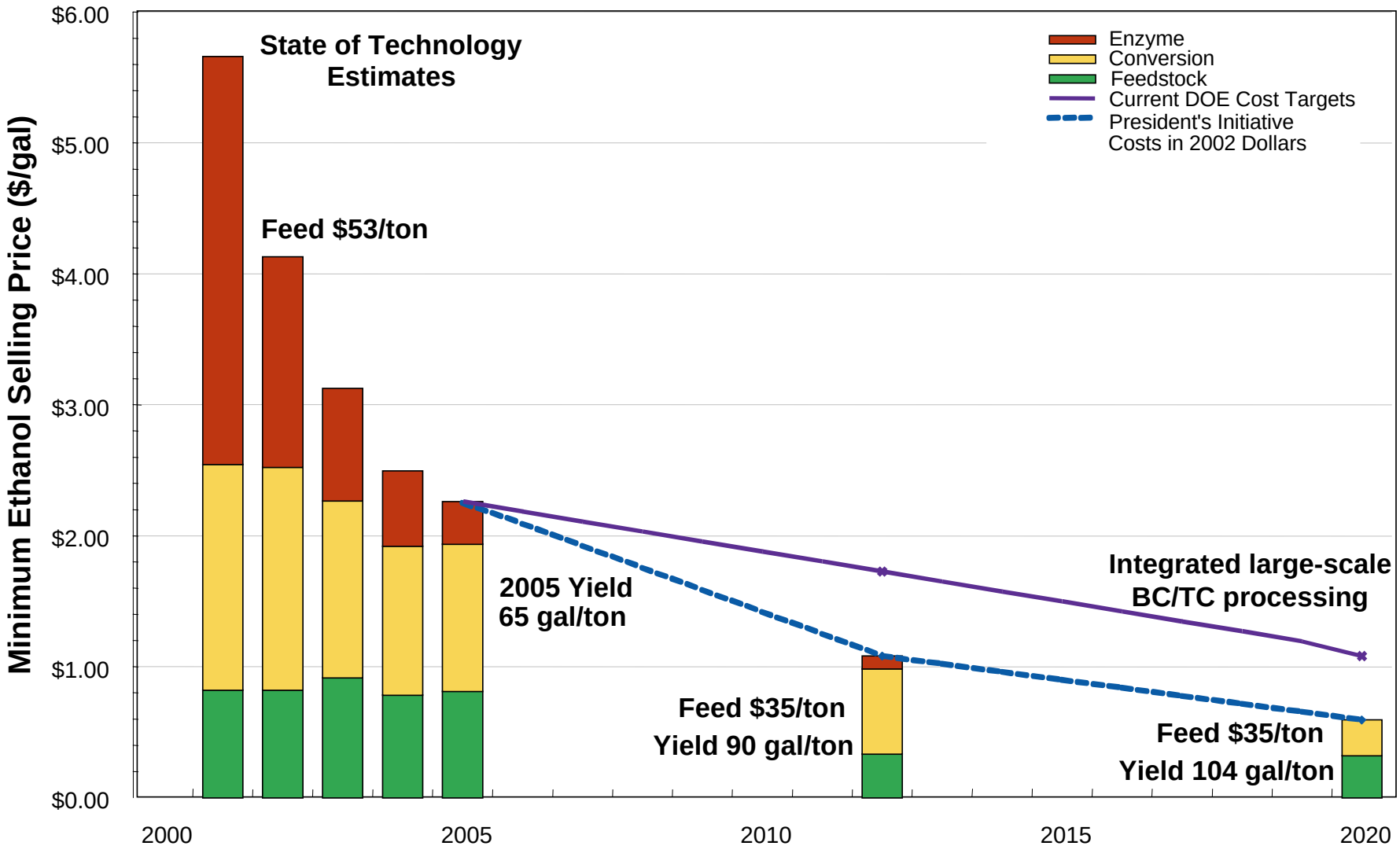
- **Abengoa Bioenergy + Dyadic International**
  - Facility in Spain. Fungal technology-cellulases & xylanases
- **Iogen (Canada, Shell Oil is an investor)**
  - Modified steam explosion pretreatment + fungal enzymes
  - Planned facilities in Idaho (USA), Germany, Saskatchewan (Canada)
- **Broin (Iowa USA) + Novozymes (Denmark)**
  - BPX™ treatment process
- **Bioengineering Resources, Inc. (USA)**
  - Microbial syngas fermentation

Other Activities

- **DuPont – Research program with Diversa, Michigan State U., NREL**
- **Archer Daniels Midland (ADM, USA). Improved yields from corn kernels.**
- **Chevron and BP to establish bioenergy research centers.**

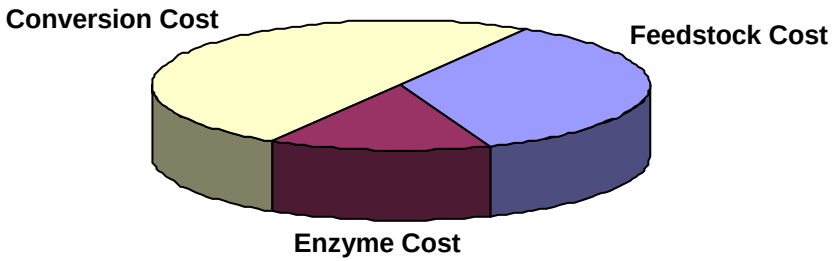
Overcoming the Remaining Barriers




Minimum Ethanol Selling Price ($/gal)
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
2000
2005
2010
2015
2020
State of Technology Estimates
Feed $53/ton
2005 Yield 65 gal/ton
Feed $35/ton Yield 90 gal/ton
Feed $35/ton Yield 104 gal/ton
Integrated large-scale BC/TC processing
Enzyme
Conversion
Feedstock
Current DOE Cost Targets
President's Initiative
Costs in 2002 Dollars

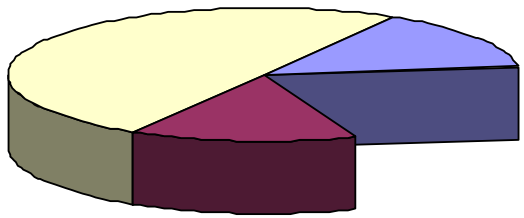
Impact of Process Improvements on Ethanol Cost

Current Cost



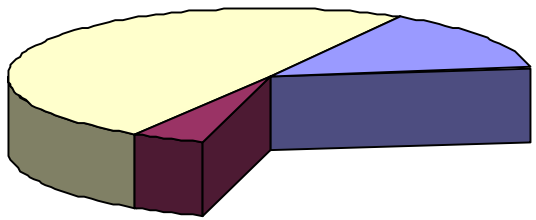
$2.26/gal

Lower Feedstock Cost



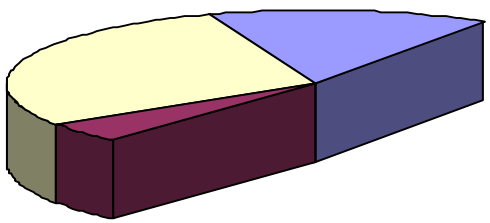
$1.78/gal

Lower Enzyme Cost



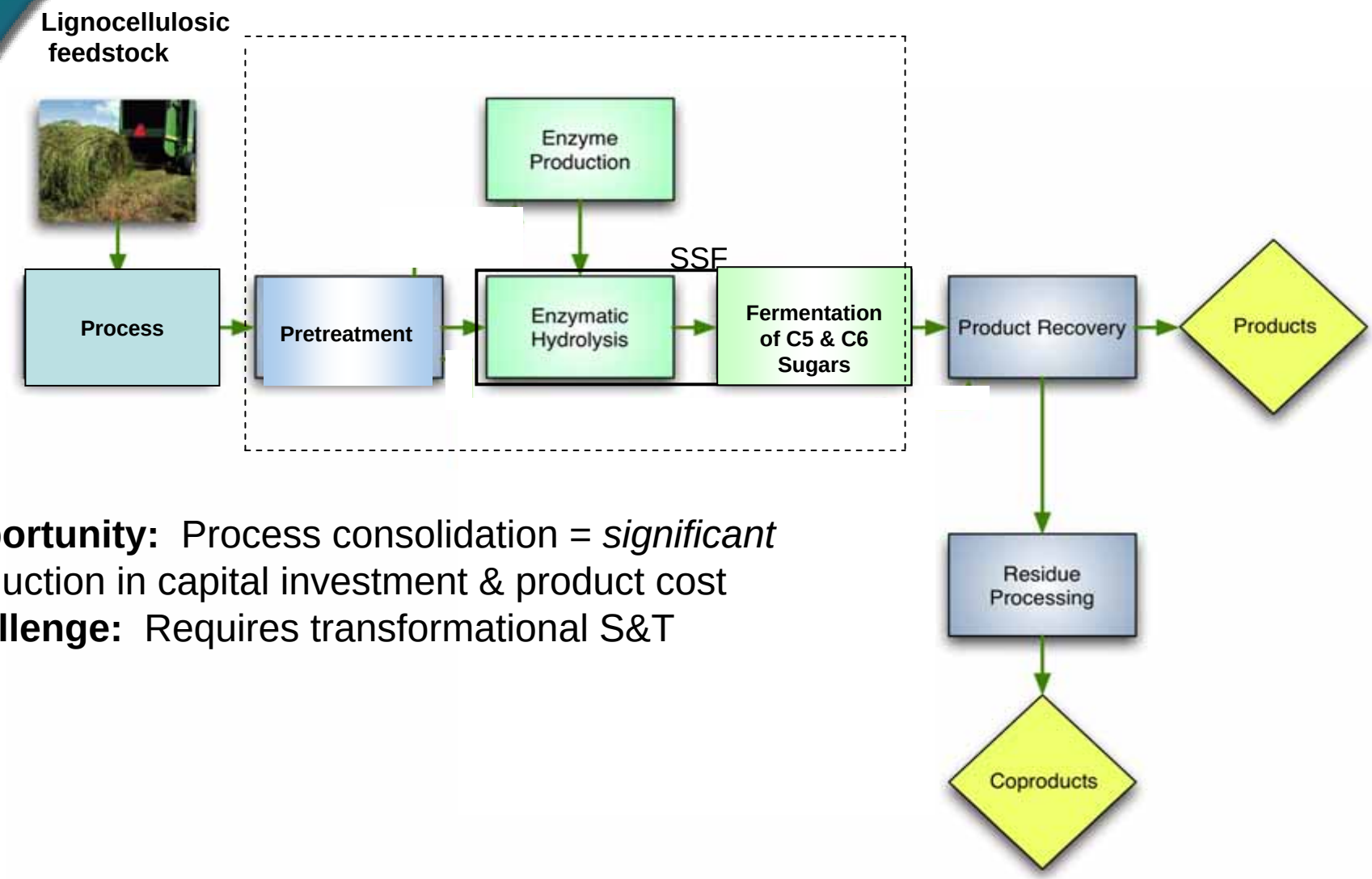
$1.56/gal

Better Conversion (Pretreatment, Enzymatic Hydrolysis & Fermentation Yields)



$1.07/gal

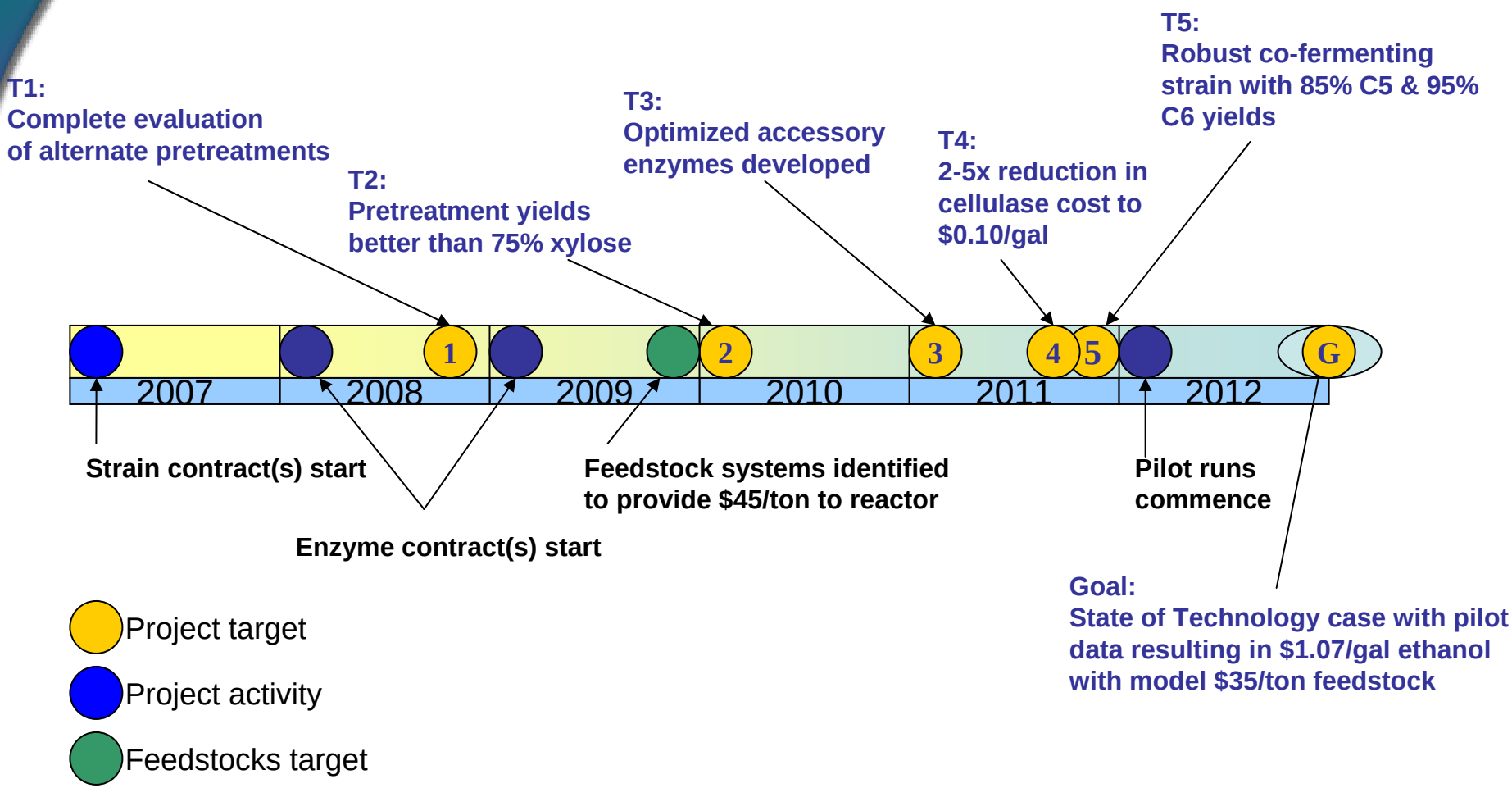
Bioethanol Production from Lignocellulose



Opportunity: Process consolidation = *significant* reduction in capital investment & product cost

Challenge: Requires transformational S&T

Critical Targets (T) and Activities



U.S. Department of Energy Research

Office of Science

- Genomics: GTL Program - $135M in 2007
- GTL Bioenergy Research Centers - $250M in 2008 (new $$)

Office of Energy Efficiency & Renewable Energy

- Office of Biomass Programs - $150M in 2007

U.S. Department of Agriculture

$180M in 2007

Research Priorities

"Process design studies consistently indicate that steps associated with overcoming the recalcitrance of cellulosic biomass are the most costly, involve the greatest technical risk , and have the largest potential for R&D-driven improvement." (Lynd, 2003)

- **Pretreatment to separate cellulose and hemicellulose**
- **Enzymatic treatment to liberate C5 & C6 sugars**

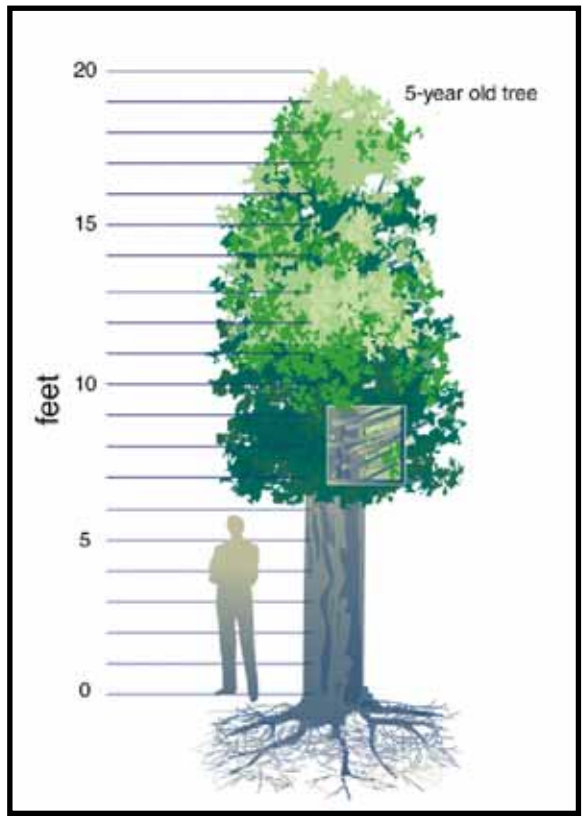
Additional research is also needed.

- **Simultaneous bioconversion of C5 & C6 sugars: yield & productivity enhancement**
- **Ethanol recovery**

And – Domestication of biofuel crops.

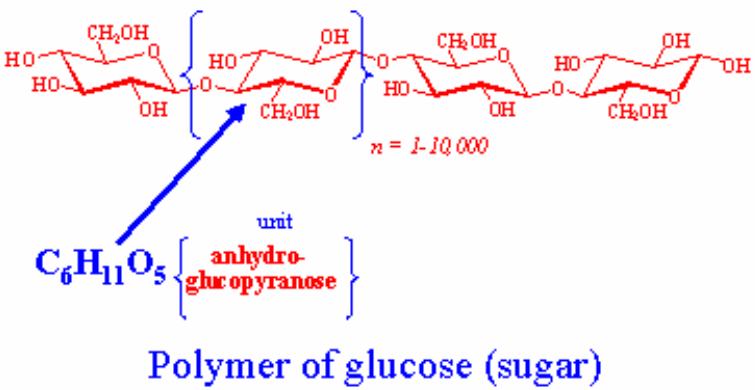
Domesticated *Populus* Attributes

- Controlled C allocation
- No response to competition
- Reduced height growth
- Less extensive root system
- Improved wood chemistry
- Pest resistance
- Optimized photoperiod response

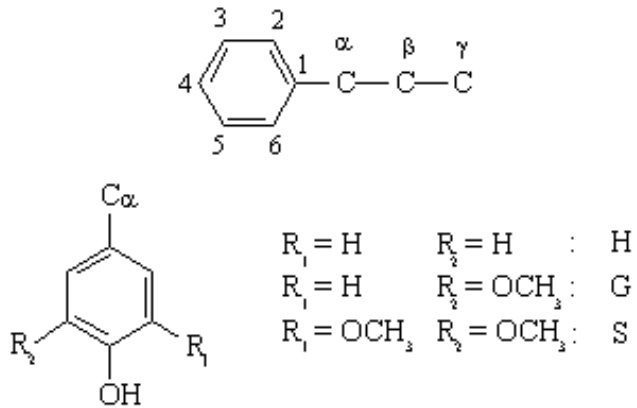


Major Components of Biomass

Molecular Structure of Cellulose



Lignin Monomers



<u>Challenge</u> – *Complete and efficient utilization of all biomass components present in plants as very complex chemical and physical structures.*

Biofuel Production via Thermochemical Conversion

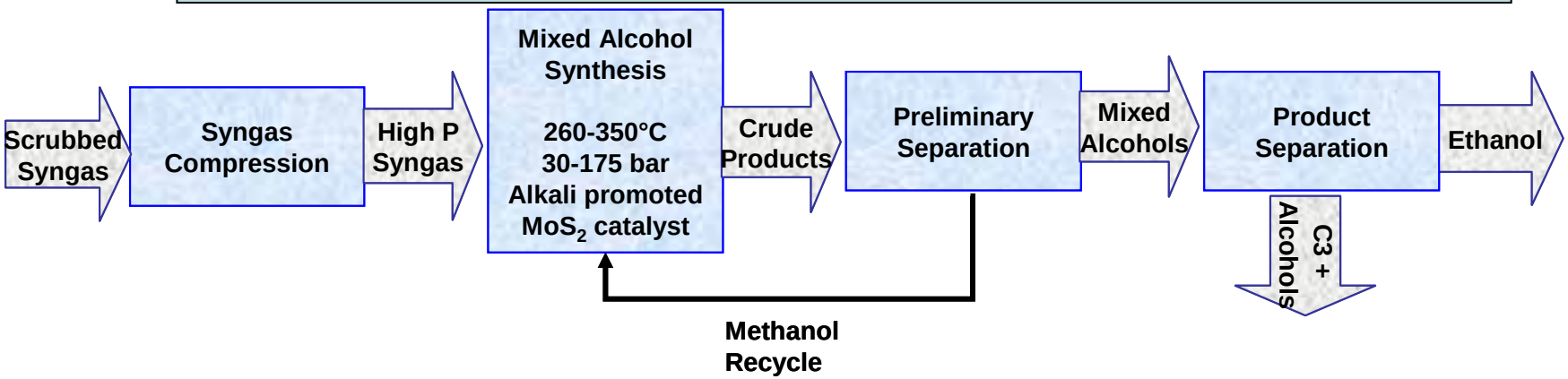
gasification, pyrolysis

Opportunity: Reduce scale of operations, decentralize.

Apply microtechnology, nanotechnology, biotechnology, catalysis.

Challenge: Requires transformational S&T

e.g., Current Thermochemical Route to Ethanol for "Non-fermentable" Biomass



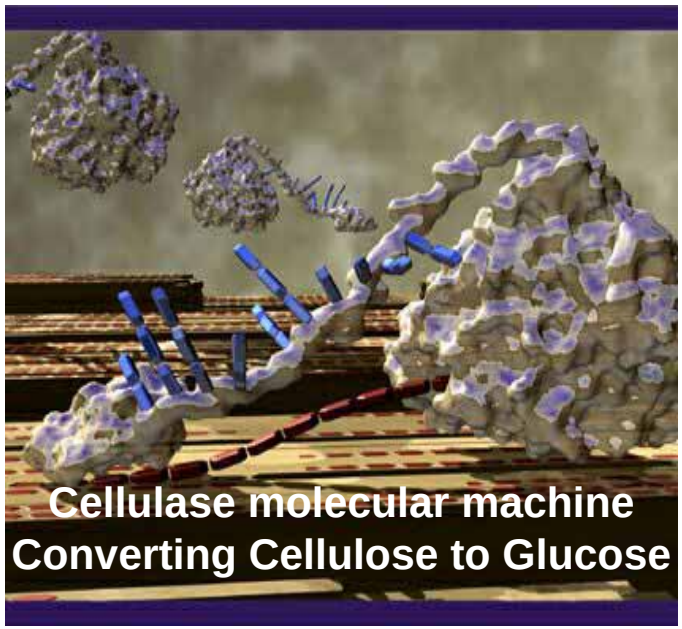
There are multiple potential entry points for *transforming* technology to address:

- **Poor yields (currently 10% single pass)**
- **Scale (currently economical only at very large scale)**

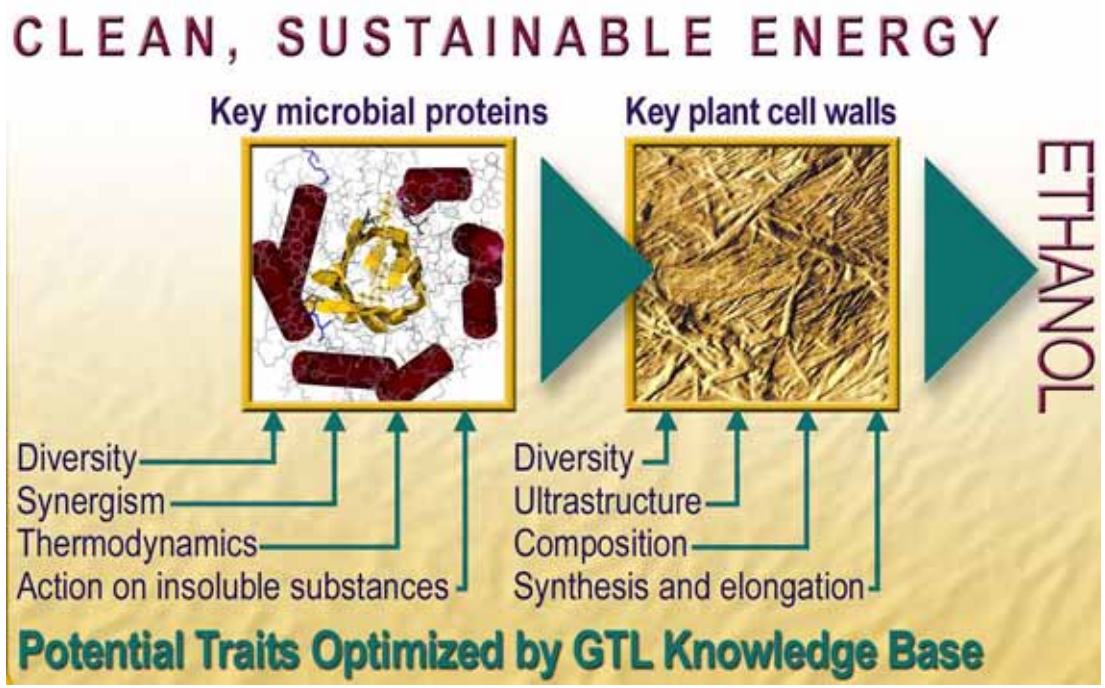
DOE Genomics: GTL Program

Understanding Molecular Machines

Then putting them to work

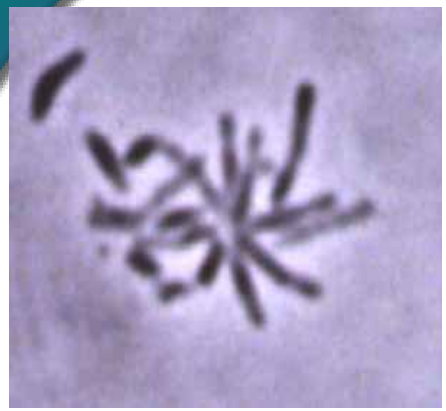


Cellulase molecular machine
Converting Cellulose to Glucose

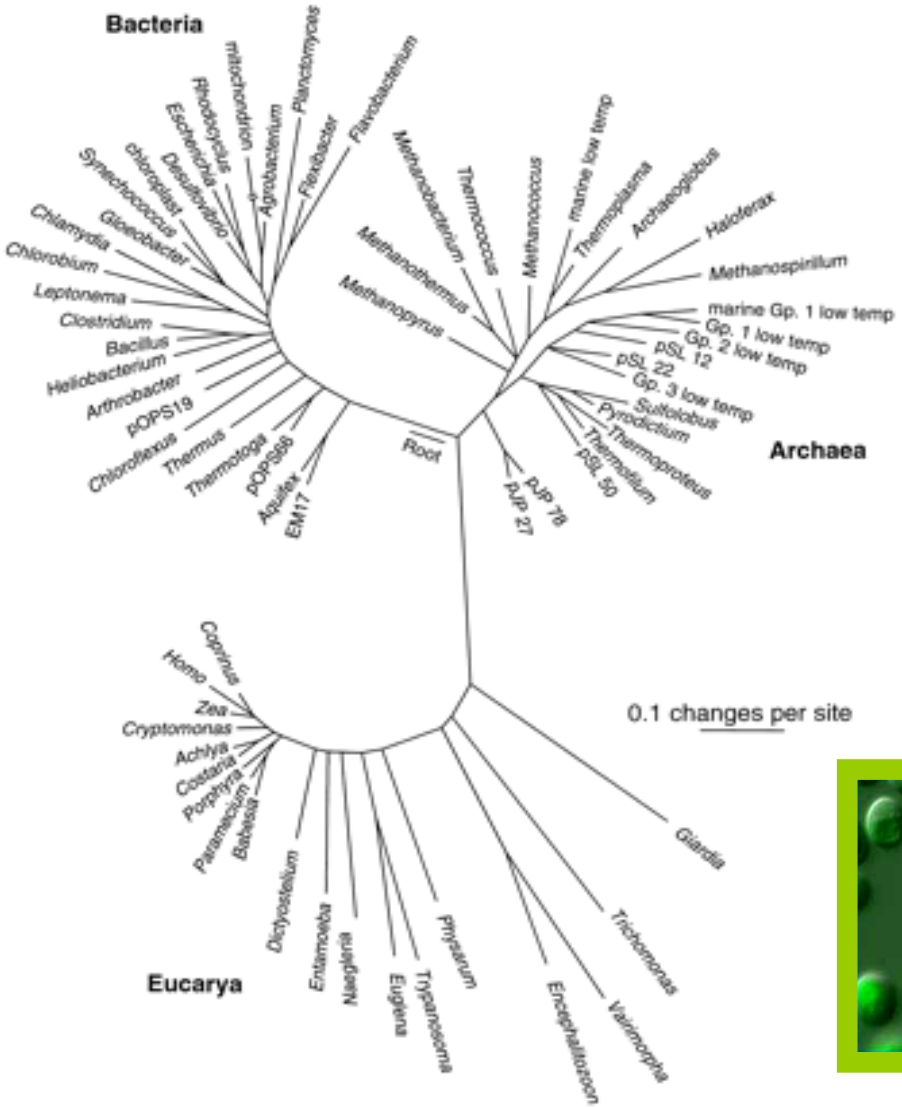


Potential - ***Make lignocellulosics a viable energy feedstock for creating the biomass energy industry.***

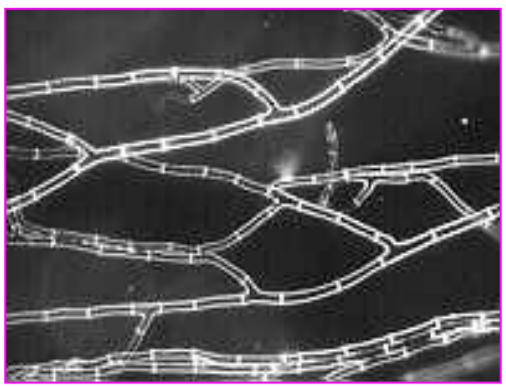
Microbial Diversity & Versatility



Bacteria

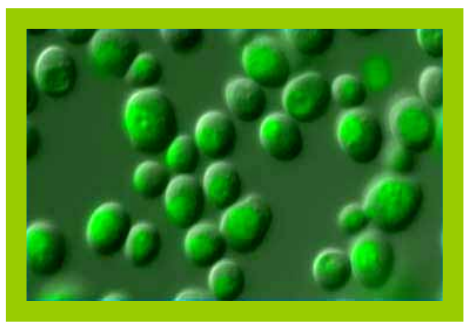


Extremophiles



Filamentous fungi

Microalgae



What are the Possibilities ??
Biofuels, Bioproducts, Biopower

Leading Opportunities for GHG Mitigation
- **Photocatalytic H_2 production**
- **Dark H_2 production**
- **CO_2 and N_2 fixation**

Important Contributors
- **Fossil energy biotechnology**
- **Industrial biotechnology**

Dark Horse Candidates
- **Gas hydrates – mining & formation**
- **Geologic energy production**
- **Microbial electricity**

Biorefinery of the Future