Office of Science
U.S. Department of Energy

Battelle Global Energy Technology Strategy Program (GTSP) Steering Group Meeting

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Grand Challenges for Biology, Payoffs for the Nation

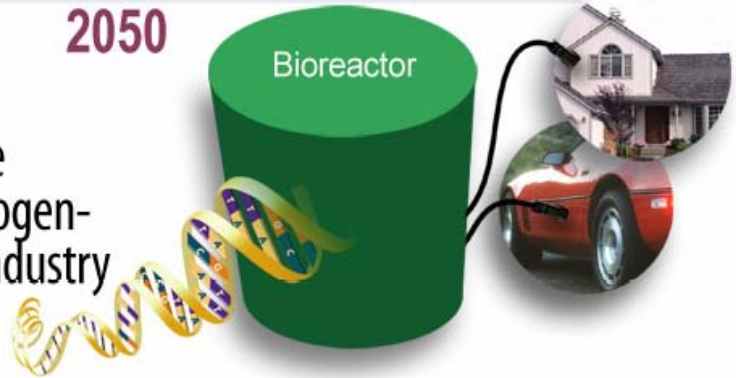
Enhance or develop new sources of fuels and electricity for U.S. energy security

2025

- Efficiently convert plant cellulose to ethanol

2050

- Mobilize biohydrogen-based industry



Develop knowledge base for effective cleanup strategies for intractable environmental problems

2020

Save billions of dollars in toxic waste cleanup and disposal

Understand earth's natural carbon cycle for more accurate assessments of sequestration strategies

2040

Help stabilize atmospheric carbon dioxide to counter global warming

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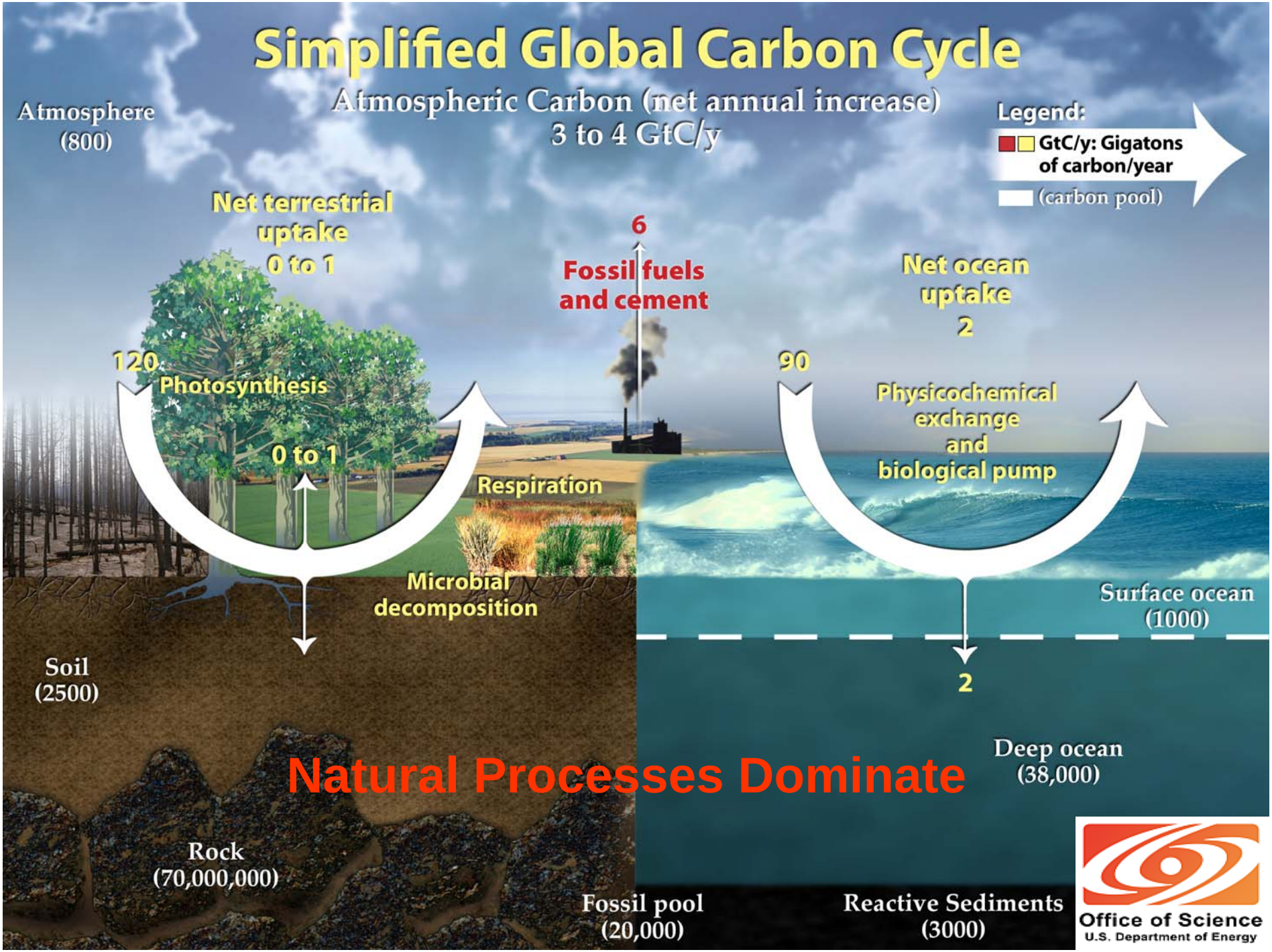
Simplified Global Carbon Cycle
Atmospheric Carbon (net annual increase)
3 to 4 GtC/y
Atmosphere
(800)
Legend:
GtC/y: Gigatons of carbon/year
(carbon pool)
Net terrestrial uptake
0 to 1
6
Fossil fuels and cement
Net ocean uptake
2
120
Photosynthesis
90
Physicochemical exchange and biological pump
0 to 1
Respiration
Microbial decomposition
Surface ocean
(1000)
Soil
(2500)
2
Natural Processes Dominate
Deep ocean
(38,000)
Rock
(70,000,000)
Fossil pool
(20,000)
Reactive Sediments
(3000)
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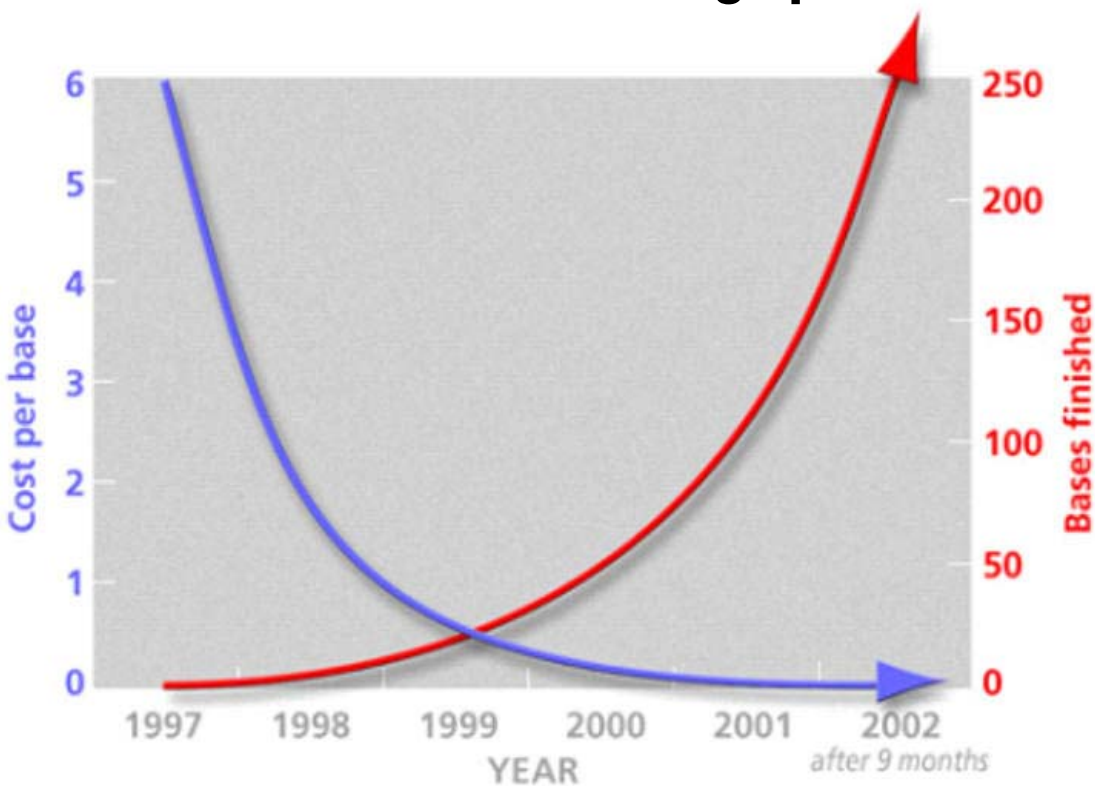
Human Genome Project

Making the Impossible Routine

DOE R&D Contributed to:

- **Decreased Cost**
- **Increased Throughput**



Cost per base in dollars. Millions of bases finished.

Providing the Paradigm for Genomes to Life Facilities

Program Goals

Using DNA sequence and high-throughput technologies

goal 1

Identify and characterize the molecular machines of life

goal 2

Characterize gene regulatory networks

goal 3

Characterize the functional repertoire of complex microbial communities in their natural environments at the molecular level

goal 4

Develop the computational capabilities to advance understanding of complex biological systems and predict their behavior

Systems Biology

Gain a comprehensive and predictive understanding of the dynamic, interconnected processes underlying living systems

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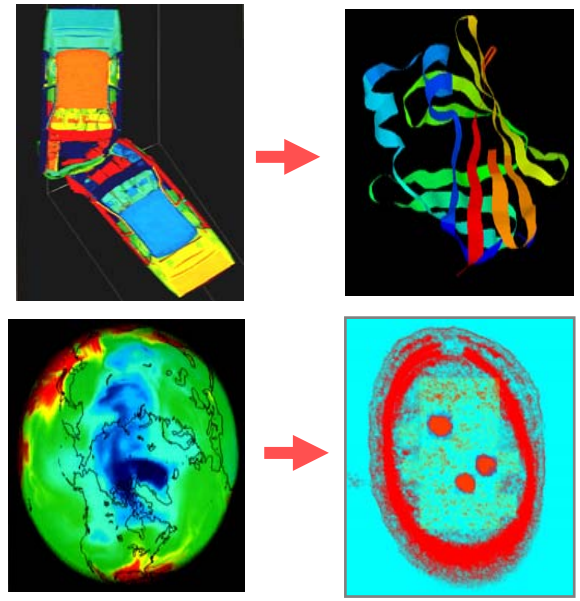
Ultimate Goal is to Provide Predictive Models of Microbes

This goal drives data collection and computing strategy.



Experimental:

- Complete datasets
- Quantitative measurements
- Comprehensive physical characterization:
  - **Protein expression and interactions**
  - **Spatial distributions**
  - **Process kinetics**

Computational:

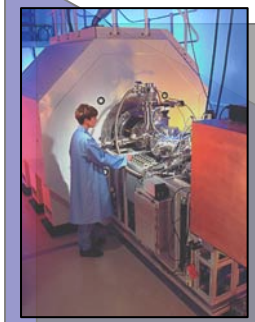
- Automated data analysis and validation
- Automated integration of diverse data sets
- Human and computer-accessible databases
- Molecular, Pathway and cell-level simulations

The goals require a new synergy between computing and biology.

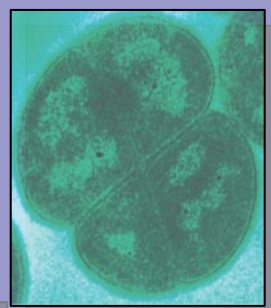
GTL User Facilities Hallmarks

For the Research Community

Technology Integration for Tomorrow's Biology

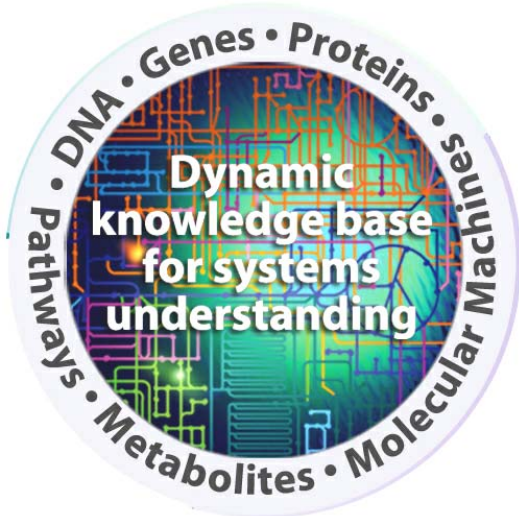


Advanced Technologies

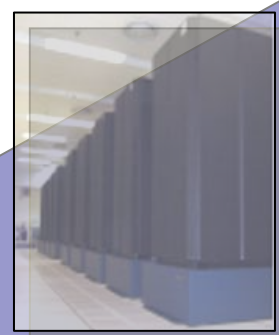


Microbial Genomics

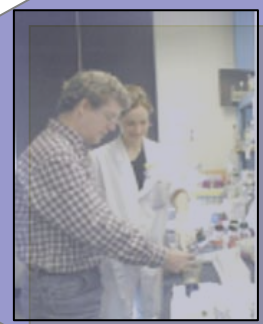
High-Throughput Methods



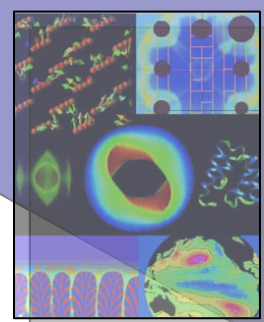
DOE Mission Applications



Informatics and Databases



Biosystems Training



Computing and Simulation

BER Proposed Facilities Will --

- Speed researchers' access to proteins and other experimental products by factors of 100 to 1000
  - Improve throughput by 100 to 1000 times
  - Decrease costs by factor of 100
- Make possible a systems understanding of a microbe so that multiple capabilities can be integrated into a single organism
- Reduce the time to understand and engineer a new biological organism from years or longer to months

Lignocellulosic Ethanol: A Viable Energy Option

The Potential

- **Lignocellulosic ethanol can be developed as a primary fuel for transportation to cost competitively displace our dependence on oil**

The Benefits

- **Invest our energy dollars at home**
- **A domestic and globally secure supply**
- **GHG/ CO2 neutral or negative (at no extra cost)**
- **Major new crops for our farmers – jobs in every state**
- **Revitalize lands, air and water, and provide wildlife habitat**

The Challenge

- **Biomass into ethanol: a problem of unprecedented scale and complexity**

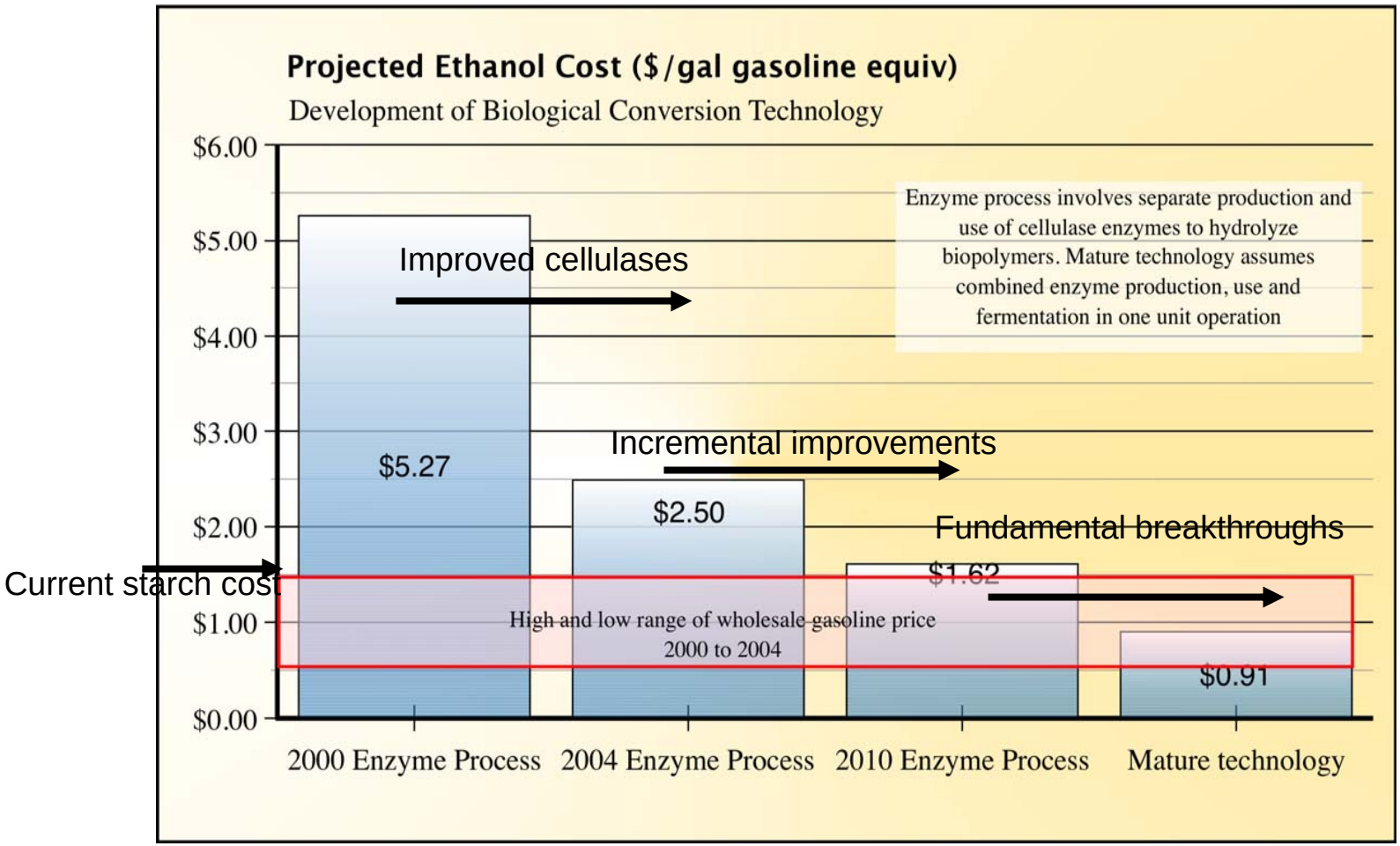
Lignocellulosic Ethanol: Our Plan

To meet the challenge we need:

- a new level of biological investigation and understanding
- synergistic cross-labs teaming and expanded facilities are required

– Apply the DOE model for strategic scientific research, high technology, and computing to biology
– Build on the national investment in genomics to establish a systems approach to biology
– Progress will support all facets of the technology chain from basic research to commercialization
– The resultant capabilities and knowledge will dramatically shorten the technology cycle – bringing new discoveries into products in a timely manner.
– These capabilities will energize industrial biotechnology in this country and support other DOE energy and climate goals – hydrogen, carbon management, and environmental restoration

Predicted Cost Reduction



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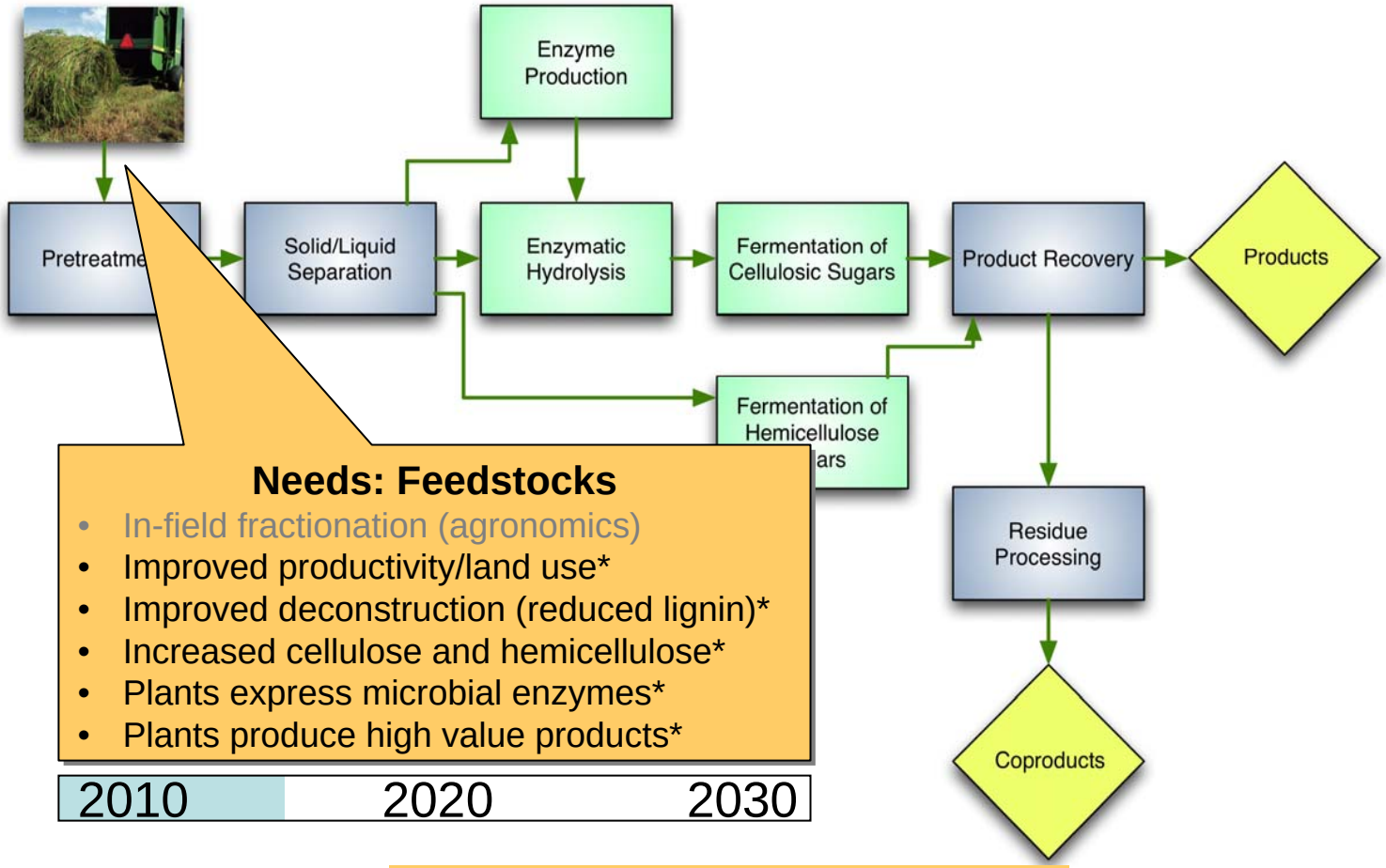
Natural Progression of Process Simplification



Needs: Feedstocks

- In-field fractionation (agronomics)
- Improved productivity/land use*
- Improved deconstruction (reduced lignin)*
- Increased cellulose and hemicellulose*
- Plants express microbial enzymes*
- Plants produce high value products*

2010 2020 2030

* Needs addressable by GTL

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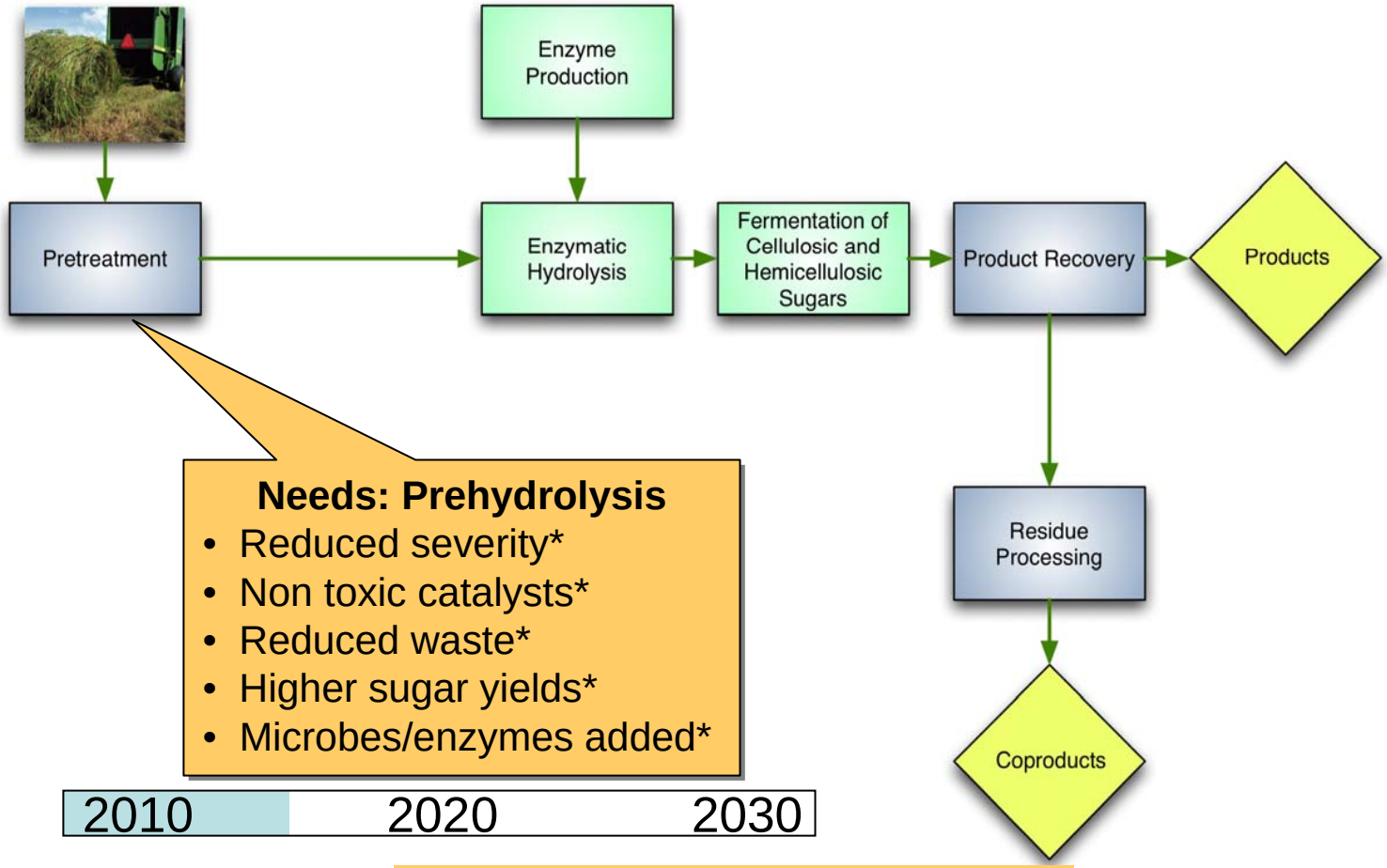

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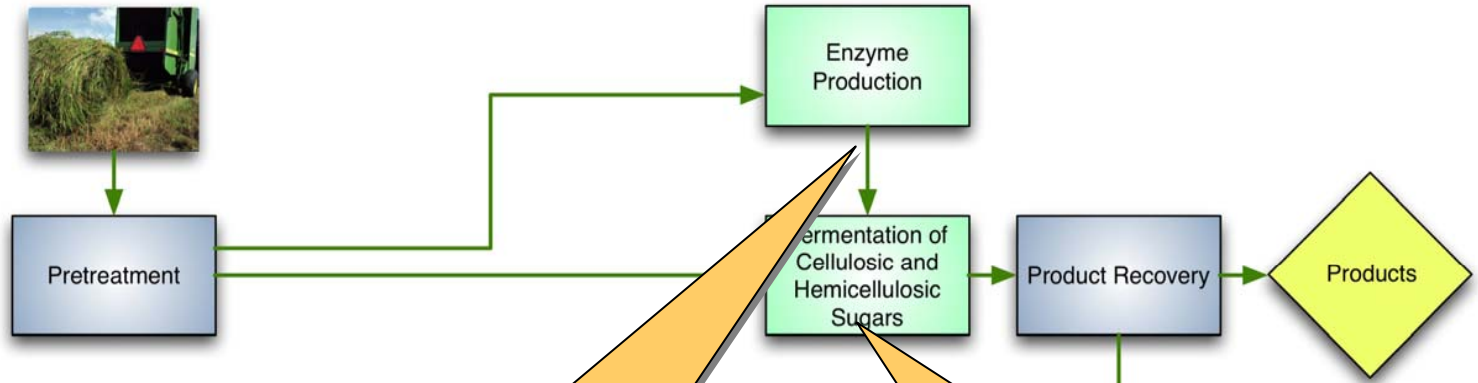

Needs: Enzyme Cocktails

- Higher specific activity*
- Higher thermal tolerance*
- Reduced product inhibition*
- Broader substrate range*

2010 2020 2030

Needs: CoFermentation Strains

- C6 and C5 sugar microbes*
- Robust process tolerance*
- Resistance to inhibitors*
- Byproducts still marketable (DDGs)*

2010 2020 2030

* Needs addressable by GTL

DDGs=distillers dried grains

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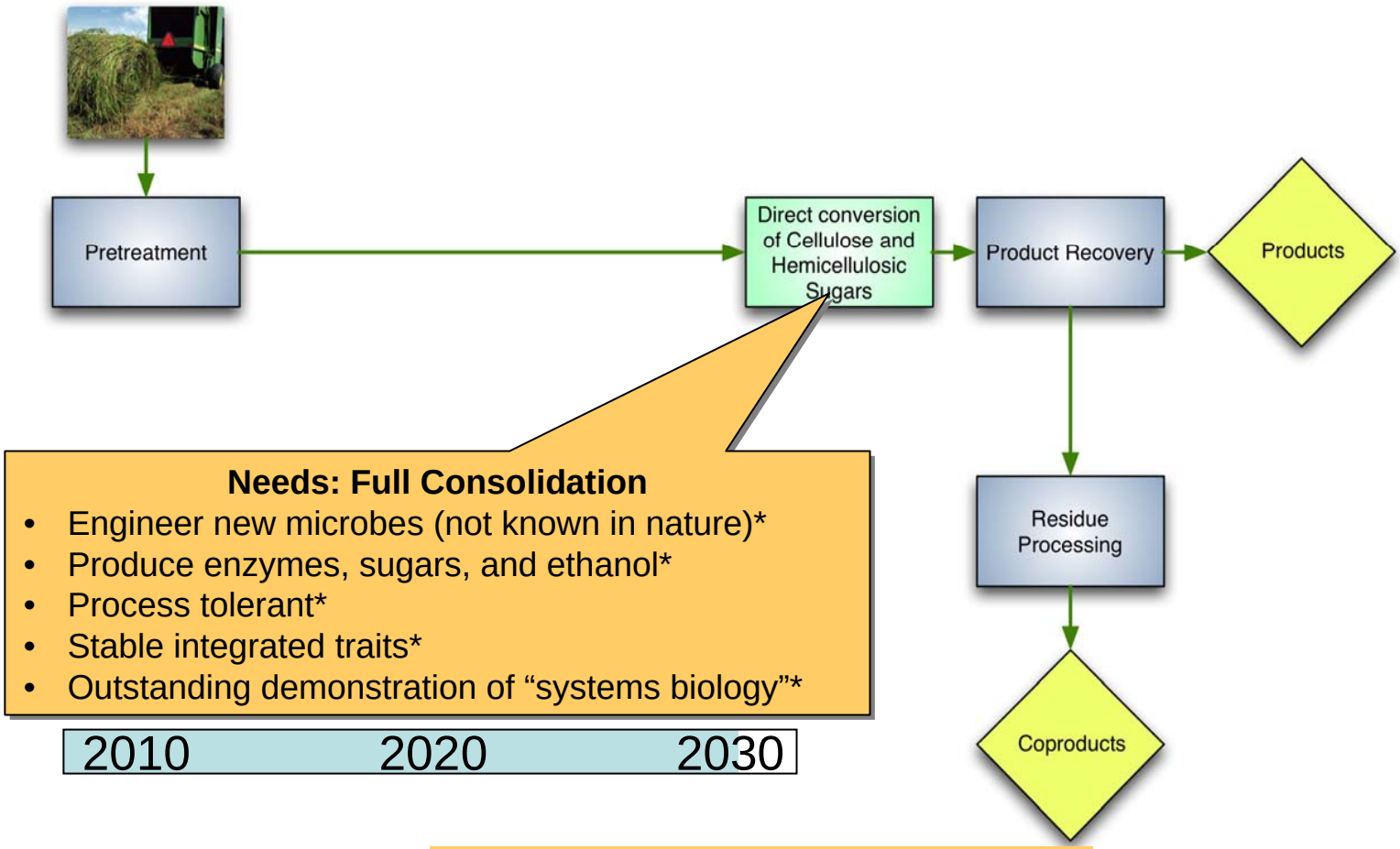

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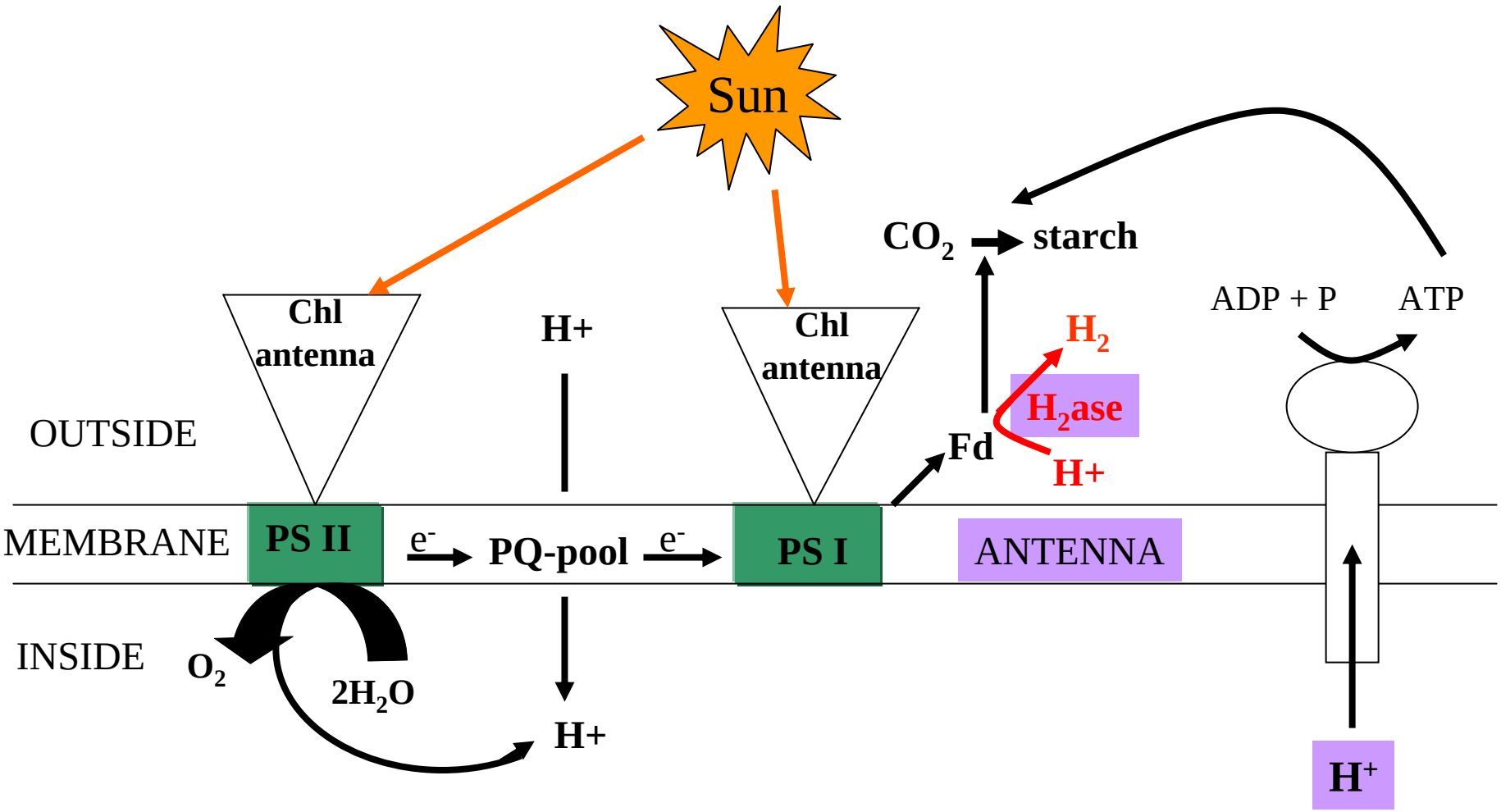
PHOTOSYNTHETIC PATHWAYS

(light reactions)