NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Harnessing Innovation for a Renewable Energy Future

Presented at the Green Engineering Summit

October 5, 2006

Dan E. Arvizu
Director, National Renewable Energy Laboratory

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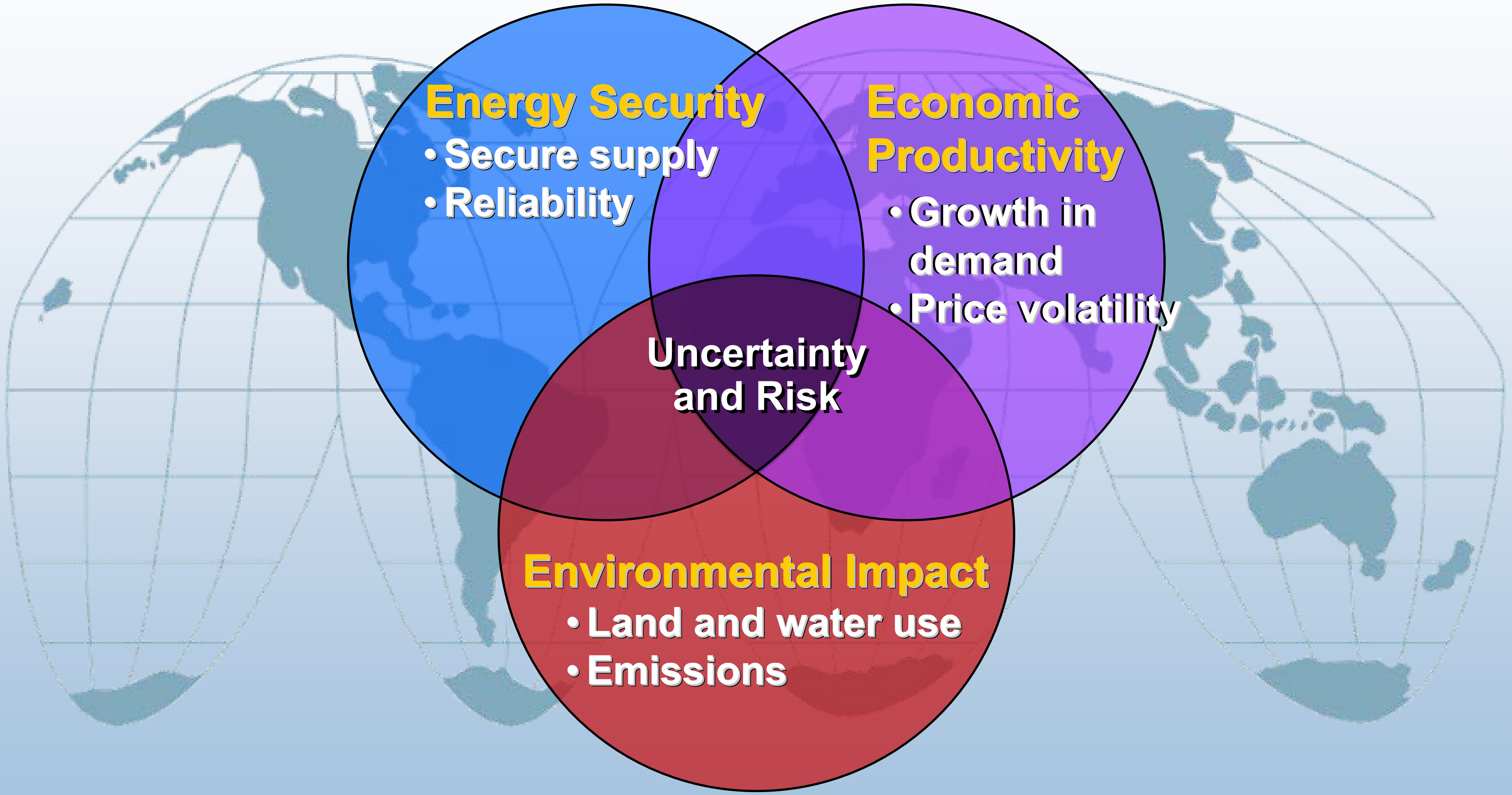
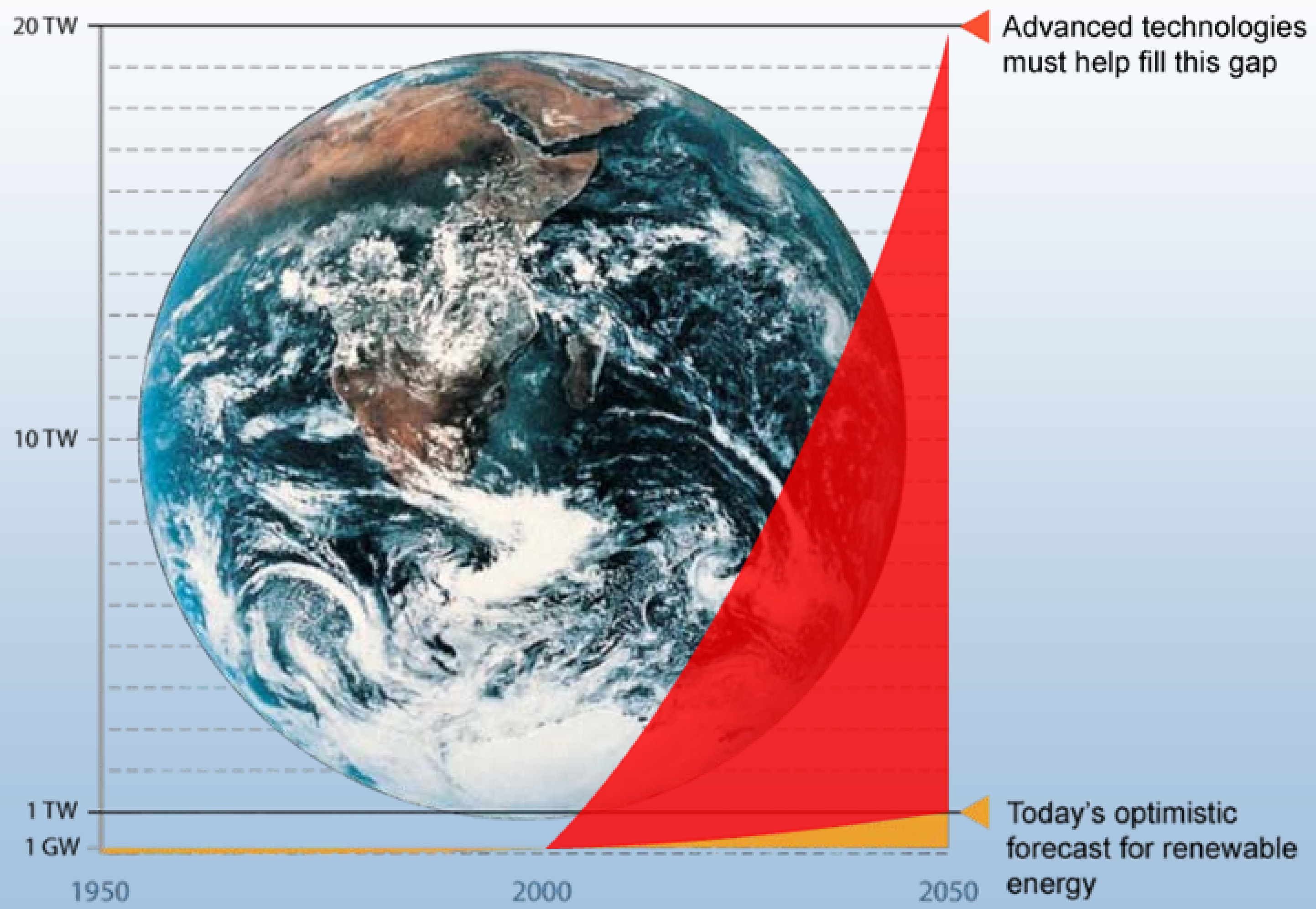
Keynote presentation for the Green Engineering Summit held in Anaheim, California on October 5, 2006.

Energy Solutions Are Enormously Challenging



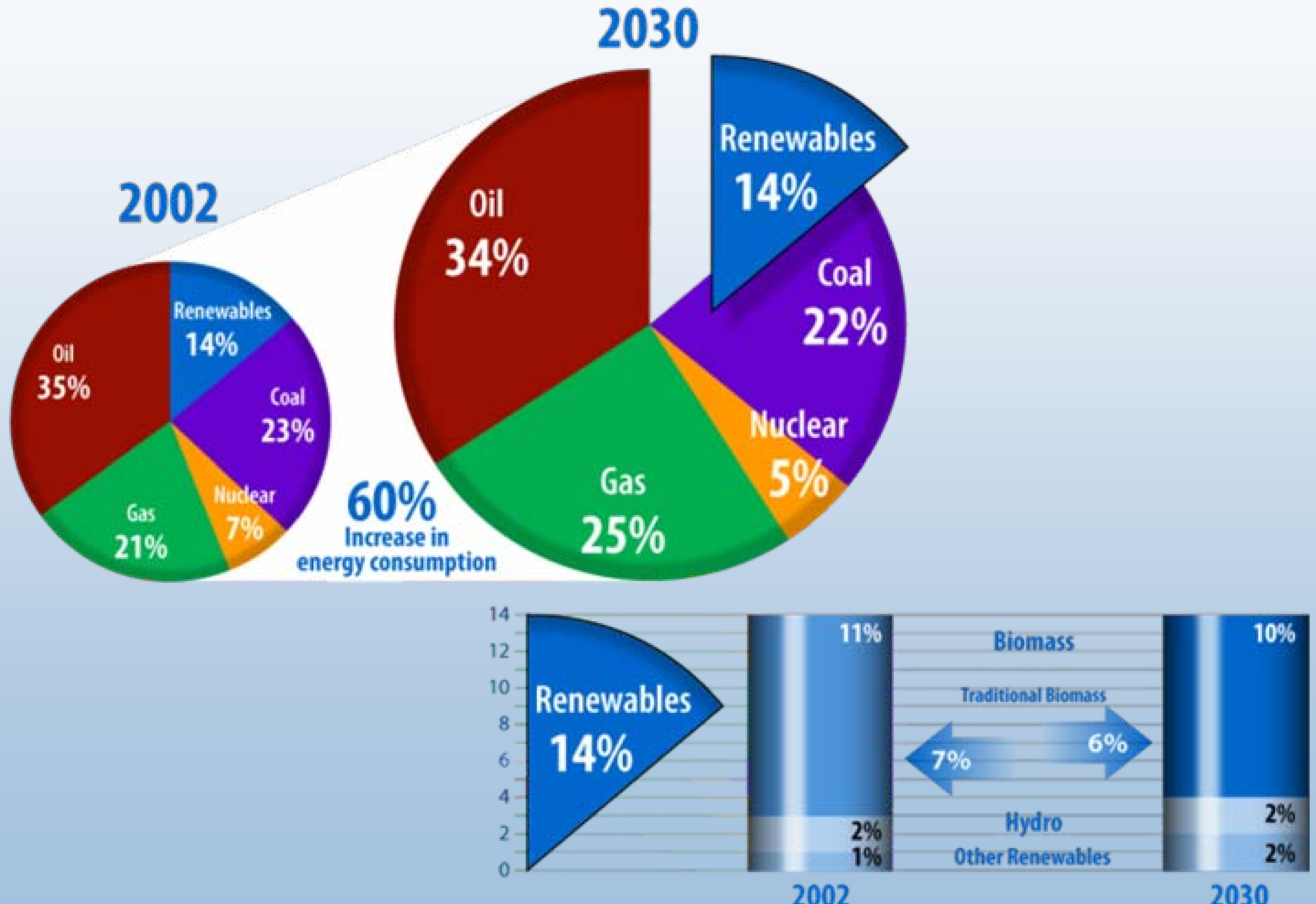
We need a balanced portfolio of options

Magnitude of Challenge Requires Global Action and a Change in Trajectory



Source: Arvizu, NREL

World Energy Supply and the Role of Renewable Energy



Source: OECD/IEA, 2004

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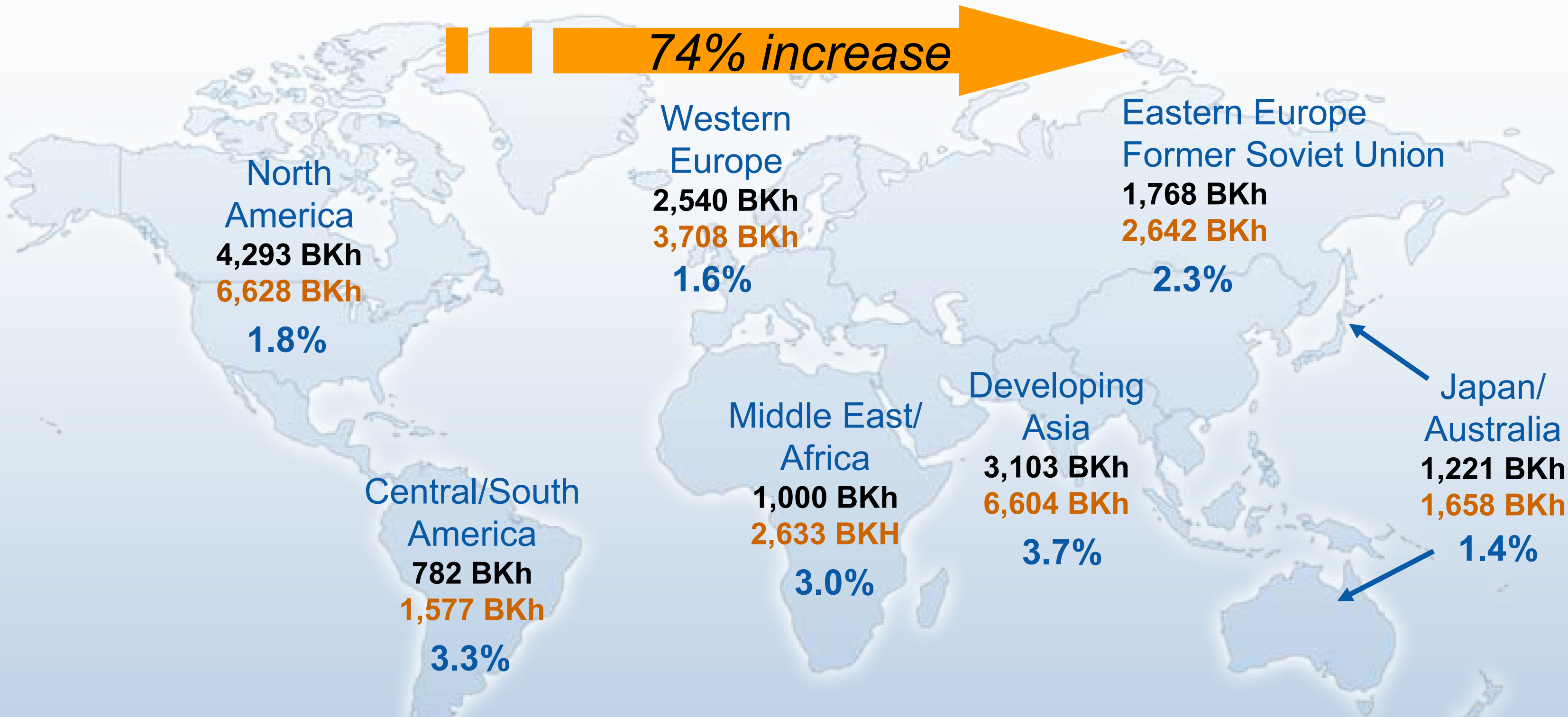
Electricity Outlook: 2001-2025



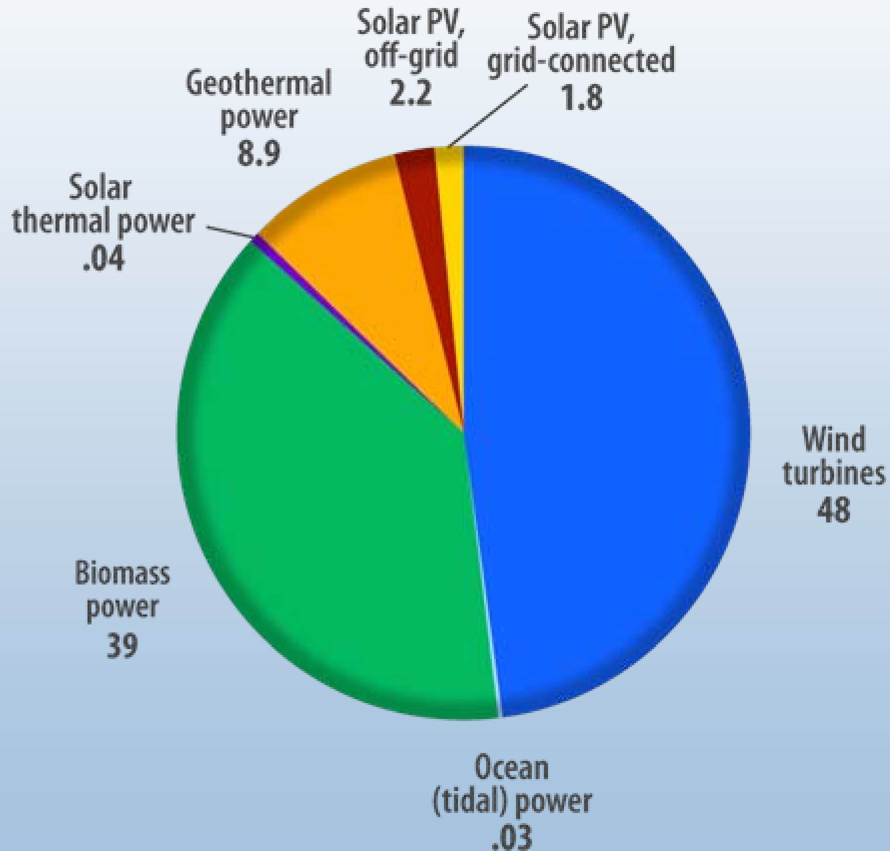
- Total annual average world electricity growth: 2.4% from 2001 to 2025
- Growth rates in transitioning economies higher than in developed economies
- Natural gas and coal will be near-term fuels of choice for generation
- Distributed generation and renewable energy will offer attractive options

Source: International Energy Outlook 2003, Table A9

Global Renewable Energy Indicators

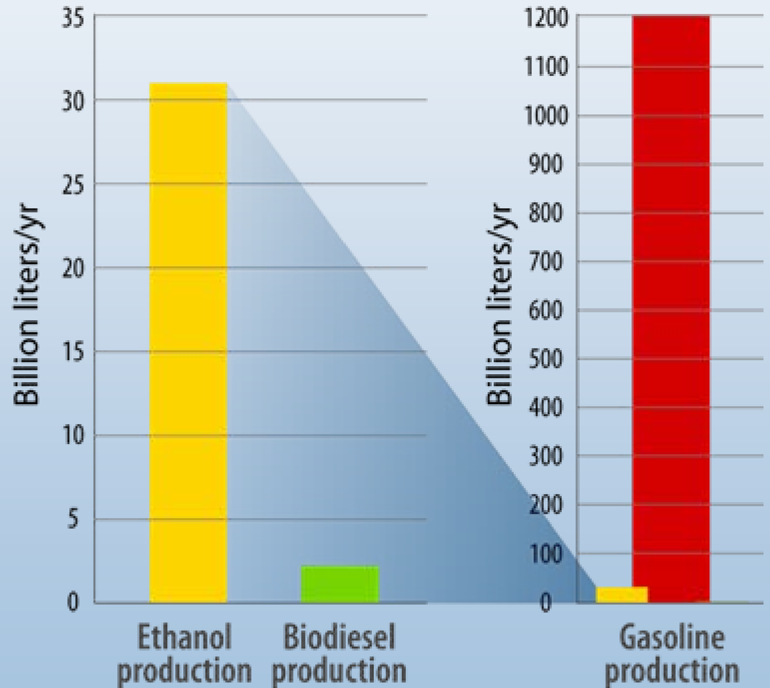
Power Generation

Existing Capacity* – GW



Transportation Fuels

Billion liters/year



Note: Does not include hydropower.

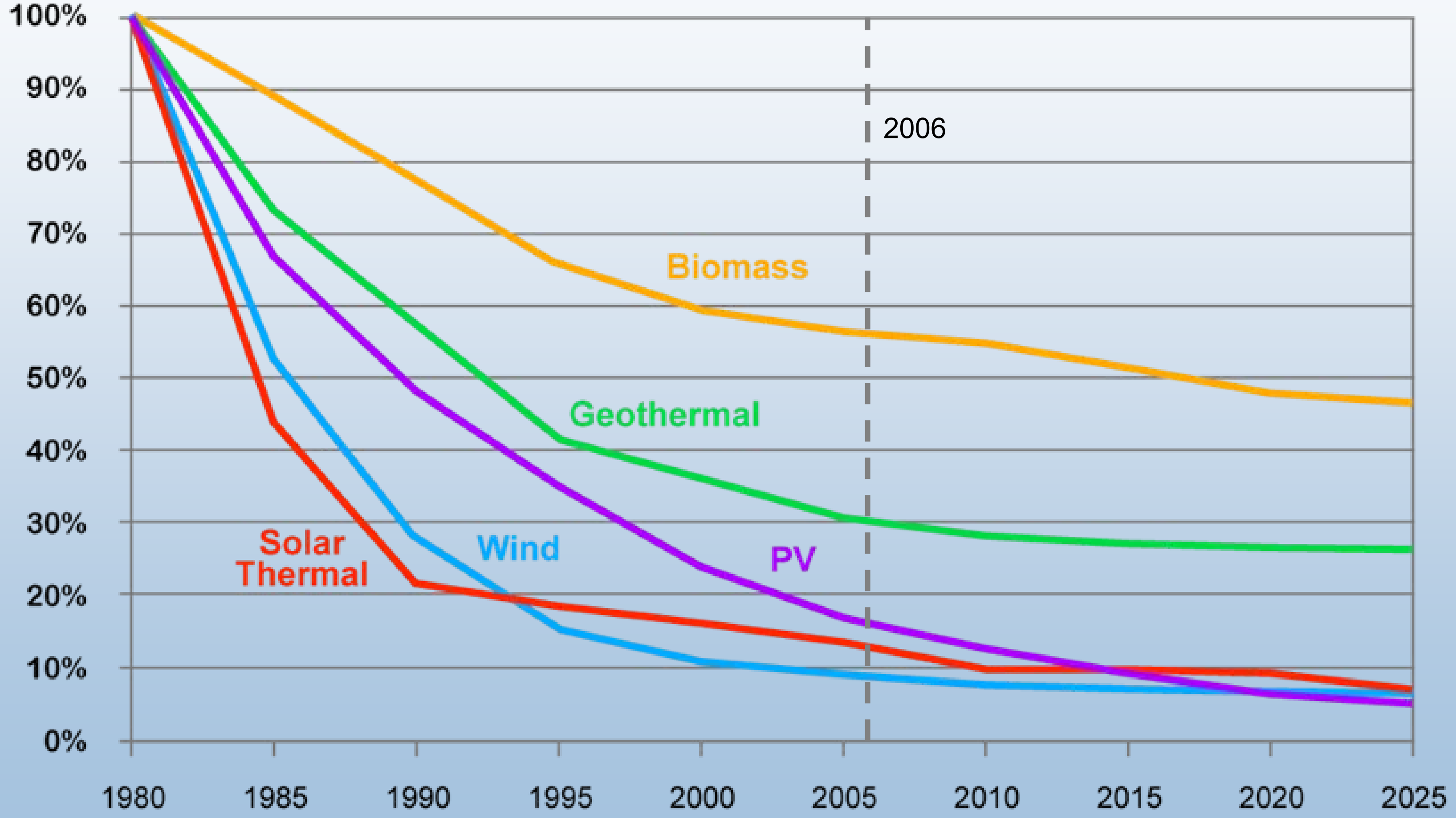
Source: REN21 Renewables 2005 Global Status Report

Technology-Based Solutions:
There is no single or simple answer

- Energy efficiency
- Renewable energy
- Nonpolluting 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 such as hydrogen and electricity

Renewable Energy Costs Have Decreased

Historical and Projected



Costs as percentage of 1980 levels

Source: NREL 2005, 2002

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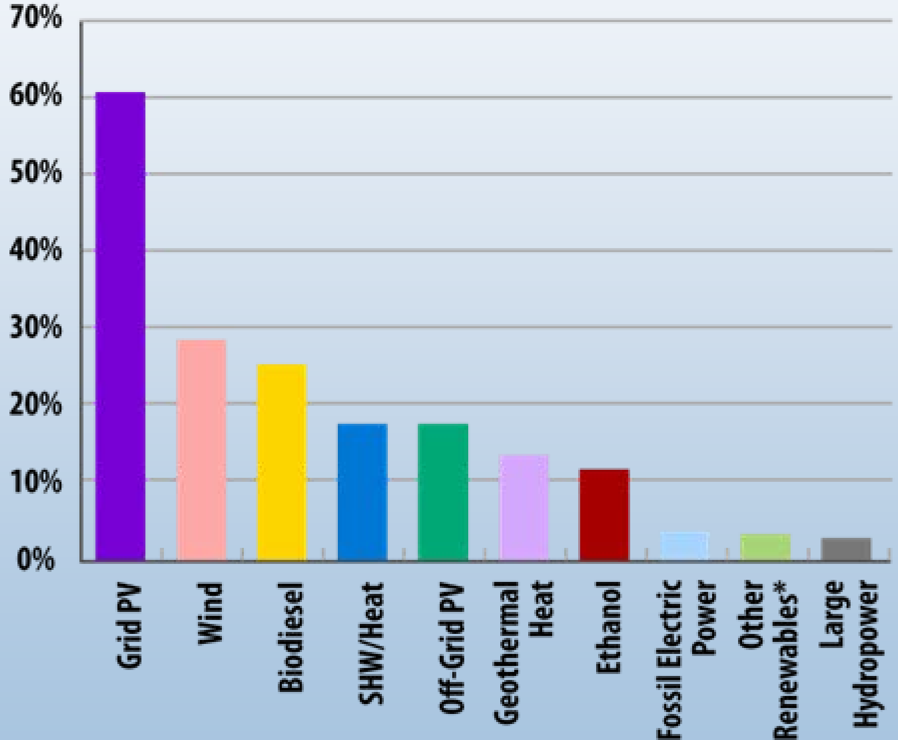
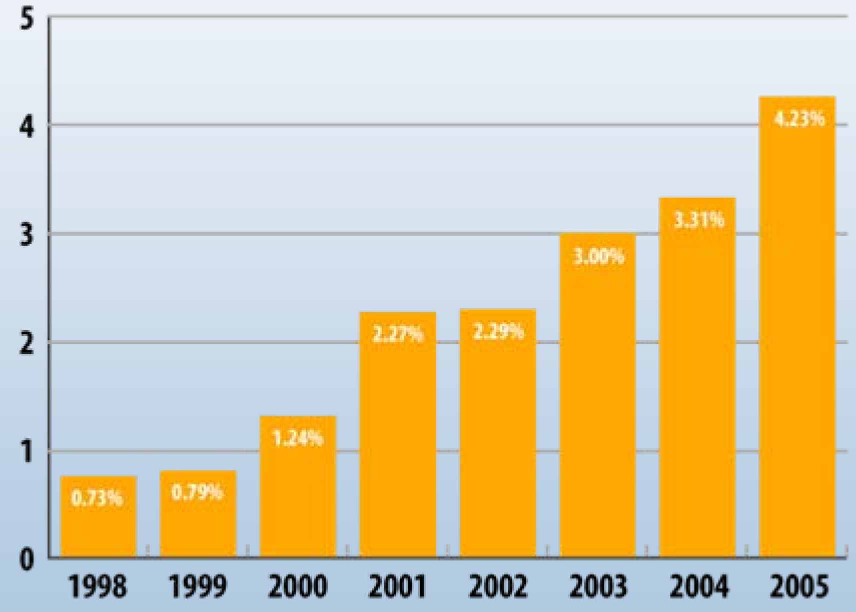
Renewable Energy Is Growing

Renewable Energy Annual Growth Rates 2000-2004



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



Sources:
Renewables 2005 Global Status Report, REN21
Clean Energy Trends 2006, Nth Power LLC

Energy Efficiency and 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 and Storage

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

Foundational Science

Solar Photovoltaics

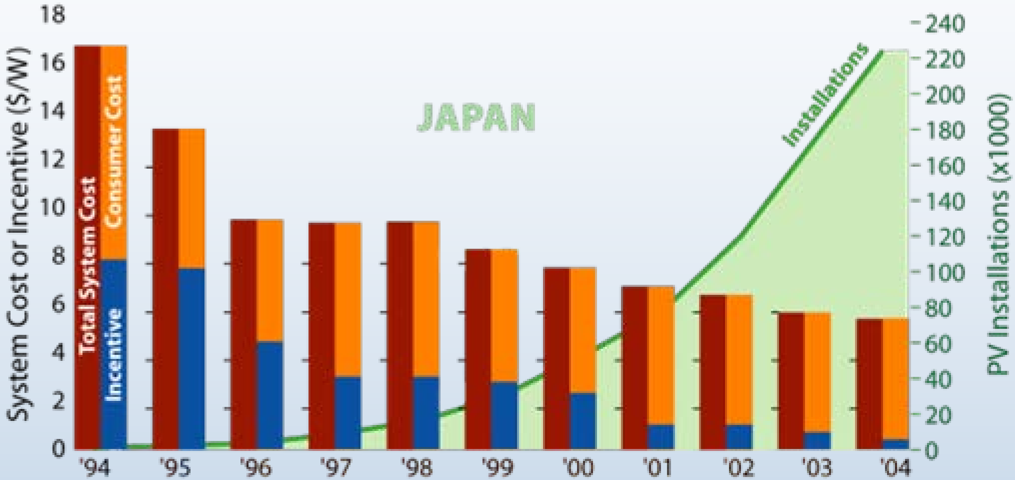
Status:
- 450 MW
- Cost 18-23¢/kWh

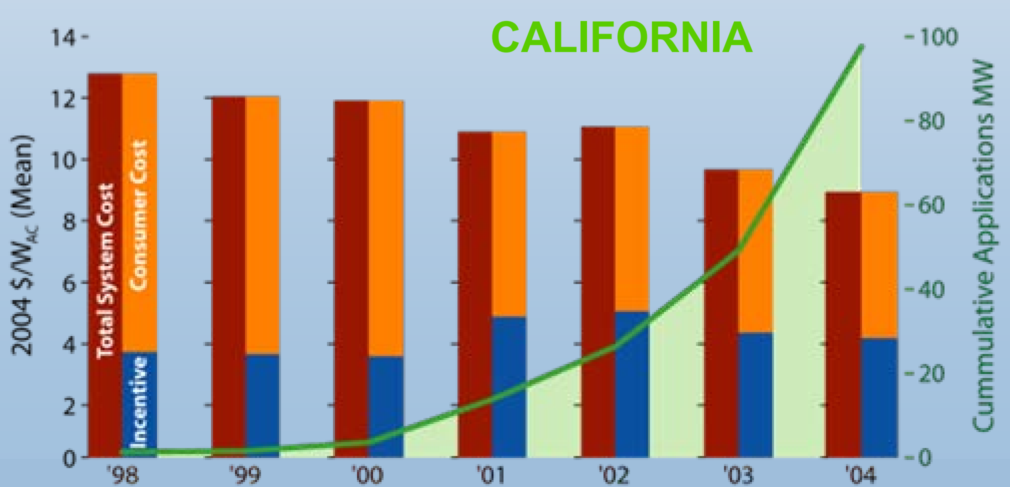
Potential:
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

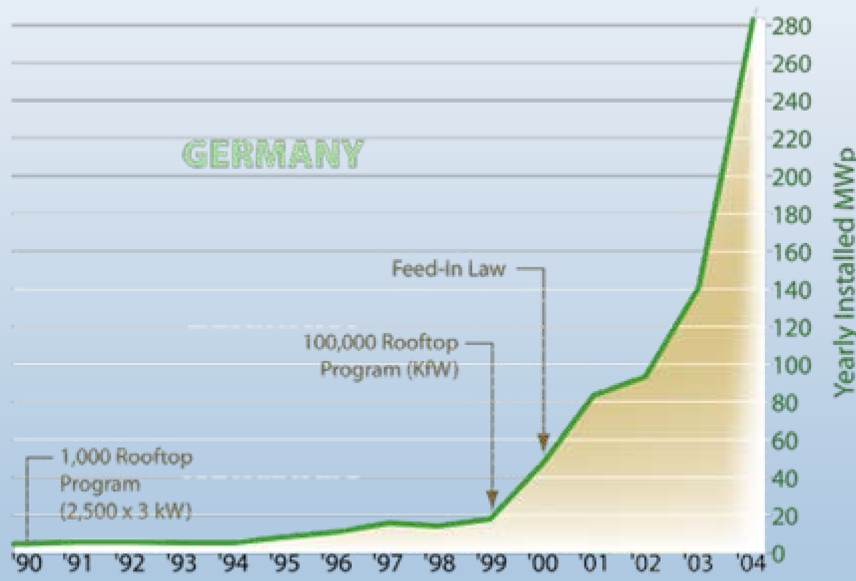
NREL Research Thrusts:
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

Source: U.S. Department of Energy, updated March 16, 2006

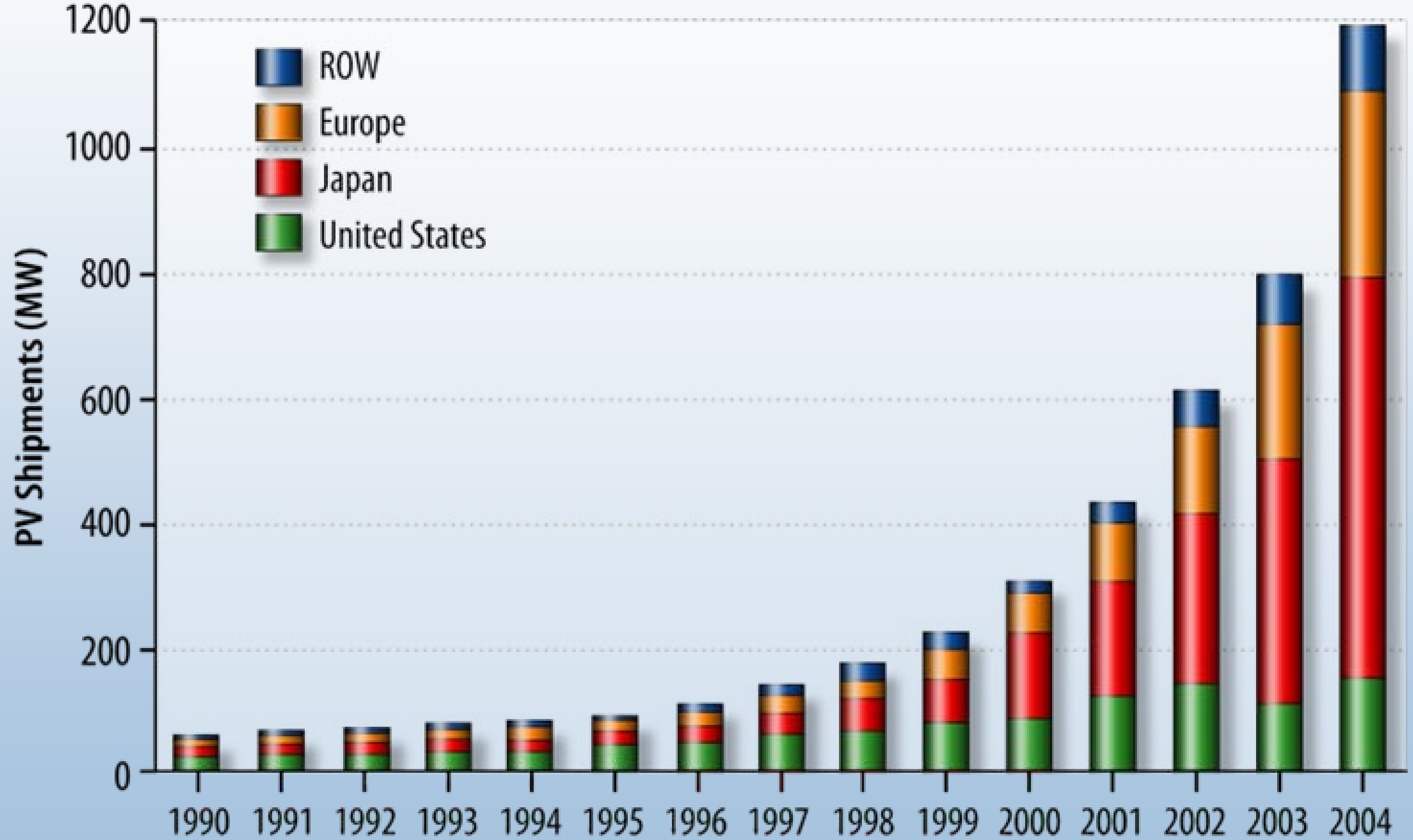
Worldwide Markets Have Driven Cost Reductions





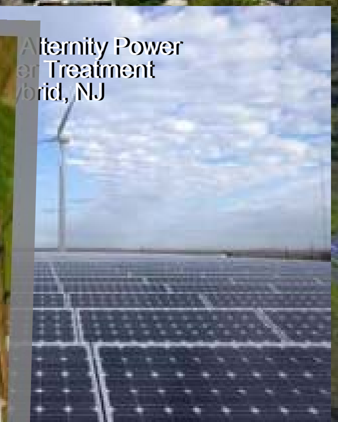


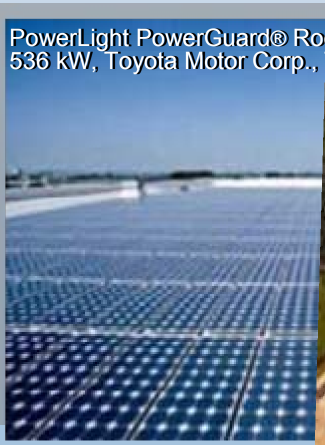
Worldwide PV Shipments are Growing Dramatically



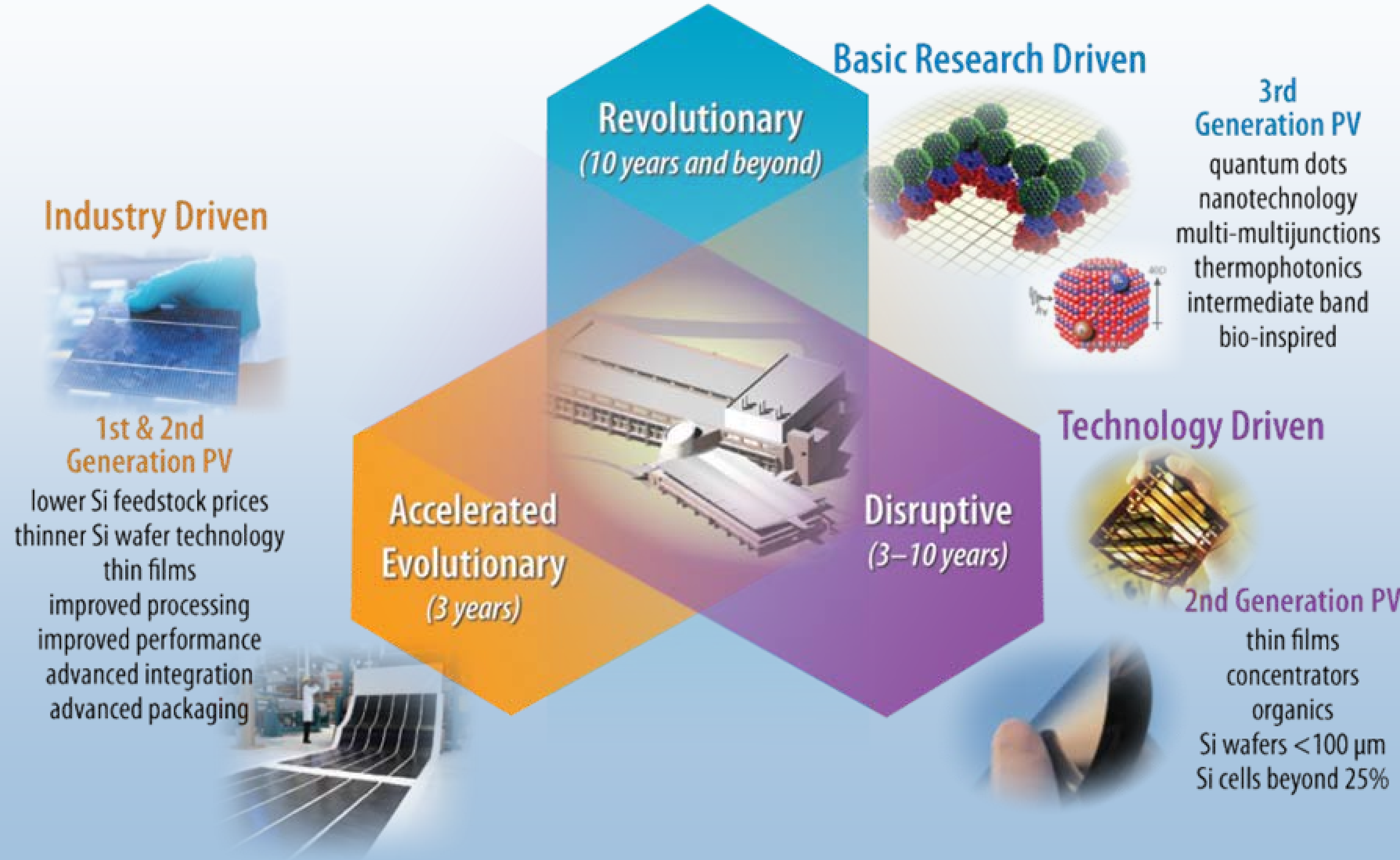
Source: Paul Maycock, PV News, February/March 2005.

…toward our destination



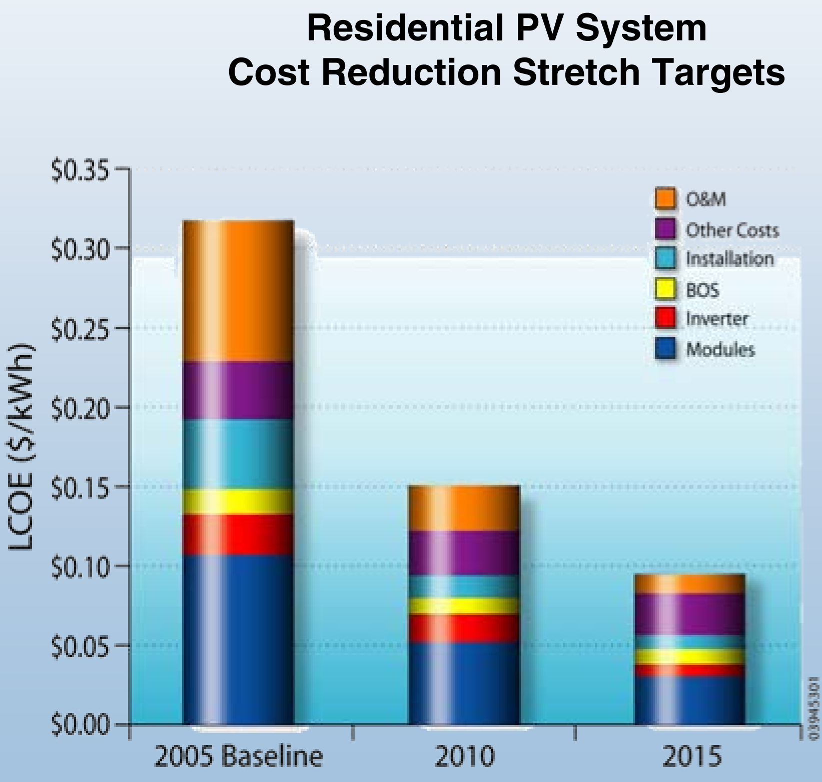


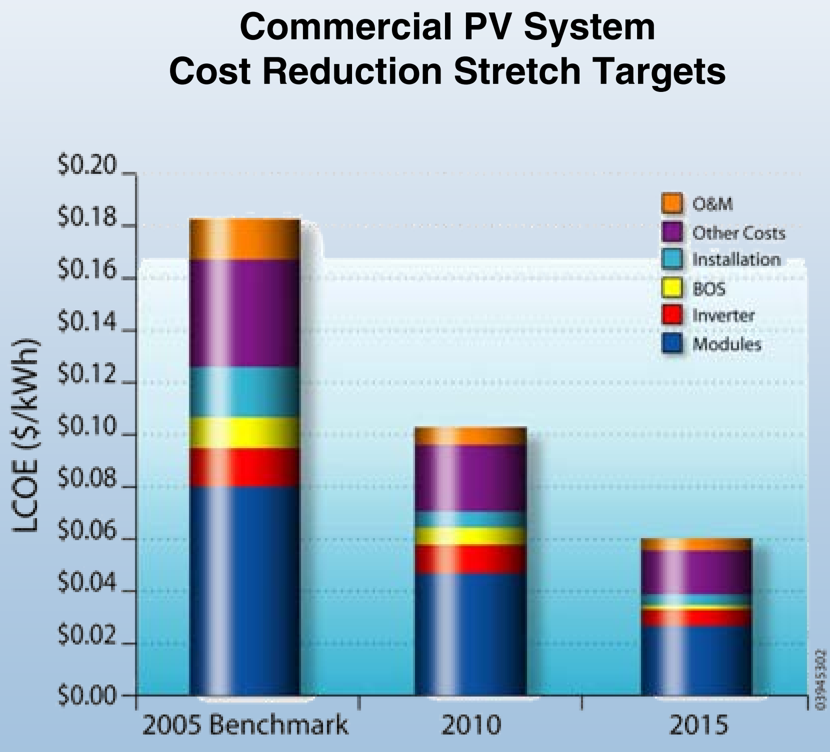
Technology Investment Pathways



Status of Solar America Initiative

Reducing the cost of PV technology so it is competitive by 2015





Source: DOE, “Changing the Way We Power Our Homes and Businesses”

Wind

Today's Status

- 10,000 MW installed as of August 2006
- Cost 6-9¢/kWh at good wind sites

DOE Cost Goals

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

Long Term Potential

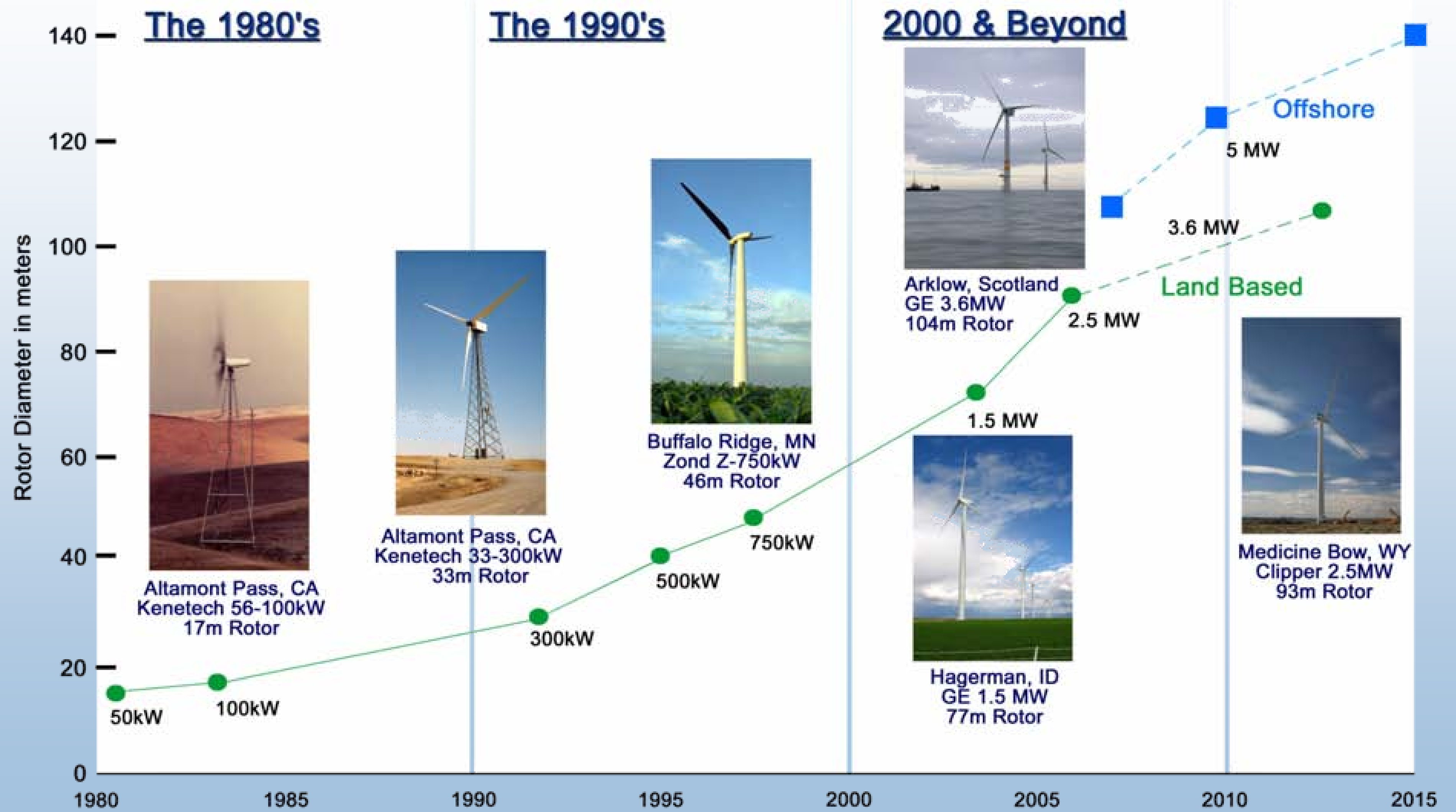
- 20% of the nation's electricity supply

NREL Research Thrusts

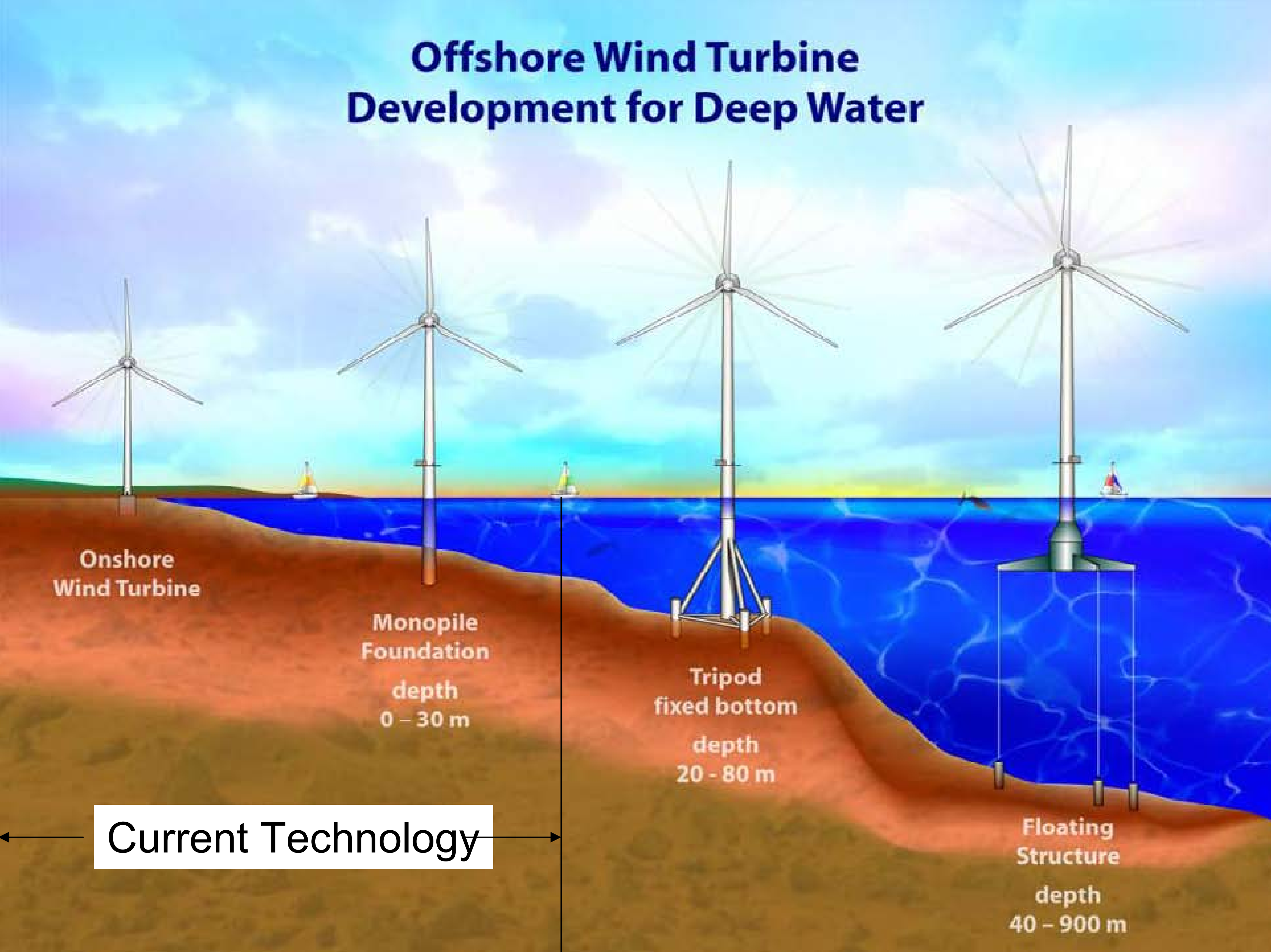
- Low wind speed technology
- Distributed wind technology
- Advanced rotor development
- Utility grid integration

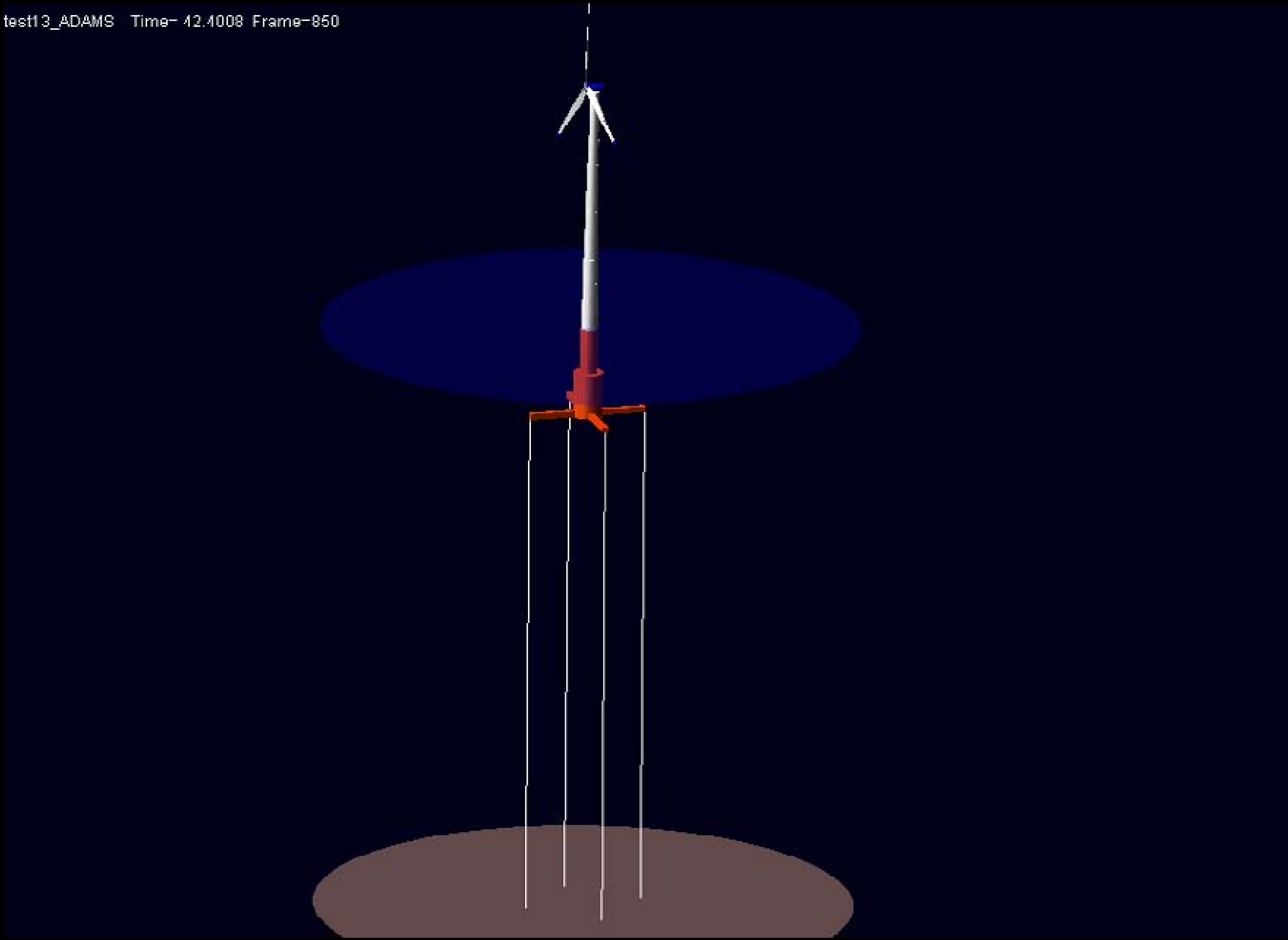
Updated September 7, 2006
Source: U.S. Department of Energy, American Wind Energy Association

Evolution of U.S. Commercial Wind Technology



Clipper LWST Prototype
2.5 MW with 93 m Rotor


Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology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A Future Vision for Wind Energy Markets

Today 2006

Bulk Power Generator
5-8¢ at 13mph
With No PTC

- Land Based
- Bulk Electricity
- Wind Farms

Less than 1% of Electricity Market

Tomorrow

Land Based Electricity Path → **Land Based LWST Large-Scale 2–5 MW** → **Transmission Barriers** →

LWST Turbines:
- 3.6¢/kWh at 13mph
- Electricity Market

2012

Offshore Electricity Path → **Offshore Turbines 5 MW and Larger** → **Cost & Regulatory Barriers** →

Offshore LWST Turbine:
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind Sites

2014 and Beyond

Advanced Applications Path →
- **Hydrogen**
- **Clean Water**
- **Plug Hybrids**

→ **Cost & Infrastructure Barriers** →

Custom Turbines for Multi-markets:
- Electricity
- H2 production
- Desalinate water
- Transport & Storage

2020 and Beyond

Biofuels

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

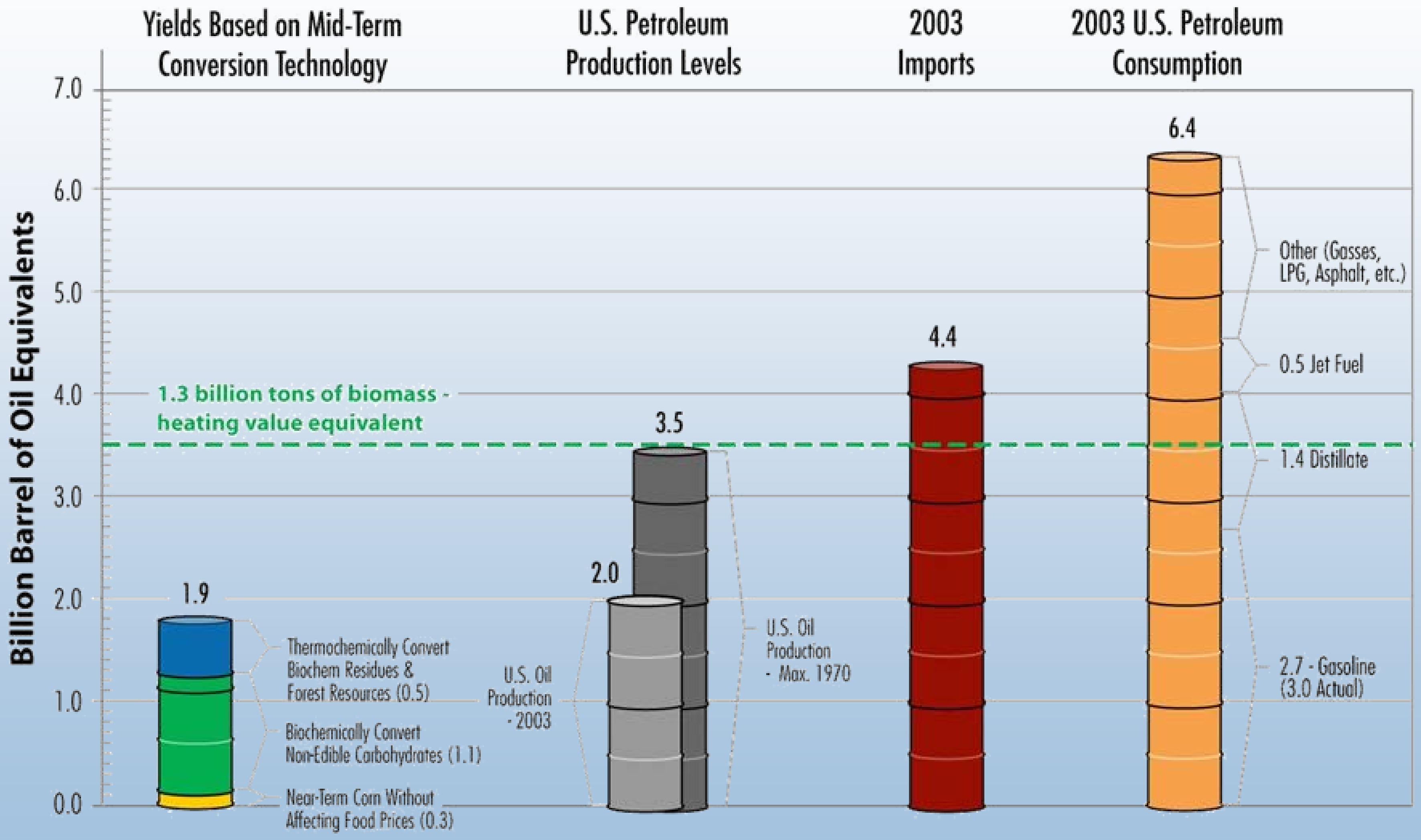
- 2012 goal – cellulosic ethanol ~$1.42/gge
- 2030 goal – all ethanol = 30% of transportation fuels

NREL Research Thrusts

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

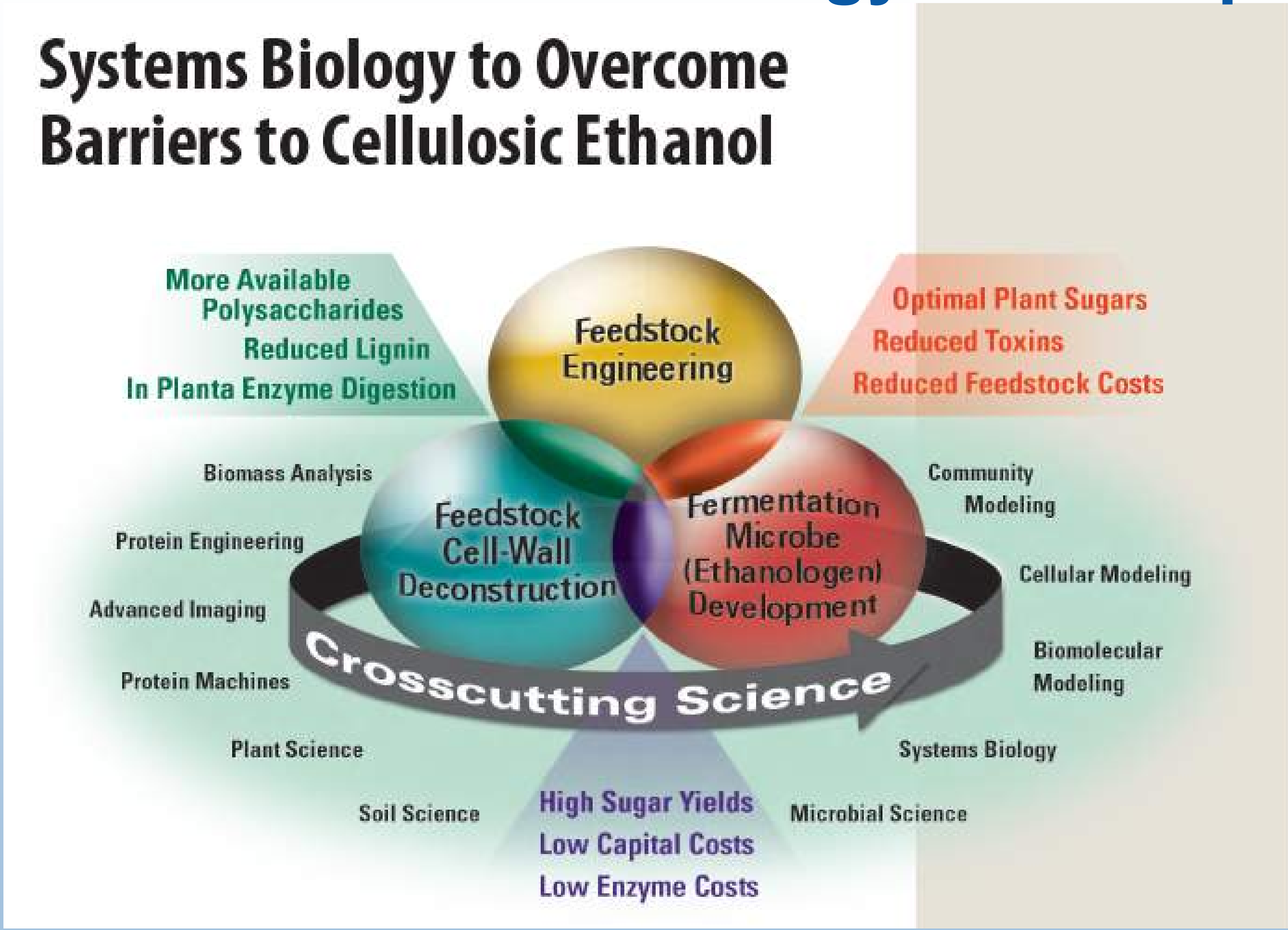
Source: U.S. Department of Energy, National Biodiesel Board, Renewable Fuels Association

Significance of the 1.3 Billion Ton Biomass Scenario



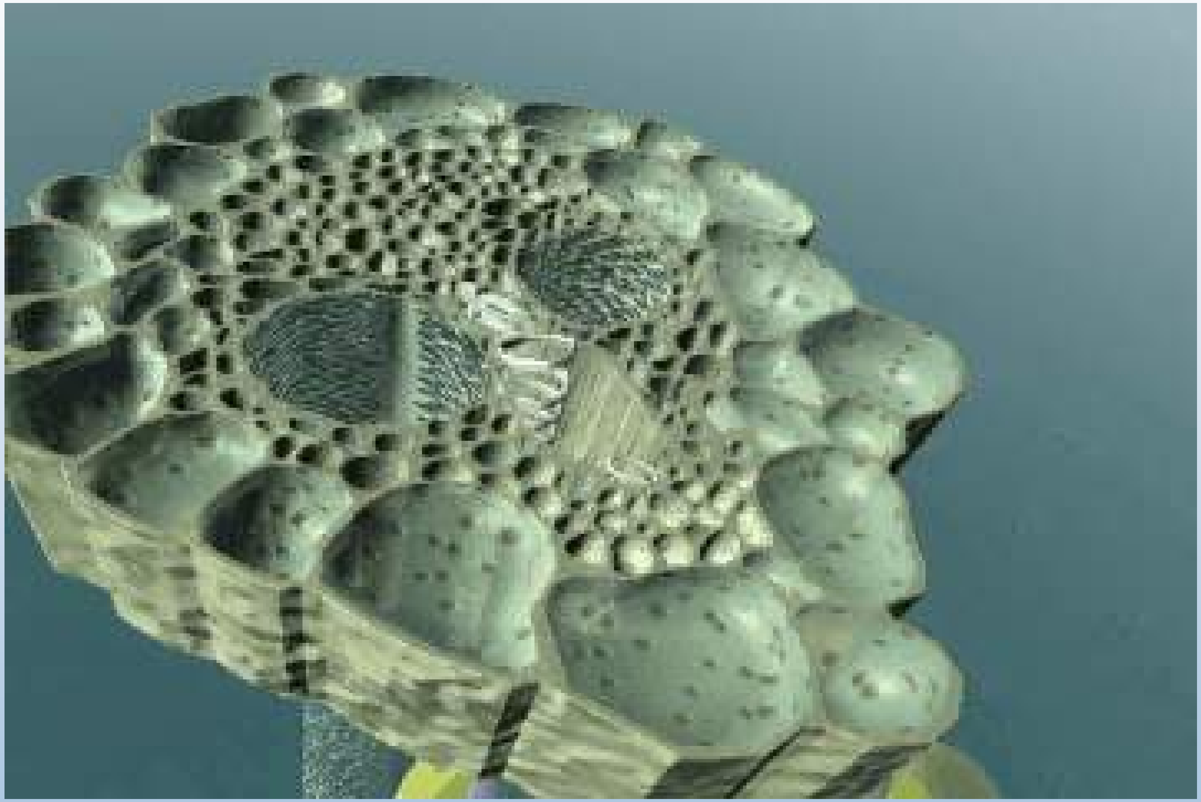
Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

From DOE GTL Bioenergy Roadmap



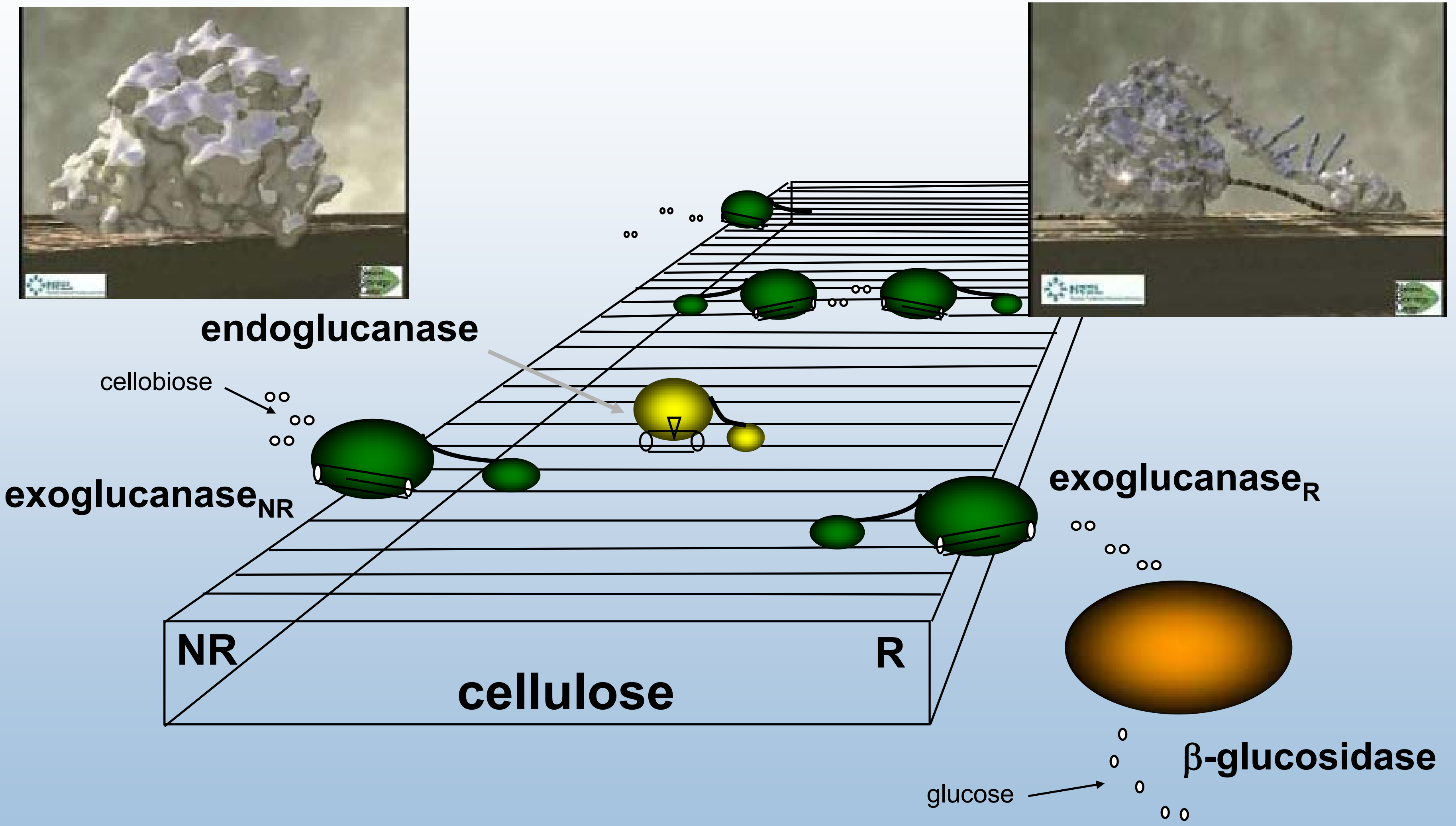
Feedstock Engineering

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

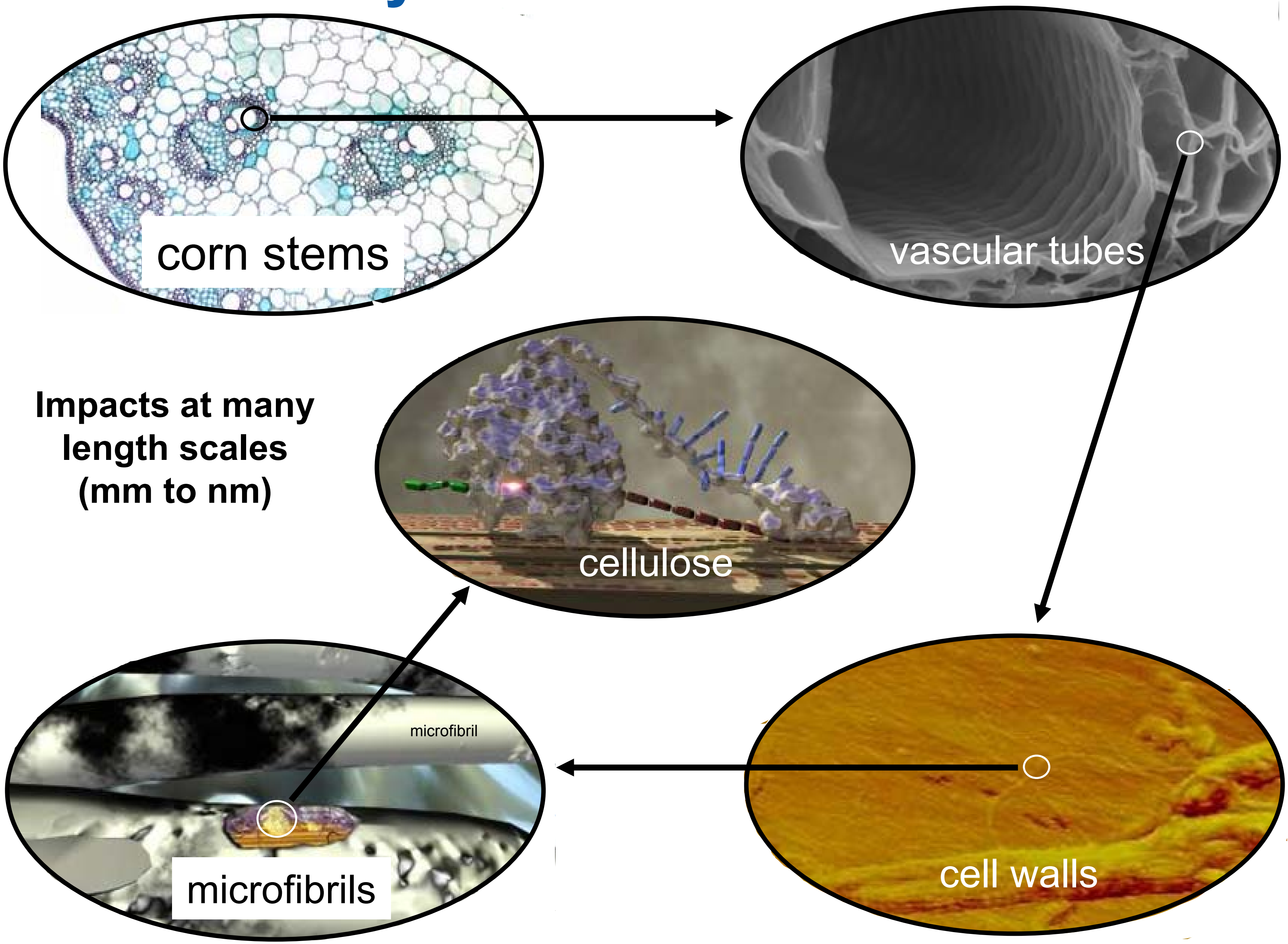


NREL “Corn Stem Tour”

Cellulases Must Function on an Insoluble Substrate

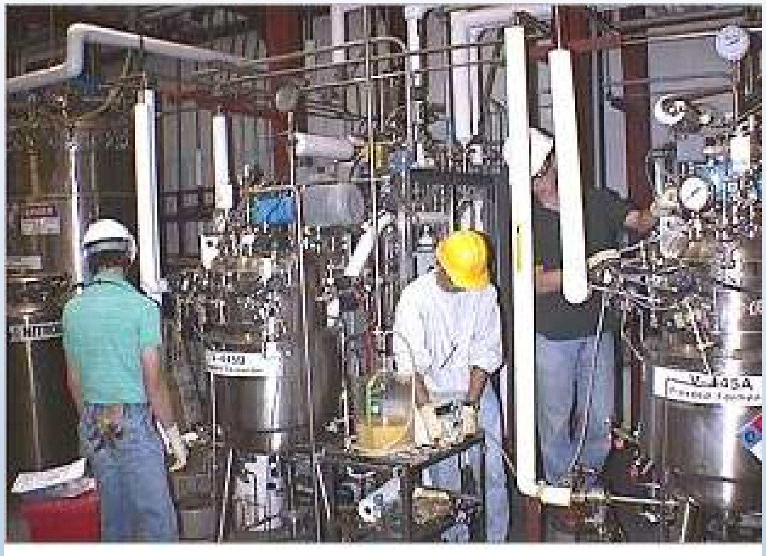


Summary: Biomass Recalcitrance



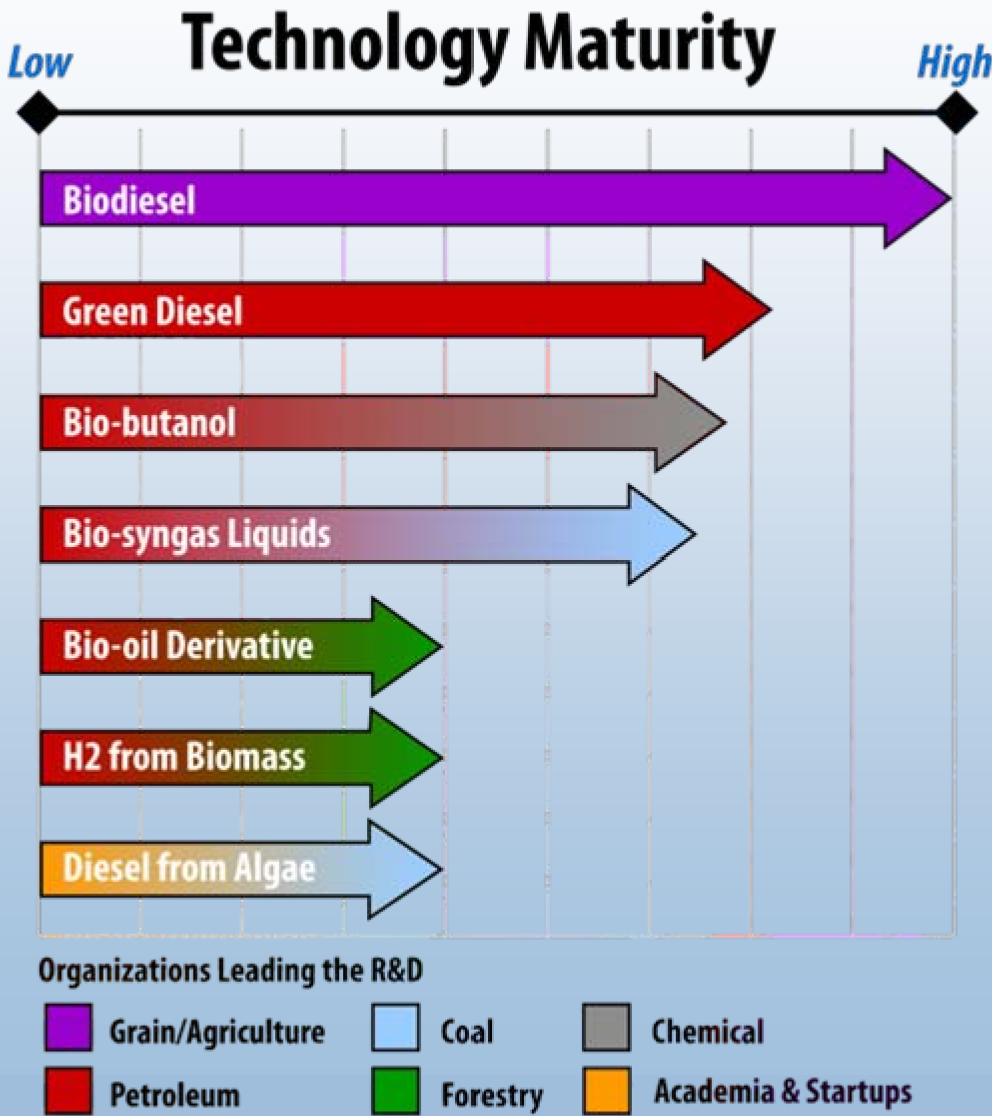
Challenges in Biomass Sugar Fermentation

- 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)

Biofuels R&D



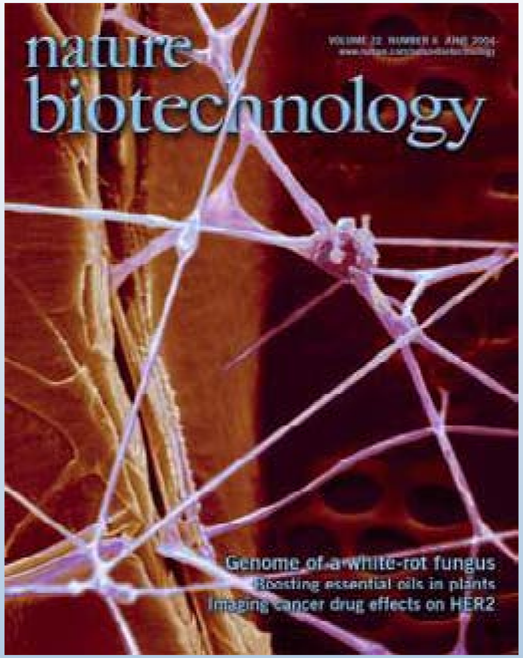
Key Drivers	Value Added
New market for excess oils, fats, and greases.	Petroleum compatible and biodegradable.
Lower cost and higher product quality than FAME.	Utilize existing assets. High quality jet fuel or diesel.
New market for grain and agriculture products. Large supply of lignocellulose.	Better gasoline blending properties than ethanol.
Integration of biomass with Coal, Coke, Shale, or Heavy Oils.	High quality jet fuel or diesel. Reduced criteria for sequestration, and economy of scale (in combination with fossil).
Technical fit with woody biomass and liquid bio-crude.	Potential to integrate into existing large scale refinery and pipeline infrastructure.
Potential transportation fuel from any fuel/power source.	Ideal feed for fuel cells, and lowest tail pipe emissions.
Lg. source of biomass on non-arable land, and capture of CO^2.	High quality jet fuel or diesel yield per acre, with both off-shore and on-shore potential.

Renewable Fuels & Low GHG Emissions

Summary and Future Outlook for Bioethanol

Challenges and barriers:

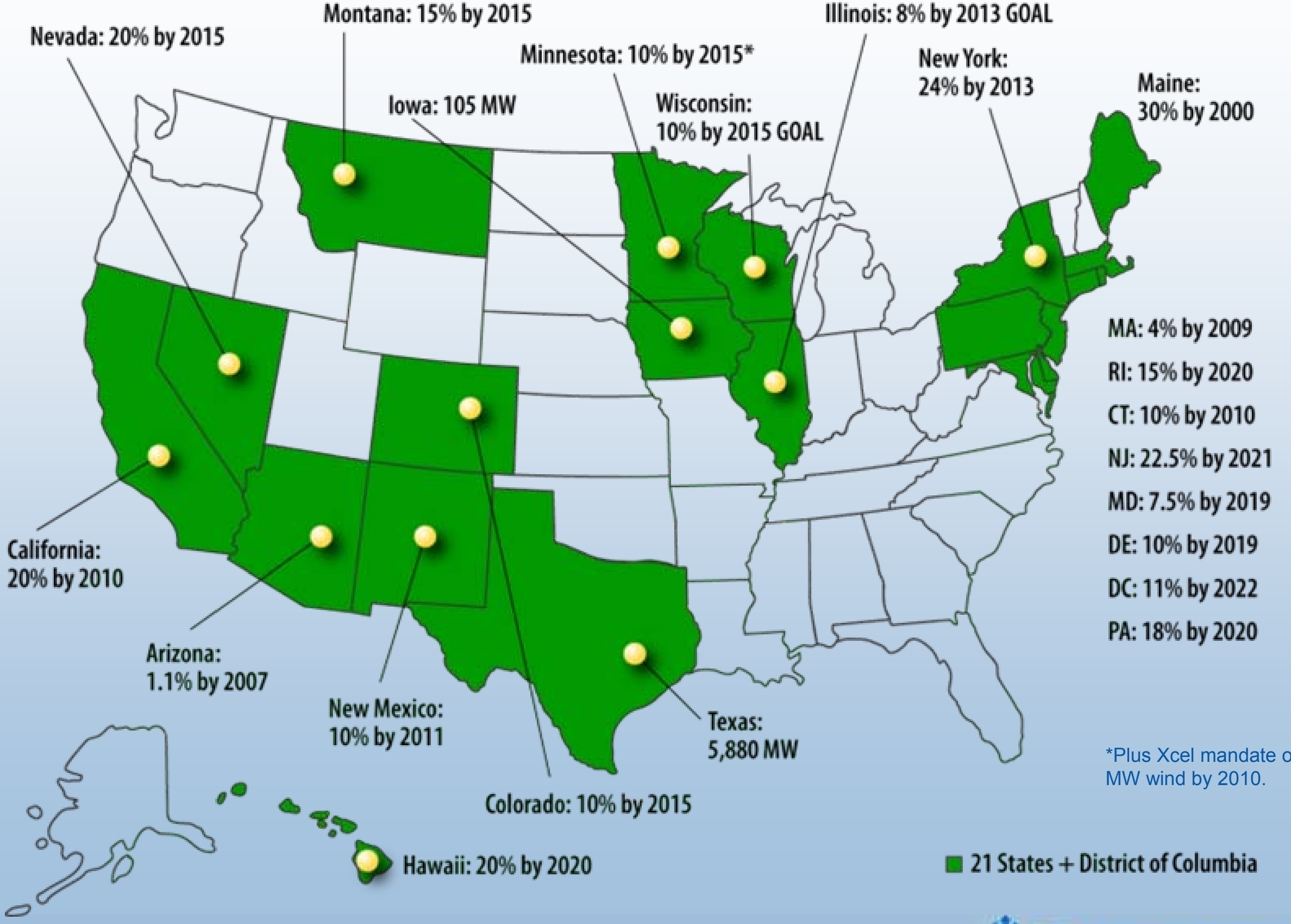
- High cost of feedstocks, biomass pretreatment, loadings of cellulase enzymes
- Inability of current fermentation strains to convert ALL biomass sugars
- Overall sugar to ethanol yields far less than theoretical
- Disagreement over “readiness” for commercialization



We need a deeper understanding of:

- Genetic controls of plant composition and ultrastructure
- Resistance of lignocellulosic biomass to deconstruction
- Structure and function of cellulases and other plant cell wall depolymerizing enzymes
- Cellular controls for multi-sugar transport and ethanol fermentation
- Cell’s mechanisms for toxicity response

State Policy Framework
Renewable Electricity Standards



*Plus Xcel mandate of 1,125 MW wind by 2010.

Source: DSIRE database, August 2006

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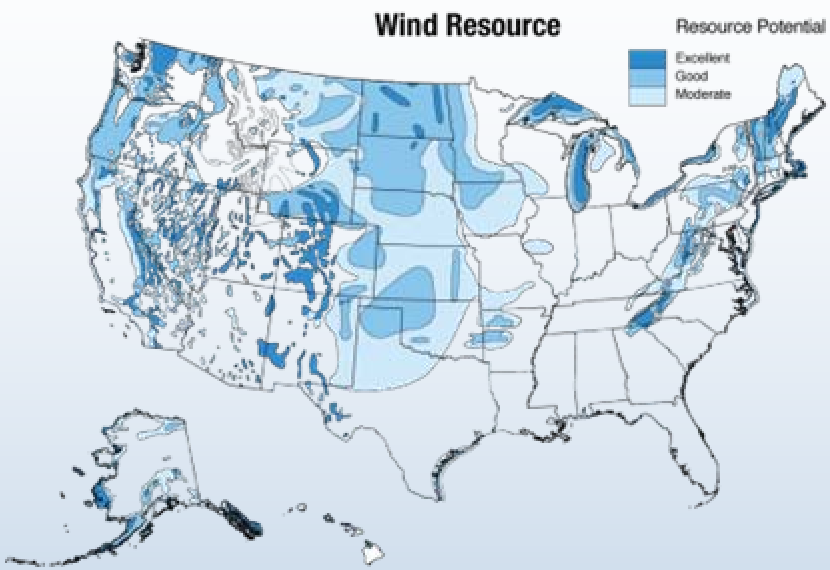
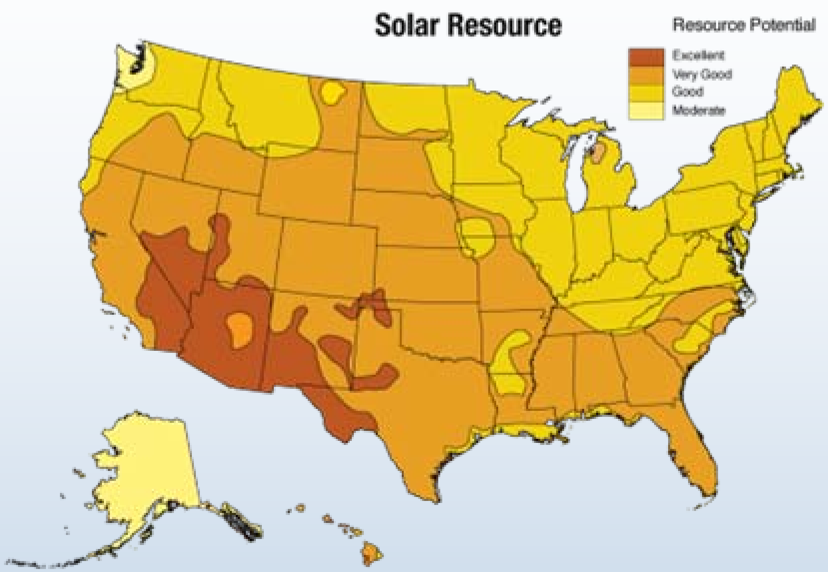
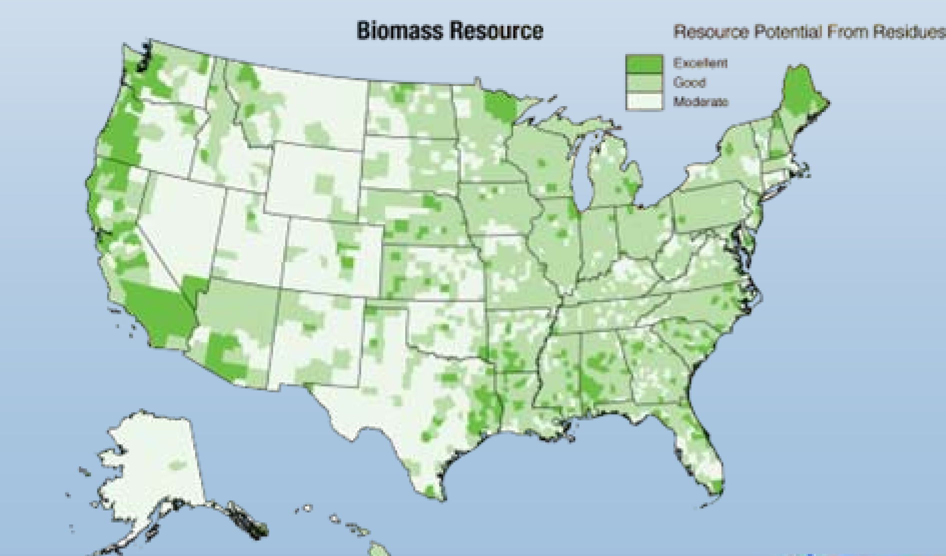
National Resources







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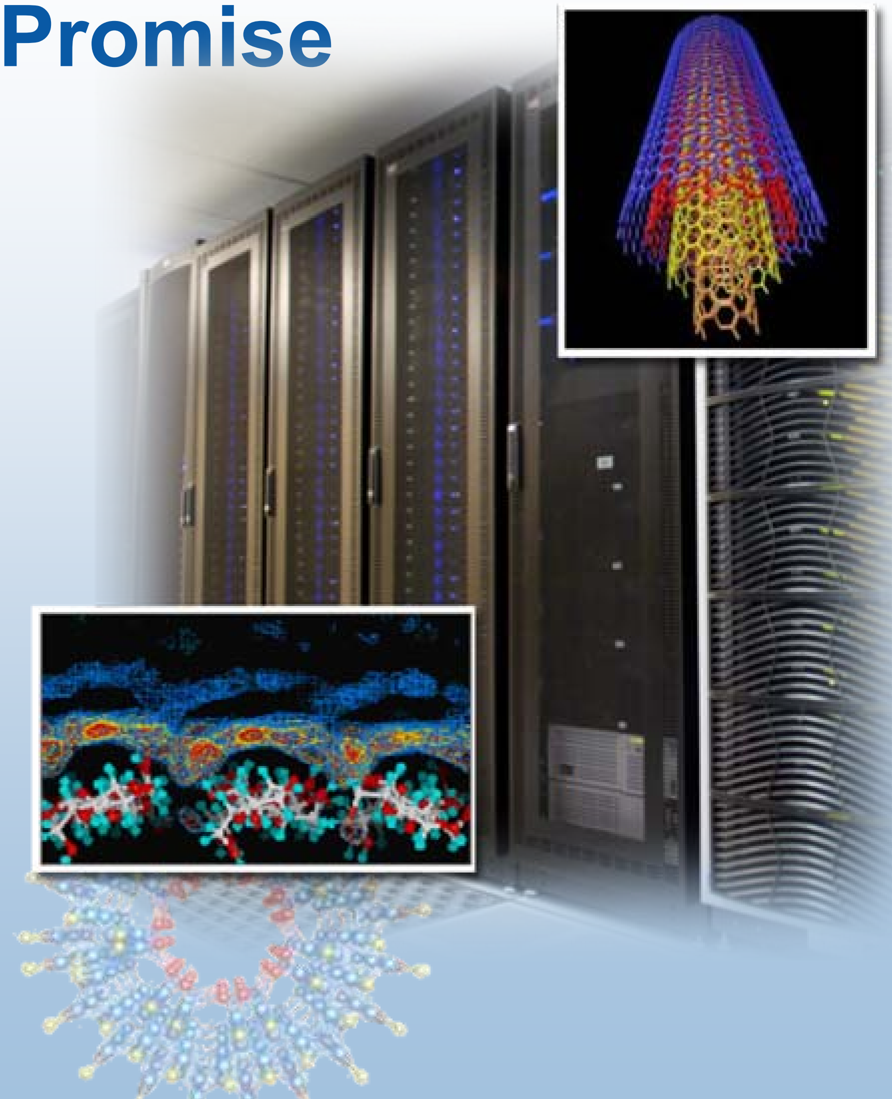
Harnessing Innovation in Renewable Energy Science and Technology: The Future Promise

- Supercomputers
- Genomics
- Nanoscience
- Cellulosic and biofuels applications
- Hydrogen



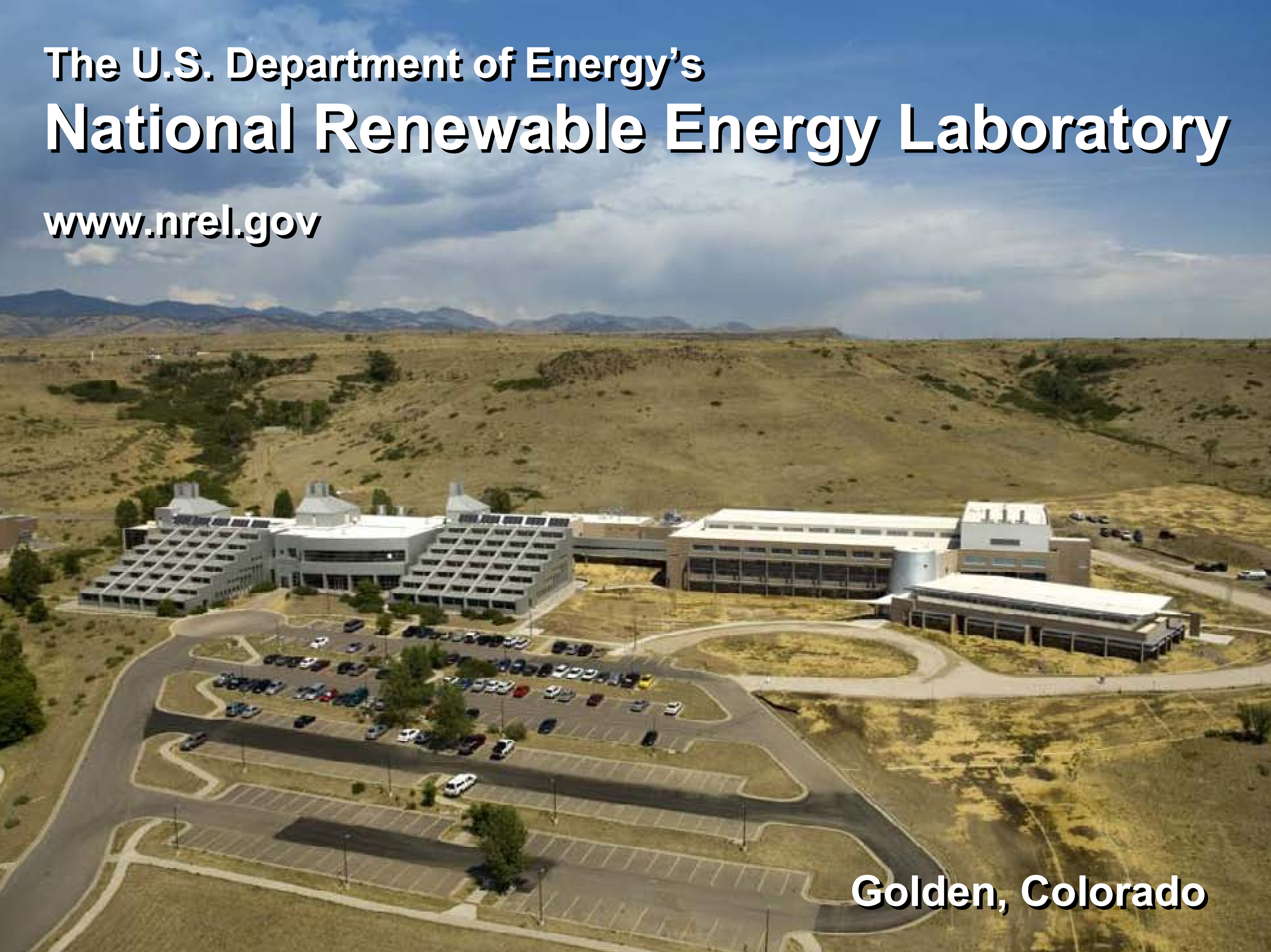
Nano/Bio/Info

Renewable Energy: Getting There Involves…

Technologies
- Efficient buildings and vehicles
- New biofuels
- Clean generation
- Storage

Policies
- Predictable and consistent

Markets
- Infrastructure
- First plant costs
- Supplier/consumer acceptance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