National Renewable Energy Laboratory

Innovation for Our Energy Future

Renewable Fuels & Vehicles Overview

to

State Energy Advisory Board

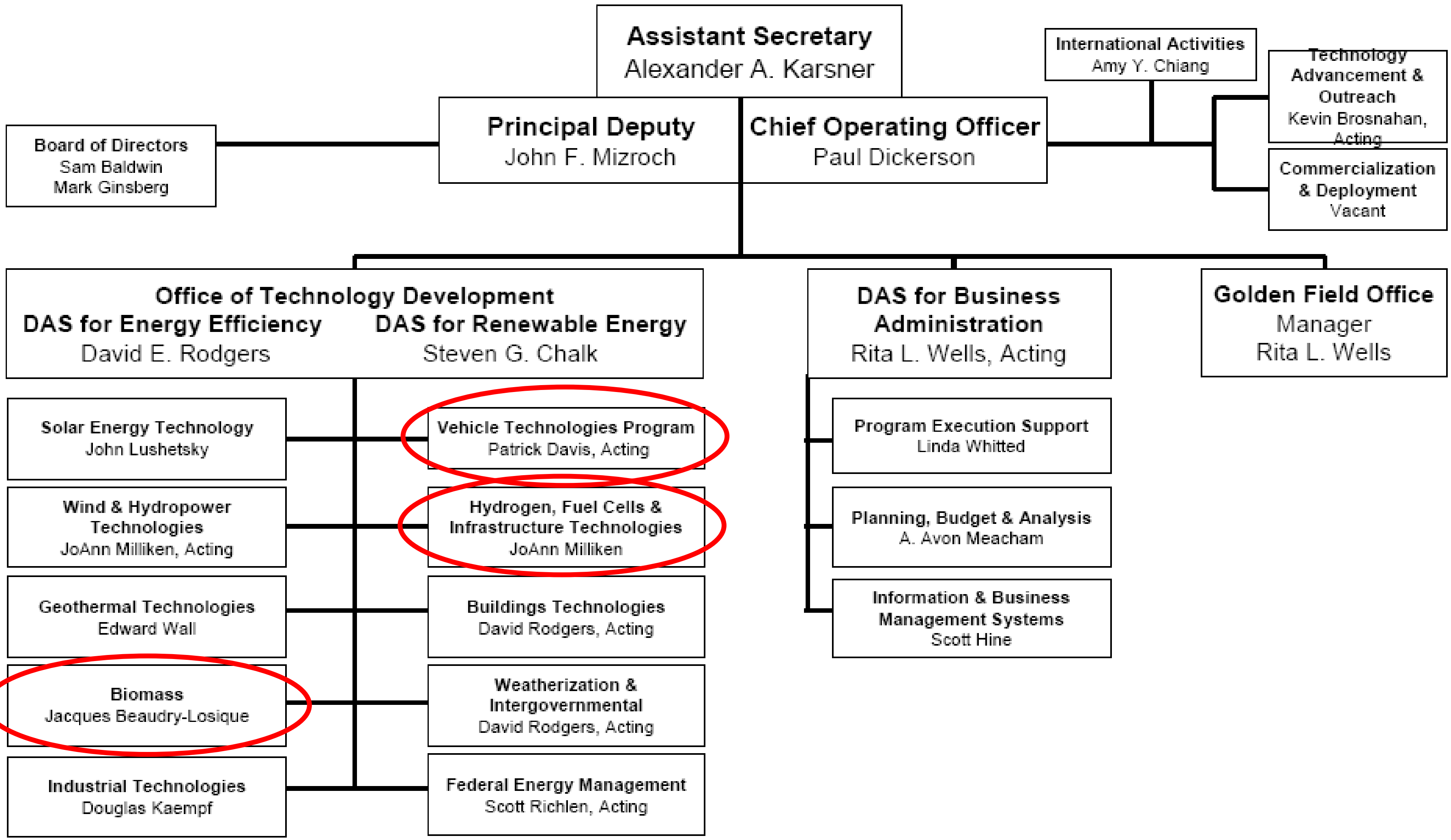
STEAB

Dale Gardner

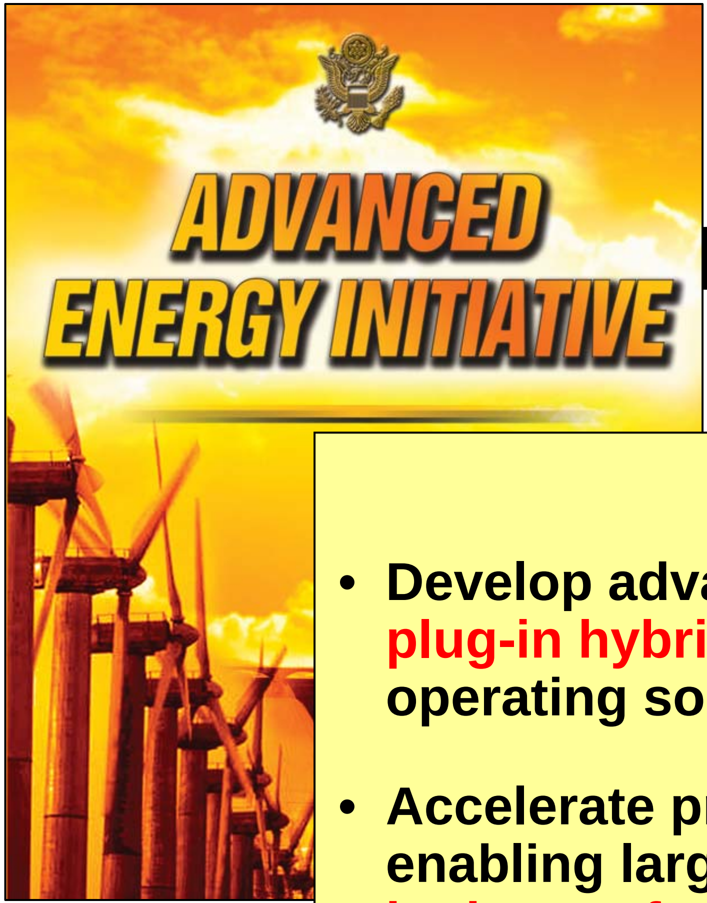
Associate Director, Renewable Fuels S&T

12 August 2008

DOE Programs Supported



Advanced Energy Initiative



"Changing the way we Fuel our Vehicles"

Goals

- **Develop advanced battery technologies that allow plug-in hybrid electric vehicles to have a 40 mile range operating solely on battery charge.**
- **Accelerate progress towards the President's goal of enabling large numbers of Americans to choose hydrogen fuel cell vehicles by 2020.**
- **Foster the breakthrough technologies needed to make cellulosic ethanol cost competitive with corn-based ethanol by 2012.**

Biofuels

U.S. Biofuels Status

- **Biodiesel** [1]
  - 171 commercial plants
  - 2.2 bgy capacity (2008)
  - 450 mg produced (2007)
- **Corn ethanol** [2]
  - 162 commercial plants
  - 9.4 bgy capacity (+ 4.2 bgy planned) (2008)
  - 6.5 bg produced (2007)
- **Cellulosic ethanol (2008)**
  - 13 demo plants DOE-funded
  - ~250 mgy capacity projected

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association

U.S. Transportation Fuel Goals & RFS

- **President's "20-in-10"**

  35 billion gallons of <u>alternative</u> fuels by 2017

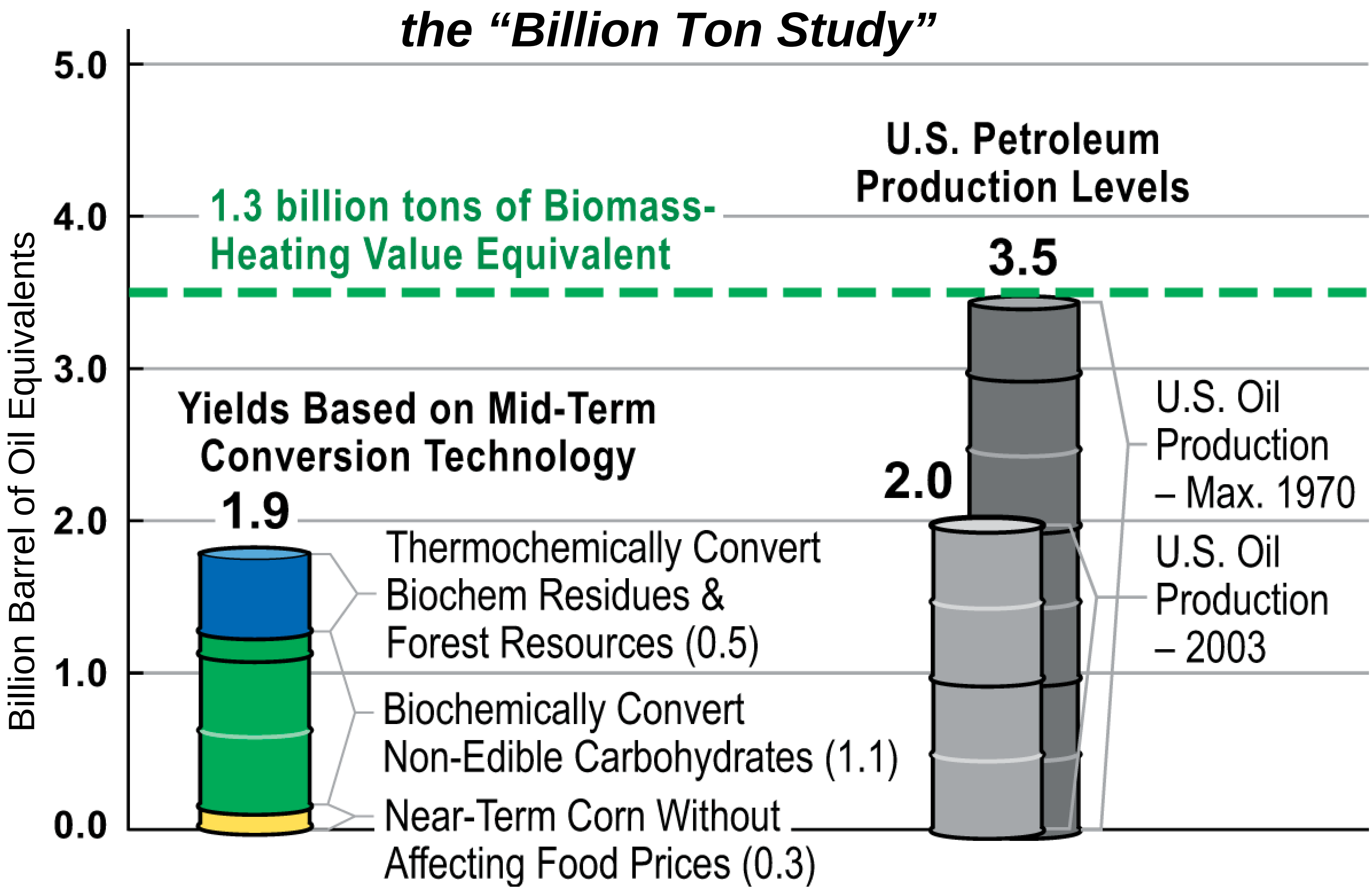
- **Energy Independence & Security Act 2007 "RFS"**

  36 billion gallons of <u>renewable</u> fuels by 2022

- **DOE "30x30 Goal"**

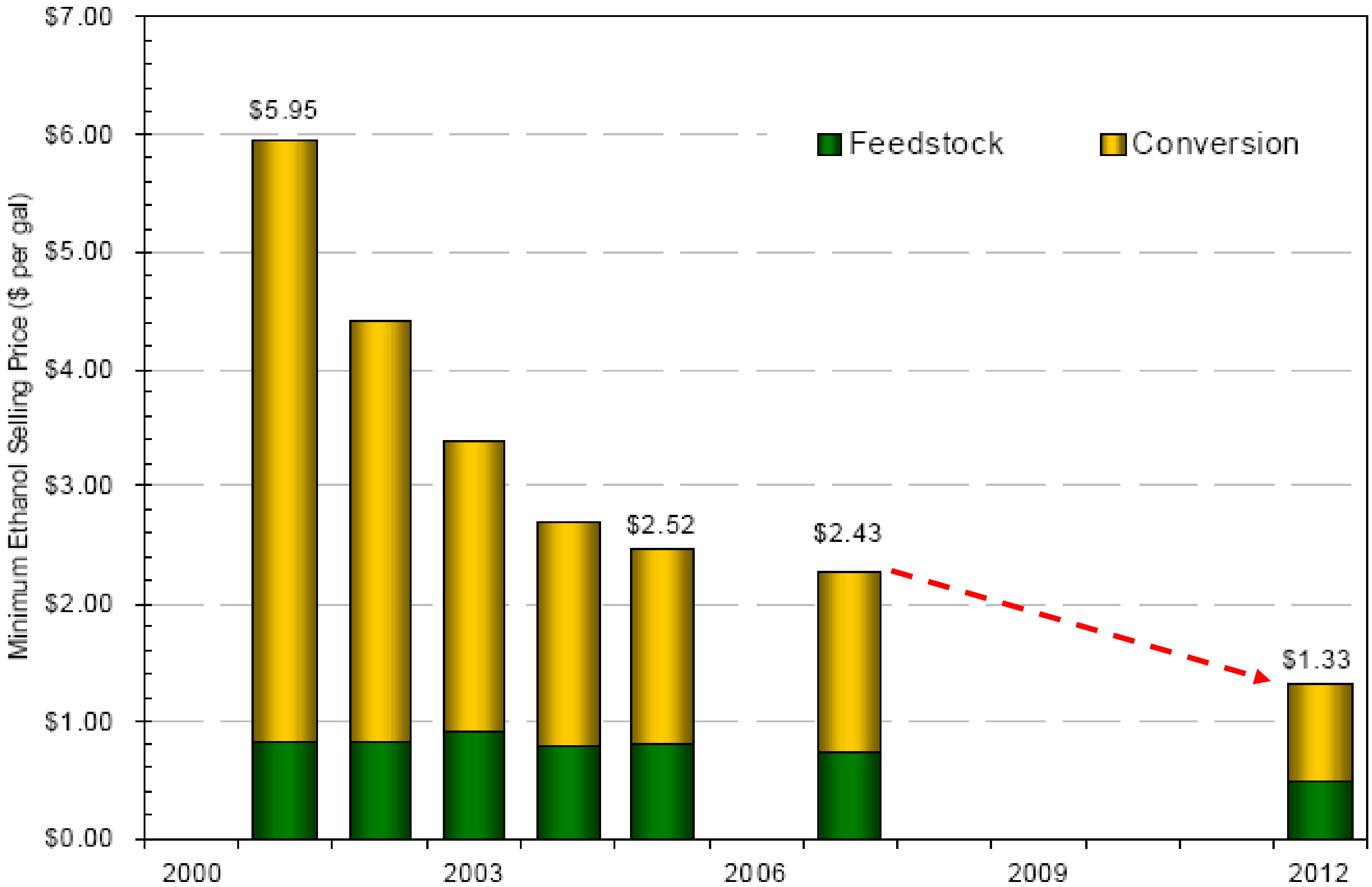
  60 billion gallons of <u>ethanol</u> (30% of today's gasoline consumption) by 2030

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

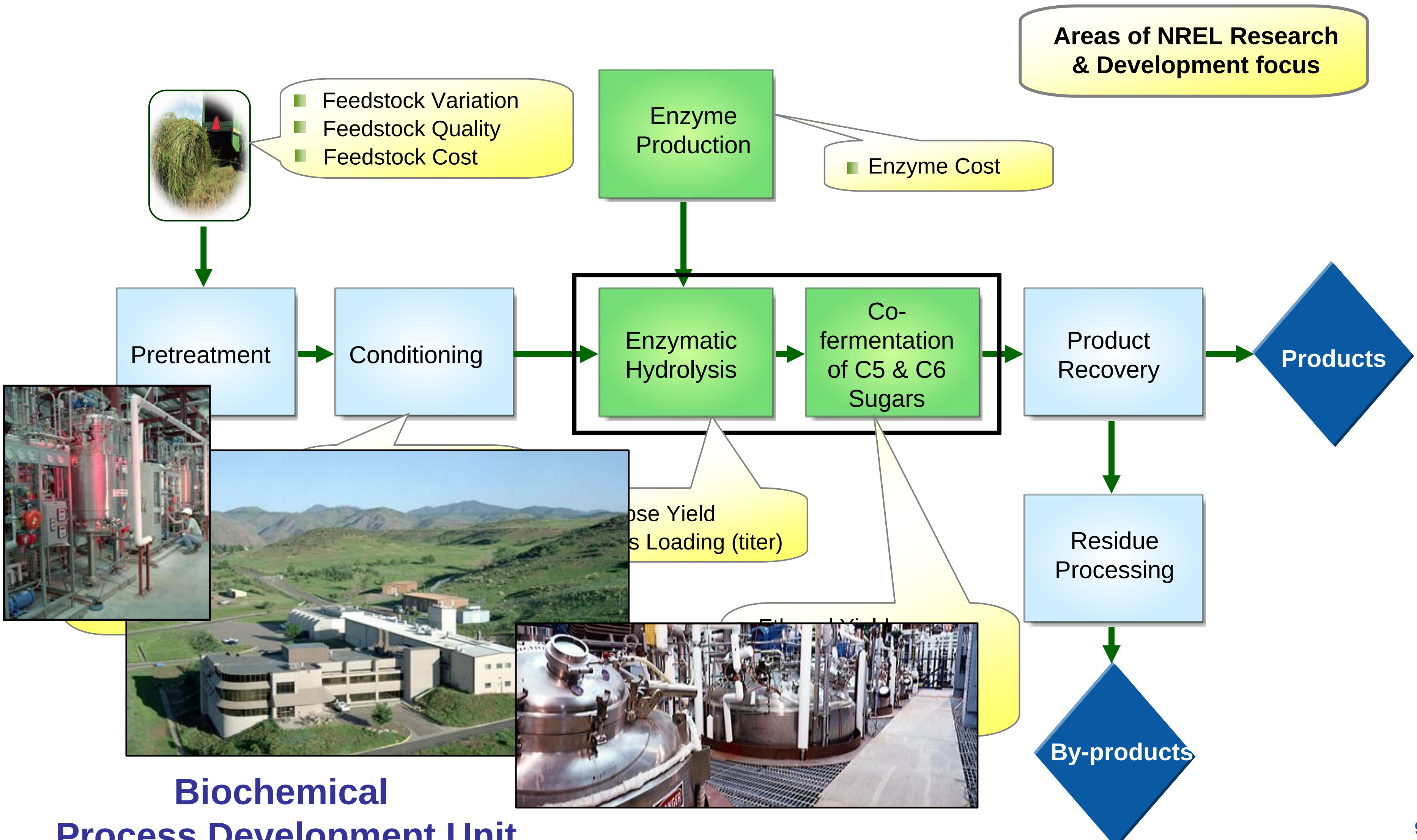
State of Technology – Biochemical



State of technology progress toward the 2012 goal (estimated 2007 dollars)

Technical Barrier Areas for $1.33

Biochemical Ethanol



Biochemical Process Development Unit

Technical Barrier Areas for $1.33

Thermochemical Ethanol

Areas of NREL Research & Development focus

Feedstock Interface

- Size Reduction
- Storage & Handling
- De-watering
- Drying

Gasification

Gas Cleanup & Conditioning

Fuel Synthesis

Heat & Power

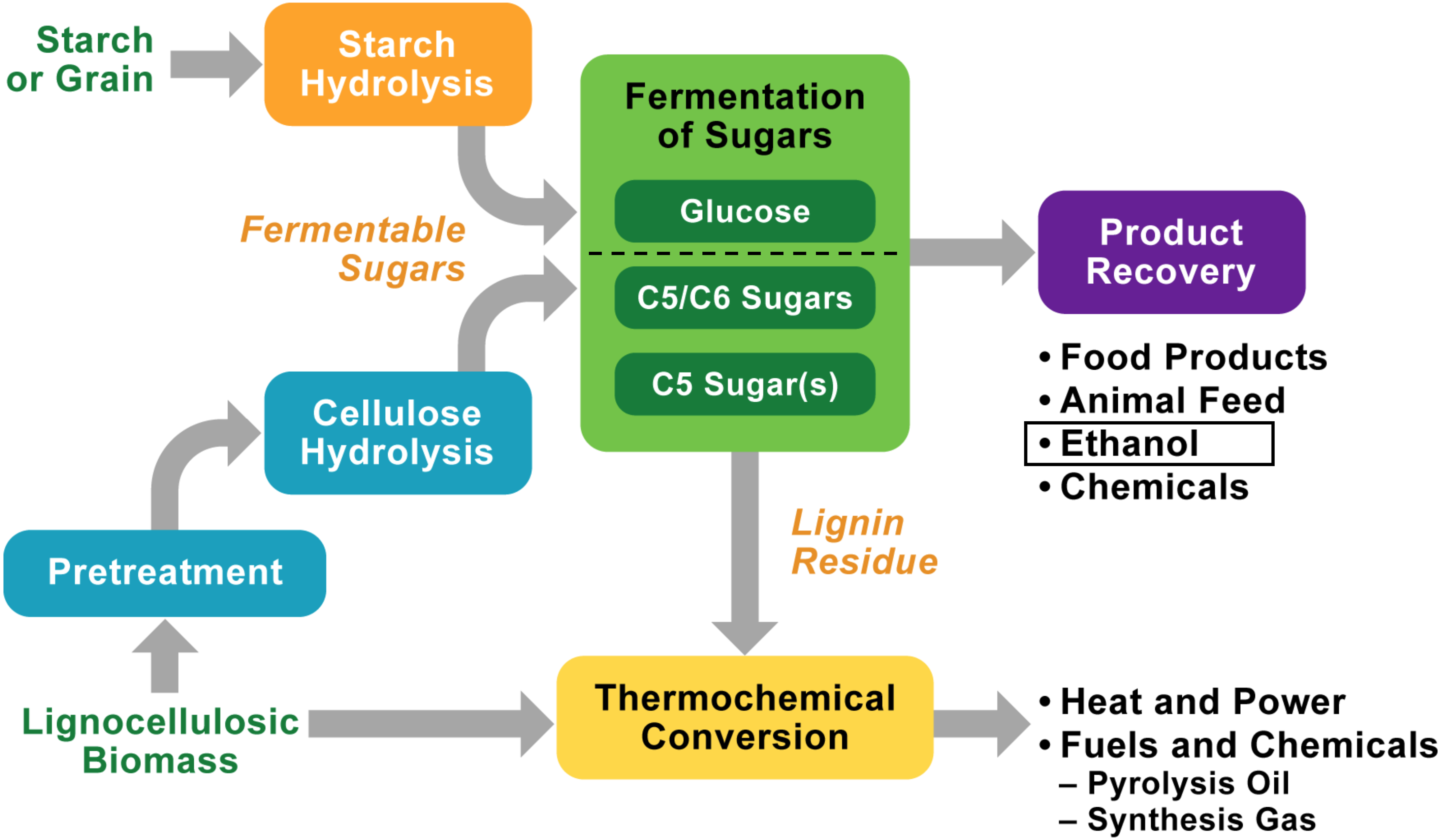
Products: Ethanol

Separations
Recycle
Selectivity

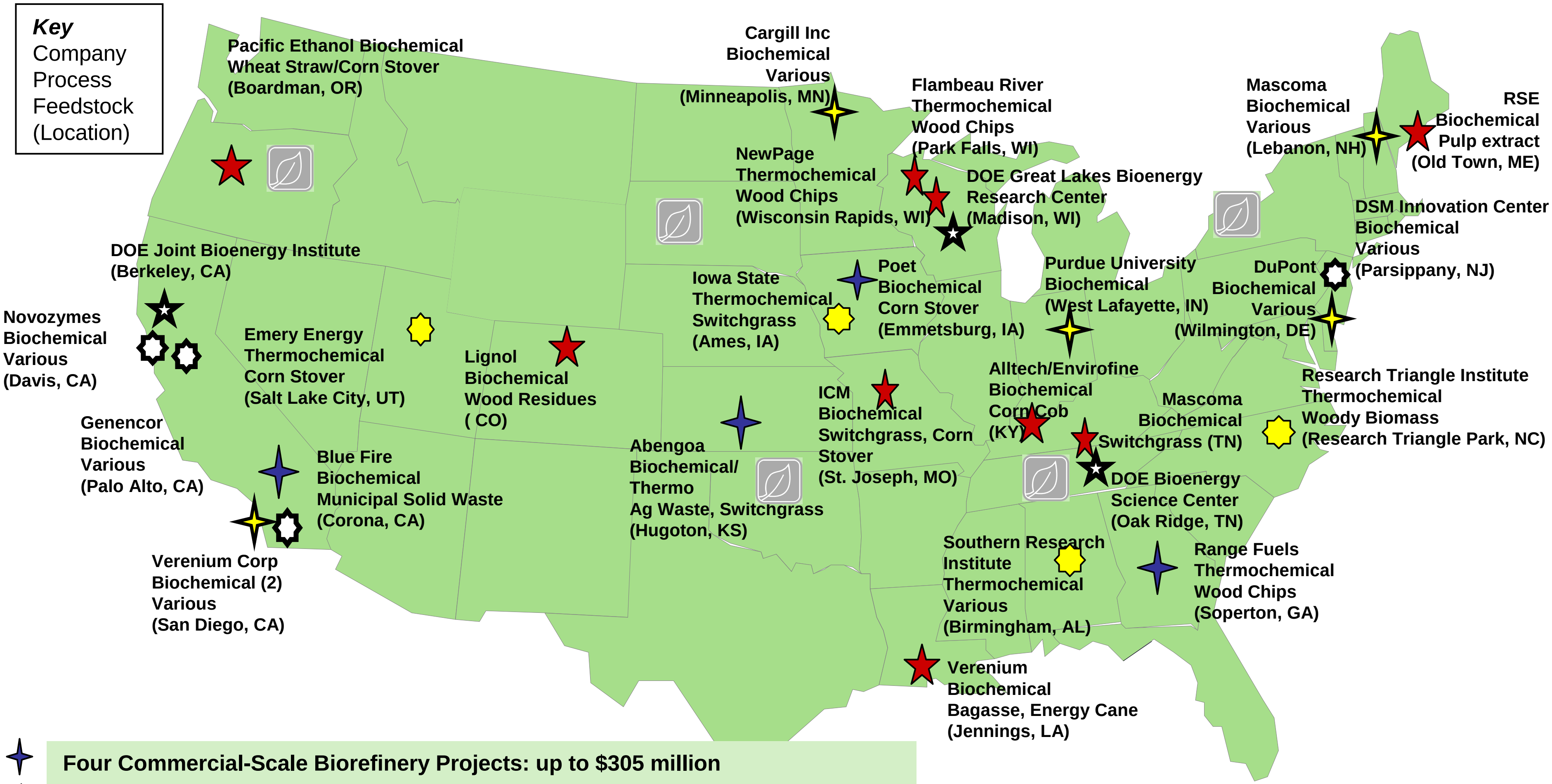
By-products:
Methanol
n-Propanol
n-Butanol
n-Pentanol

Thermochemical Process Development Unit

Integrated Cellulosic Ethanol Biorefinery



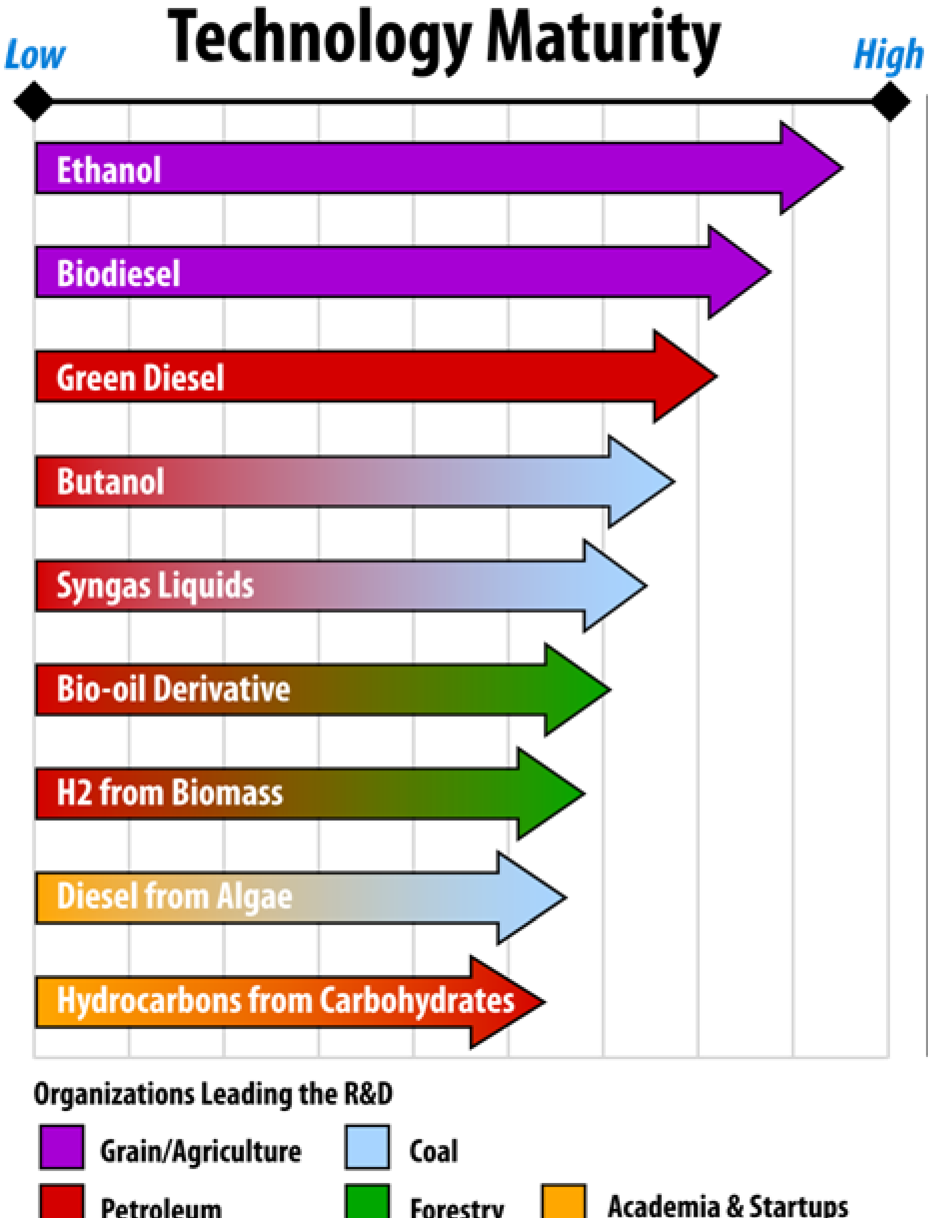
Major DOE Biofuels Project Locations



- Four Commercial-Scale Biorefinery Projects: up to $305 million
- Nine Small-Scale (10%) Biorefinery Projects: up to $240 million (first round)
- Three Bioenergy Centers: up to $405 million
- Four Thermochemical Biofuels Projects: up to $7.7 million
- Four Improved Enzyme Projects: up to $33.8 million
- Five Projects for Advanced Ethanol Conversion Organisms: up to $23 million

Regional Partnerships
South Dakota State Univ., Brookings, SD
Cornell University, Ithaca, NY
Univ. of Tennessee, Knoxville, TN
Oklahoma State Univ., Stillwater, OK
Oregon State Univ., Corvallis, OR

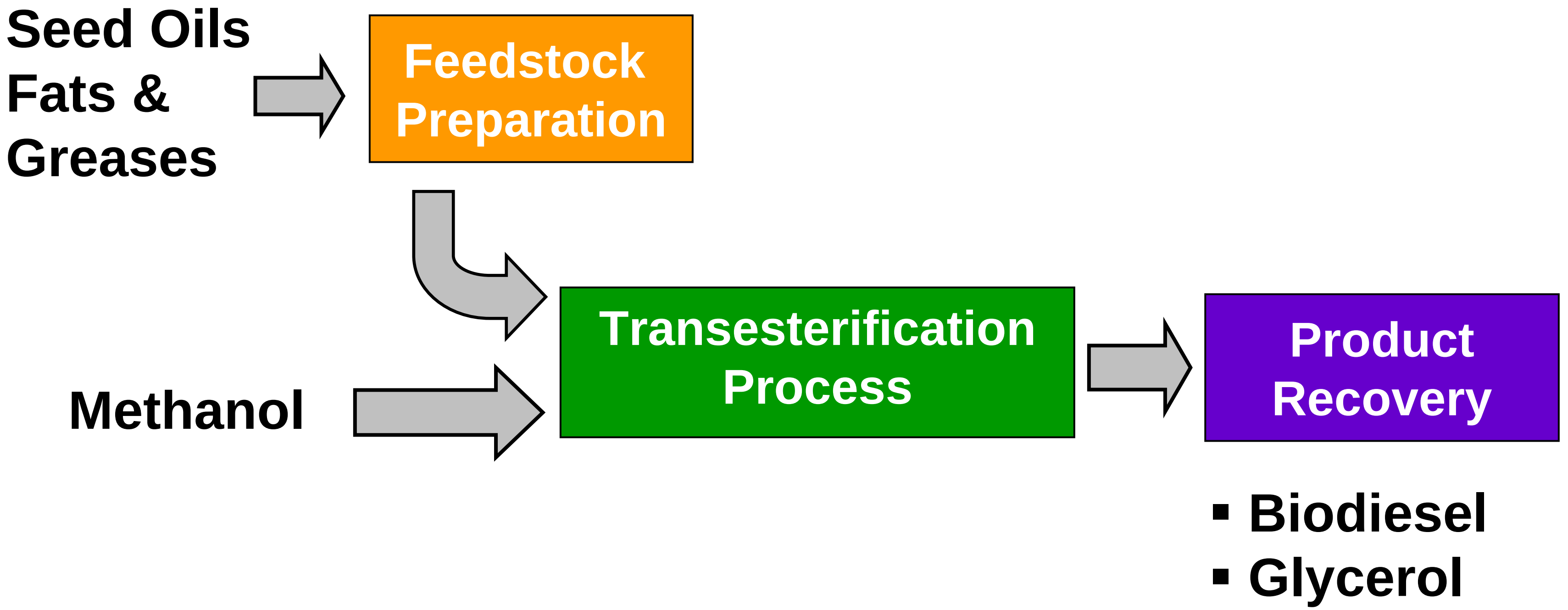
Range of Biofuels



Key Drivers	Value Added
New market for grain and agriculture products. Large supply of lignocellulose.	High octane gasoline blend stock from carbohydrates.
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.
Better compatibility with petroleum products.	Potential for higher reaction rates than fermentation, and potential as H2 carrier.

Renewable Fuels & Low GHG Emissions

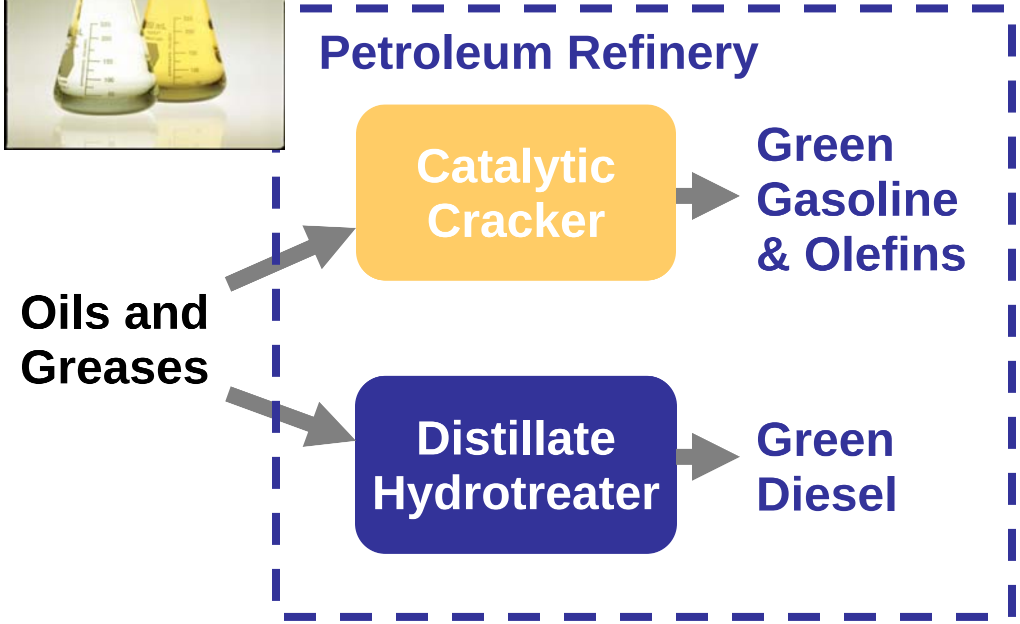
Current Biodiesel Conversion Process



(Existing Biodiesel "Biorefineries")

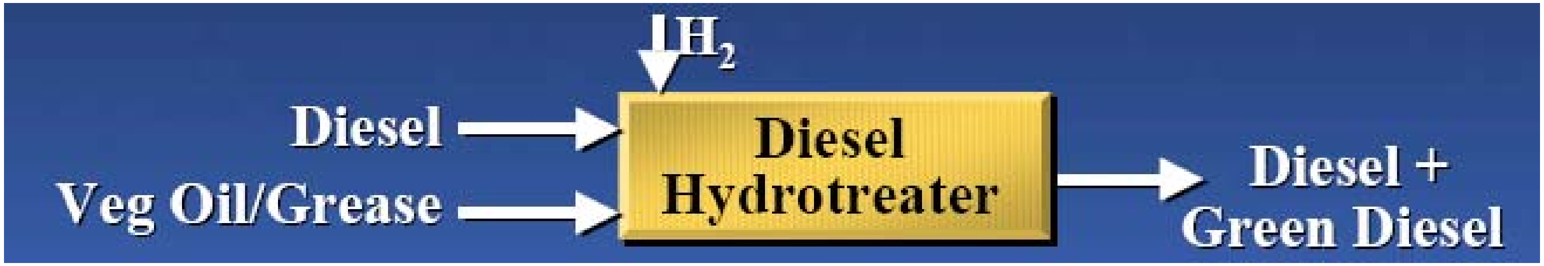
Green or Renewable Diesel

Oils, Fats, and Greases as Bio-Renewable Petroleum Refinery Feedstocks



- Co-processing of oils and greases with petroleum fractions
- Utilize existing refinery process capacity
- Lower conversion costs than biodiesel
- Higher quality diesel blending component
- Gasoline/Diesel ratio flexibility, depending upon season, needs, etc.

Green Diesel and Jet Fuel

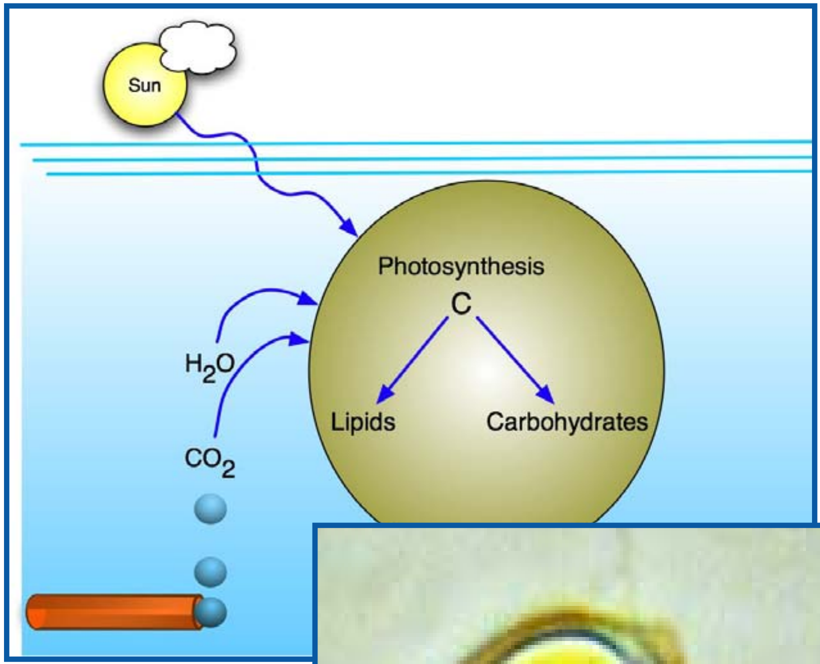


- **Hydrotreating of biorenewable oils in existing refinery units**
- **Lower capital costs than biodiesel**
- **Excellent fuel properties**

Feed	
% Oil or Grease	100
% H_2	1.5-3.8
Products	
% water, CO_2	12-16
% Lt HC	2-5
% Diesel	83-89
Cetane Number	80-100
ppm S	<10

Source: U.O.P. Corp.
1st International Biorefinery Conference, August 2005

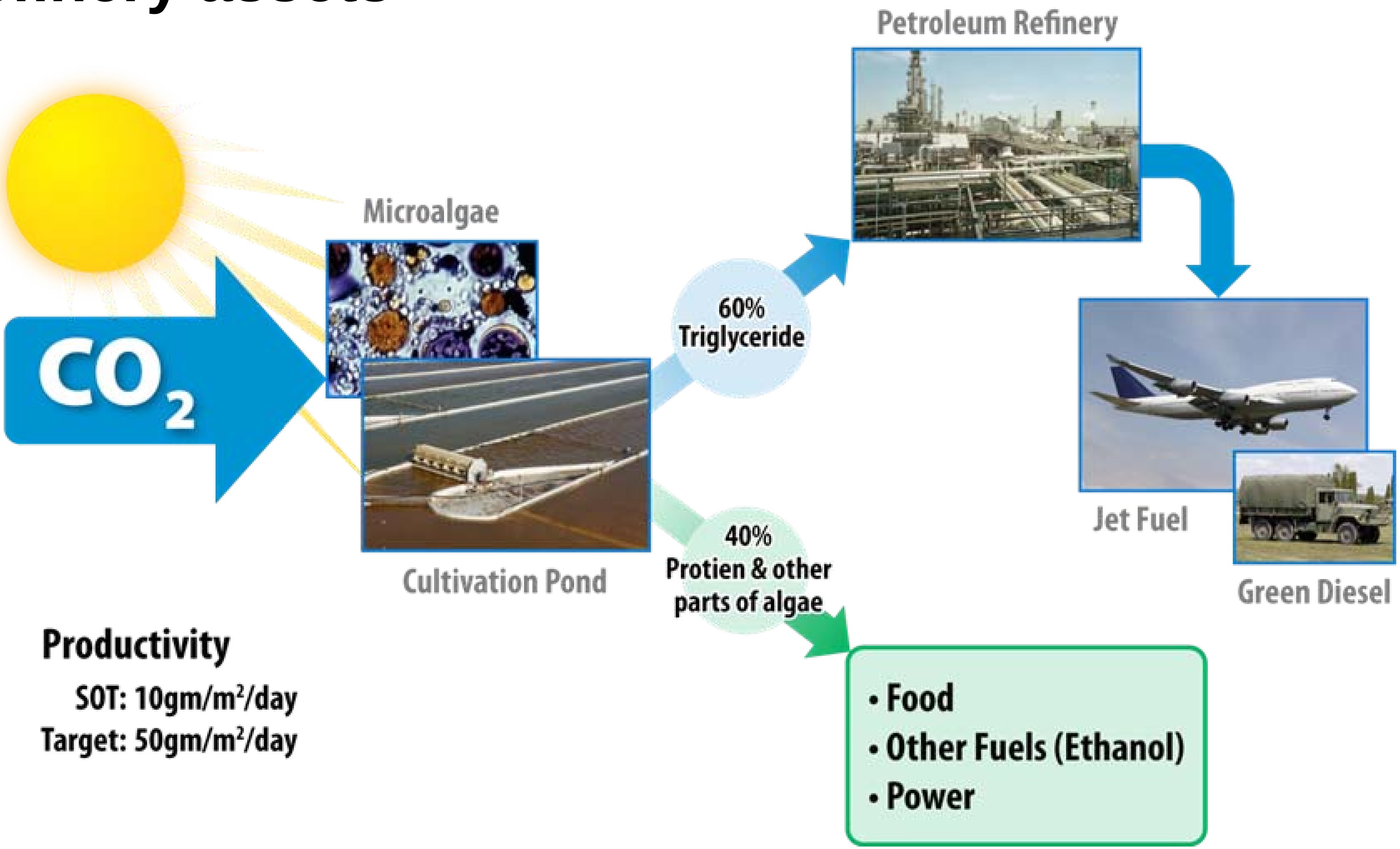
Algae as a Source of Biofuels



- **Source of additional lipids (oils) and/or carbohydrates**
- **Complements terrestrial biomass production**
    - o Reduces pressure on land use
    - o Avoids food vs fuel debate
    - o Saline, brackish, waste water-compatible
    - o Option to utilize large waste CO_2 resource (e.g. coal power plant)
- **Potential for greater productivity than their terrestrial cousins**
    - o Up to 50 times more productive than traditional oilseed crops
    - o Very large resource potential for producing additional biodiesel
- **Growing DOE, DoD, and Industry interest and funding**

Algae to Jet Fuel

Offers oil source for utilization of existing refinery assets



Land Use Required

(Basis -- algal oil needed for 5 Billion gal/yr jet fuel)

Near Term: with current state of the art

4,000,000 acres
(6,500 square miles)

Arizona:

73 million acres

114,000 sq. mi.

Longer Term: with targeted research plan

530,000 acres
(830 square miles)

Emerging Biofuels Challenges

- **Overcoming the corn ethanol Food vs Fuel debate**
- **Sustainability considerations for all aspects of Biofuel production and use**
- **Looking beyond second generation Cellulosic Ethanol to third generation feedstocks and fuels**
  - “Infrastructure compatible biofuels”
  - Higher energy density

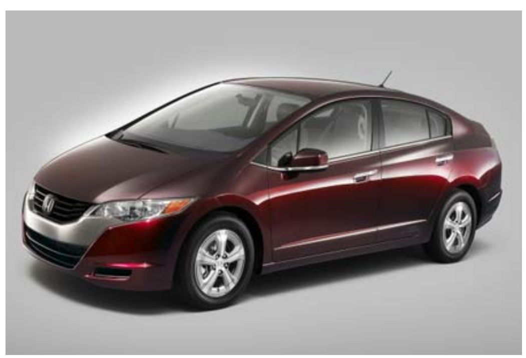
Hydrogen & Fuel Cells

U.S. Hydrogen & FCV Status

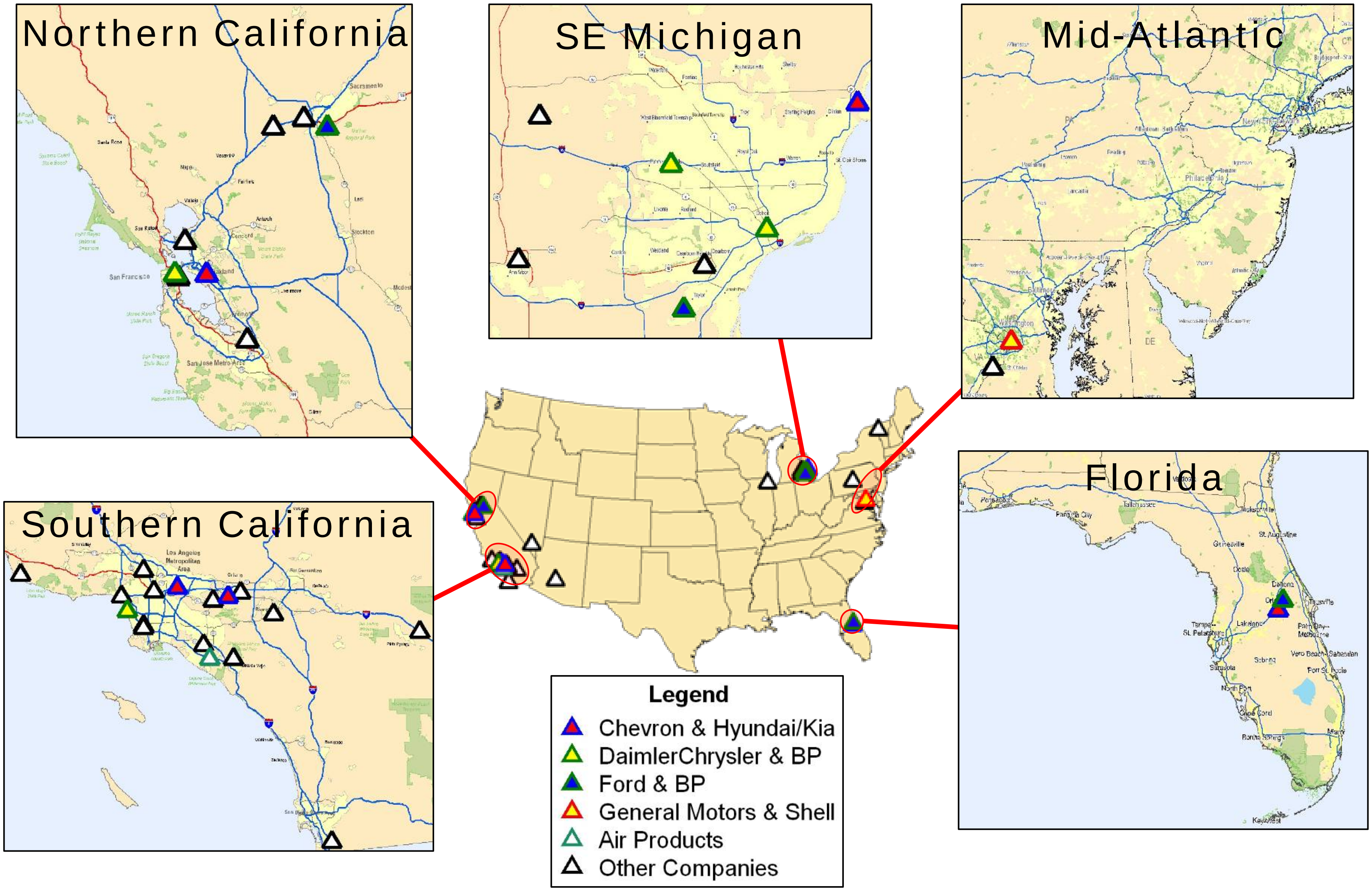
- **DOE Technology Validation "Learning Demonstration"**
  - 122 FCVs
  - 16 fueling stations

Chevy Equinox

Honda Clarity



Learning Demonstration Locations

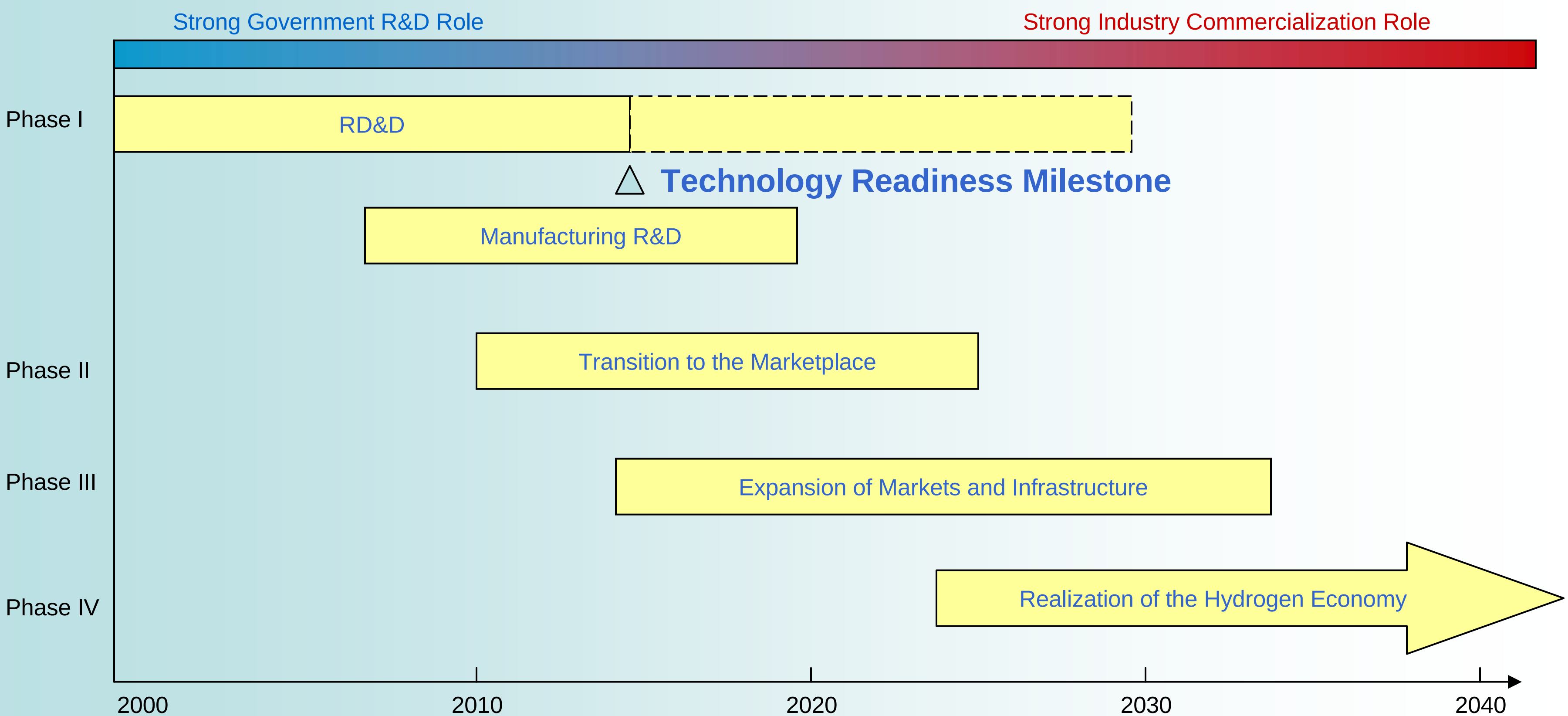


President's Hydrogen Fuel Initiative

- **Originally announced in 2003, then restated as part of 2006 Advanced Energy Initiative (AEI)**

  - " Make it practical and cost-effective for large numbers of Americans to choose to use clean, hydrogen fuel cell vehicles by 2020."
  - "Reduce our oil demand by over 11 million barrels per day by 2040 – approximately the same amount of crude oil America imports today."
  - $1.2B over FY04 – FY08

Hydrogen Economy Timeline



Transitional Phases:

I. Technology Development Phase: Research to meet customer requirements and establish business case leads to the technology readiness milestone

II. Initial Market Penetration Phase: Portable power and stationary/transport systems are validated; infrastructure investment begins with governmental policies

III. Infrastructure Investment Phase: H2 power and transport systems commercially available; infrastructure business case realized

IV. Fully Developed Market and Infrastructure Phase: H2 power and transport systems commercially available in all regions; national infrastructure

DOE's Hydrogen Program 2015 Goals

Onboard Storage

300 miles

Fuel Cells

$30/kw - 5,000 hrs

Production

≤ $3.00/kg

- Sorption Center of Excellence
- Manufacturing R&D
- Market Transformation
- H2 from Renewables

NREL

- Technology Validation Demos
- Safety, Codes & Standards
- Education
- Analysis

NREL

NREL Hydrogen Technology Thrusts

 **Hydrogen production**

 **Hydrogen delivery**

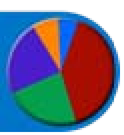
 **Hydrogen storage**

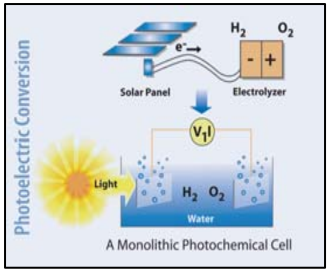
 **Hydrogen manufacturing**

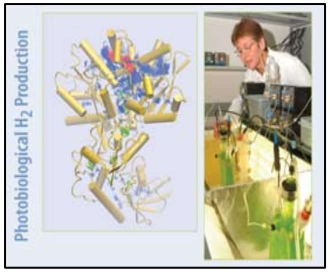
 **Fuel cells**

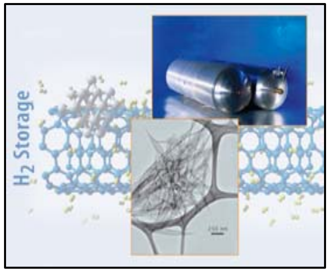
 **Technology validation**

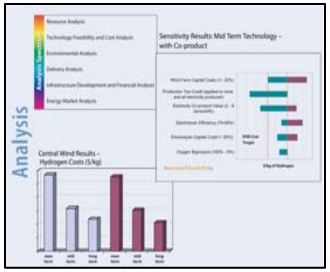
 **Safety, codes, & standards**

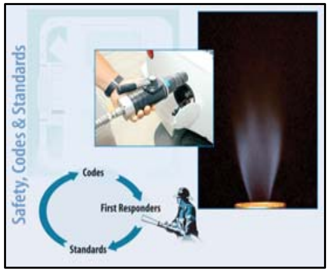
 **Analysis**











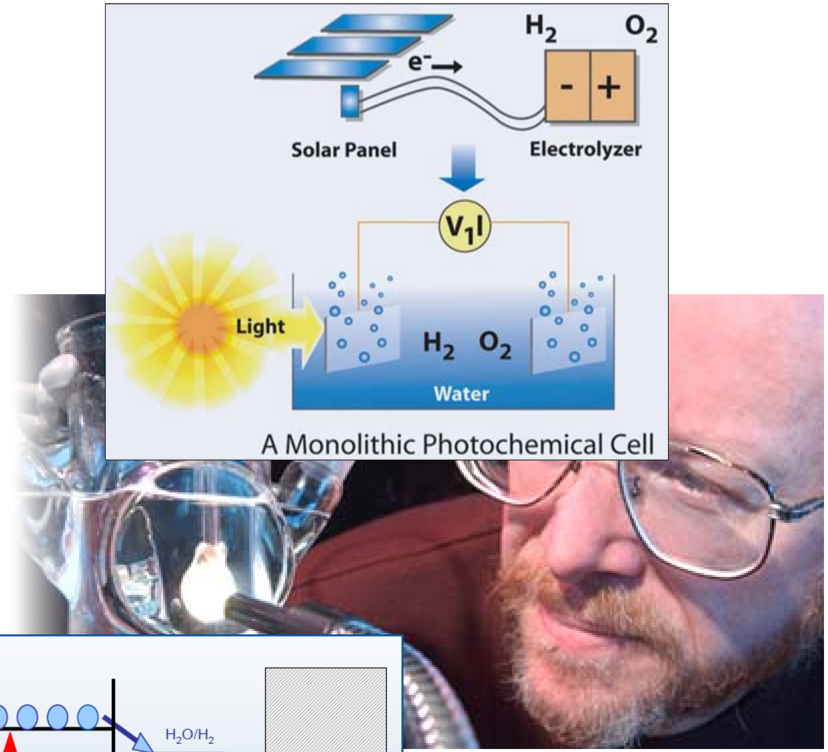
Renewable Hydrogen Production

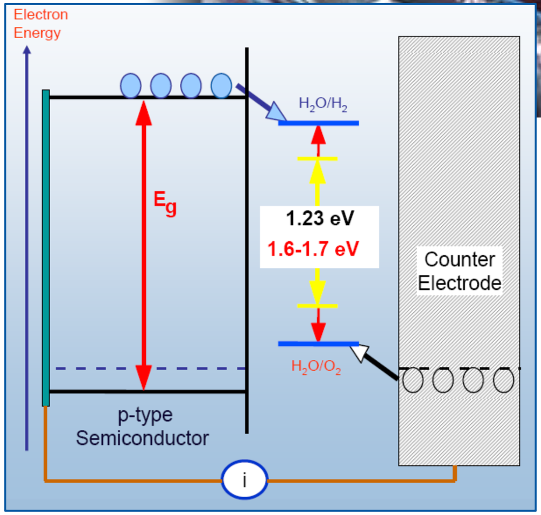
- Photoelectrochemical hydrogen production from water
- Photobiological hydrogen production by algae and cyanobacteria
- Dark fermentation
- Biomass thermochemical hydrogen production
- Solar thermochemical hydrogen production
- Renewable energy electrolysis

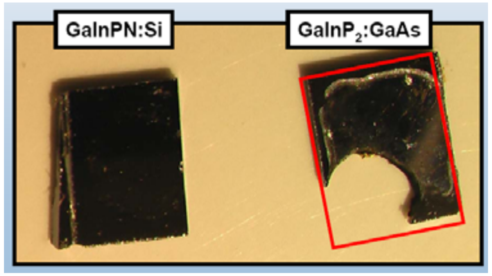
H_2 Production: Photoelectrochemical

Photoelectrochemical materials are specialized semiconductors that use energy from sunlight to dissociate water molecules into hydrogen and oxygen.

NREL's work involves identifying and developing durable and efficient photoelectrochemical materials, devices, and systems.



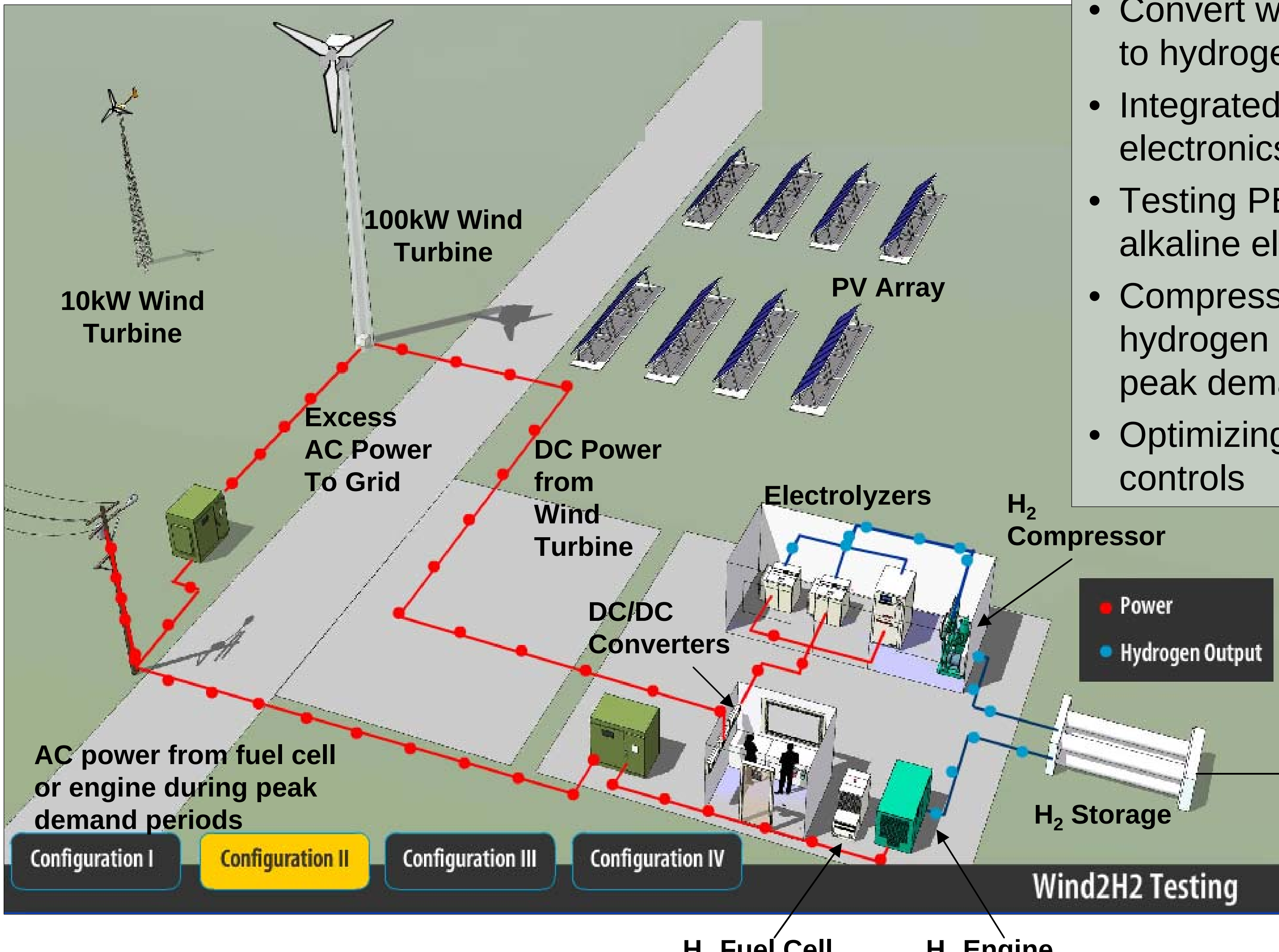




Wind-to-Hydrogen Project

Partnership with Xcel Energy (utility)

- Convert wind and solar to hydrogen
- Integrated power electronics
- Testing PEM and alkaline electrolyzers
- Compress and store hydrogen for use during peak demand
- Optimizing system controls



2008: H2 Vehicle Fueling Station

Emerging Hydrogen & FC Challenges

- **Keeping the momentum -- impediments include:**
  - FY08 is end of 5 year Presidential H2 Fuel Initiative
  - Recent focus on “near term” solutions
- **H2 fuel infrastructure – significant change from hydrocarbon fuel systems**
- **Getting past the “million $$ vehicle” image and hydrogen safety perceptions**

Transportation

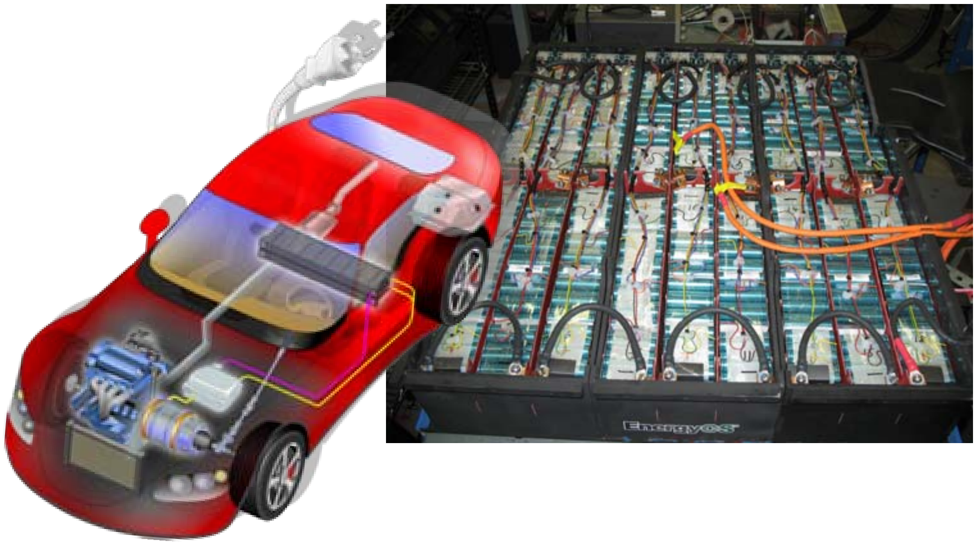
U.S. Alternative Propulsion Status

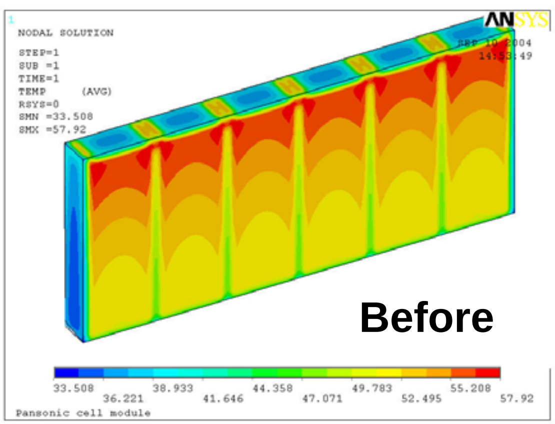
- **E85 (85% ethanol / 15% gas)**
  - ~1,300 stations
  - ~ 6 million FFVs
- **Compressed Natural Gas (CNG)**
  - 150,000 vehicles
  - Only one passenger vehicle still in production (Honda)
- **Plug-In Hybrid Electric Vehicles**
  - None in OEM production
  - Several kit manufacturers

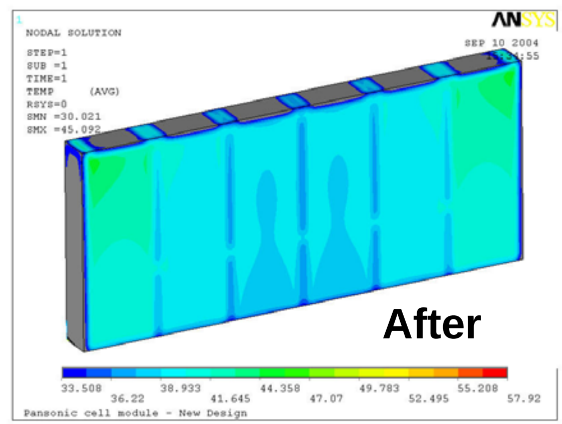
Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, 3 – American Coalition for Ethanol, all other information based on DOE and USDA sources

Plug-In Hybrid Electric Vehicles (PHEVs)

Lithium-Ion Battery Pack



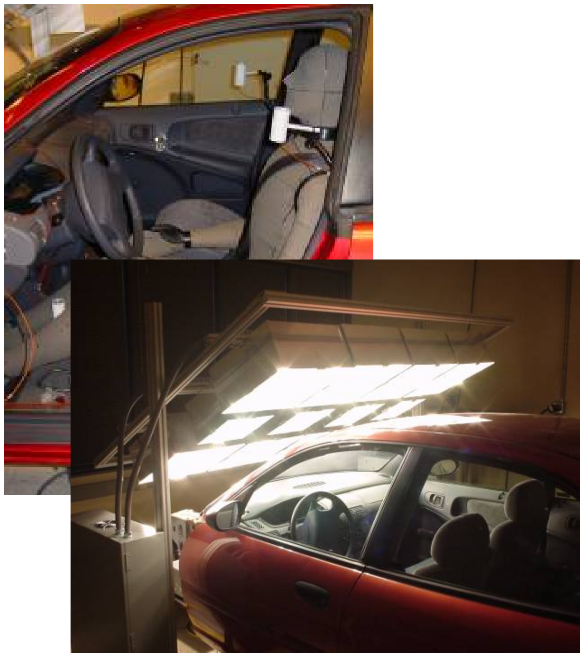




Renewable PHEV Charging

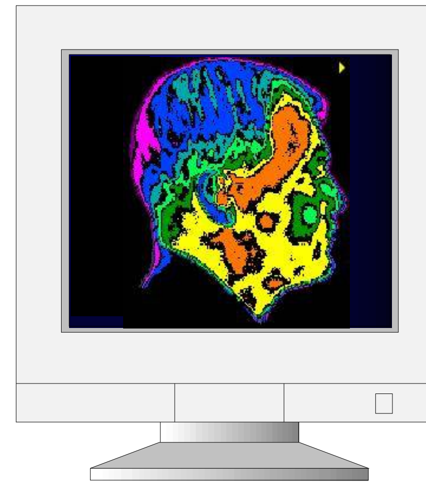
Vehicle Ancillary Loads Reduction

Thermal Comfort Assessment Tools



Thermal Testing

Human Thermal Physiological Model



Human Thermal Comfort Empirical Model

NREL Fuels Performance

Coordinating Research Council
- FACE
- Biodiesel Stability
- E10/E20/E85

Fuel Surveys
- Biodiesel
- E85

ReFUEL
- Emissions
- Fuel Economy
- Combustion
- Durability
- Speciation

Fuels Chemistry Lab

- Test Methods
- Impurities
- Chemical analysis

NBB CRADA - Biodiesel
- Quality/Stability
- Compatibility with Emission Controls
- Real-World Evaluation

ASTM
- Specs & Test
- Method Development
- Biodiesel
- E85

IQT Projects
- Fundamental Ignition Studies
- Pollutant formation
- FACE Fuels Testing

Implementation -- Data, Analysis, & Tools

Emerging Vehicle Challenges

- **Ethanol**
  - Increasing the # of E85 fueling stations and FFVs
  - Intermediate blend (E15, E20) testing and certification
- **PHEVs**
  - Understanding charging and grid effects
  - Fast-tracking a demonstration program
- **Efficiency improvements for gasoline and diesel vehicles**

Our Ultimate Challenge

- **Getting Renewable Energy and Energy Efficiency to significance in our Nation’s infrastructure**

- **“moving at speed – deploying at scale”**

- **And, we must rely on the States to lead the charge**

Renewable Fuels Science & Technology

Biofuels **Hydrogen** **Transportation**