National Renewable Energy Laboratory
Innovation for Our Energy Future

Looking Ahead – Biofuels, H_2, & Vehicles

21st Industry Growth Forum

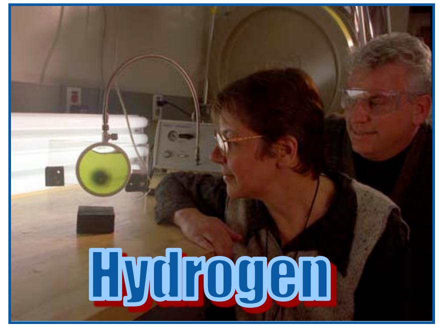
Dale Gardner

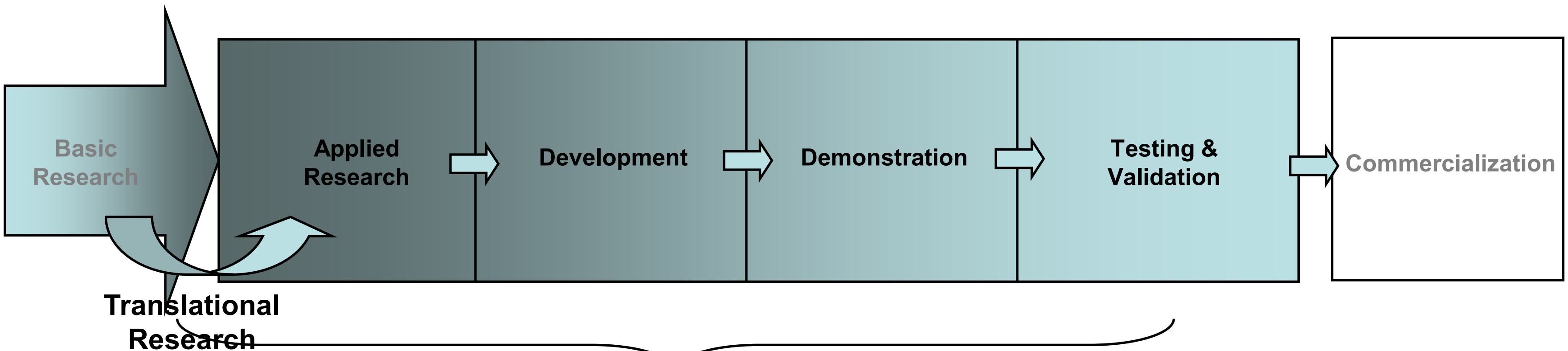
Associate Laboratory Director, Renewable Fuels & Vehicle Systems

28 October 2008

NREL/PR-4A0-44538

NREL's Renewable Fuels & Vehicle Systems S&T



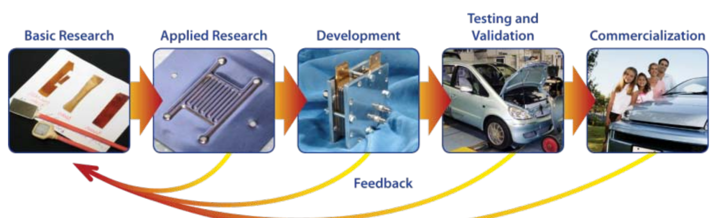


High risk R&D

Next generation & leapfrog technologies

Acceleration of progress

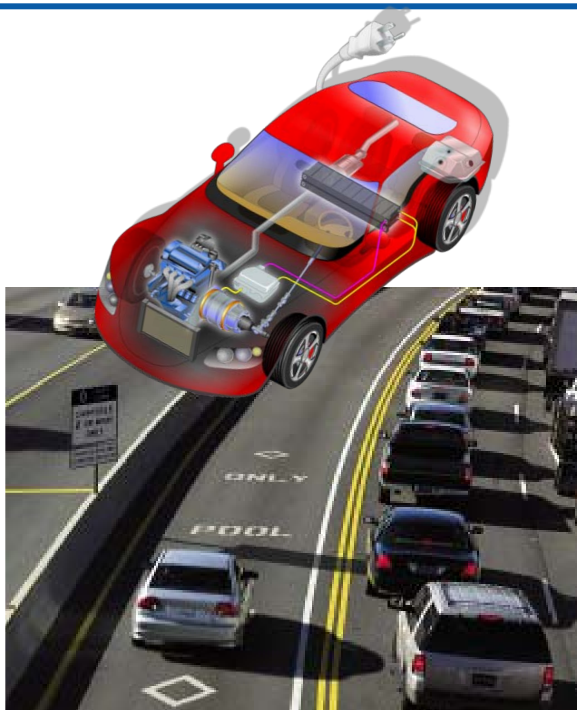
Unique capabilities & facilities



Biofuels

U.S. Fuel Capacity Goals

<u>USA Consumption</u>
Gasoline: 140 bgy
Diesel: 60 bgy



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

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

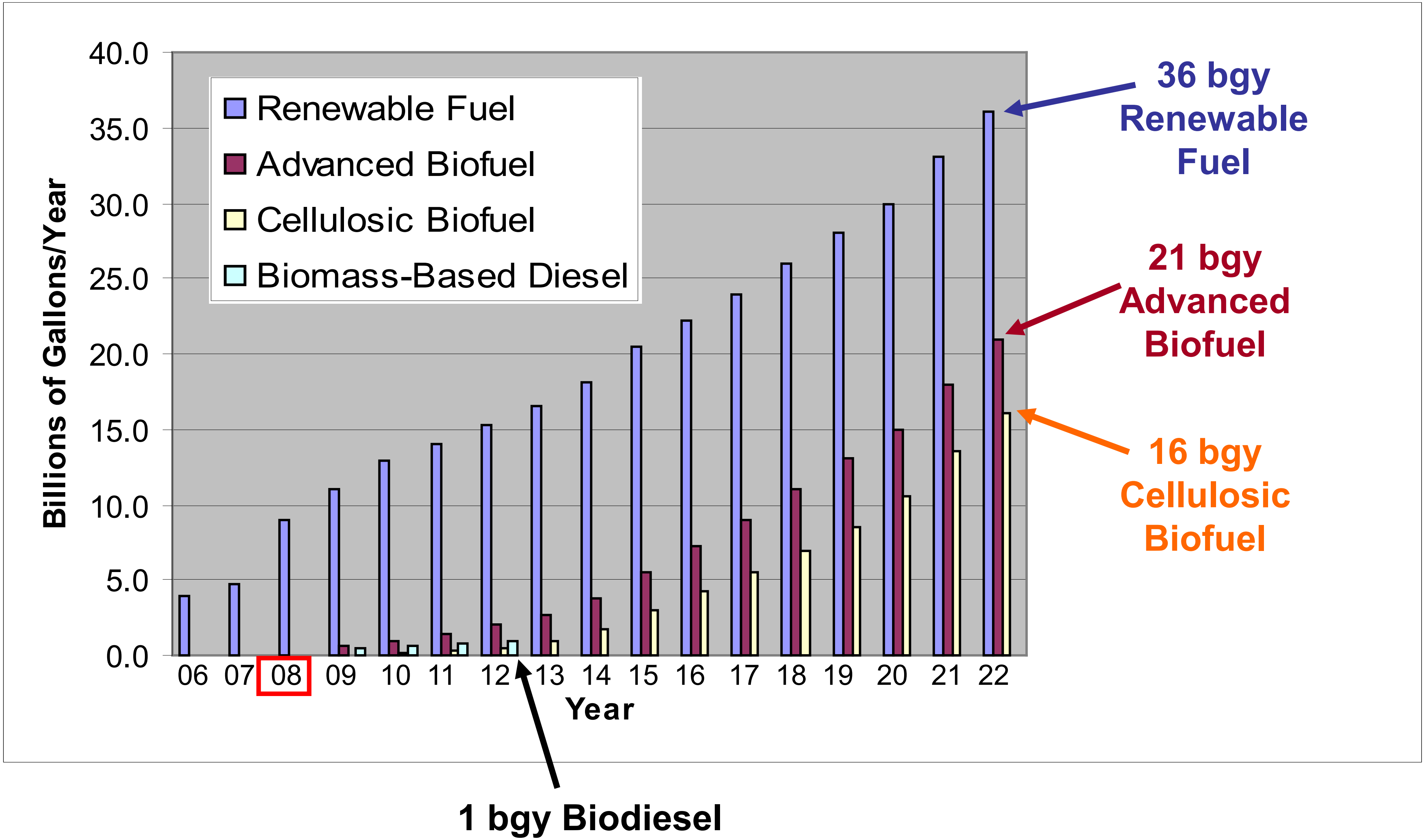
- **Renewable Fuel Standard (RFS) legislation**

  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

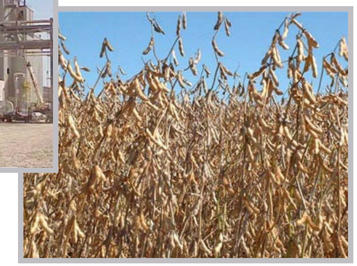
Renewable Fuel Standard



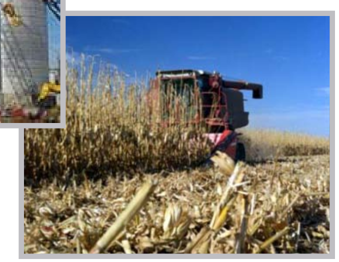
U.S. Current Biofuels Status

USA Consumption
Gasoline: 140 bgy
Diesel: 60 bgy

- **Biodiesel** [1]
  - 176 commercial plants
  - 2.6 bgy capacity (2008)
  - 0.46 bg produced (2007)

- **Corn ethanol** [2]
  - 178 commercial plants
  - 11.6 bgy capacity (+ 2.2 bgy planned) (2008)
  - 6.5 bg produced (2007)

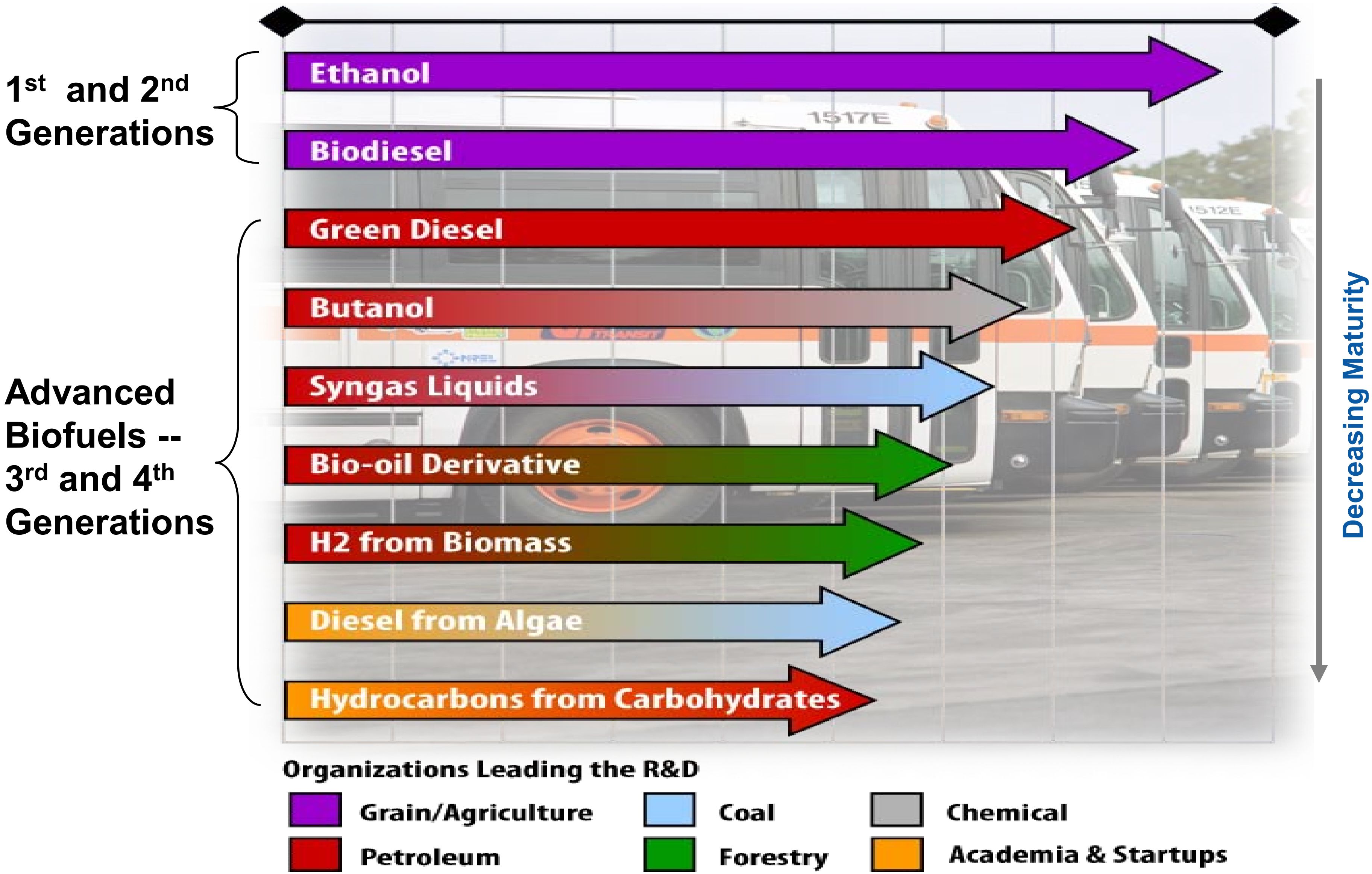



- **Cellulosic ethanol (2008+)**
  - 13 demo plants DOE-funded
  - ~.250 bgy capacity projected


bg = billion gallons; bgy = billion gallons per year

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

Range of Biofuels & Technology Maturity



Generation 1 (Corn Ethanol & Biodiesel)

- **1st generation --** from sugar or starch crops, plant oils, or animal fats

Corn

Starch → Sugar → Ethanol

Soy Bean

Soy Oil → Biodiesel

Generation 1.5 (Additional Crops)

- **1.5 generation --** sugar, starch, and plant oils that do not compete significantly for food and feed

Cassava

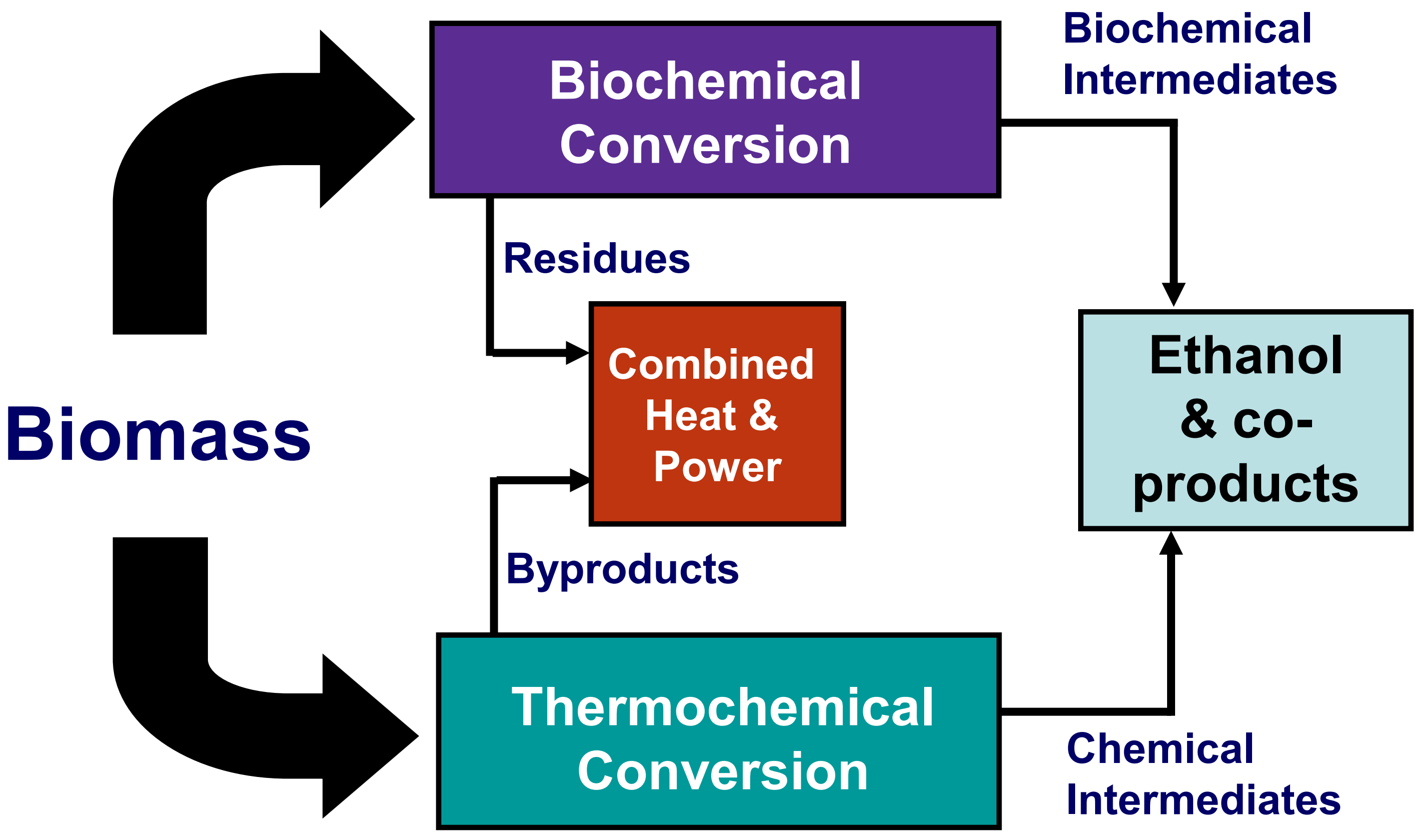
Starch → Sugar → Ethanol

Jatropha

Jatropha Oil → Biodiesel

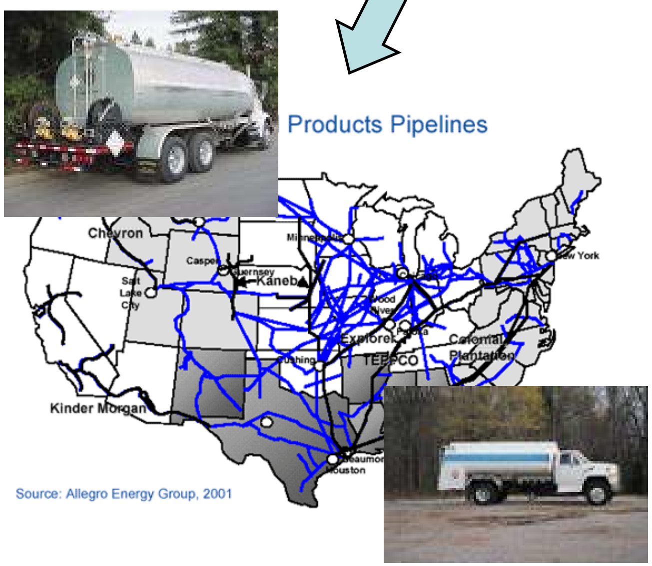
Generation 2 (Cellulosic Ethanol)

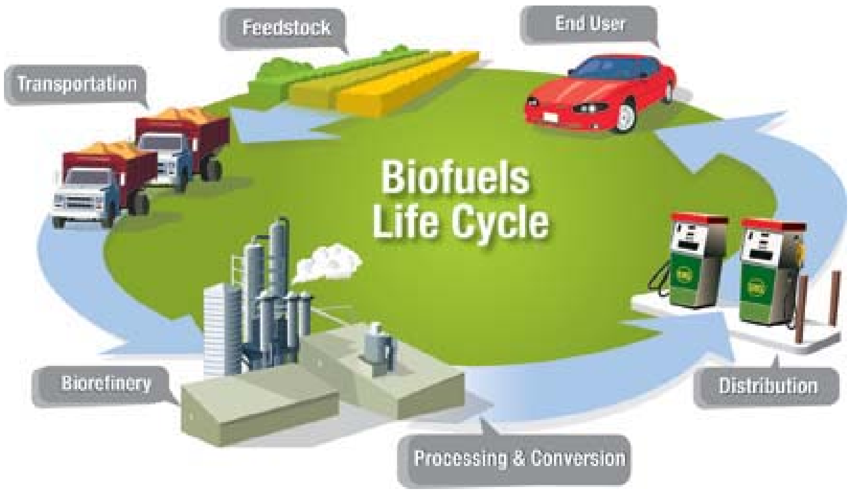
- **2nd generation --** from lignocellulosic biomass materials, primarily producing ethanol via biochemical or thermochemical conversion



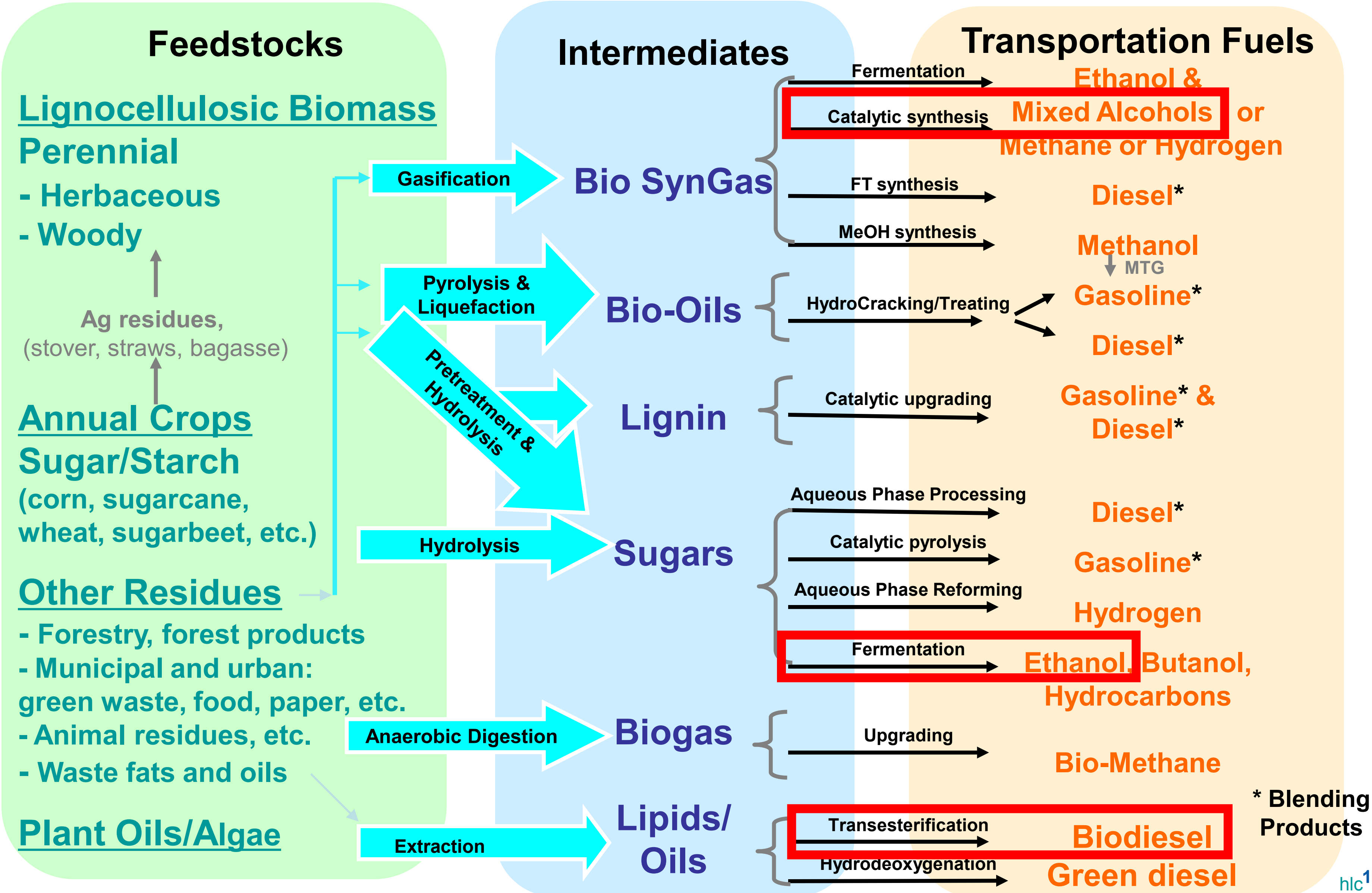
Why Follow-On Generations ?

- **3rd & 4th Generations -- beyond ethanol**
  - Higher energy density
  - Suitability for wide range of end use
  - Better temp and cold start ability
  - Infrastructure compatibility





Wide Range of Biofuel Technologies

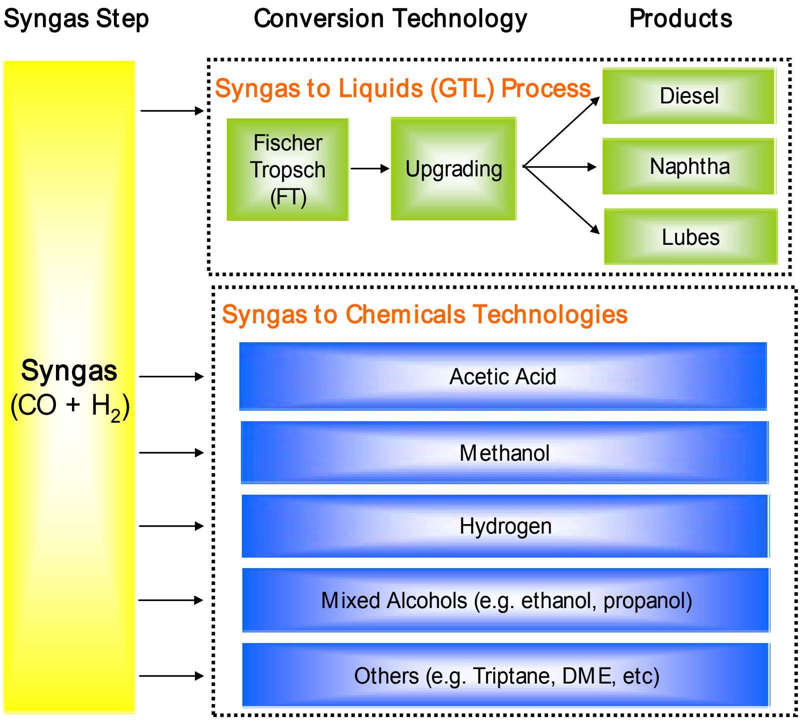


National Renewable Energy Laboratory

Innovation for Our Energy

Generation 3 (New Feedstocks & Fuels)

- **3rd Generation**
  - New energy feedstocks, e.g. algae
  - Higher energy density molecules, via thermochemical conversion

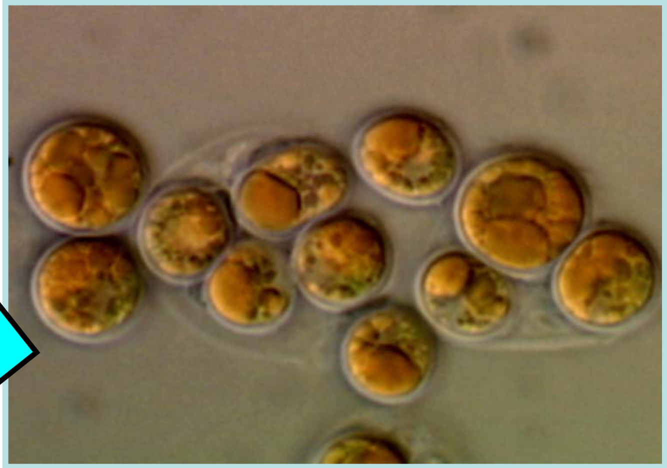


→ **Upgrading** → **Hydrotreating** → **Gasoline** / **Diesel**

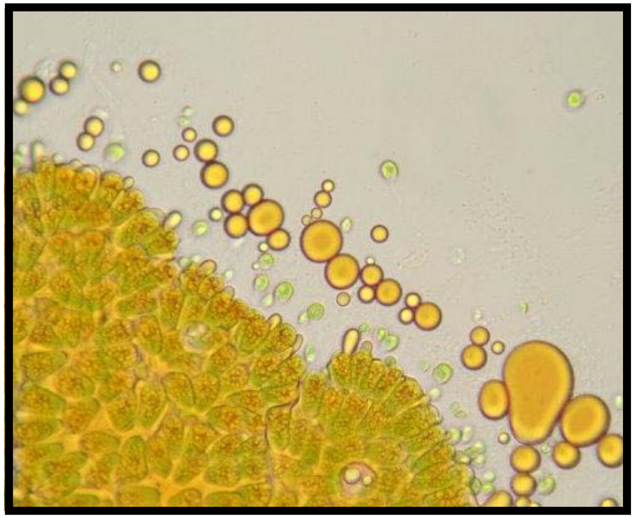
Comparing Potential Oil Yields

Crop	Oil Yield Gallons/Acre
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed	127
Jatropha	202
Oil palm	635
Algae	1,200 – 10,000

Today's Technology Estimate (1,200) — Optimistic Future Technology (10,000)

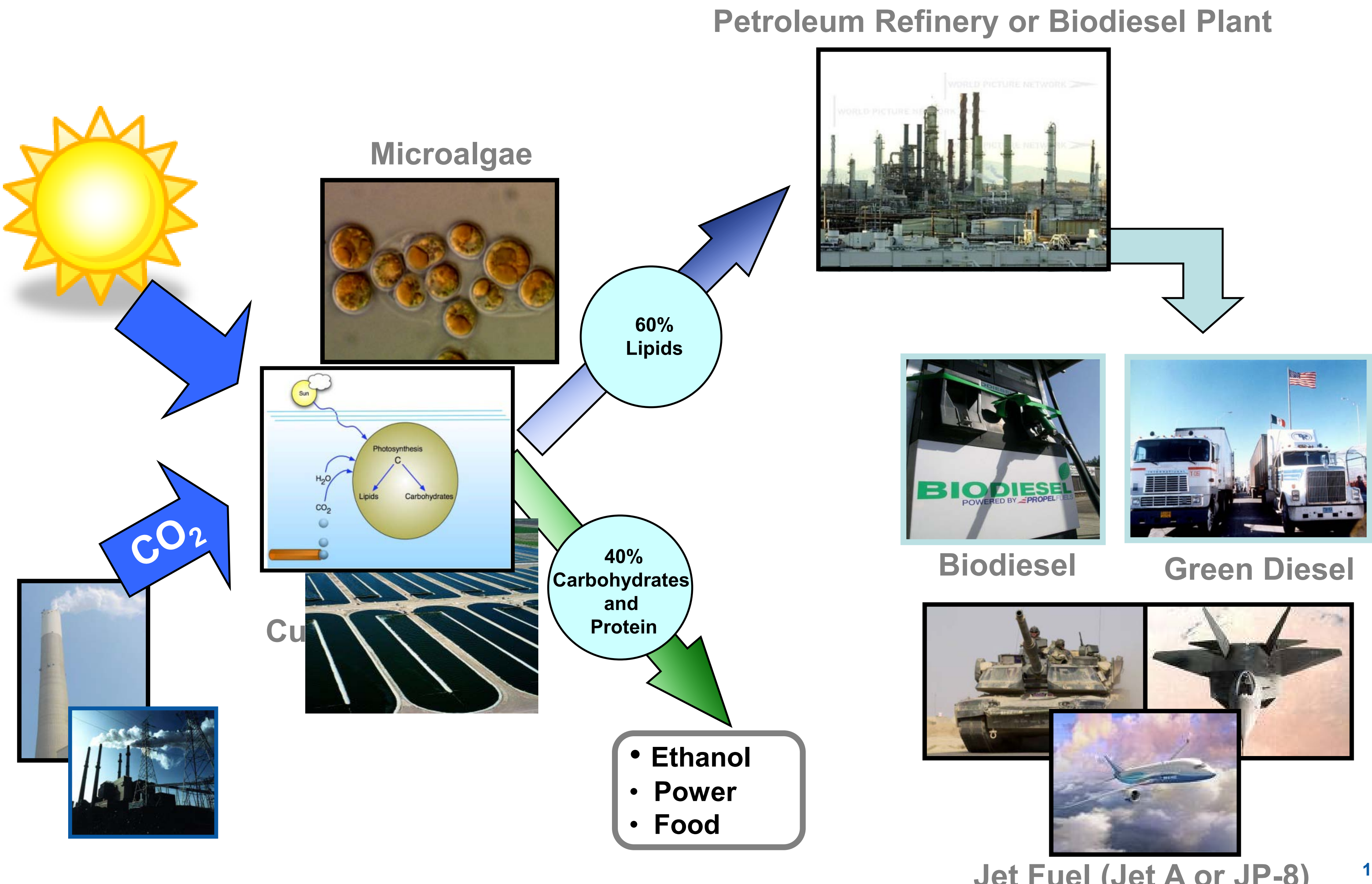


Microalgae – 3rd Generation Feedstock



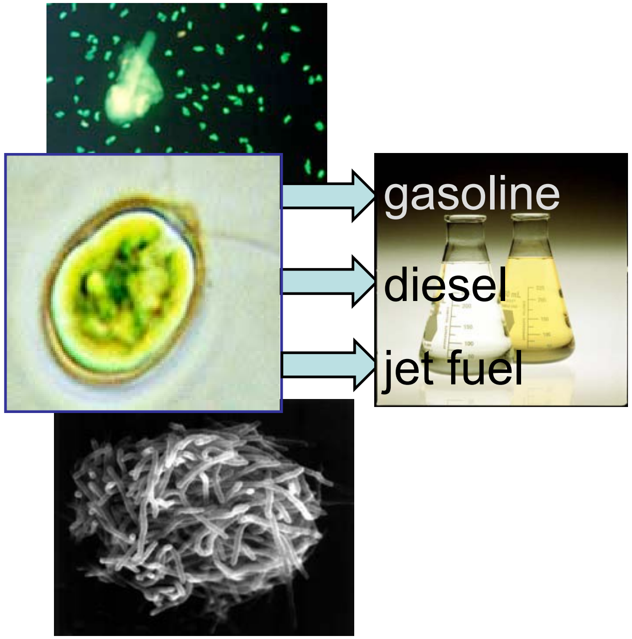
- **Algae have potential to produce more lipids (plant oils) per acre than other terrestrial plants -- *potentially 10X to 50X***
  - Lipids are the preferred starting point to make diesel or jet fuel
- **Algae cultivation can utilize:**
  - Marginal, non-arable land
  - Saline or brackish water
  - Large waste CO_2 vent resources (e.g. flue gases from coal electricity plants)
- **Minimal competition with food, feed, or fiber**

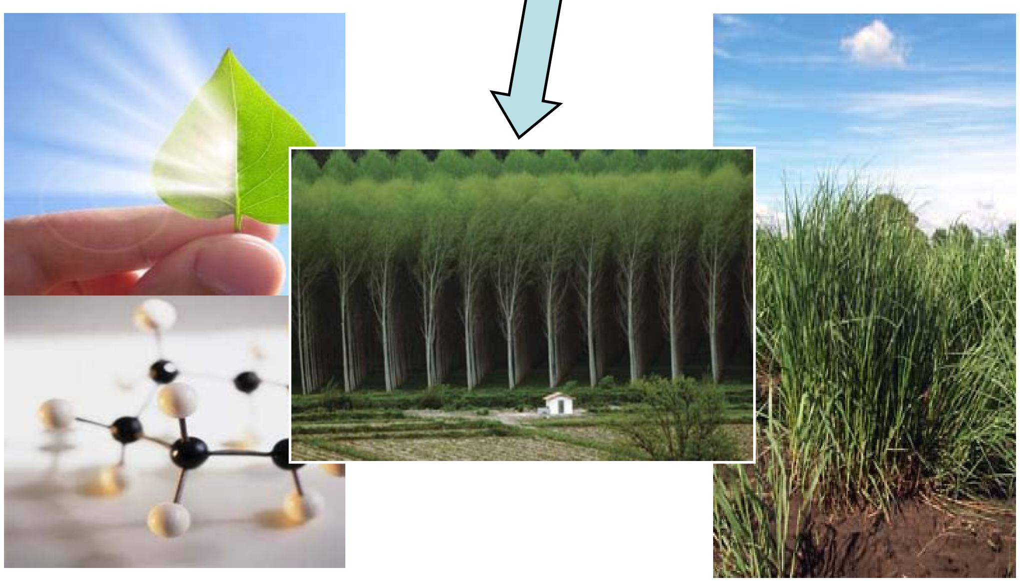
Biofuels From Microalgae



Generation 4 (Systems Biology Advances)

- **4th Generation –**
  - Higher energy density molecules, directly from organisms
  - Crops engineered for self lignocellulosic destruction



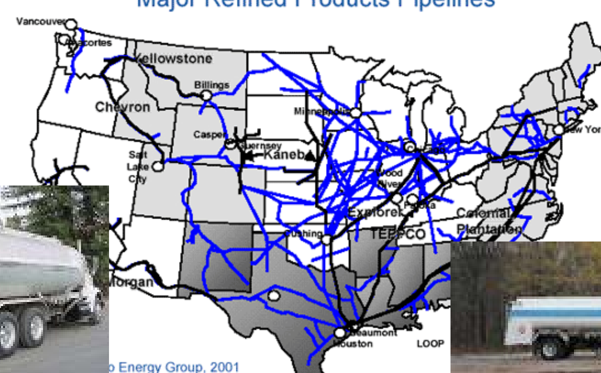


Infrastructure – Feedstock & Product

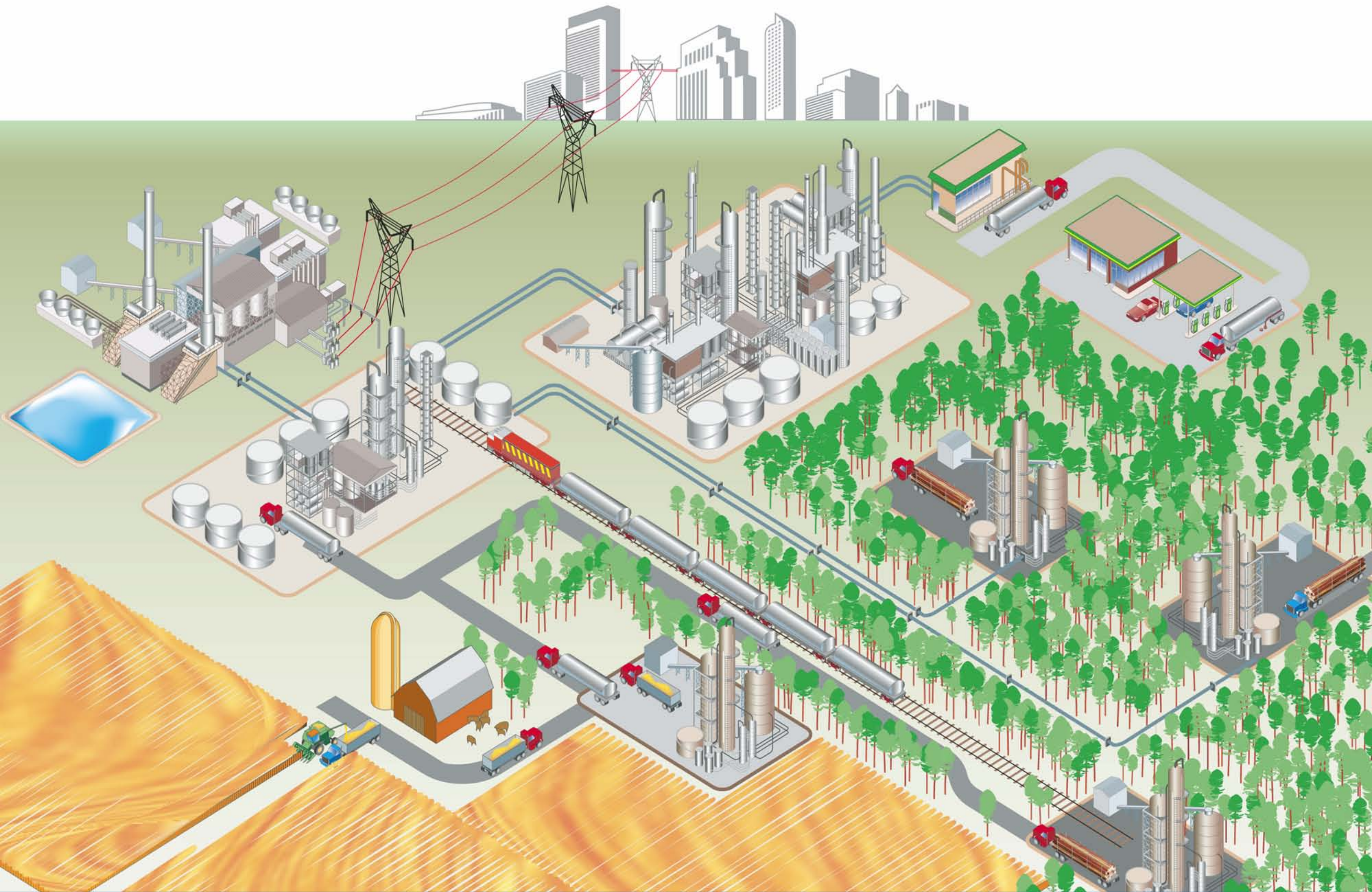
- **Need innovative thinking to accelerate our ability to transport large amounts of biomass and new fuels**

Feedstock Production → Feedstock Logistics → Biofuels Production → Biofuels Distribution → Biofuels End Use

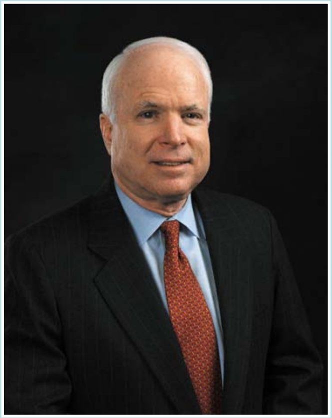
Major Refined Products Pipelines



Decentralized Biomass Liquids Scenario



John McCain & Barack Obama on Biofuels



THE LEXINGTON PROJECT
AN ALL OF THE ABOVE ENERGY SOLUTION

- Will commit to pursue 2nd generation alcohol-based fuels, such as cellulosic ethanol
- Eliminate mandates, subsidies, tariffs, and price supports that focus exclusively on corn-based ethanol

- Will invest $150B over 10 years in alternative energy sources such as . . the next generation of biofuels and fuel infrastructure . . .
- Will require 60 billion gallons of advanced biofuels to be phased into the U.S. fuel supply by 2030

Hydrogen & Fuel Cells

DOE's 2015 Hydrogen Program Goals

Production

$2.00 - 3.00/kg
(pathway independent)

Onboard Storage

300 mile range

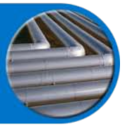
Fuel Cell

$30/kw &
5,000 hrs

DOE Hydrogen Program

NREL Hydrogen Technology Thrusts

Hydrogen production



Hydrogen delivery

Hydrogen storage

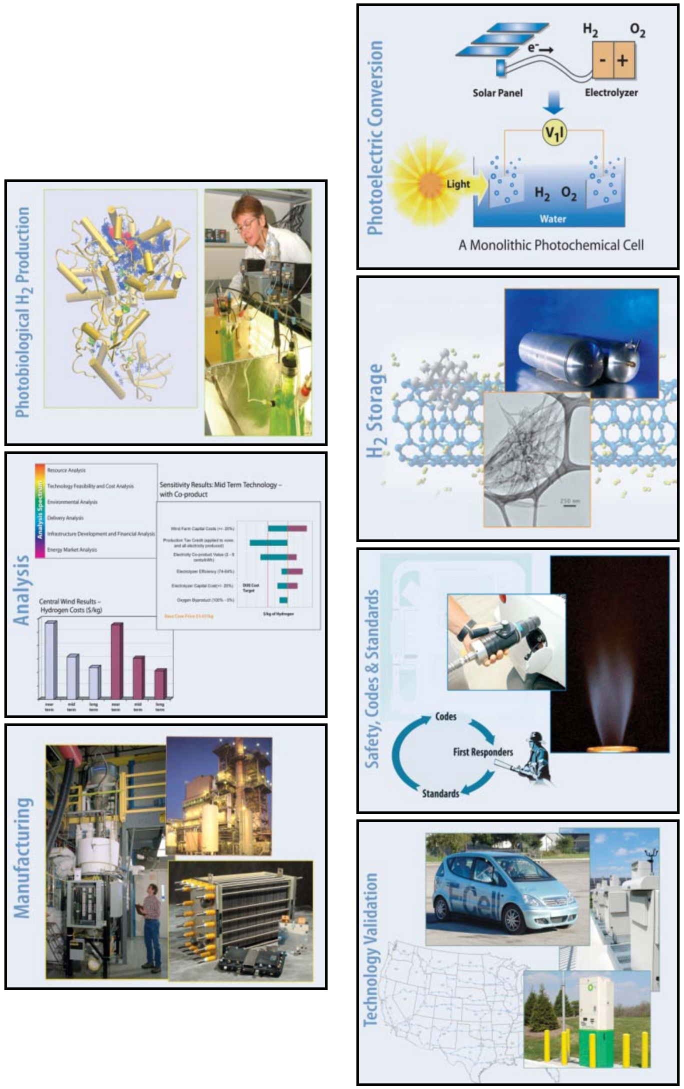
Hydrogen manufacturing

Fuel cells

Technology validation

Safety, codes, & standards

Analysis



EERE FY09 Hydrogen Budget Drivers

Technology Barriers

Hydrogen Production Cost *

(One cost-competitive pathway required for critical path.
Target: $2 – 3 /gge — *met by distributed reforming of natural gas*)

Hydrogen Storage Capacity & Cost

(Targets: 2.7kWh/L, 3kWh/kg, and $2/kWh)

Fuel Cell Cost and Durability

(Targets: $30 per kW, 5000-hour durability)

Economic & Institutional Barriers

Safety, Codes & Standards Development

Delivery Infrastructure

Domestic Manufacturing and Supplier Base

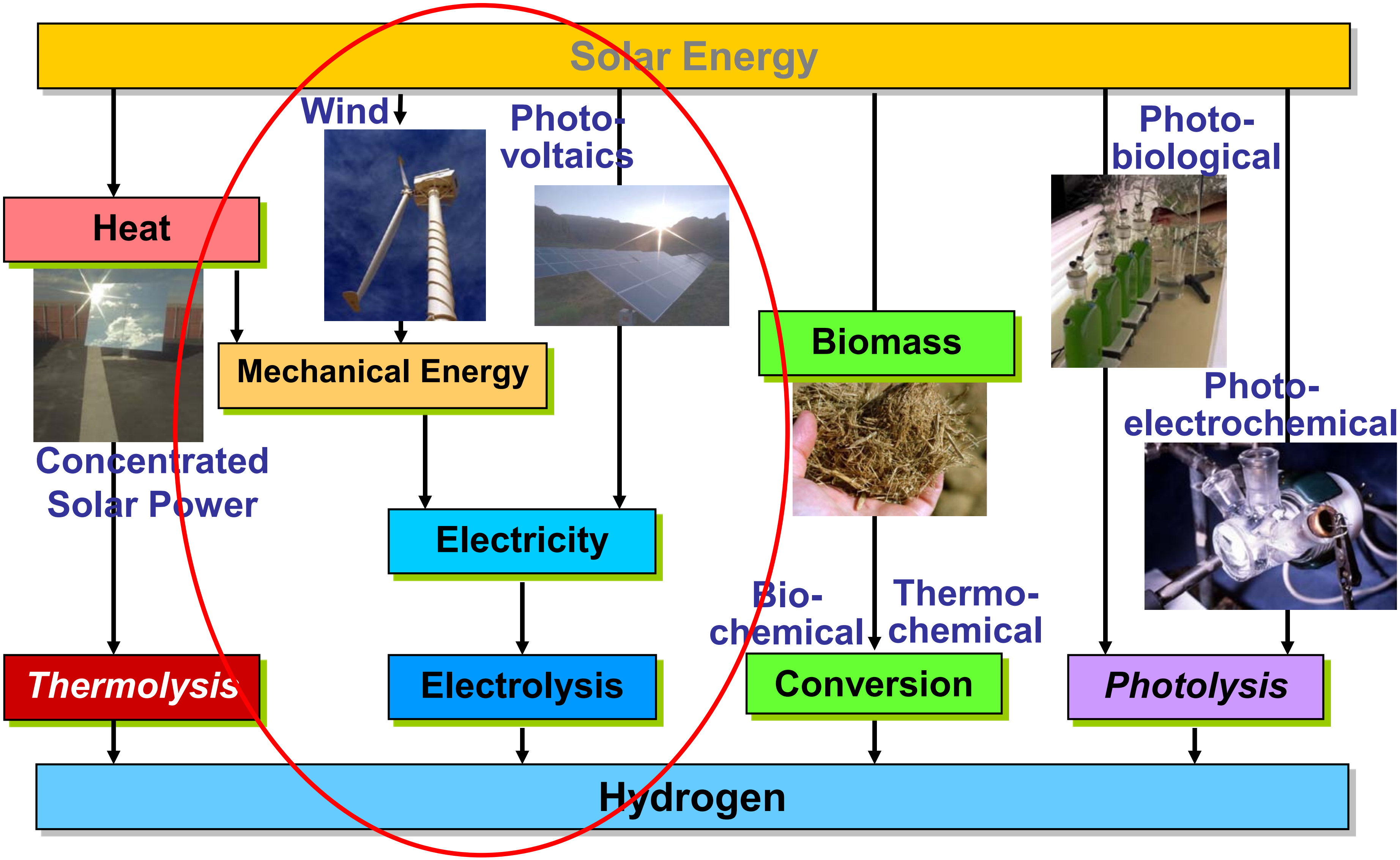
Public Awareness & Acceptance

Critical Path Barriers for Fuel Cell Vehicle Technology Readiness in 2015

Critical Path for hydrogen cost is one cost-competitive production pathway. Multiple pathways are needed for longer-term energy security and sustainability.

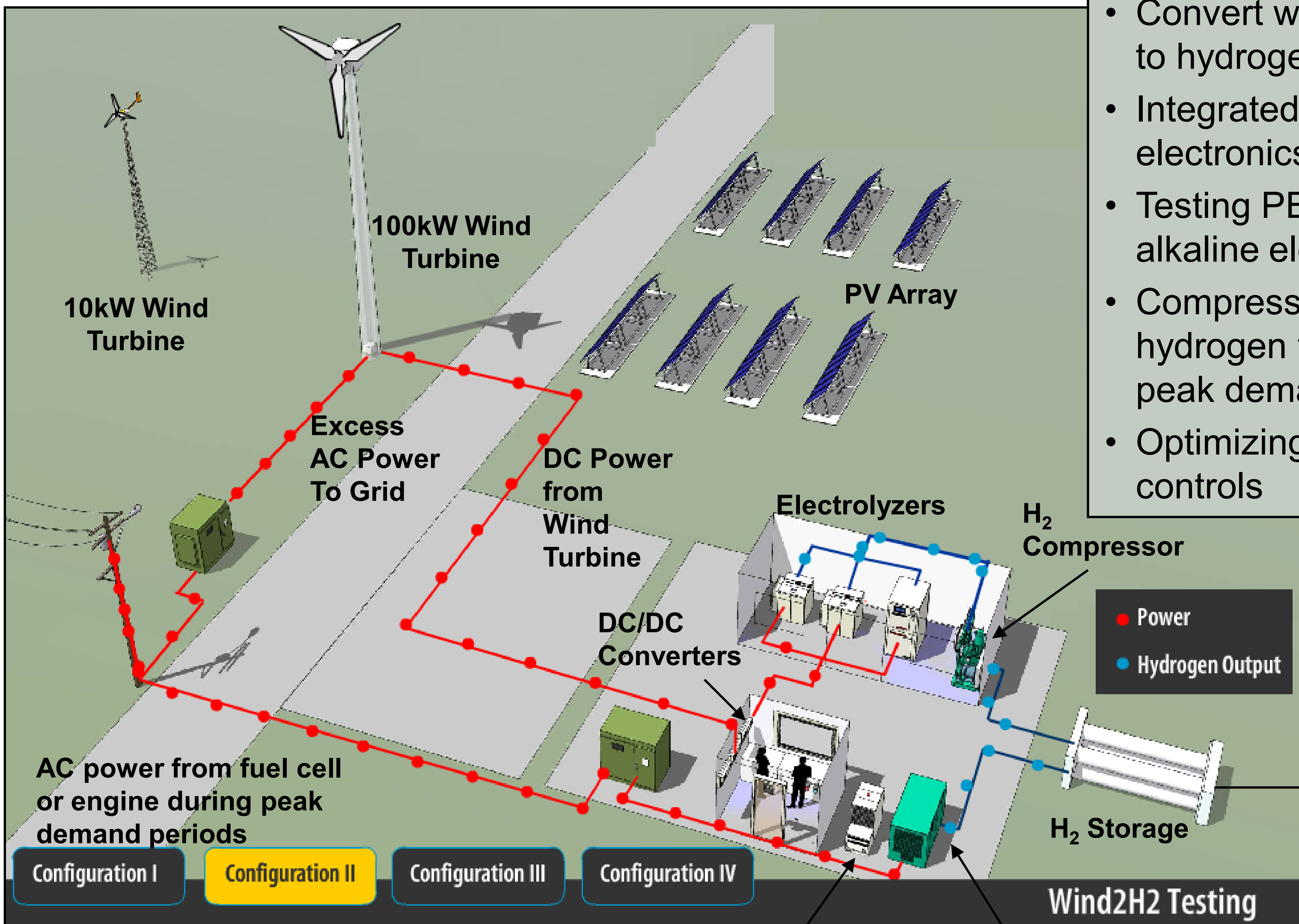
Source: EERE Hydrogen, Fuel Cells, & Infrastructure Technologies Program

Renewable Energy Paths to Hydrogen



Wind-to-Hydrogen Project (with Xcel)

- 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

Electrolysis Cost Reduction

- **Reduced cost of cell stack**
  - New materials
  - New designs and manufacturing methods
  - Increased current density (more hydrogen per cell)

- **Standardized designs**
  - Reduced engineering
  - Efficient procurement and global sourcing
  - Look for global standards, not only national

- **Large centralized electrolysis plants**

- **Increased market -> higher volumes -> assembly line manufacturing**

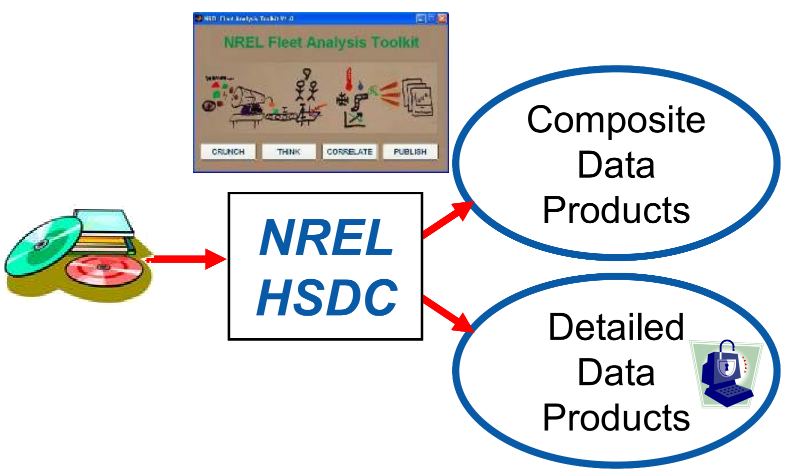
Hydrogen & Fuel Cells

- **Market Transformation – early hydrogen and fuel cell penetration**
  - Dual use
  - Stationary applications
  - Niche transportation-related markets

- **Manufacturability -- fuel cells, electrolyzers, and other hydrogen-unique systems**
  - Will require new processes and vendors to support mass production
  - Need to get ahead now, or delay hydrogen introduction past technology readiness
  - Significant opportunity for innovation

Hydrogen & Fuel Cell Vehicle Learning Demo

>120 Hydrogen Fuel Cell Vehicles from 4 OEMs



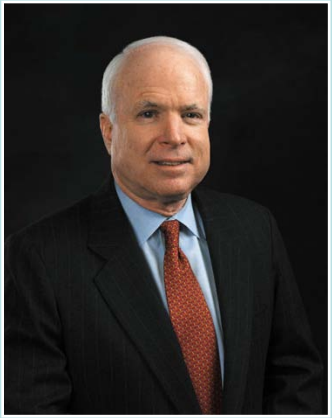
>16 Hydrogen Stations from 5 Energy Companies

General Motors & Honda

- Project Driveway program to put the fuel cell powered Chevrolet Equinox in the hands of customers in various parts of the United States.
- Plans for production of 100+ vehicles.
- Initially be available only in the NYC, D.C., and SoCal, where greatest number of hydrogen filling stations exist.

- Limited number of FCX Clarity vehicles will be leased to Southern Californians starting this year.
- Honda plans to deliver about 200 FCX Clarity hydrogen-powered fuel cell vehicles to customers in the first three years of its fuel cell lease program.
- Conducting a customer pre-qualification and selection process is underway.

John McCain & Barack Obama on Hydrogen



THE LEXINGTON PROJECT
AN ALL OF THE ABOVE ENERGY SOLUTION

- Mentioned hydrogen/fuel cells in speeches, but energy policy is silent on the topic

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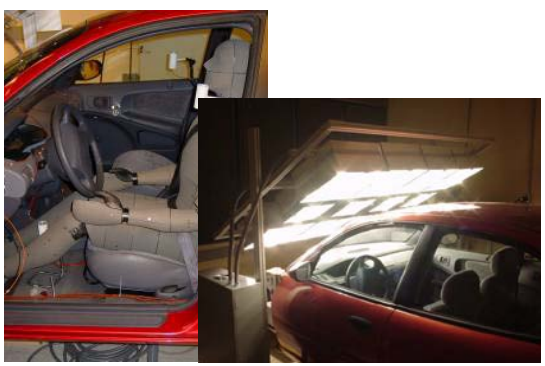
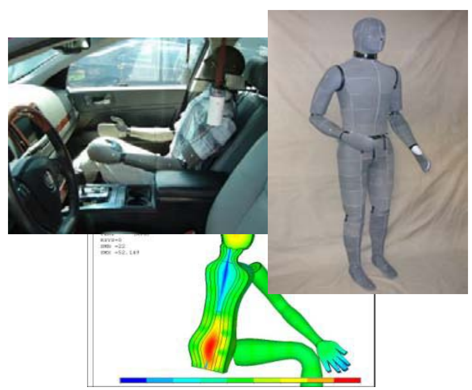
Advanced Vehicle Technologies

Vehicle Efficiency Improvements

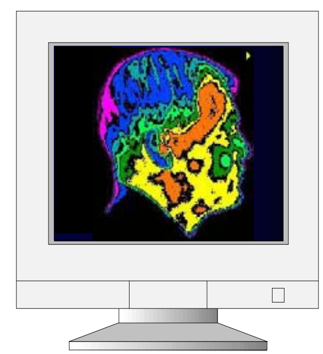
- **Need continued advances in gas and diesel ICEs, e.g.**
  - Engines and accessory equipment
  - Materials and light-weighting
  - Tire rolling resistance
- **In anticipation of increased electric drive vehicles, need ancillary load reductions**
  - Air conditioning/thermal comfort advancements
  - Motor and power electronics improvements
  - Electrical load reductions needed for increased electronics



Thermal Testing in Vehicles



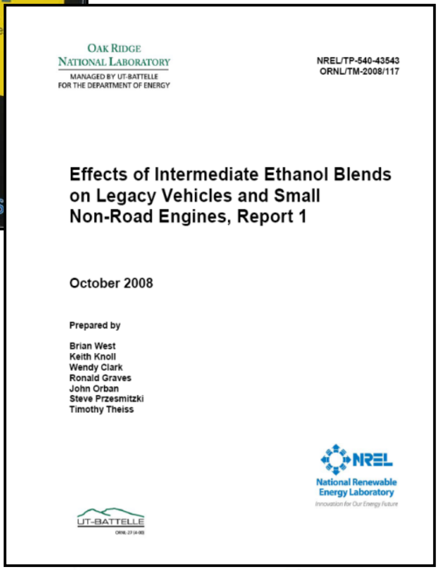
Human Thermal Physiological Model



Human Thermal Comfort Empirical Model

Ethanol Intermediate Blends

- **In order to absorb the ethanol capacities mandated by the RFS, probably need to move from E10 to E15/20**
  - E10 max'es out at ~ 15 bgy
  - E85 infrastructure and FFVs probably not developing fast enough
  - E15 or E20 could get us to approx 23 bgy or 30 bgy, respectively


OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

NREL/TP-540-43543
ORNL/TM-2008/117

Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1

October 2008

Prepared by

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Keith Knoll
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John Orban
Steve Przesmitzki
Timothy Theiss

NREL National Renewable Energy Laboratory

UT-BATTELLE

- **What we need to get there**:
  - Vehicle/engine testing, mods, certification for higher blends, and
  - Address SNRE issues
    - o Engine modifications, as required, or
    - o Develop an E0/10 infrastructure to serv the SNREs

Electric Drive Vehicles

- **Energy Storage (Lithium Ion battery challenges)**
  - **Safety:** Overcharges, charging in extremely cold weather, short circuits, “thermal runaway”, other abuse conditions
  - **Performance:** Very low/very high temperature operation; deterioration at very low or very high charge levels, high energy/power densities, low volume
  - **Durability:** Last thousands of charge/discharge cycles, deep discharge issues, achieve a 15+ year calendar life, while maintaining 80% levels
  - **Cost:** USABC has targeted $500/system for HEV batteries $3,400 for 40-mile PHEV systems

EnergyCS – lithium ion battery pack in Prius PHEV conversion

- **Power electronics**
  - Weight & volume
  - Thermal management

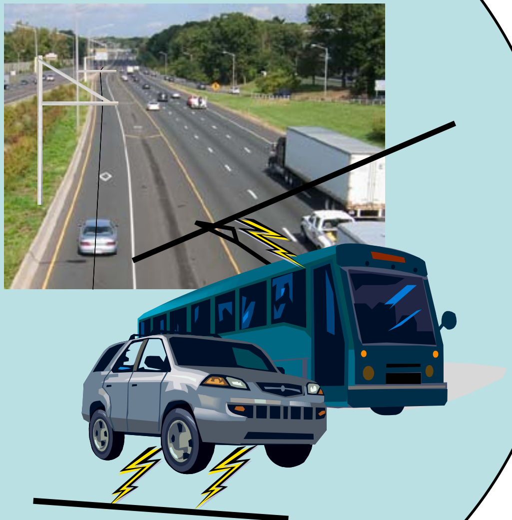
EEStor -- barium titanate powder ultracapacitor called the EESU, 52 kwh, 336 pound package

COURTESY: GENERAL MOTORS

Recharging Infrastructure

- **Recharging – we need to address:**
  - Public and work access, not just home
  - Using renewable electricity
  - "Cordless", on-the-move capability

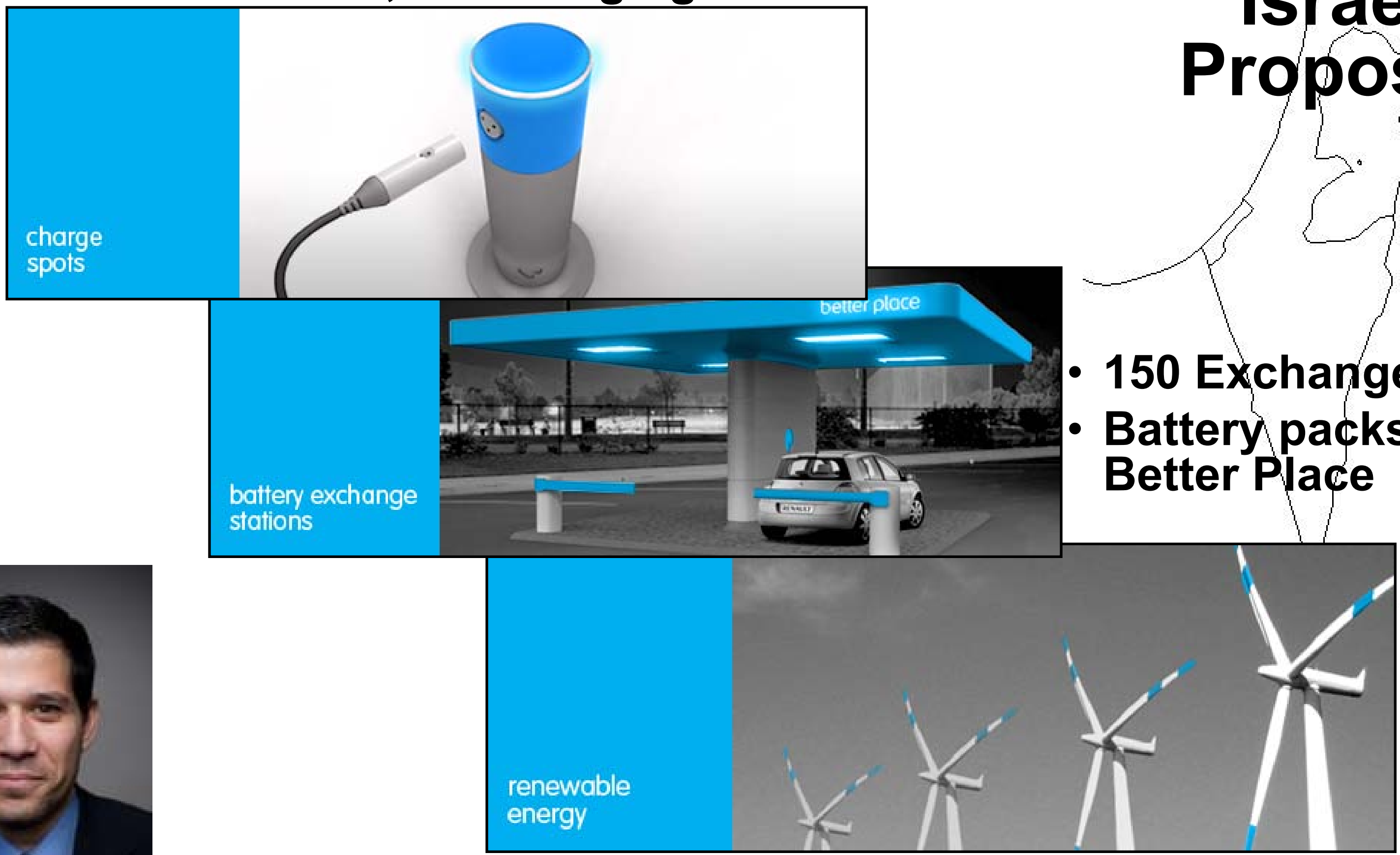
NREL Prius PHEV Conversion



The “Better Place” Solution

better place

- 500,000 Charging Locations



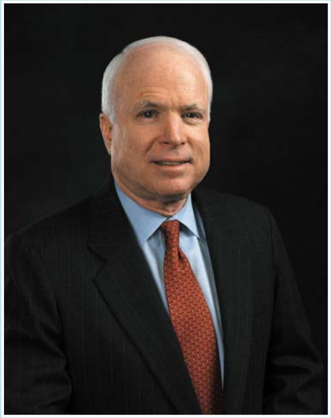
Israel Proposal

- 150 Exchange Stations
- Battery packs owned by Better Place

Shai Agassi, CEO

Vehicles: Renault
Batteries: AESC & A123

John McCain & Barack Obama on Vehicles



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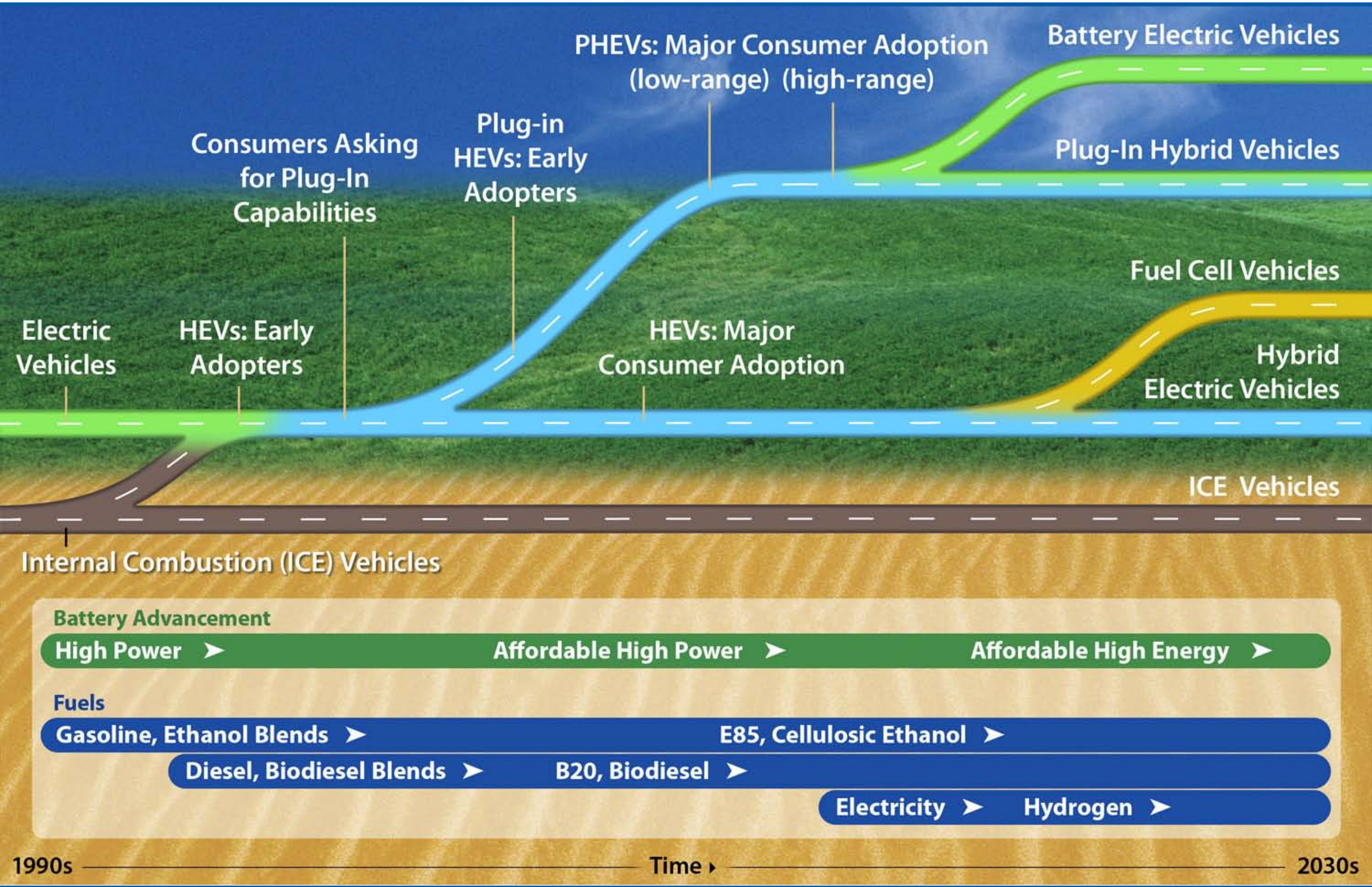
- Clean Car Challenge -- $5,000 tax credit for zero-carbon cars
- $300M prize for battery full commercial development
- Call on automakers for more rapid/complete switch to FFVs than they have proposed (50% by 2012)
- Effectively enforce existing CAFÉ standards

- Will invest $150B over 10 years in alternative energy sources such as . . the commercialization of PHEVs . . .
- Put 1 million PHEVs on road by 2015 (> 150 mpg)
- Mandate all new vehicles to be FFVs by end of first term
- Increase fuel economy standards 4% per year

A Portfolio of Transportation Technologies



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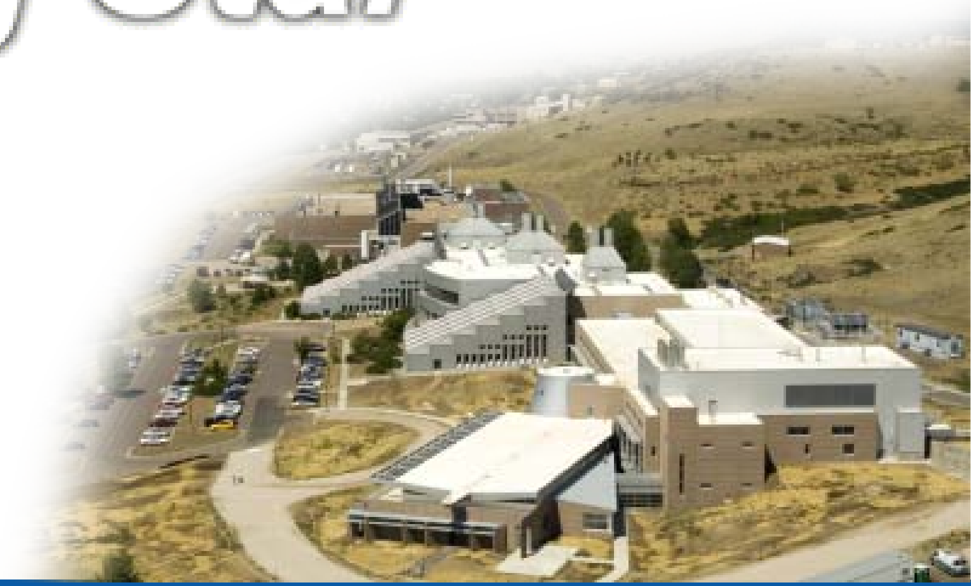
Golden, Colorado


Rising Star



NREL's "Rising Stars"

- Andy Aden
- Debbie Brodt-Giles
- Jason Cotrell
- Tony Markel
- Matthew Reese
- Charles Teplin
- Michael Woodhouse