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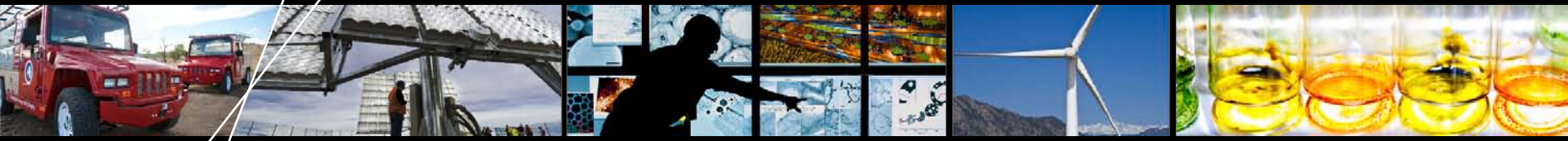
NATIONAL RENEWABLE ENERGY LABORATORY

Realizing a Clean Energy Future



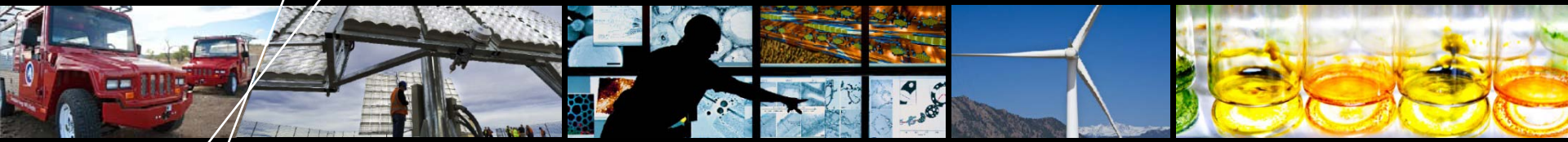
IEEE Energy Conversion Congress and Exposition 2012

September 19, 2012

Dr. Dan E. Arvizu

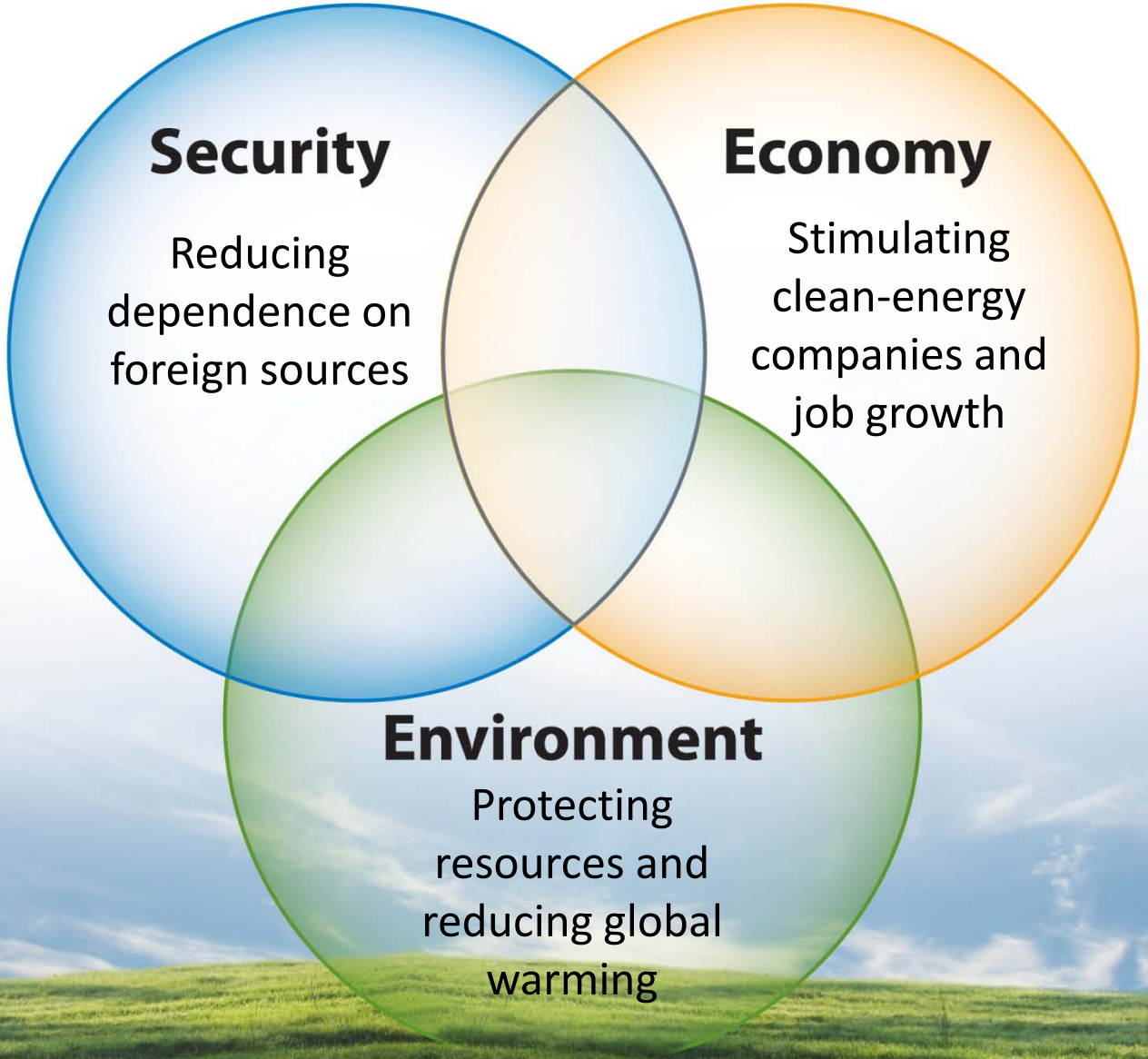
Laboratory Director

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Energy Context

National Energy Imperatives



A Profound Transformation is Required

Today's Energy System

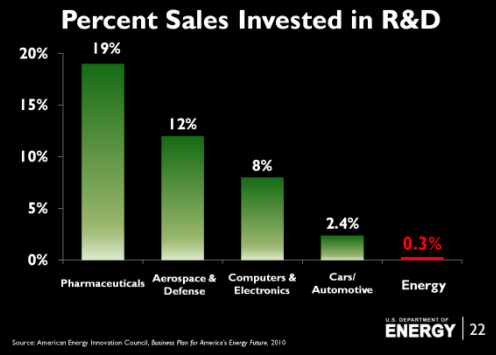
- Dependent on non-domestic sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Significant carbon emissions
- Role of electricity increasing

TRANSFORMATION

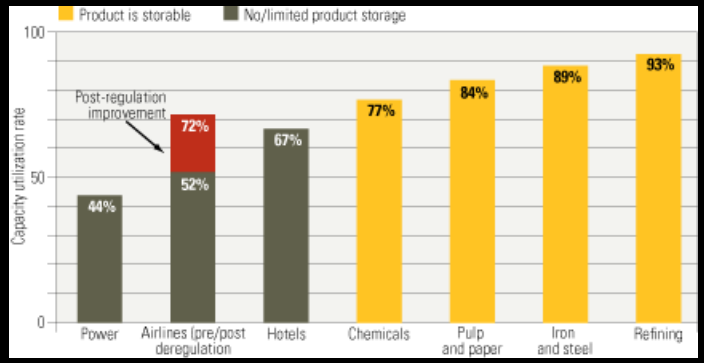
Sustainable Energy System

- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates economic development
- Accessible, affordable and secure

Energy Sector Challenges



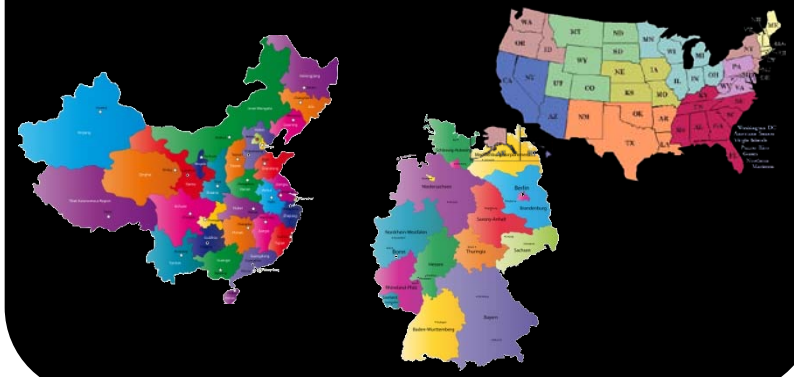
R&D Investment Drives Innovation



Asset Utilization

Capital Intensive with Long Life Cycles

National Strategies Driving Energy Market



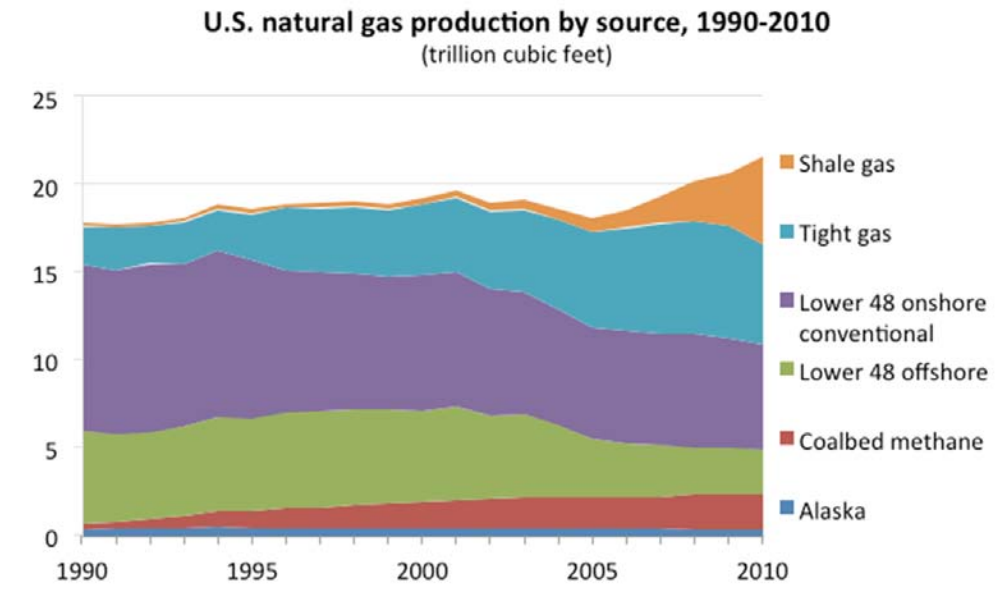
The Role of Natural Gas?

"We are in the midst of a natural gas revolution in America that is a potential game changer for the economy, environment and our national security—if we do it right."

—Tom Friedman

New York Times, August 4, 2012

Dramatic Change in US Gas Production



JISEA

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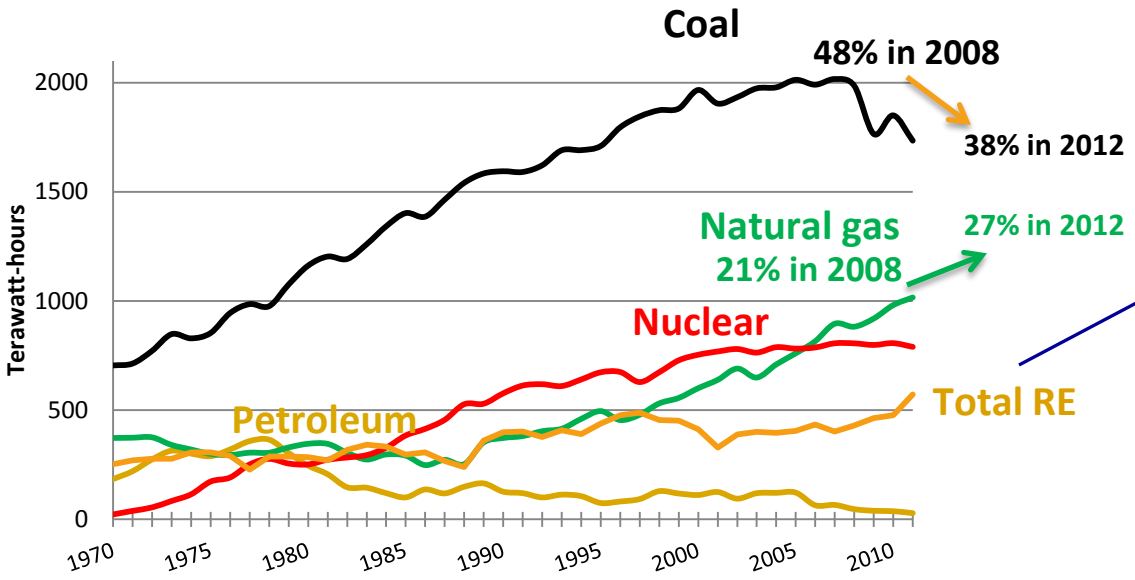
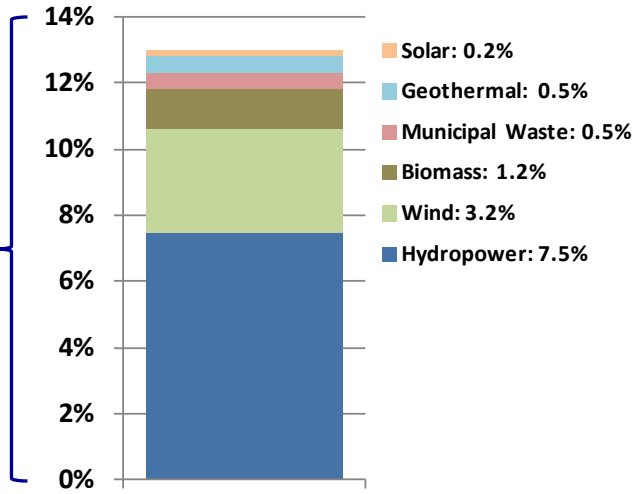
"Will it be a transition to a clean energy future or does it *defer* a clean energy future?" — Hal Harvey

U.S. Electric Sector Trends

U.S. Electric Sector Net Generation

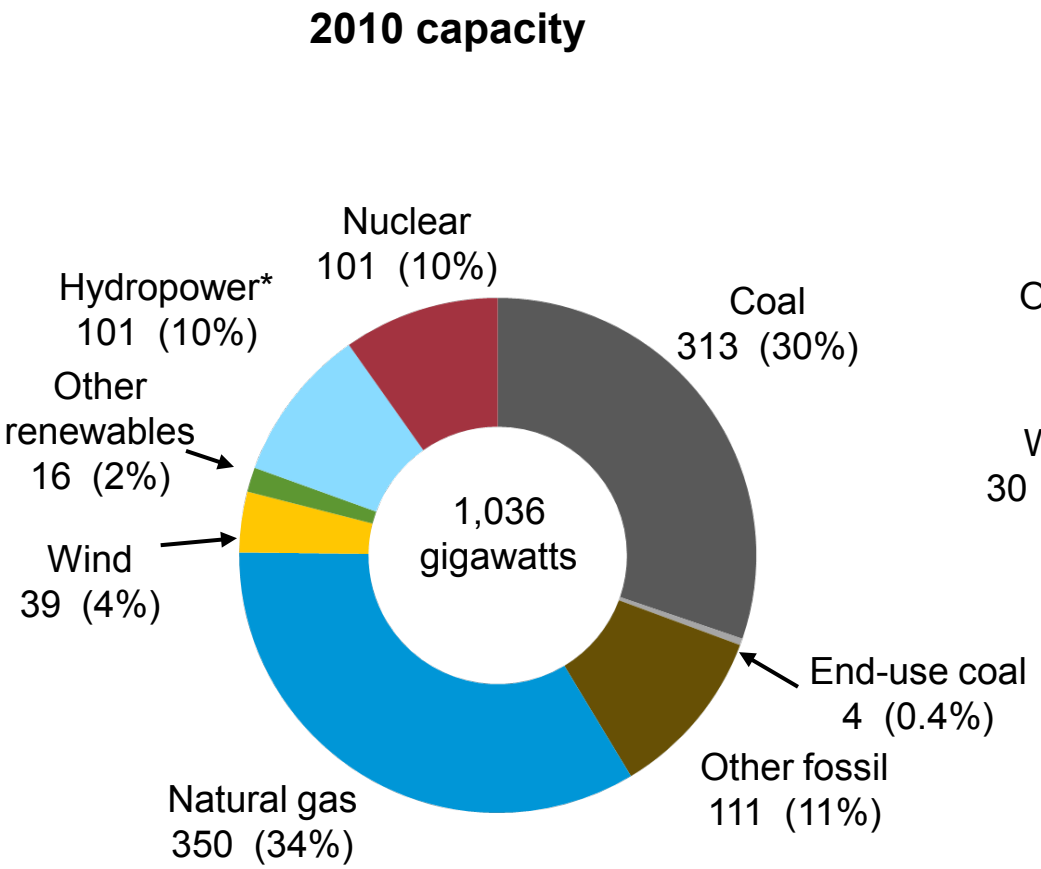


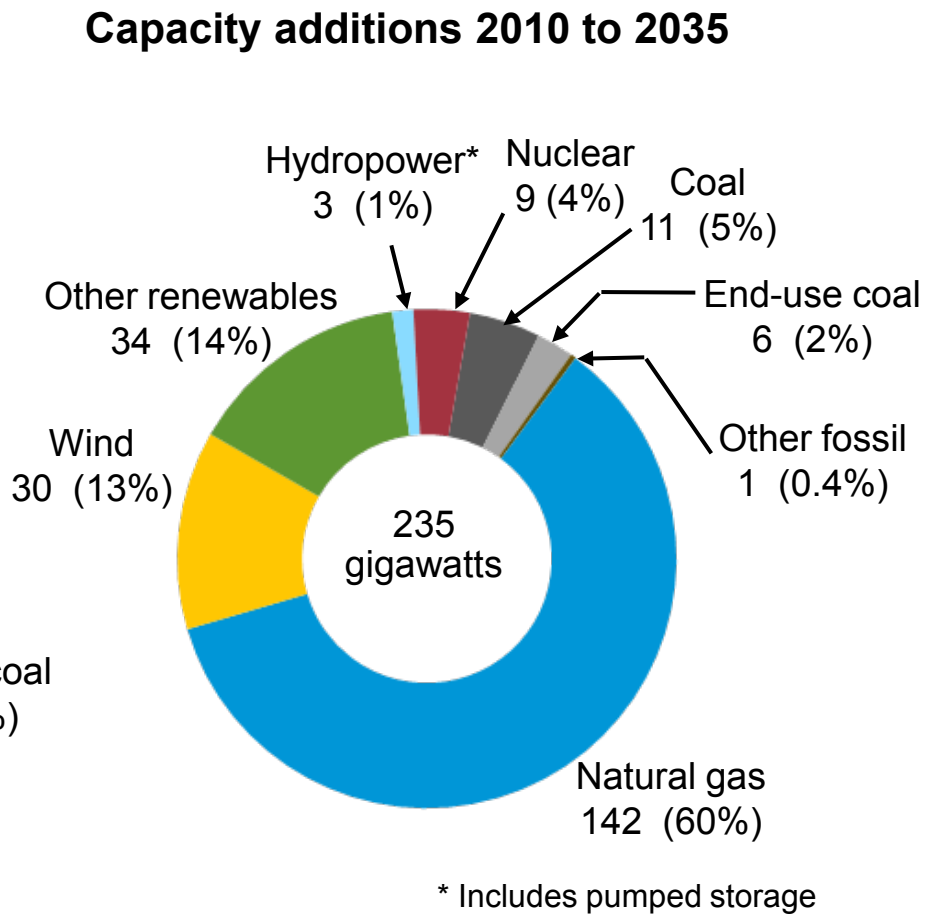
U.S. Renewable Generation



Source: EIA, Annual Energy Outlook 2012

Natural gas, wind and other renewables account for the vast majority of capacity additions from 2010 to 2035



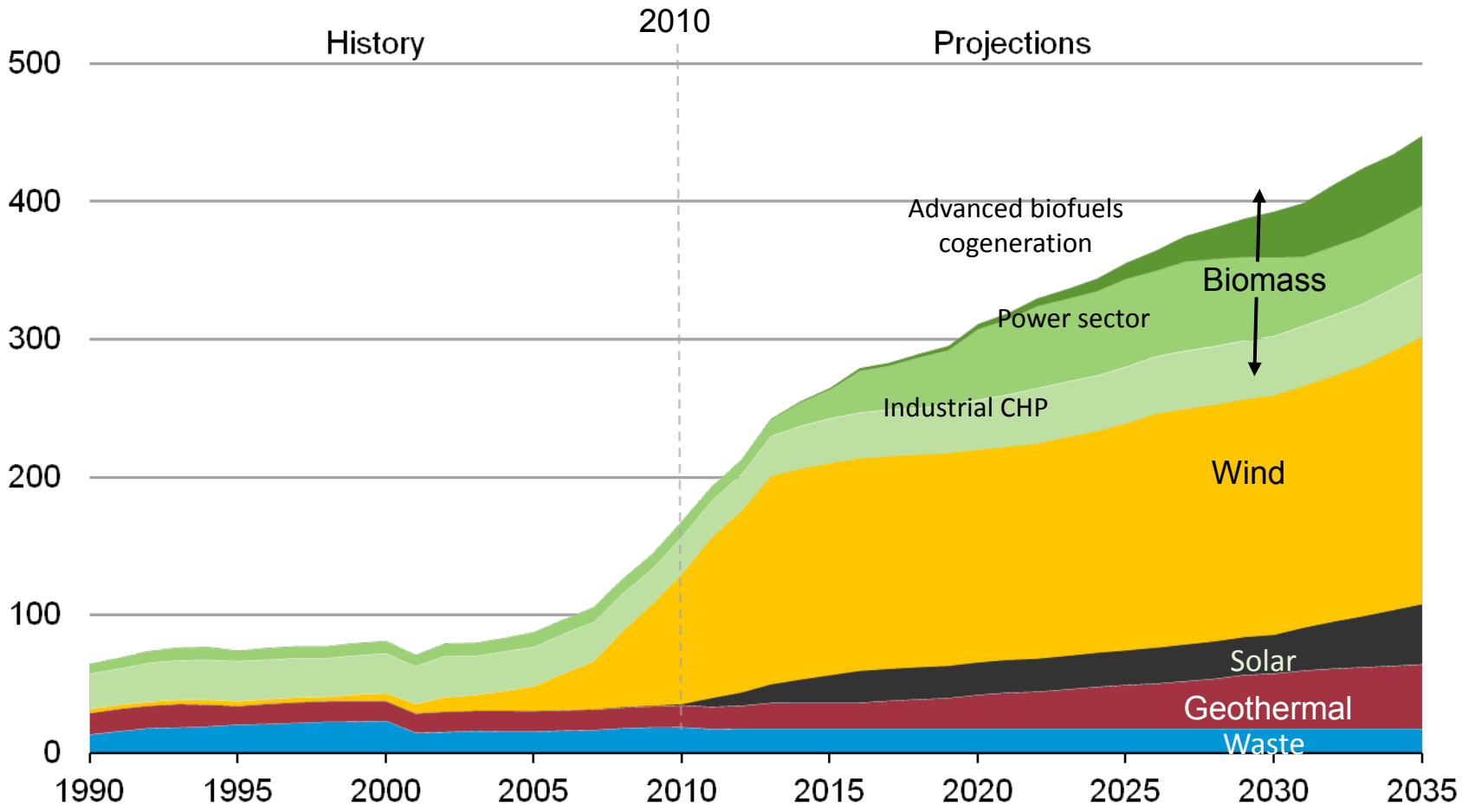


* Includes pumped storage

Source: EIA, Annual Energy Outlook 2012

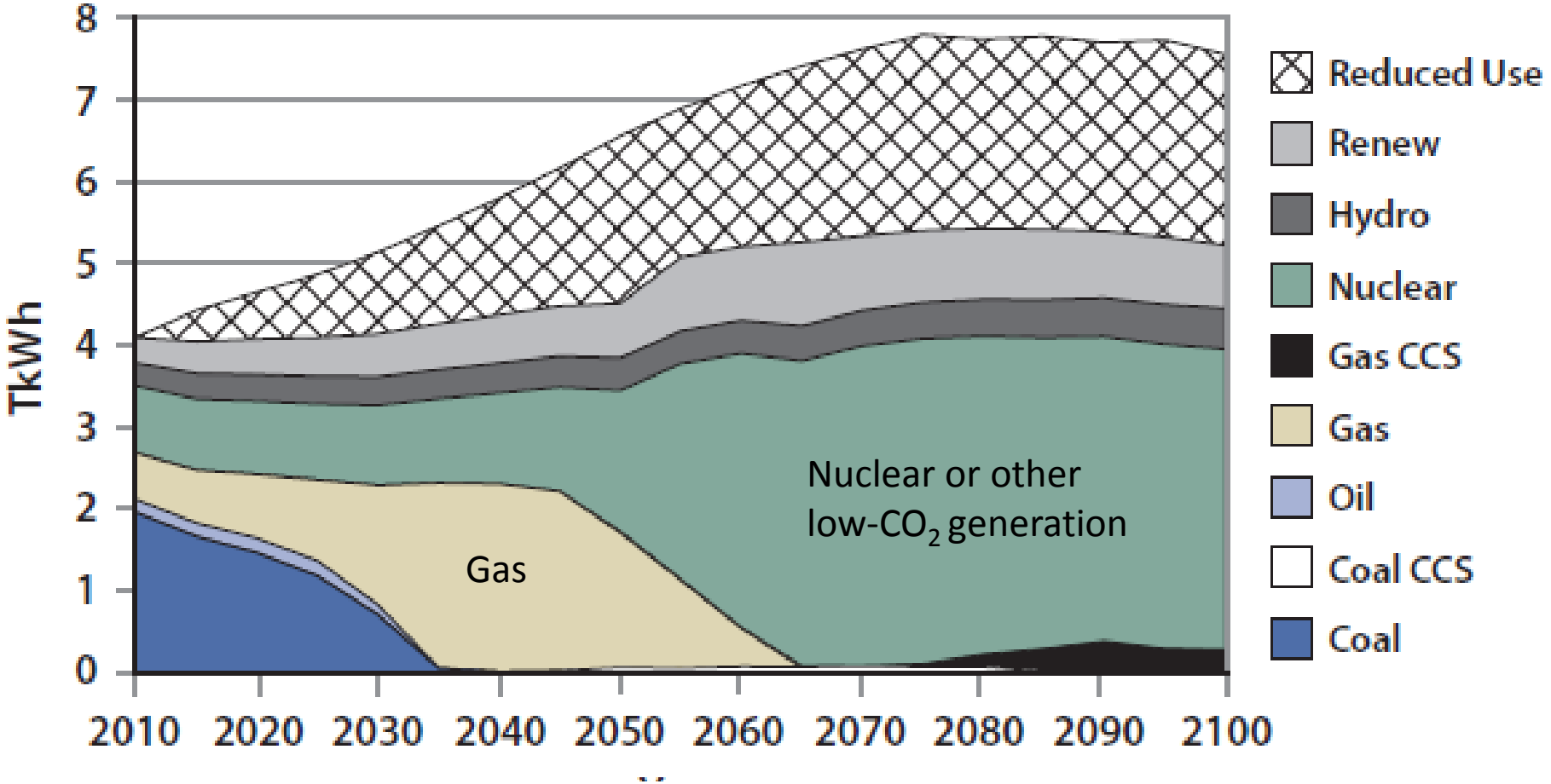
Non-hydro renewable sources more than double between 2010 and 2035

Non-hydropower renewable generation
Billion kilowatthours per year



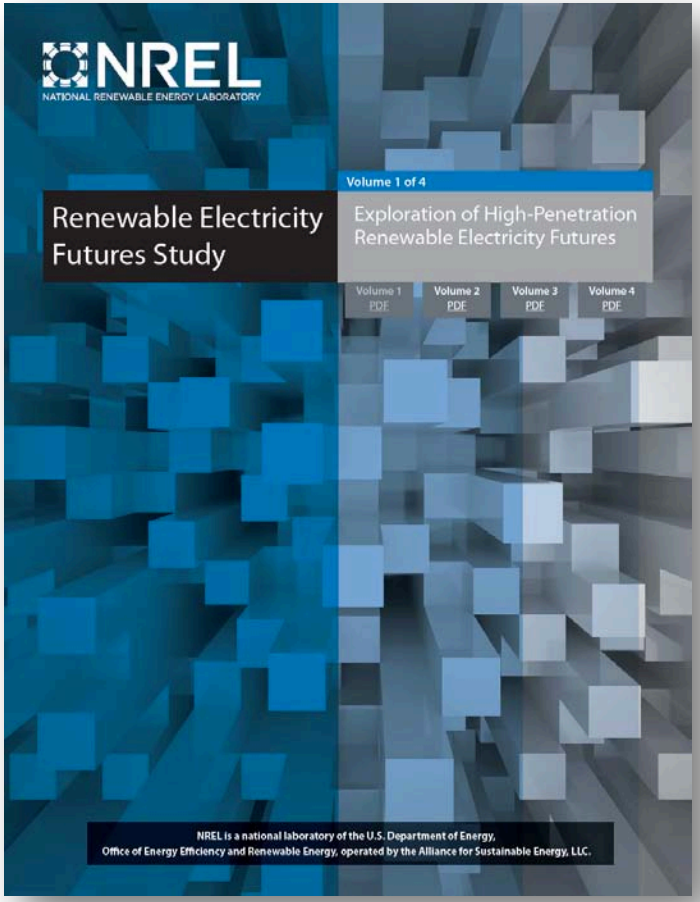
Source: EIA, Annual Energy Outlook 2012

MIT Future of Natural Gas Study



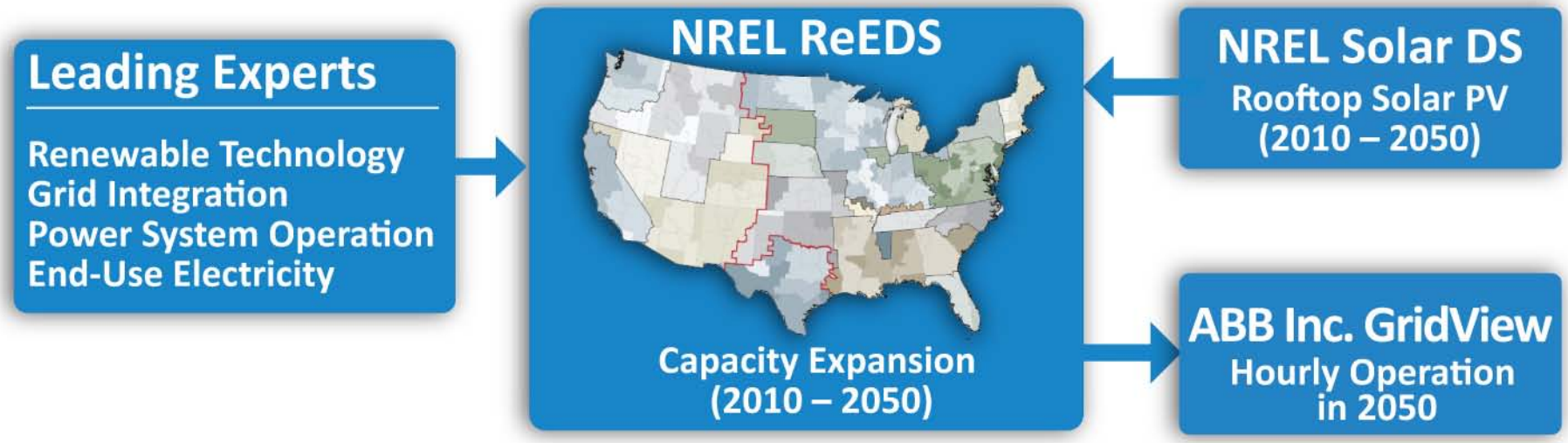
* Fig. 3.12 Energy Mix in Electric Generation under a Price-Based Climate Policy, Mean Natural Gas Resources and Regional Natural Gas Markets (TkWh) [reduced GHG 80% below 2005]

Renewable Electricity Futures Study



U.S. DOE-sponsored collaboration with over 110 contributors from about 35 organizations including national laboratories, industry, universities, and NGOs

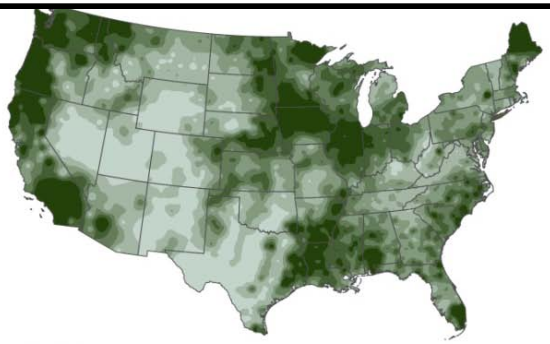
State of the Art Electric System Models

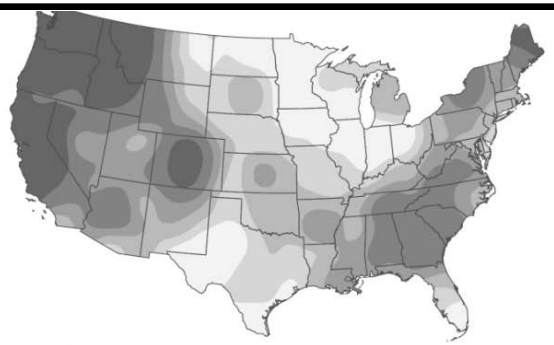


- Unprecedented geographic and time resolution for the contiguous United States
- Over two dozen scenarios of RE generation focused on 2050

Abundant Renewable Energy Resources

Biopower ~100 GW
- Stand-alone
- Cofired with coal

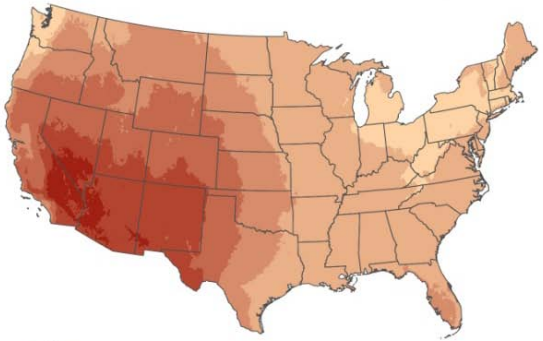


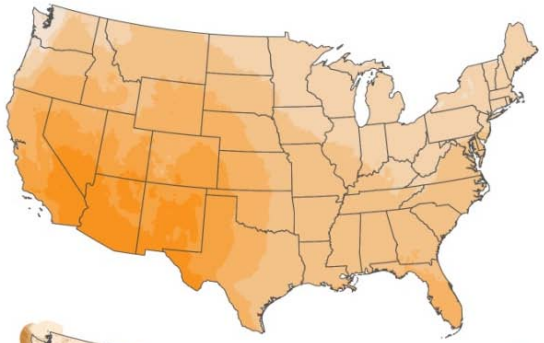


Hydropower ~200 GW
- Run-of-river

Solar CSP ~37,000 GW
- Trough
- Tower

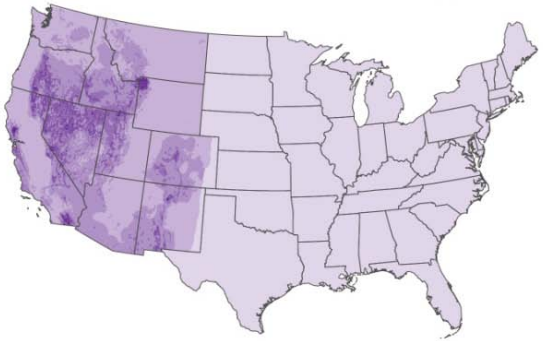
With thermal storage

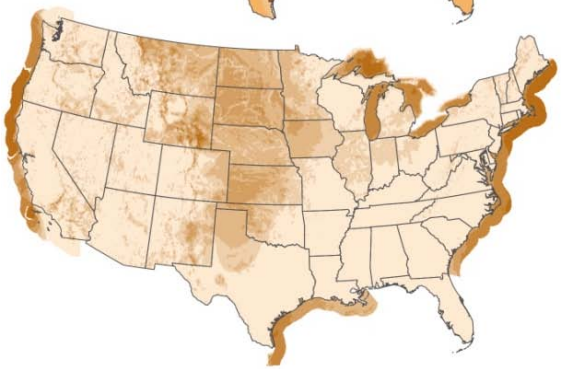




Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

Geothermal ~36 GW
- Hydrothermal



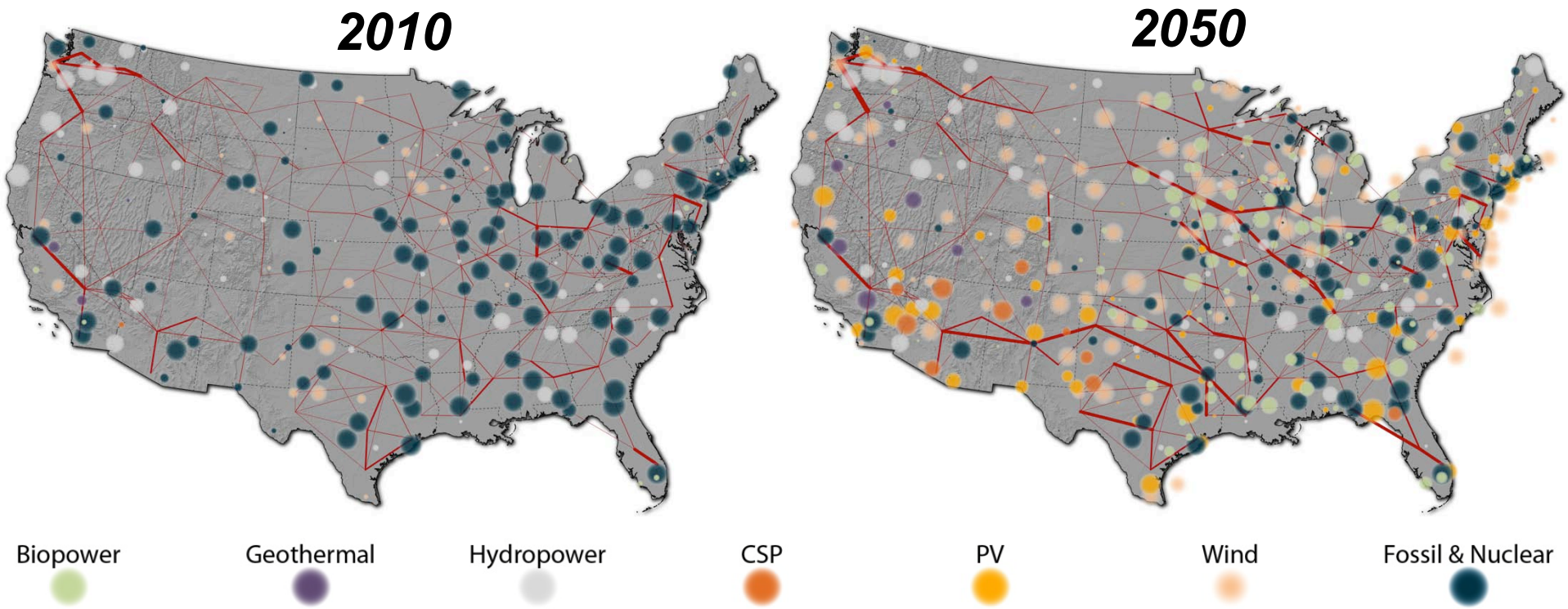


Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

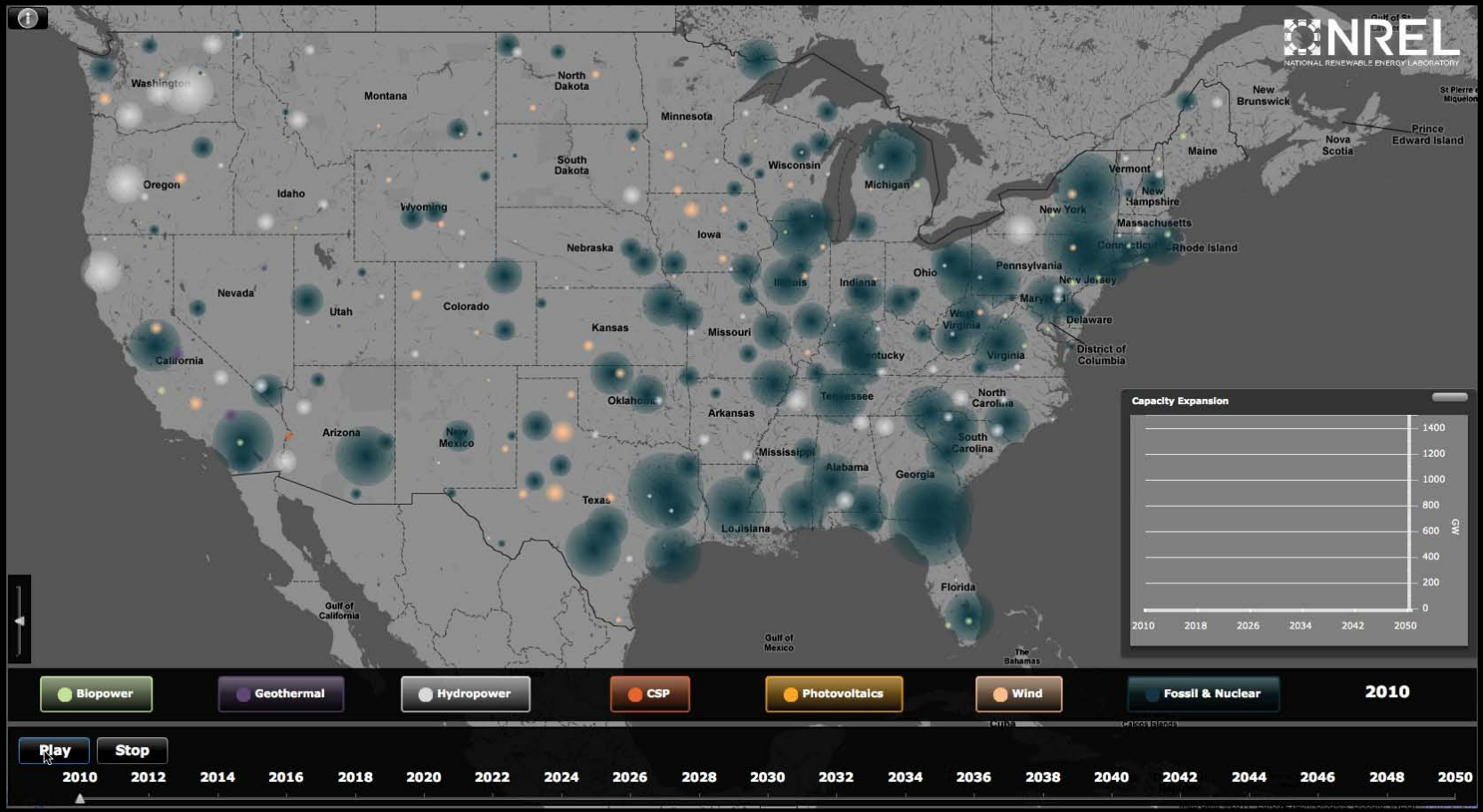
Darker Colors = Higher Resource

Geographic location, technical resource potential, and output characteristics are unique to each RE generation technology.

A Transformation of the U.S. Electricity System



RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country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Oregon
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Wisconsin
Michigan
Nebraska
Iowa
Nevada
Utah
Colorado
Kansas
Missouri
California
Arizona
New Mexico
Oklahoma
Arkansas
Texas
Louisiana
Mississippi
Alabama
Georgia
Florida
Illinois
Indiana
Ohio
Pennsylvania
New York
West Virginia
Virginia
North Carolina
South Carolina
Kentucky
Tennessee
Maryland
Delaware
District of Columbia
New Jersey
Vermont
New Hampshire
Massachusetts
Rhode Island
Maine
New Brunswick
Nova Scotia
Prince Edward Island
Gulf of California
Gulf of Mexico
The Bahamas
Capacity Expansion
1400
1200
1000
800
600
400
200
0
GW
2010
2018
2026
2034
2042
2050
Biopower
Geothermal
Hydropower
CSP
Photovoltaics
Wind
Fossil & Nuclear
2010
Play
Stop
2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050

Innovation, Integration, & Adoption

Reducing Investment Risk

- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing “partnering” facilities
- Provide analysis and expertise to inform decisions

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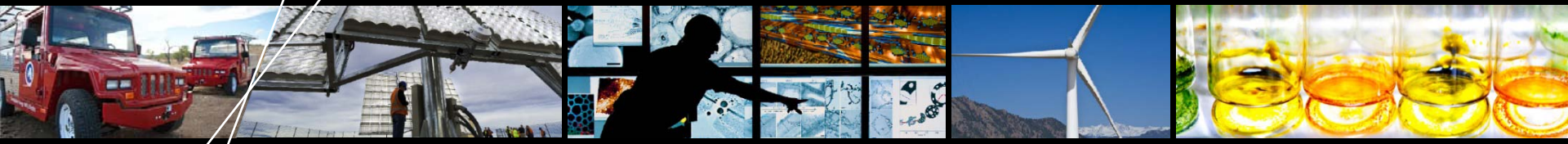
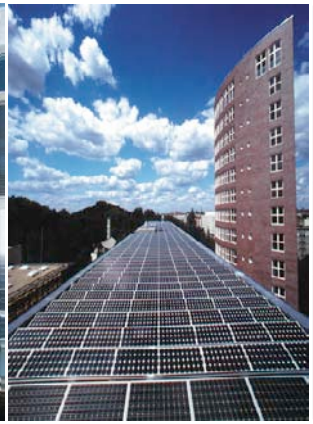


Status of the Technologies

Solar Electricity: *State of the Technology*

Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 4.0 GW
- U.S. Forecast: 22+ GWs in pipeline
- Costs. $3 to $7/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

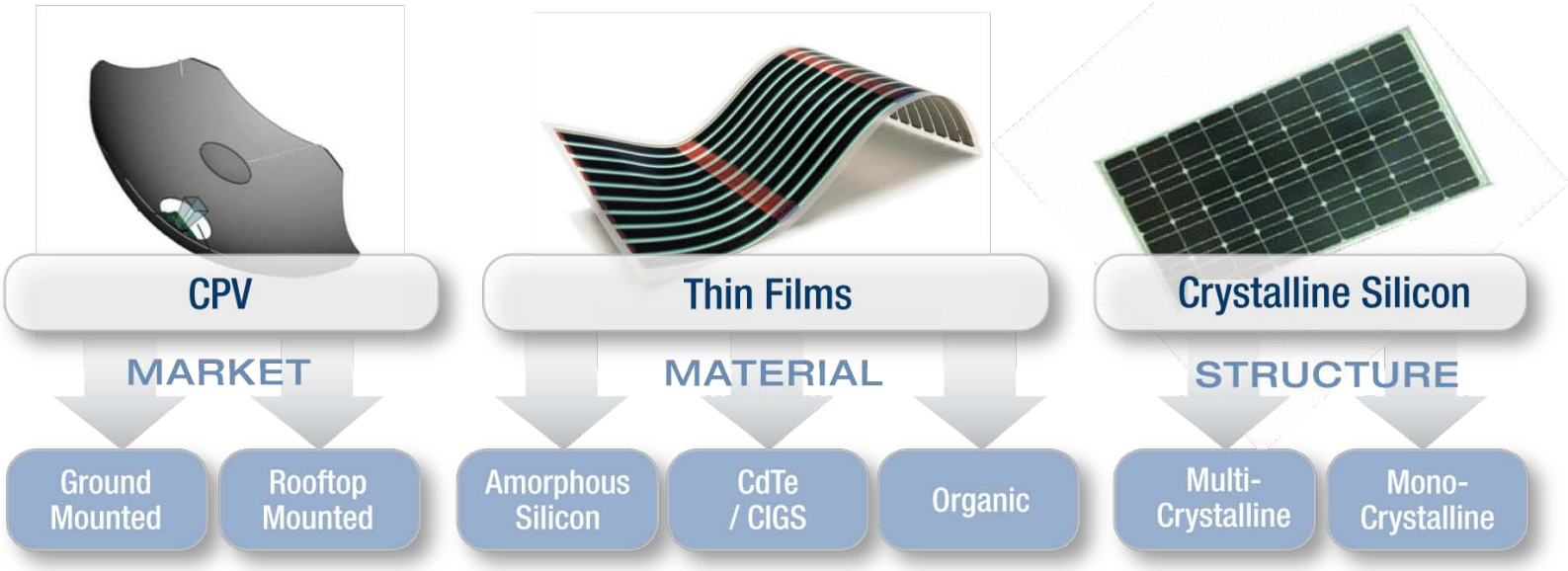
Solar Thermal Electric (CSP)

- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S Capacity: 0.5 GW
- U.S. Forecast: ~6 GWs in pipeline
- Costs. $4 to $8/W: *LCOE 12 to 20 ¢/kWr
- Technologies: Conversion; parabolic troughs, central receivers, dish. Storage; thermal, up to 15 hours.

*With federal incentives; e.g. the FTC.

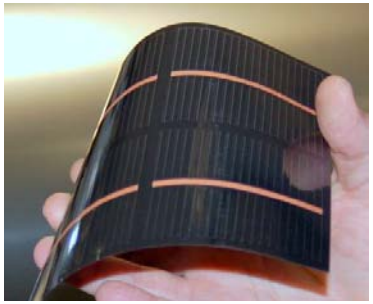
Updated: April 2012
Source: GTM/SEIA : U.S. Solar Market Insight Q4 2011 & 2011 Year-in-Review

Multiple Promising PV Technologies



20x-100x

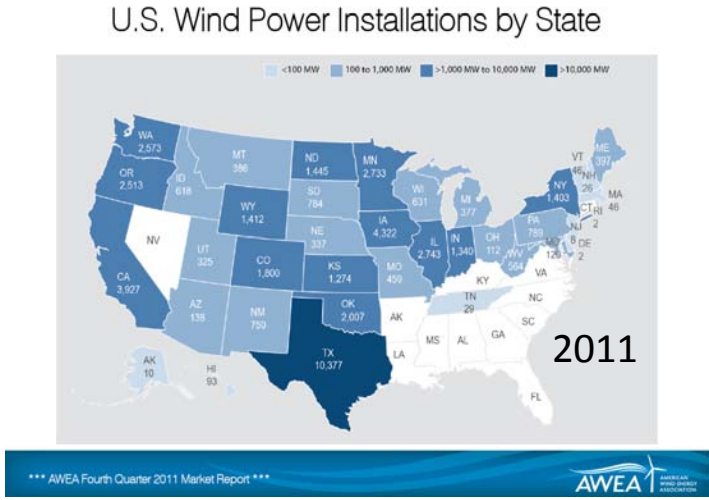
500x



Cu(In,Ga)Se_2 ~ 1-2 um

c-Si ~ 180 um

Wind energy: *State of the Technology*



- Costs: 7-10 cents/kWh LCOE*
- Installed wind project cost = $2,155/kW
- 1.5-3.0 MW commercial turbines are typical
- 10 MW prototype machines in development
- Direct drive generators more common
- Variable speed and grid-friendly operation
- Technologies targeting offshore wind markets

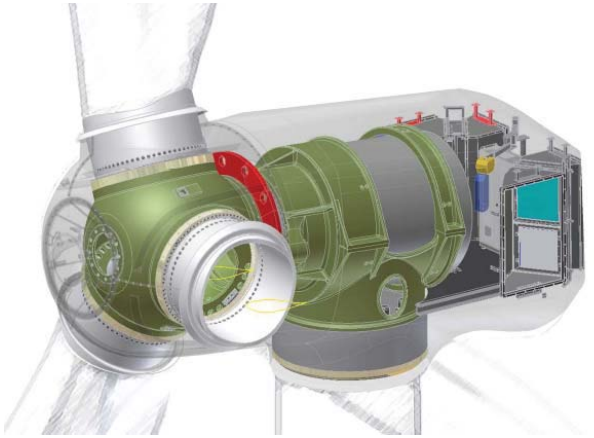
- U.S. installed capacity = 46.9 GW (12/2011)
- 38 of 50 states have utility-scale wind with 14 states > 1,000 MW installed
- Over 8.3 GW currently under construction
- U.S. wind capacity represents more than 20% of the world's installed wind power
- U.S. wind percentage of electricity is over 2.3%
- Over 400 manufacturing facilities across the U.S. make components for wind turbines

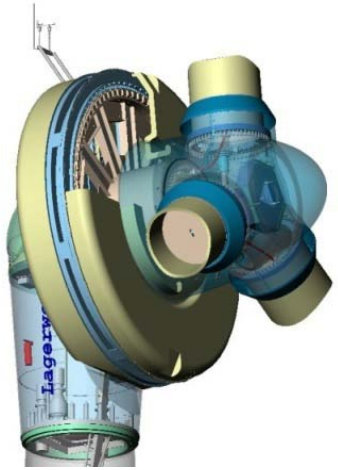
Updated: April 2012

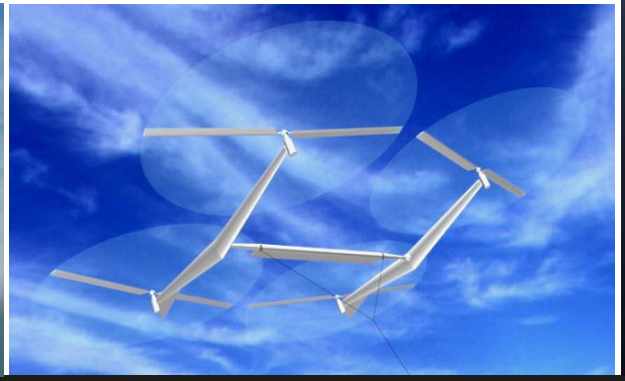
* Estimate for utility-scale wind, class 4 wind sites, no subsidies

Wind Technology Innovation

- Modular large components – blades, drivetrains, and tall towers
- Advanced drivetrain power conversion systems – superconducting direct drive generators
- Flexible, ultra-large rotors and systems
- Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation
- Floating offshore wind turbines
- Airborne wind power systems







Biofuels: *State of the Technology*

Current Status:

U.S. produced 13.5 billion gallons of ethanol and 1.1 billion gallons of biodiesel (2011)

Biorefineries:

- 219 commercial corn ethanol plants
- 180 biodiesel refineries
- 28 cellulosic ethan

Cost goal:

Cellulosic ethanol—cost parity with gasoline by 2012

Major Technology Directions:

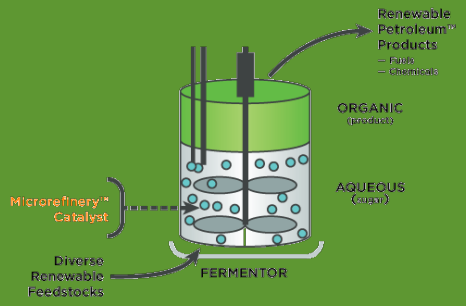
- Foundational Science: Enzymes, fermentation, understanding biomass and cell composition
- Feedstocks: Sustainable feedstock production systems
- Pretreatment & Conversion R&D: Biochemical and thermochemical conversion processes
- Advanced Biofuels and Algae: Broadening RD&D beyond cellulosic ethanol to address “drop in’ and high-energy content fuels from algae and other biomass resources

Updated: 4/2012

Biofuels Innovation

New conversion technologies are being developed, offering the possibility of revolutionary, high volume methods for producing biofuel hydrocarbon fuels for our trucks, trains, ships, and aircraft . . .

Biological Conversion



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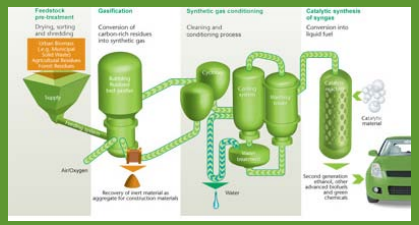
AMYRIS

Chemical Catalytic Conversion



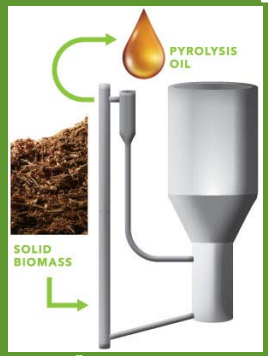
VIRENT
IT'S ABOUT TIME

RENTECH®

ClearFuels®
TECHNOLOGY, INC.

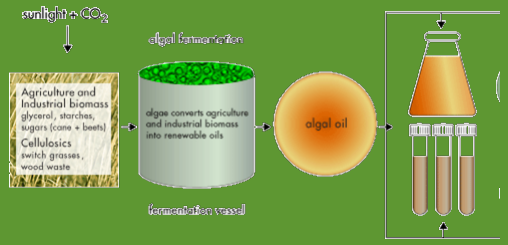
Enerkem

Pyrolysis/Bio-Oil Pathways



Envergent
TECHNOLOGIES
A Honeywell Company

Heterotrophic Algae Conversion



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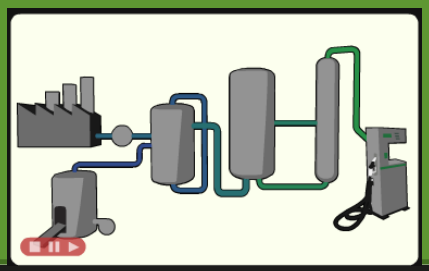
MARTEK
life enriched™

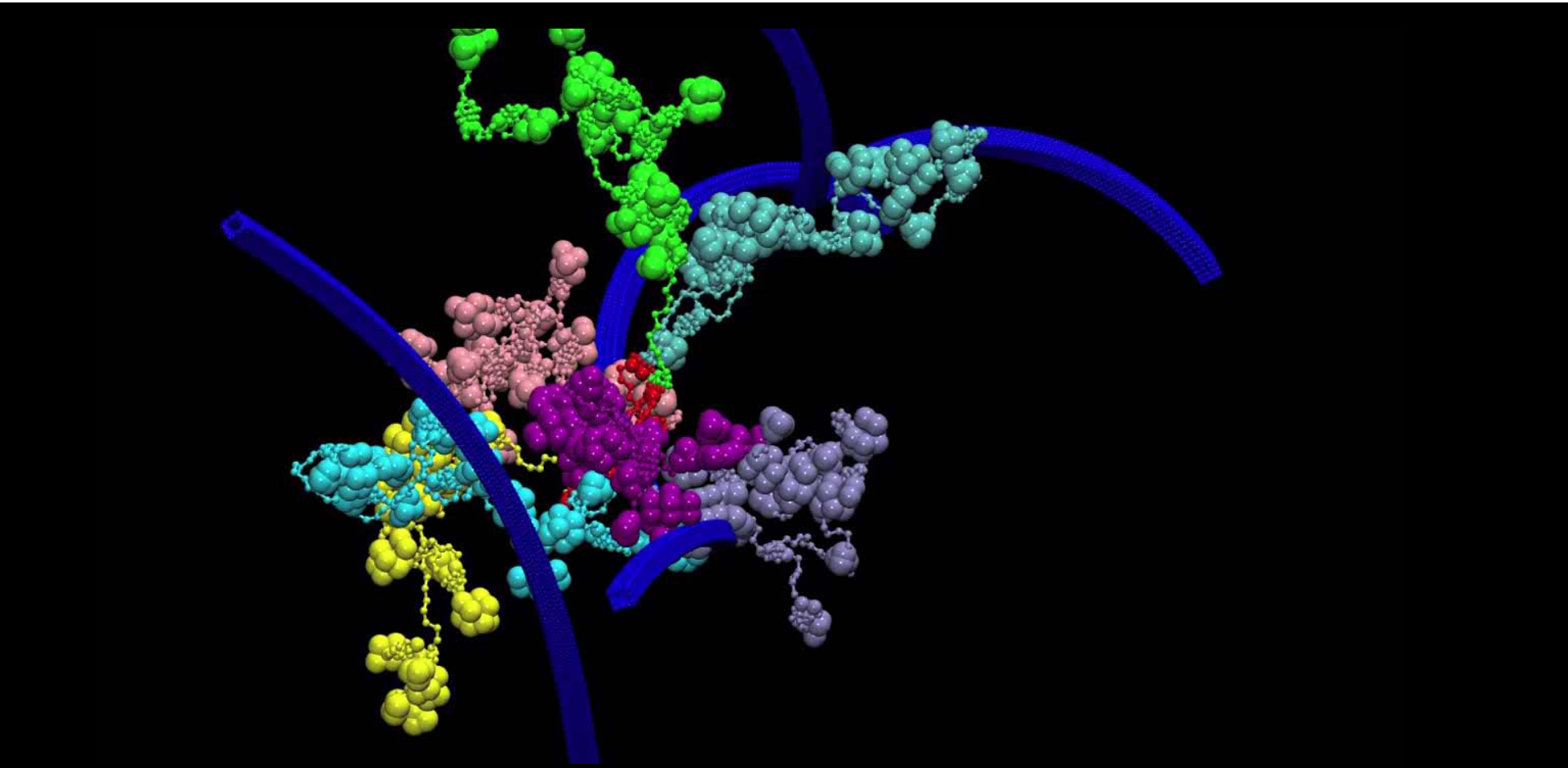
Hybrid Conversion Technologies



LanzaTech

coskata

Forward Progress: Infrastructure-Compatible Biofuels



A computer simulation of the process used by some very efficient cellulose degrading bacteria to deconstruct plant cell walls.

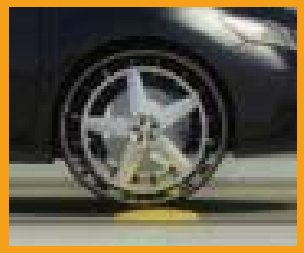
Transportation Innovation

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (power electronics & energy storage)

Start/stop

Regenerative braking



Low rolling resistance tires

Electric infrastructure

Electric powered steering

Light weighting

8 speed transmissions

Turbocharging, direct fuel injection, advanced combustion

Variable cylinder mgmt

Improved aerodynamics

Diesel powered & or Alternative Fuels, H2

Buildings Innovation

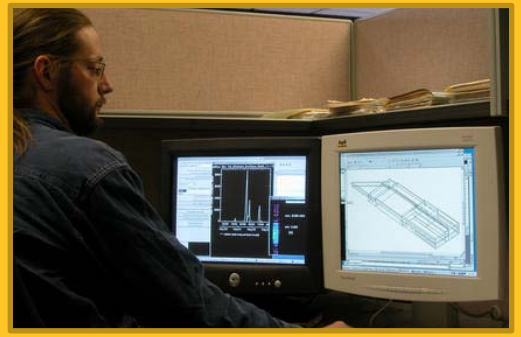
High Performance Buildings

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization & simulation Tools

Efficiency/Integration Innovation

Buildings

- **Whole building systems integration**
- Computerized building energy optimization tools
- Advanced HVAC (Heating Ventilating and air conditioning)
- Cost effective ultra energy efficient retrofits

Grid Integration

Interconnection Standards

- IEEE Standards Development
- Standards Testing and Validation

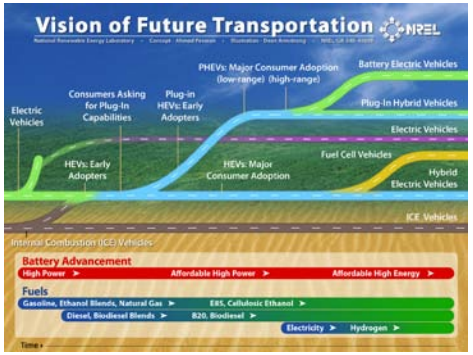
Smart-Grid Data Hub

RE Grid Integration

- Power Electronics for Interconnection monitoring and control
- Grid-to-vehicle interface

Advanced Vehicles

- Fuels utilization
- Component technologies
- Electric vehicle-to-grid interface



Energy Systems Integration Concept

System Models & Simulations
- Scalable, dynamic models
- Rich regional detail

Measured & Modeled Data
- Common Data Platform
- Robust Measured Performance Data Sets

Energy Systems Modeling

Technology & Component R&D

Energy Systems Informatics

Experiment, Test & Validate

Power System Innovations
- Interfaces & Controls
- Materials
- Test Methods
- Hybrid Systems & Storage

Experimental Facilities
- MW-Scale HIL Capability
- Validate communication & controls system interfaces

Suppliers *Design* *Prototype* *Deploy* **Users**

Business Sensitive

Forward Progress: Energy Systems Integration at All Scales

NREL is working with the Sacramento Municipal Utility District on visualizing impact of DG deployments.

To achieve a clean energy vision, we must…

Invest in innovation

Invent the future we desire

Improve access to capital

Partner on a global scale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