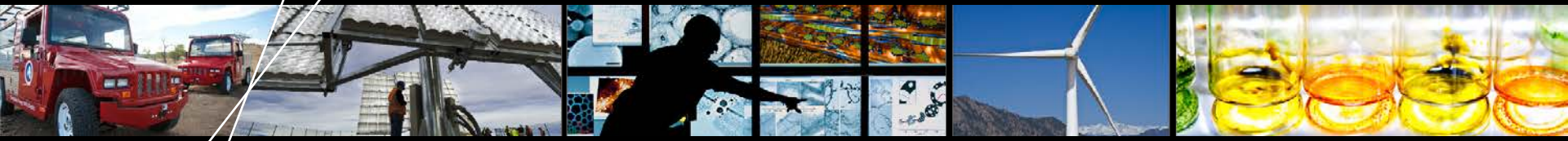
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Renewable Energy in an "All-Of-The-Above" World



RENEW Wisconsin Policy Summit

January 10, 2014

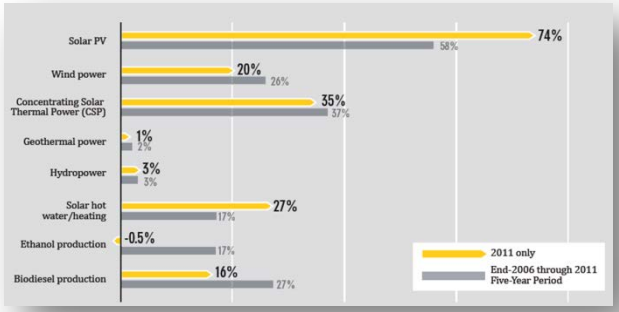
Dr. Dan E. Arvizu

Laboratory Director

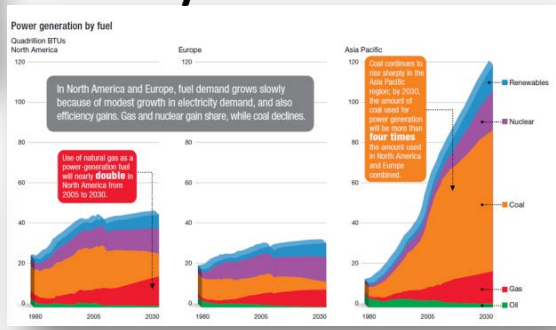
Global Dynamics in the Energy Landscape

- Renewable industry rapid growth
- Changing energy demand profile
- Fiscal challenges dominate policy
- Natural gas impacts energy landscape
- Infrastructure investment required

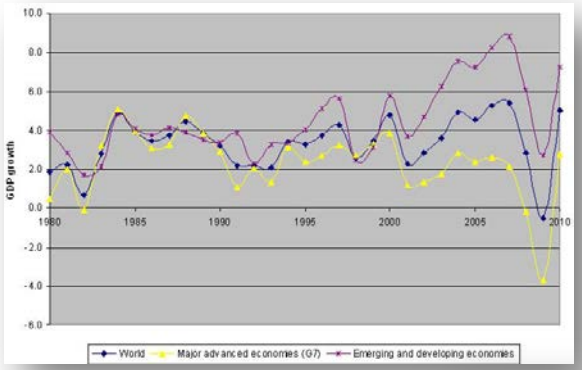
Annual RE Capacity Growth Rate



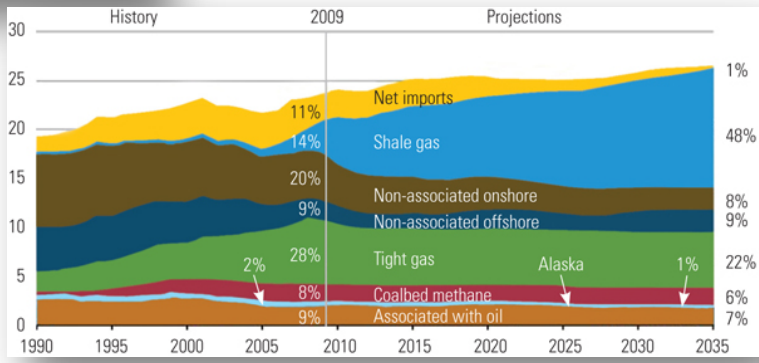
Electricity Demand to Grow



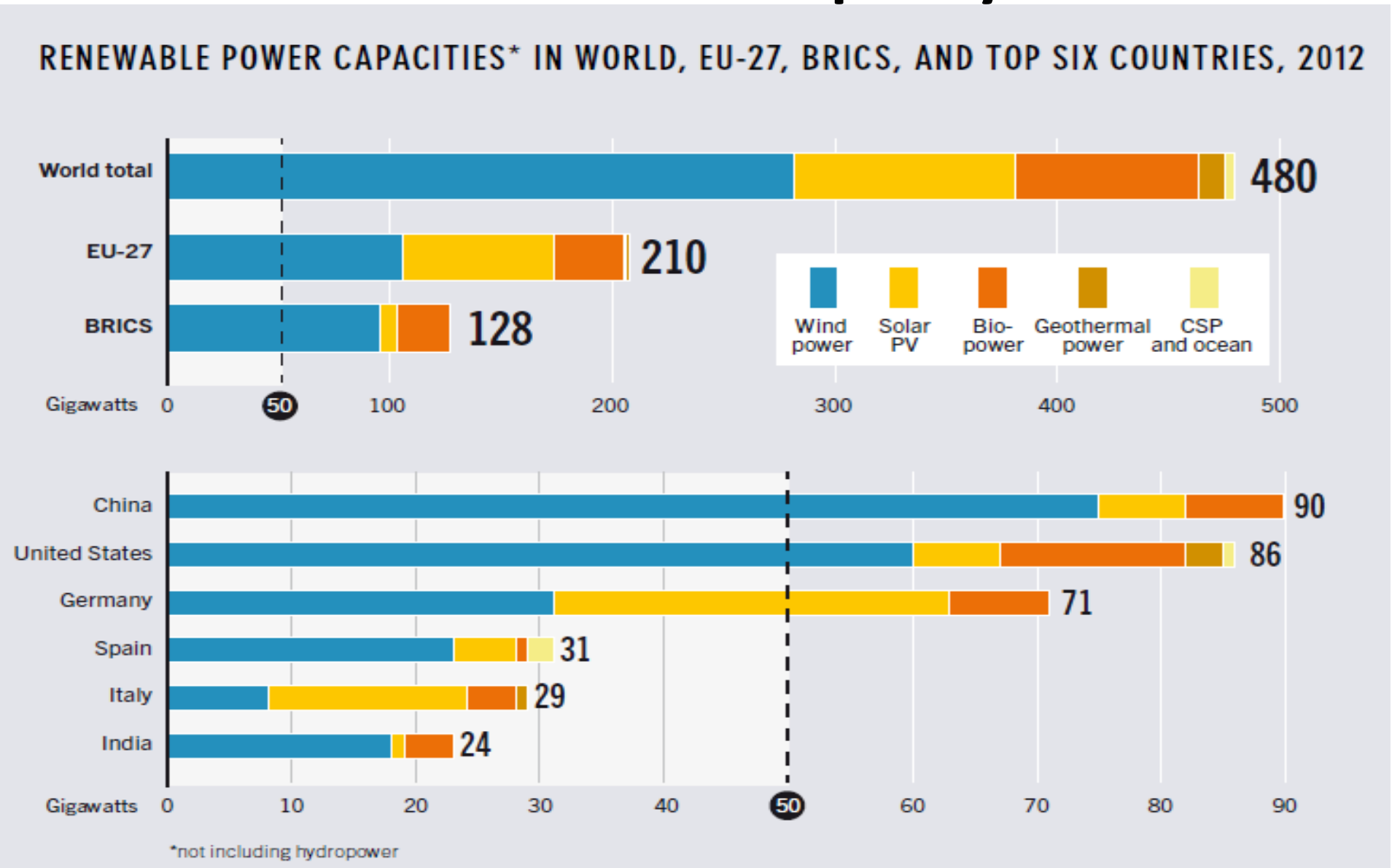
Global GDP Fluctuation



Natural Gas Will Grow

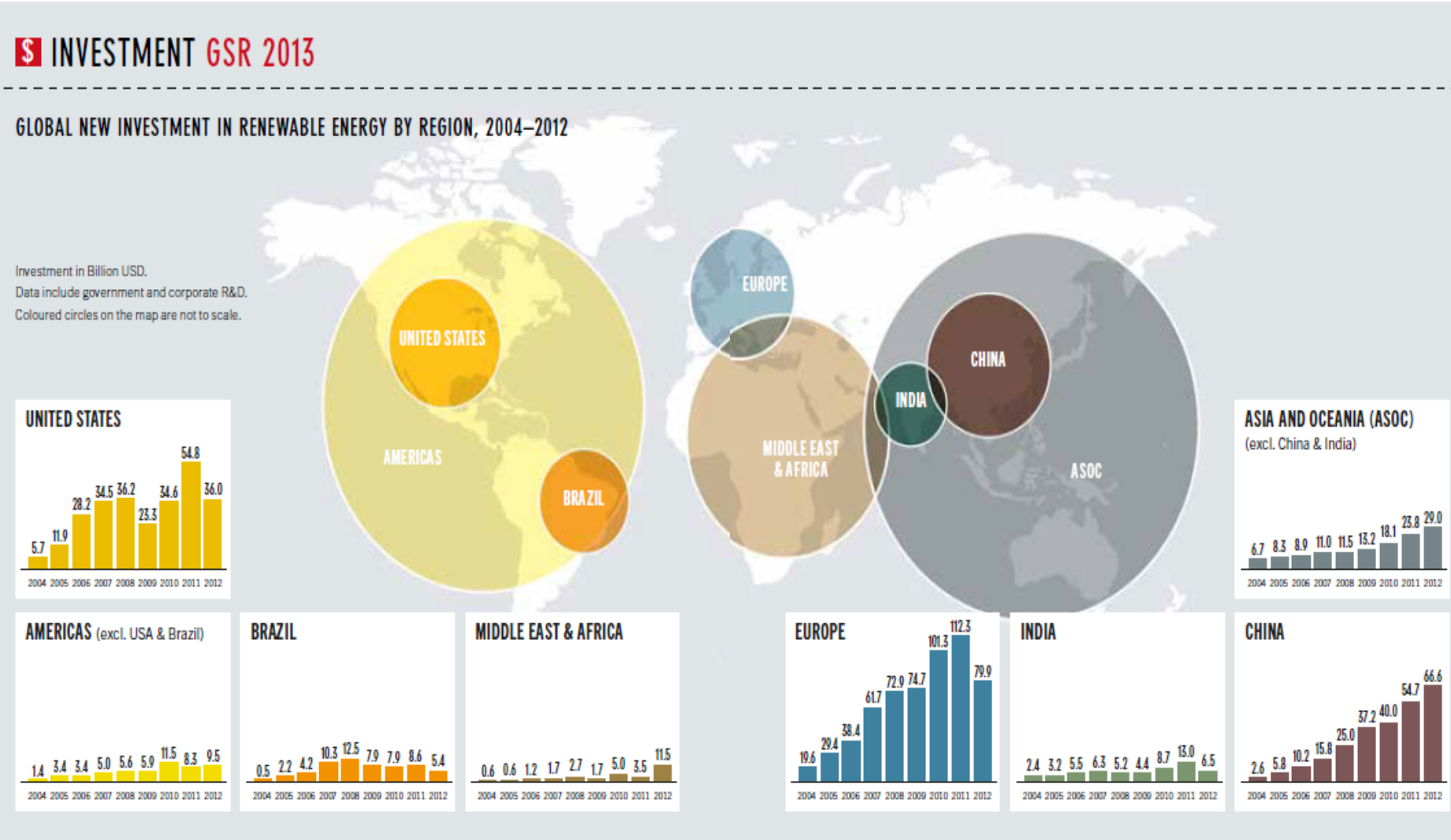


Worldwide Renewable Capacity

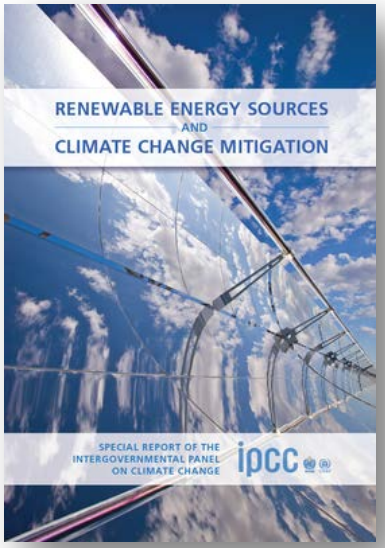


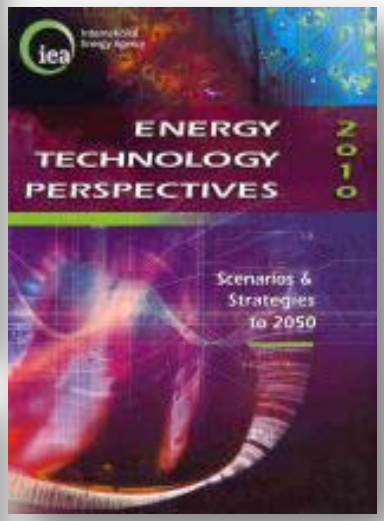
Source REN21 *Renewables 2013 Status Report*
http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/KeyFindings_2013_lowres.pdf

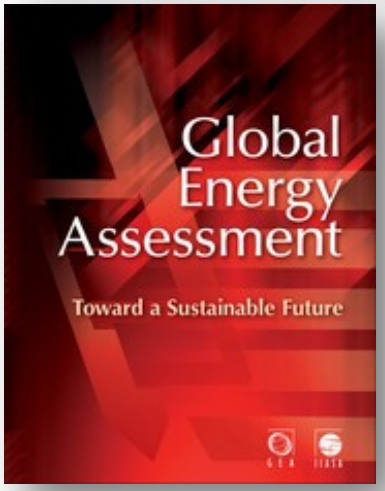
Global Investment 2013

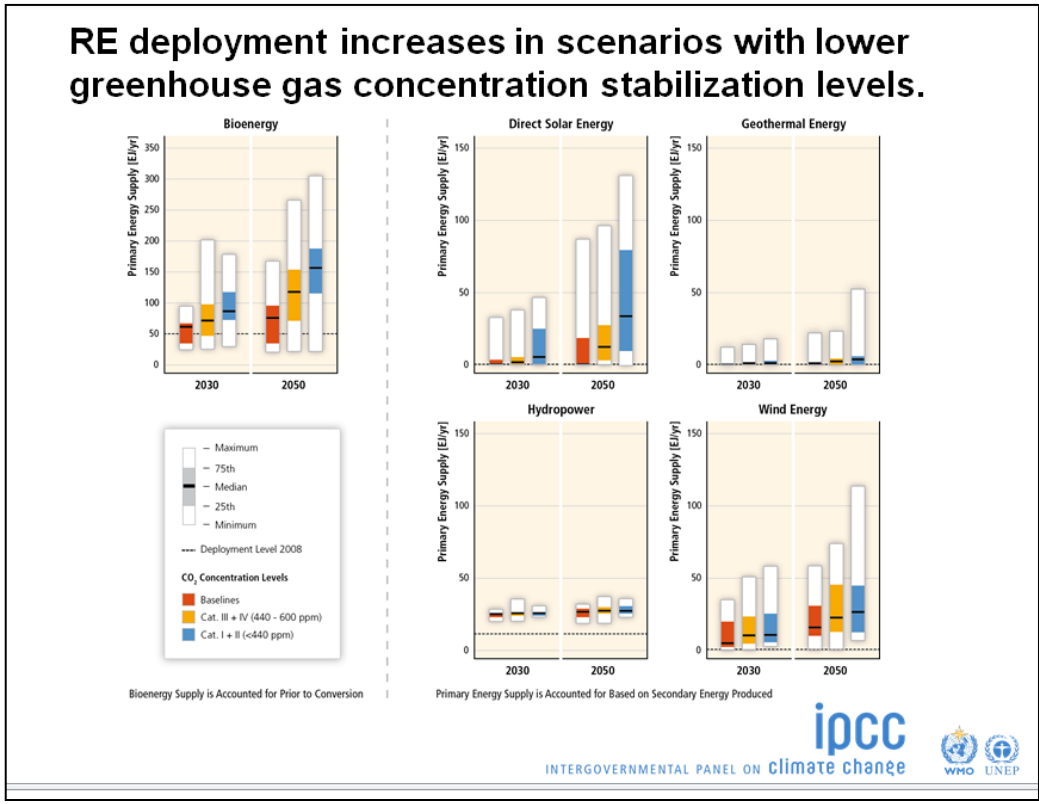


Global Assessments of Renewable Energy Potential



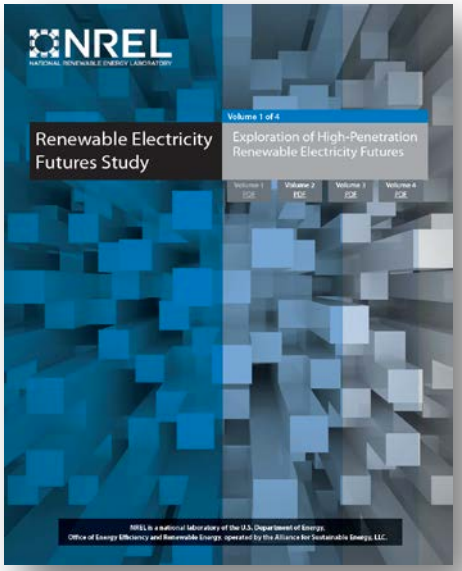


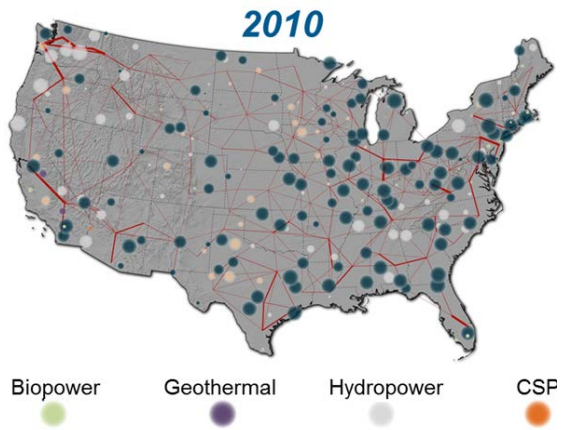


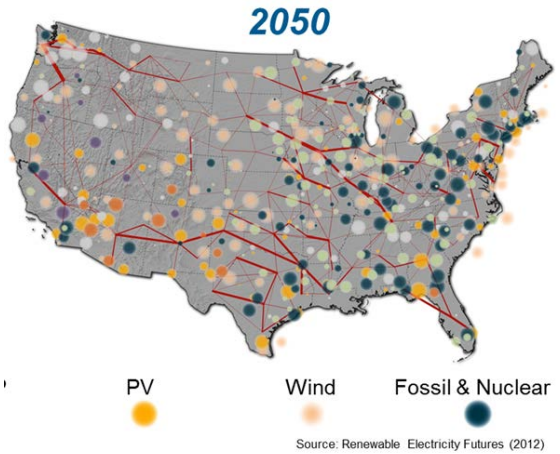


Technical potential for renewables is enormous.

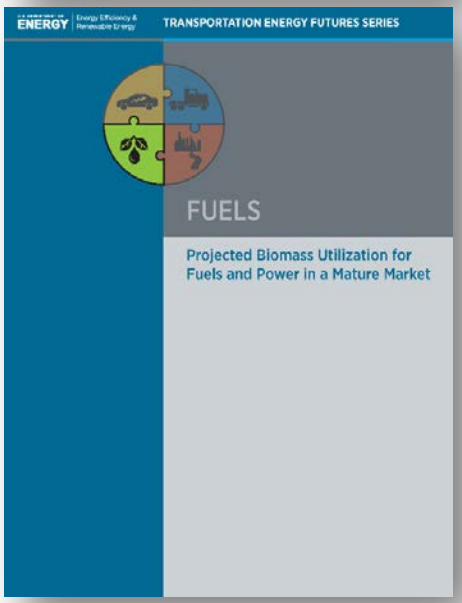
Comprehensive Studies Validate Opportunity for U.S. Renewables

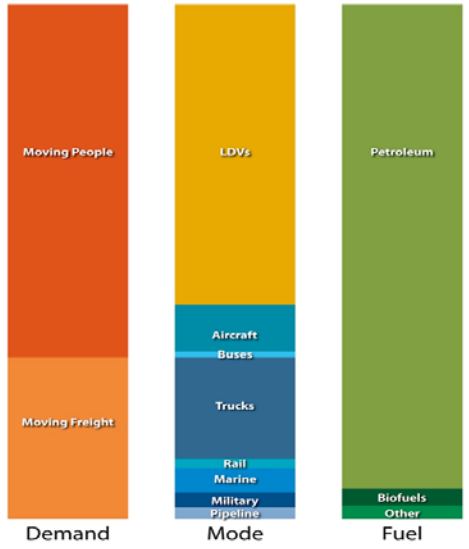


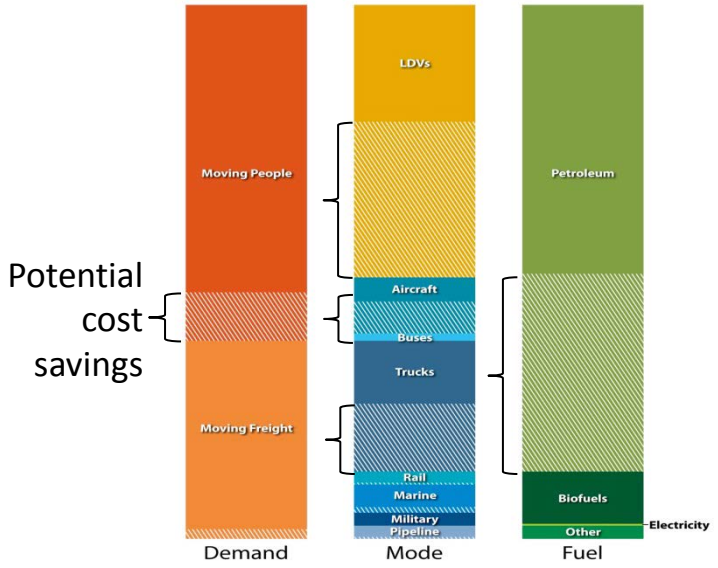




Source: Renewable Electricity Futures (2012)



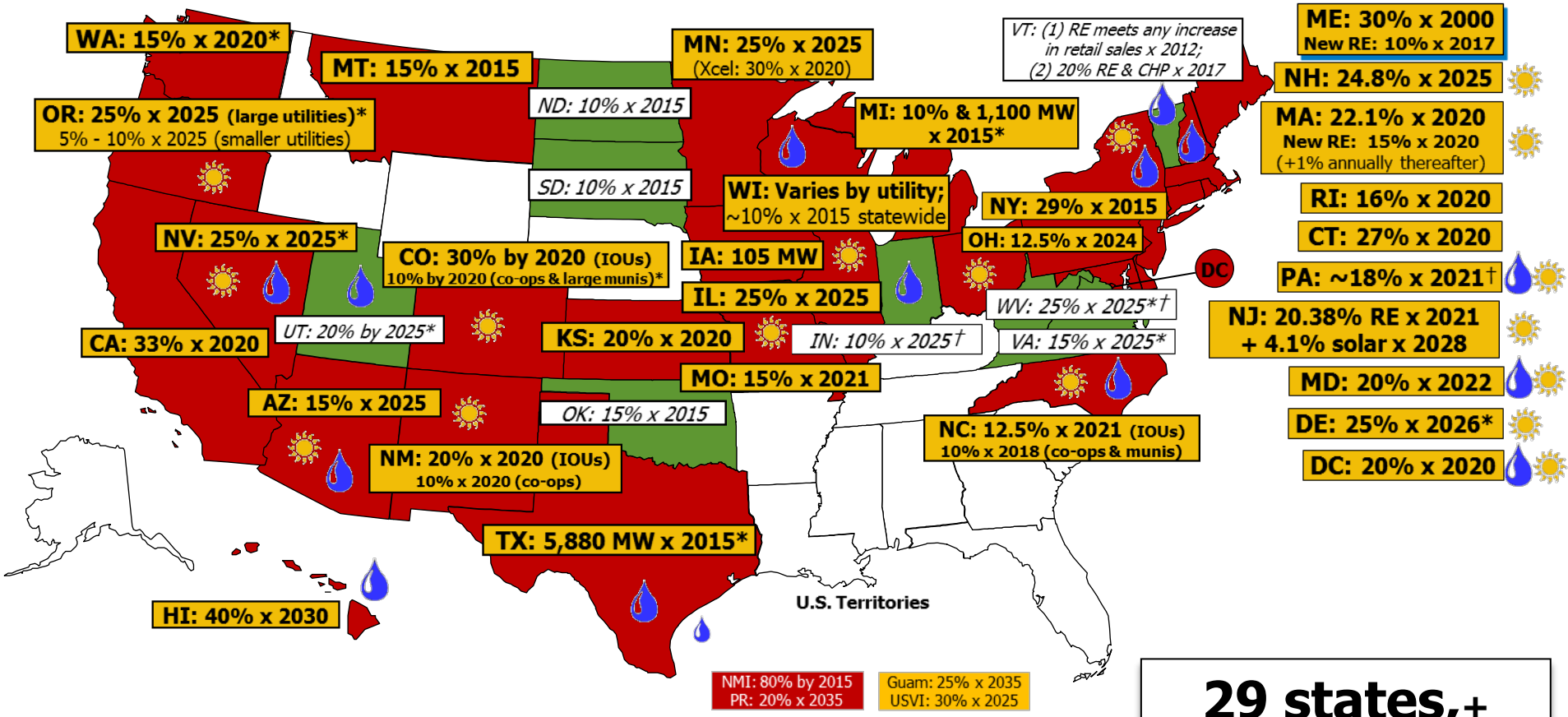




Not "*Can it be done*" but "*Here's how to do it*"

- Examination of Potential Benefits of an Energy Imbalance Market in the Western Connection
- Mobilizing Public Markets to Finance Renewable Energy Projects: Insights from Expert Stakeholders
- Using Economics to Determine the Efficient Curtailment of Wind Energy
- PV Pricing Trends: Historical, Recent and Near-Term Projections
- The Western Wind and Solar Integration Study Phase 2
- Beyond Renewable Portfolio Standards
- An Analysis of the Impact of Balancing Area Cooperation on the Operation of WECC and the Compounding Effect of Wind and Solar Generation
- An Analysis of Concentrating Solar Power with Thermal Energy Storage in a California 33% Renewable Scenario
- Transmission Planning Process and Opportunities for Utility-Scale Solar Engagement within the Western Electricity Coordinating Council
- Western Wind and Solar Integration Study

Renewable Portfolio Standard Policies



Renewable portfolio standard

Renewable portfolio goal

Solar water heating eligible

Minimum solar or customer-sited requirement

* Extra credit for solar or customer-sited renewables

† Includes non-renewable alternative resources

29 states,+
Washington DC and 2 territories,have Renewable Portfolio Standards
(8 states and 2 territories have renewable portfolio goals).

www.dsireusa.org / March 2013.

The New Frontiers: Integration and Scale

- Integration of high-penetration renewables requires enhanced system-wide flexibility and new operating paradigm
  - Variable supply and variable load
  - Increased distributed resources
  - Enhanced energy imbalance market cooperation
  - Changing roles of consumers, utilities, investors, independent power providers, technology vendors, and regulators
- Regional considerations will continue to drive progress
- Production scale and supply chain critically important to lower manufacturing costs
- Investment in technology R&D is critical
  - Better monitoring and measurements
  - Advanced analytics processing and control
  - Demand-shifting and load profile shaping techniques
  - Two way power flow control electronics

Innovation, Integration and Adoption

Reducing Investment Risk

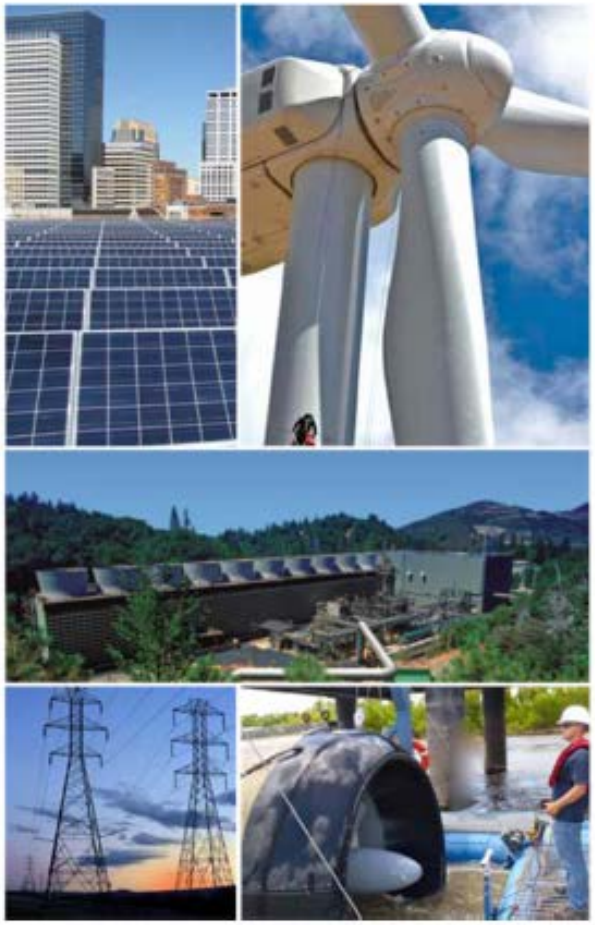
- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing “partnering” facilities

Mobilizing Capital

Sustainable
TRANSPORTATION

Renewable
ELECTRICITY GENERATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Solar Electricity: *State of the Technology*




Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 9 GW
- U.S. Forecast: 22+ GWs in pipeline
- Costs: $2 to $6/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

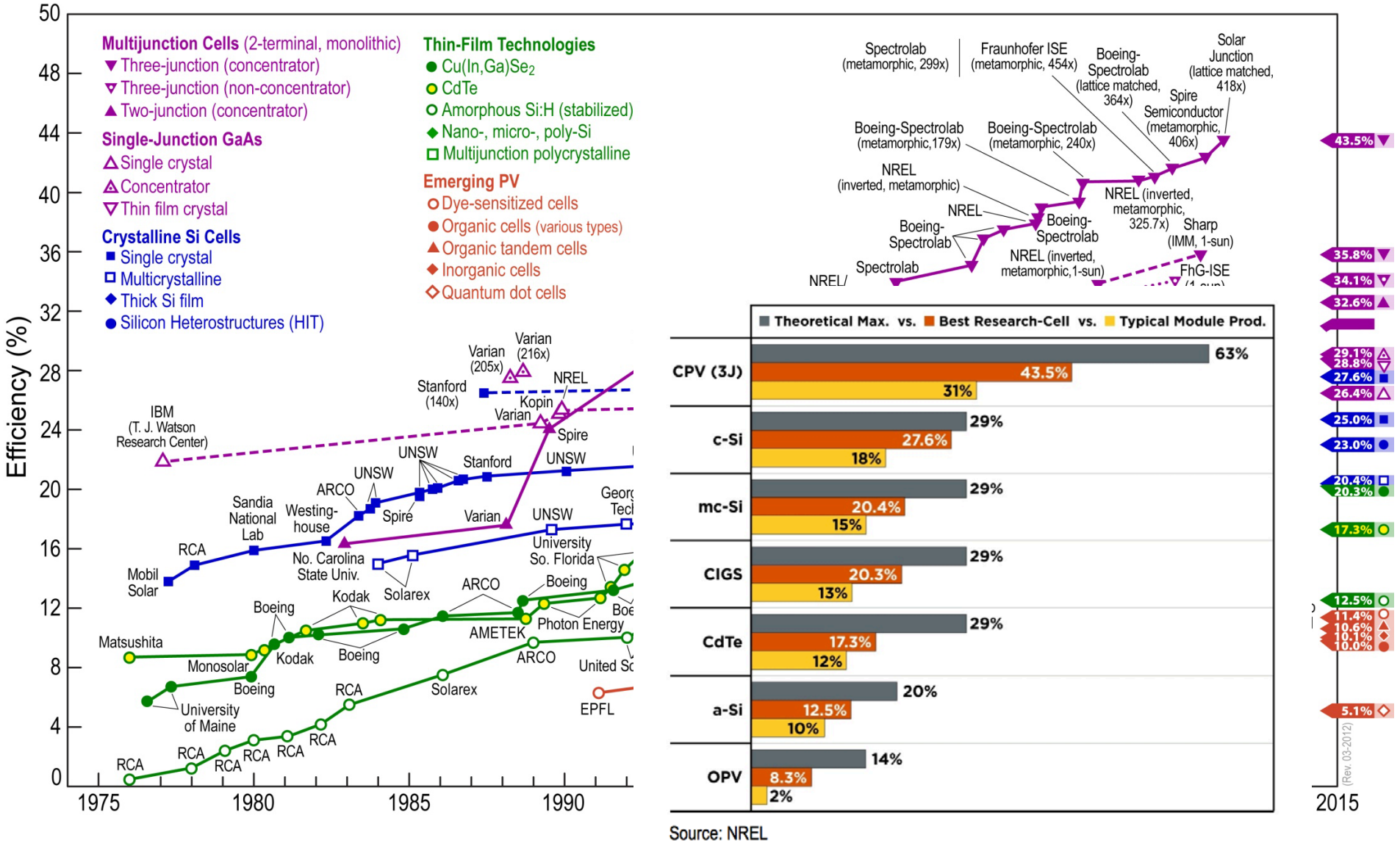
Solar Thermal Electric (CSP)

- 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.

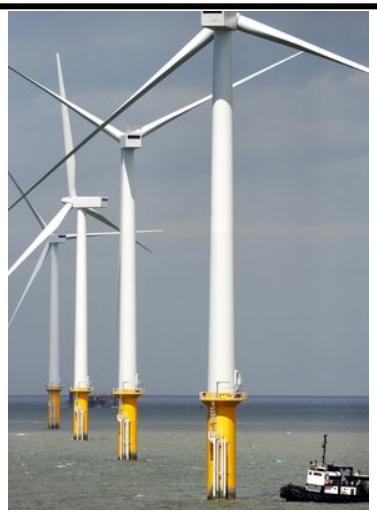
Updated: September 2013
Source: GTM/SEIA : U.S. Solar Market Insight Q4 2011 & 2011 Year-in-Review

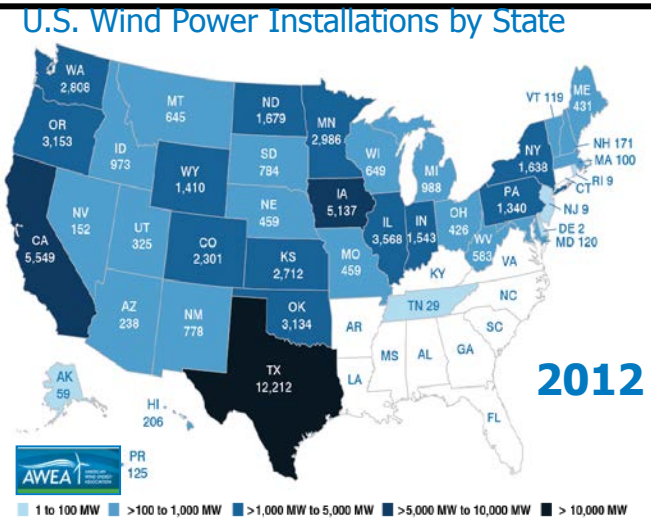
PV Research—Significant Innovation Space



Source: NREL

Wind Energy: *State of the Technology*





- Costs: 5-8 cents/kWh LCOE*
- Installed wind capital cost = $2,098/kW
- Commercial wind turbines rated at 1.5-3.0 MW in capacity are typical
- 7-10 MW wind turbines are in development and demonstration
- Direct drive generators more common
- Variable speed and grid-friendly operation
- Advanced technologies are targeting deeper water offshore wind markets

- U.S. installed capacity: 60,007 MW (1/2013)
- Wind power #1 source of new electricity generation in U.S. at 42%; 13,124 MW in 2012
- 35 of 50 states have > 100 MW installed with 15 states > 1,000 MW installed
- Wind power produced > 10% electricity in 9 states: IA = 24.5%; SD = 23.9%; CO = 11.3%
- Over 550 factories across the U.S. provide parts and services for the wind industry, which provided over 80,000 American jobs

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

Updated: April 2013

Biofuels: *State of the Technology*

Current Status:

U.S. produced 13.3 billion gallons of ethanol and 0.9 billion gallons of biodiesel (2012)

Biorefineries:

- 219 commercial corn ethanol plants
- 180 biodiesel refineries
- 28 cellulosic ethanol (includes pilot and demonstration)

Cost goal:

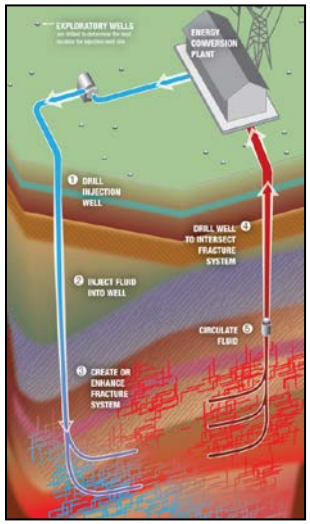
Cellulosic ethanol—cost parity with gasoline was demonstrated by NREL/EERE at pilot scale in 2012

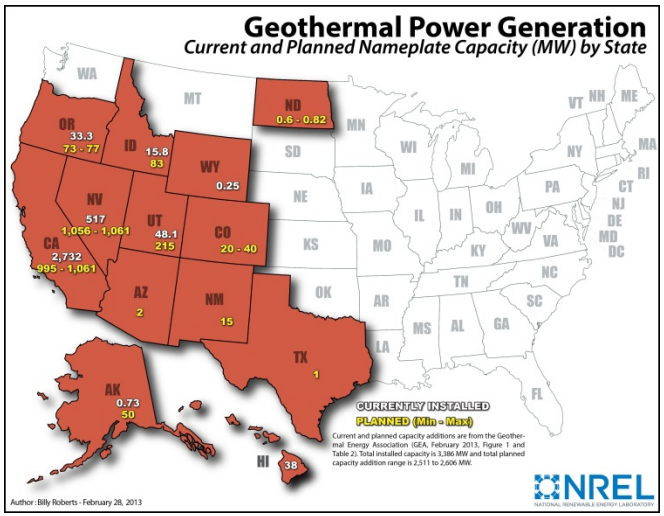
Major Technology Directions:

- Foundational Science: Enzymes, fermentation, understanding biomass and cell composition
- Feedstocks: Sustainable feedstock production systems
- Pretreatment and 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: 11/2013

Geothermal Energy: *State of the Technology*





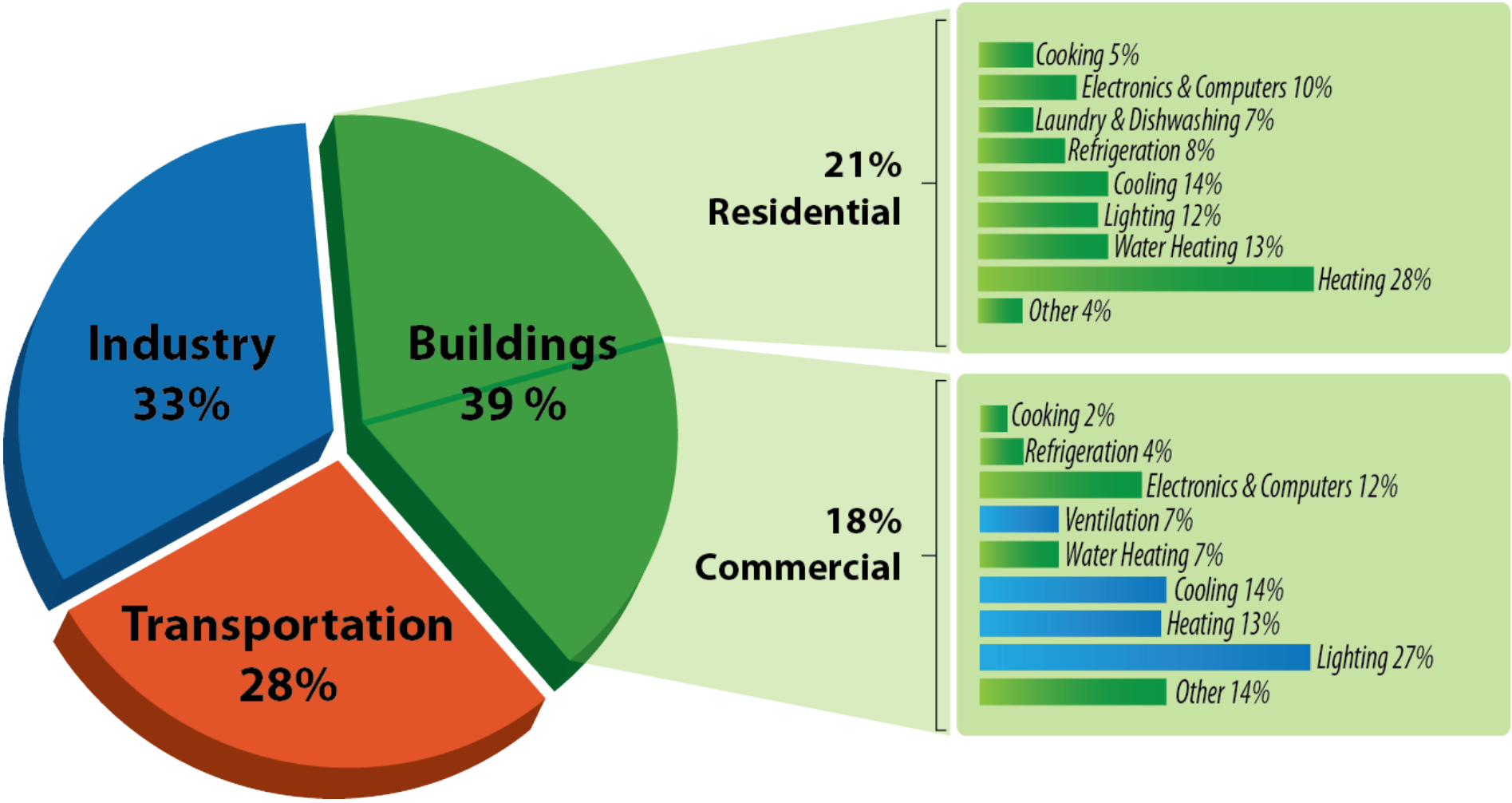
- Costs: 6-10 cents/kWh LCOE*
- Installed capital cost = $3,000-$5,000/kW
- Binary geothermal power plants typically 10-30 MW in size
- Flash and steam power plants typically 30-100 MW in size
- Distributed generation options becoming available at 30 kW and above
- Baseload generation with high availability

- U.S. installed capacity: 3,187 MW (4/2013), the largest in world
- Installed US geothermal power capacity grew 5% in 2012, 147 MW in new capacity added and 175 additional projects under development
- 8 states with installed geothermal capacity, and 5 more states with projects under development
- “Enhanced Geothermal Systems (EGS)” demonstration projects marking significant achievements, including first US commercial, grid-connected EGS system

* Based on recent PPA prices in US

Updated: April 2013

Energy Consumption in the U.S.



Source: Buildings Energy Data Book, 2006

Buildings Technologies

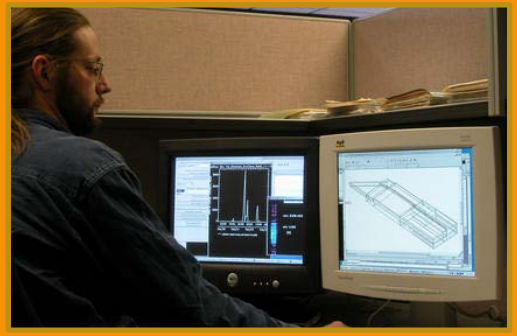
High Performance Buildings

BIPV Products and PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization and simulation Tools

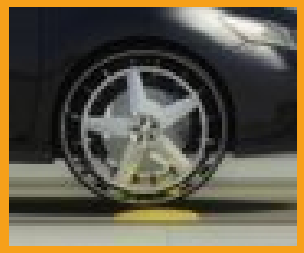
Transportation

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (power electronics and 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 and or Alternative Fuels, H2

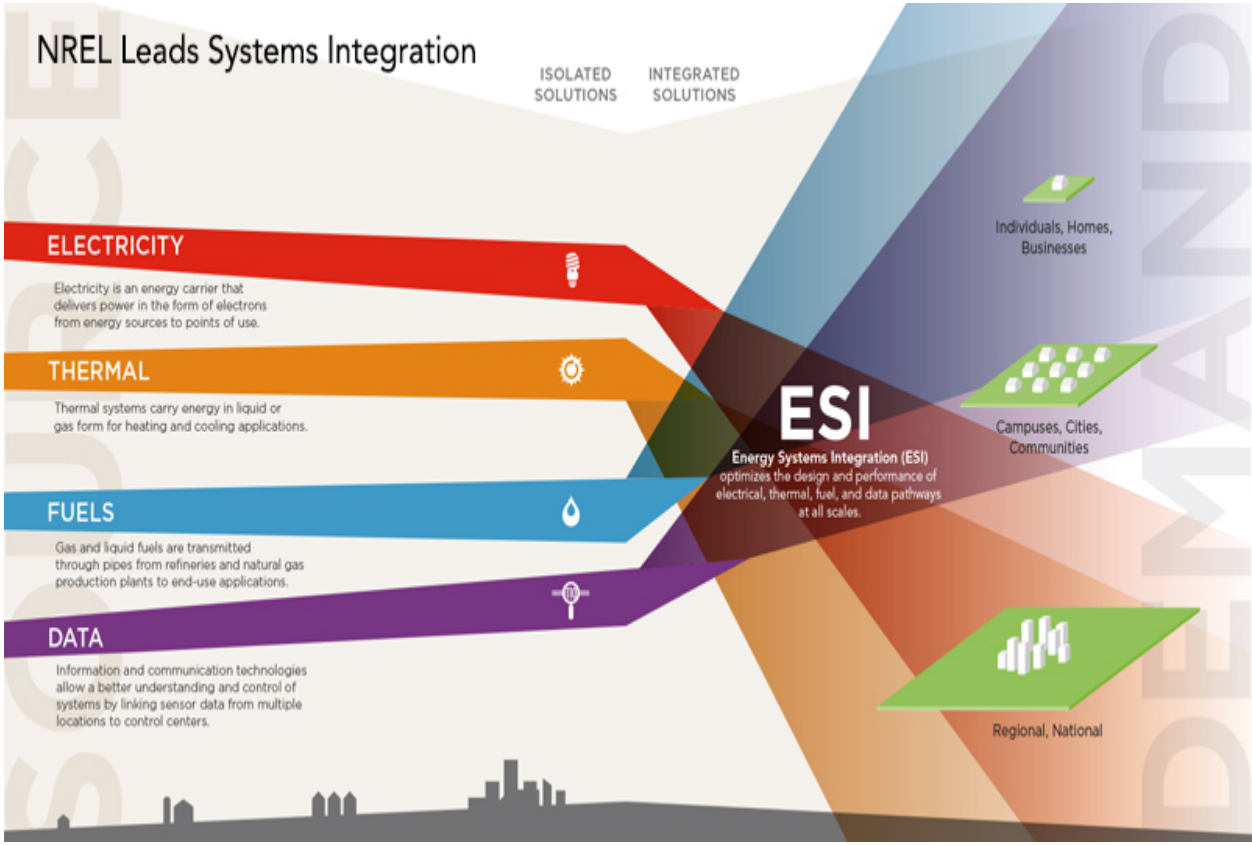
Systems Integration

Buildings

- Whole building systems integration
- Computerized building energy optimization tools
- Advanced HVAC (Heating Ventilating and air conditioning)

Advanced Vehicles

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



Grid Interconnection Standards

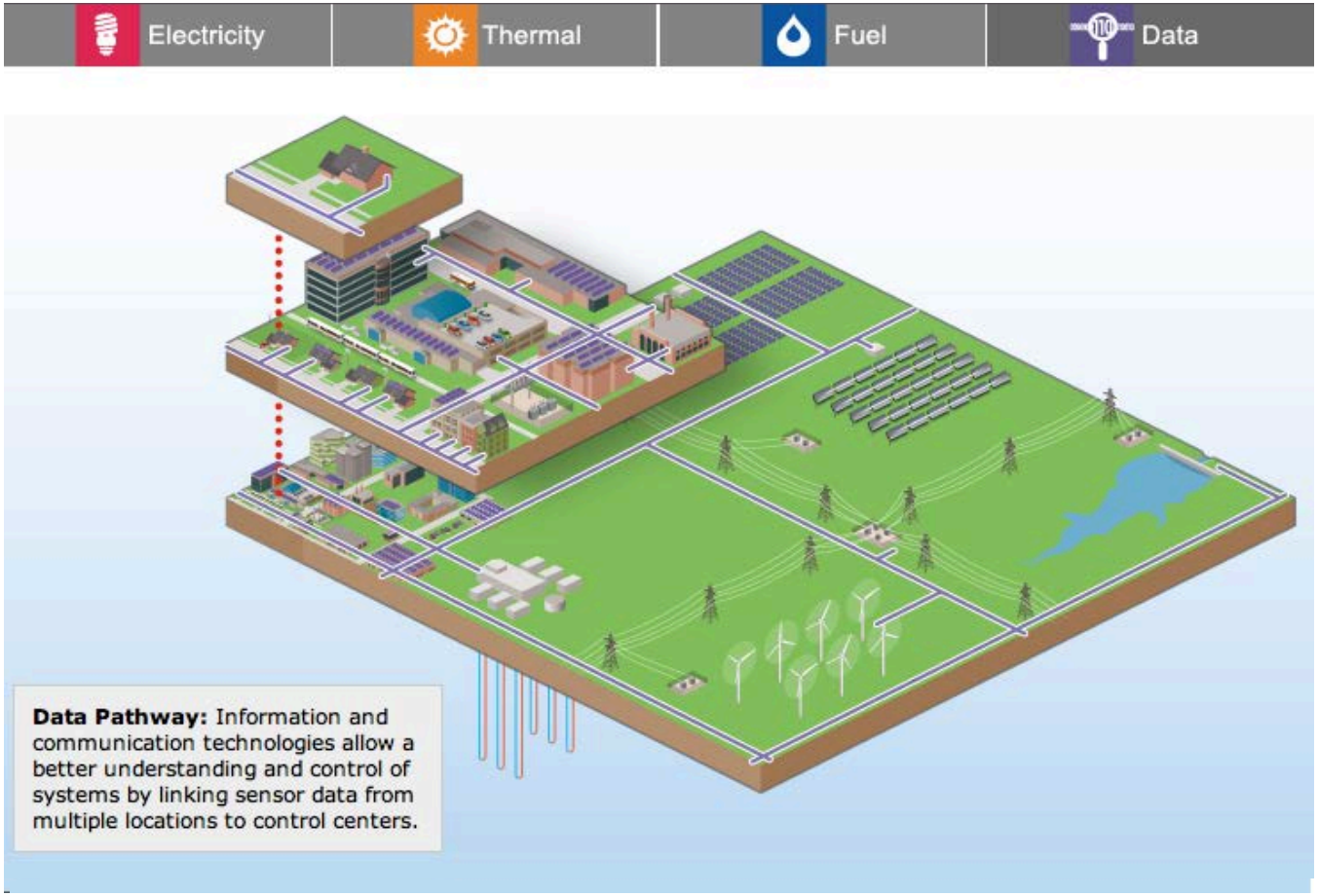
- IEEE Standards Development
- Standards Testing and Validation

RE Grid Integration

- Power Electronics for Interconnection monitoring and control

Next Step → Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



Electricity

Thermal

Fuel

Data

Energy Systems Integration – Value

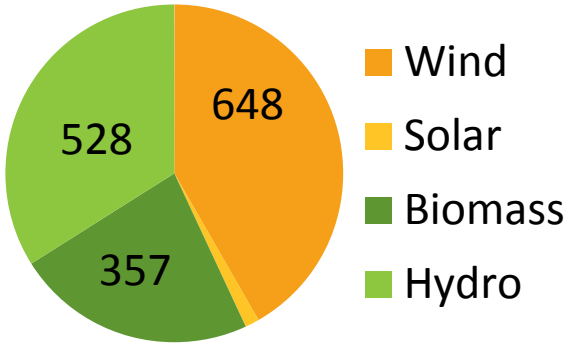
Economic	Environmental
• Cut overall energy use through optimization • Increase asset utilization and avoid excess new build • Capture system losses for valuable reuse	• Enable high penetration of renewable energy • Reduce air, land and water pollution • Meet future greenhouse gas reduction goals
• Reduce price volatility through supply diversity • Enhance system flexibility and resilience to disruption	• Manage water demands from the energy sector • Move toward long-term resource sustainability

Security

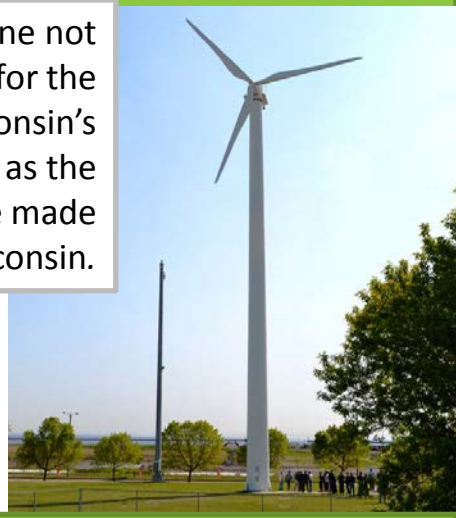
Wisconsin: Well Positioned for a New Energy Future

With its abundant supply of conventional hydroelectric power, biomass, and wind, Wisconsin is well on its way to meeting its goal of producing 10% of its electricity from renewable sources by 2015.

Wisconsin's MW Installed Renewables 2012



The Milwaukee wind turbine not only provides clean energy for the city, it helps support Wisconsin's growing wind industry, as the majority of components were made in Wisconsin.



In Wisconsin, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy partners with large and small businesses to advance clean technologies in the state (selected examples):

VIRENT

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Where Caring Meets Excellence

LTC

MATC

EATON
Powering Business Worldwide

FOREST COUNTY POTAWATOMI
Keeper of the Fire

BRIGGS & STRATTON

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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