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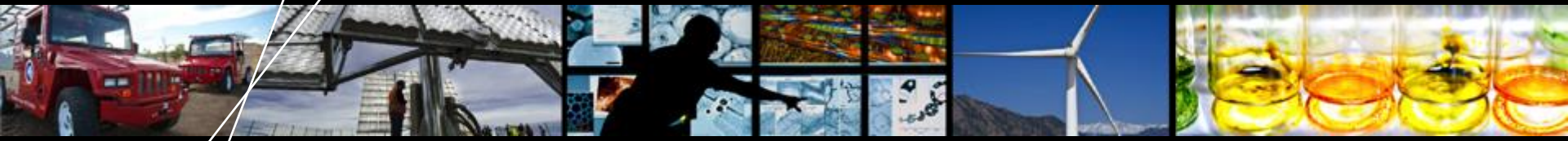
Clean Energy Transition: Reflections on the Past Decade



NREL Industry Growth Forum
Dr. Dan E. Arvizu
Laboratory Director

November 2015

Energy Market Fundamentals

Globally interconnected

Driven regionally

Shaped by public policy

Technology enabled

Investment, infrastructure and finance guide development

Energy is the "life blood" for economic growth, prosperity, and societal advancement.

9/25/2015

Energy Market Dynamics

Energy mix is changing

Global renewable industry growing, but faces challenges

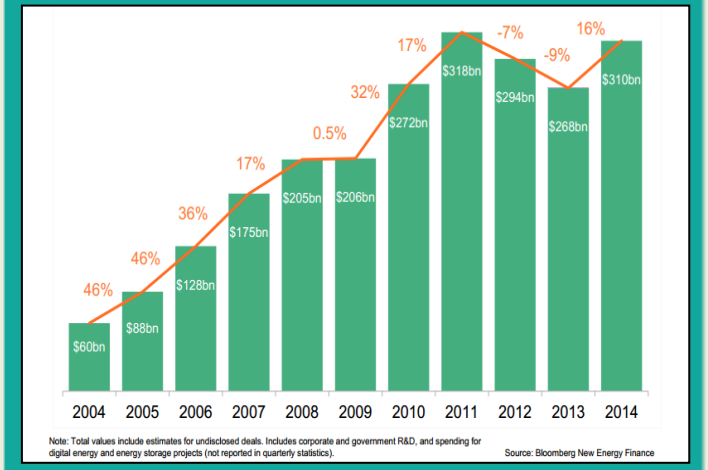
Public policy evolving—mostly local

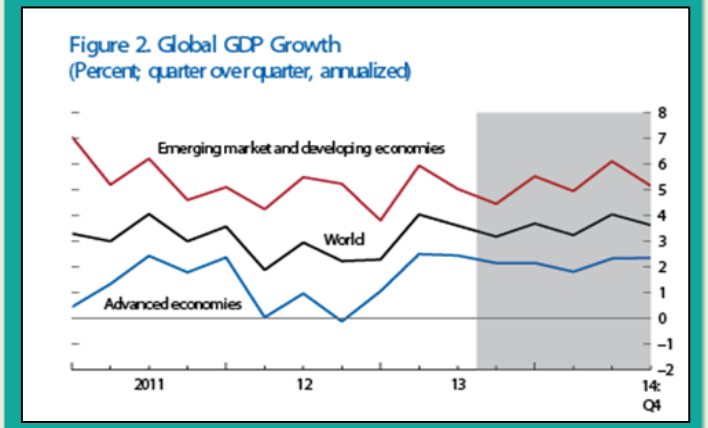
Unconventional gas a growing focus with geographic disparities

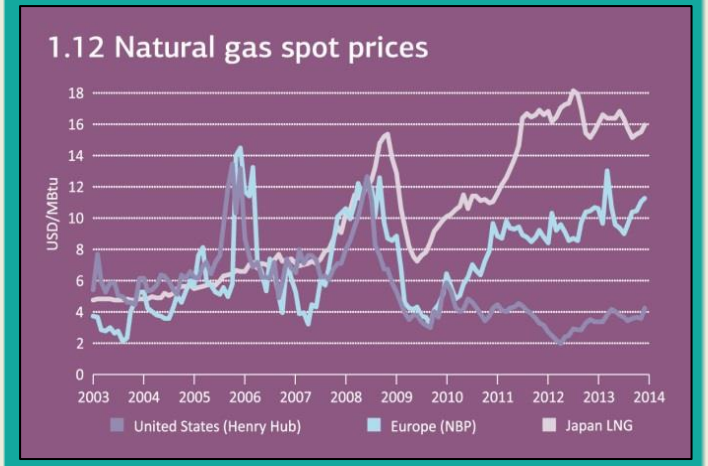
Infrastructure investments will be made, requirements are changing

Technology is creating a platform for disruptive change

Updated 3/13/2015







A Profound Transformation is Required

Today's Unsustainable Energy System

- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

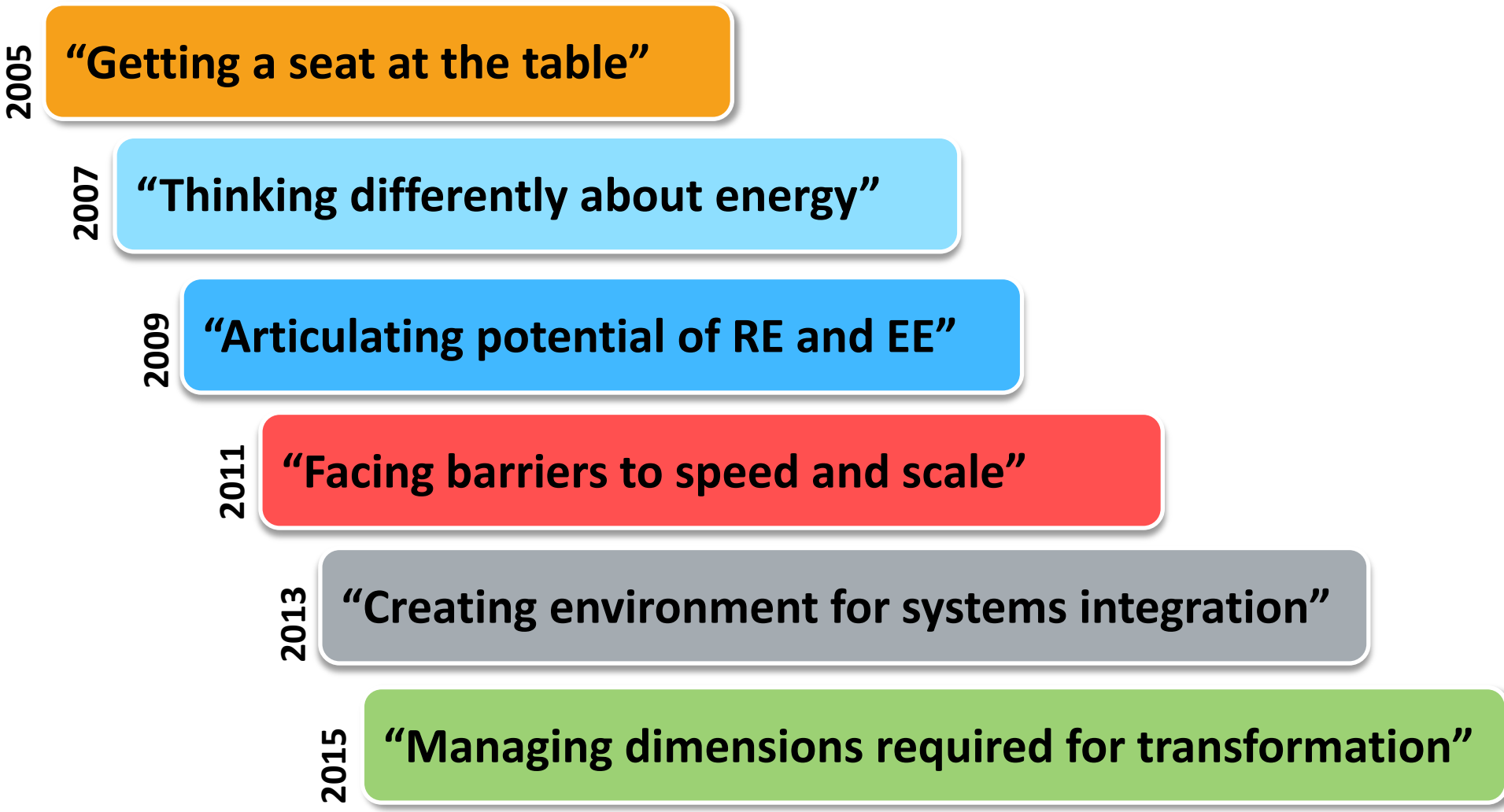
Future Sustainable Energy System

TRANSFORMATION

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- More consumer driven

Updated 3/10/2015

The Past Decade: An Evolving Focus

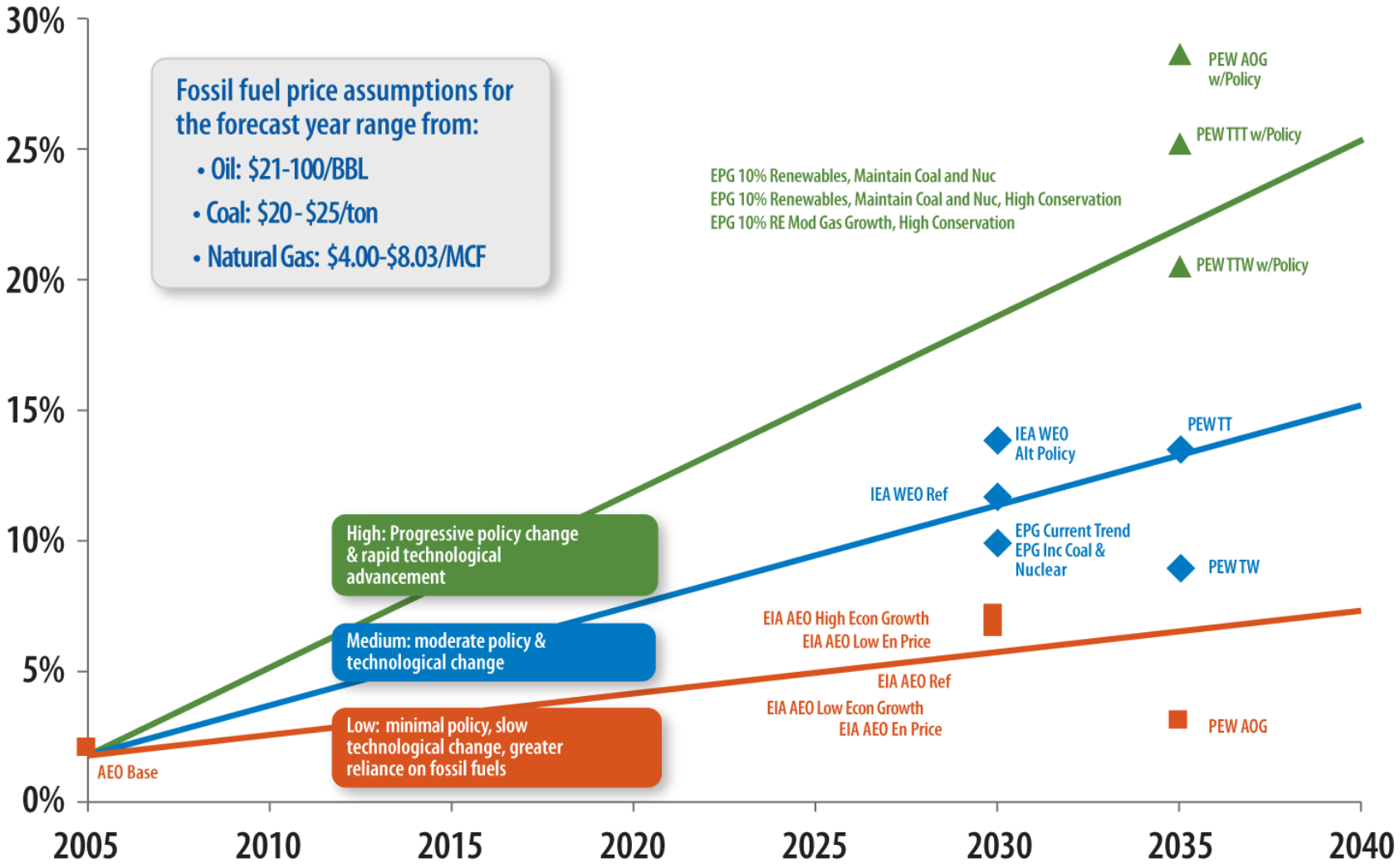


2005/2006—Getting a Seat at the Table

- The **Colorado Renewable Energy Requirement Initiative**, also known as **Initiative 37,** was approved in November 2004 with 53.6% of the vote
- Required a percentage of retail electricity sales be derived from renewable sources, beginning with 3% in the year 2007 and increasing to 10% by 2015
- Local utilities opposed the amendment

U.S. Renewable Energy Contributions

Percent of Total Non-Hydro Electric Generating Capacity



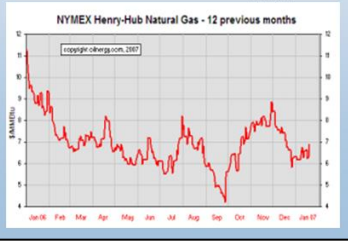
2007/2008—Thinking Differently

- Convened experts at the Santa Fe Institute
- Recast the issue
- Take a systems perspective
- Not what we produce but how it's used

Thinking Differently: Account for Externalities

Today's energy marketplace does not appropriately "value" certain public objectives or social goods, instead we have:

- Price volatility
- Serious environmental impacts
- Underinvestment in energy innovation



Energy is a means to an end, not an end in itself

Heat and power for where we live and work

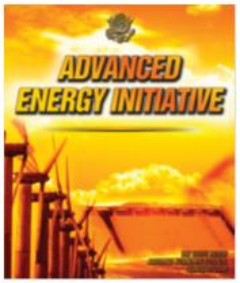
Sustainable Electricity System

Fuel and power for mobility and access

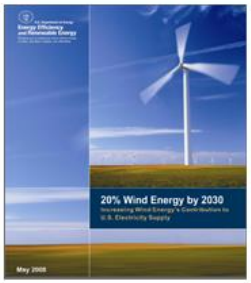
Sustainable Transportation System

2009/2010—Articulating the Potential

Setting the Bar Higher – Gigawatt-Scale Renewables

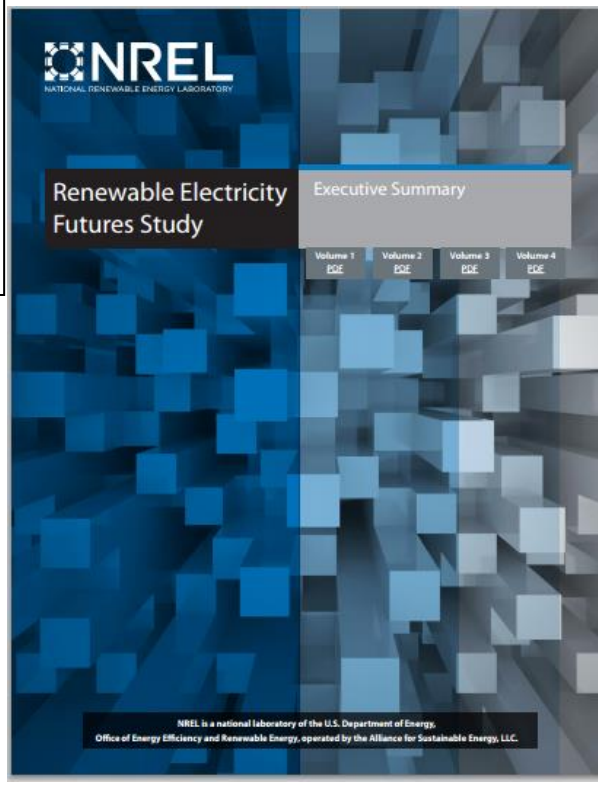


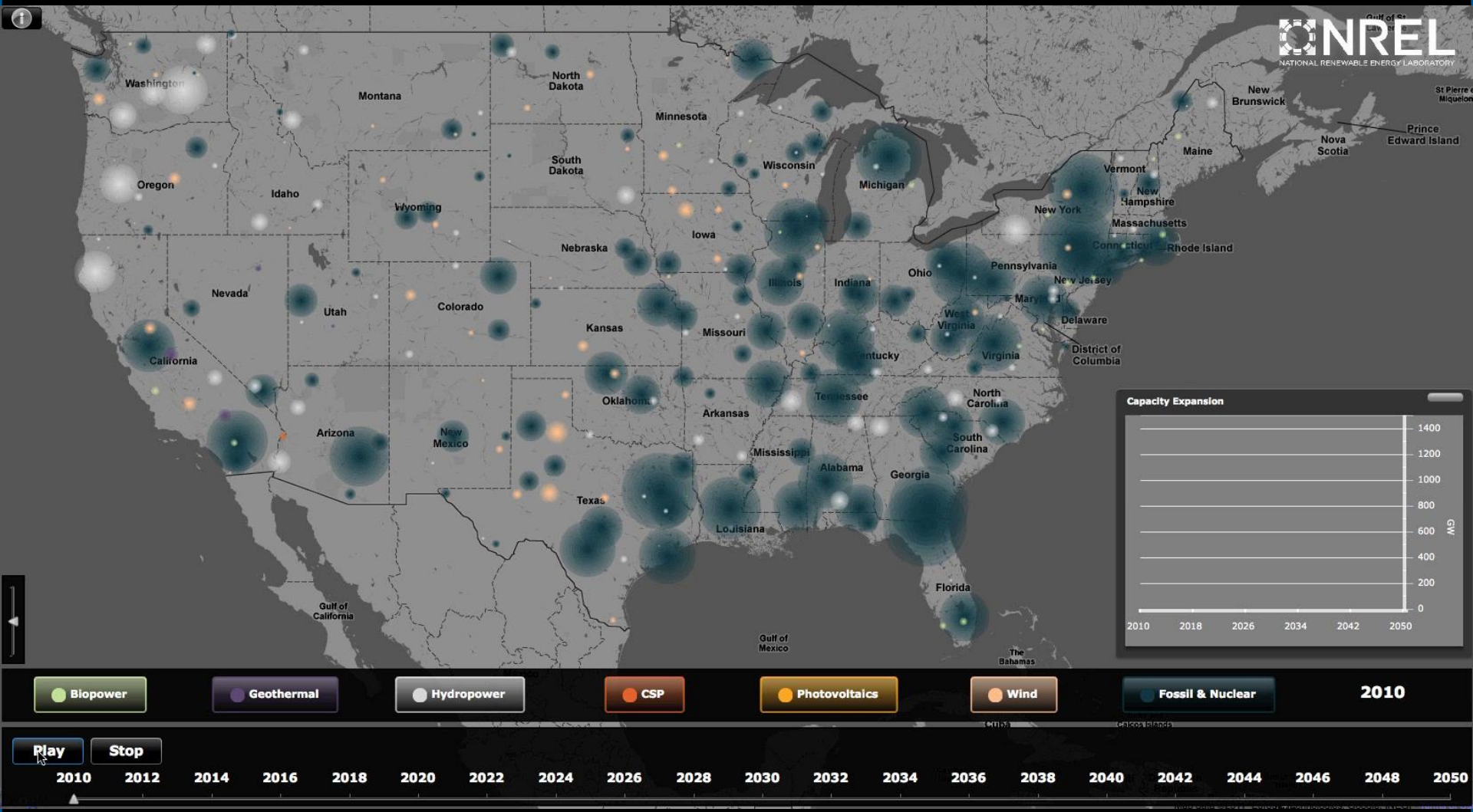
Solar Vision
10% U.S. electricity by 2025



Wind Vision
20% U.S. electricity by 2030

Energy Independence & Security Act 2007
36 billion gallons of renewable fuels by 2022

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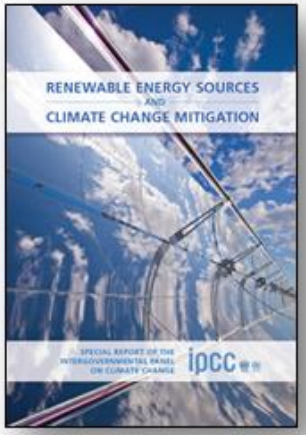
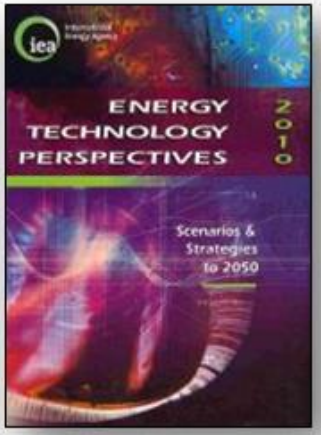
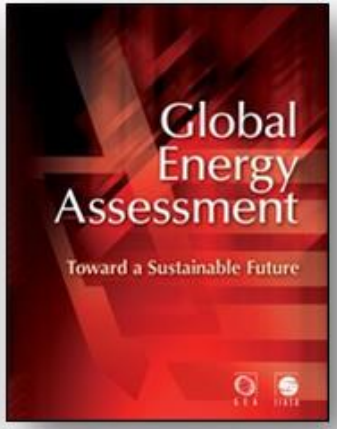
Missouri
California
Oklahoma
Arkansas
Arizona
New Mexico
Mississippi
Alabama
Georgia
Texas
Louisiana
Florida
Gulf of California
Gulf of Mexico
The Bahamas
New Brunswick
Maine
Nova Scotia
Prince Edward Island
Vermont
New Hampshire
New York
Massachusetts
Rhode Island
Pennsylvania
Ohio
Indiana
New Jersey
West Virginia
Delaware
District of Columbia
Virginia
North Carolina
South Carolina
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

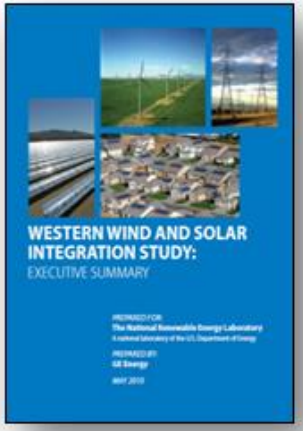
2011/2012— Facing Barriers to Speed and Scale

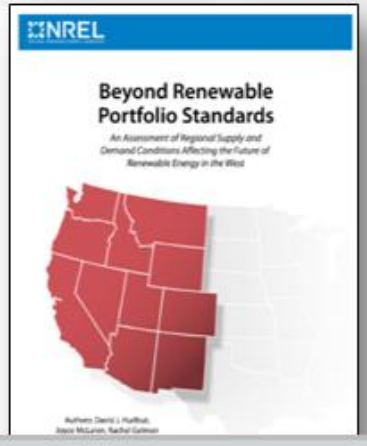
Focus on the How

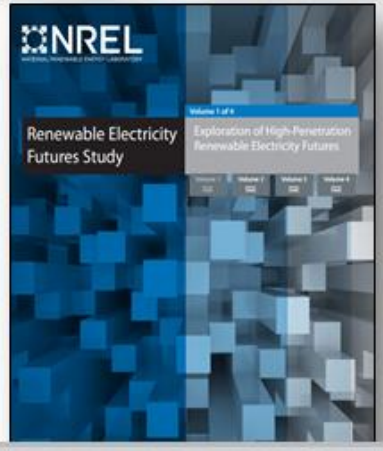


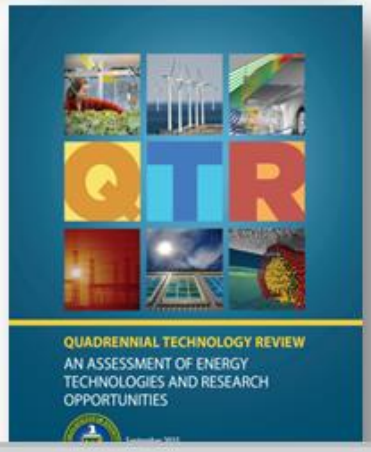






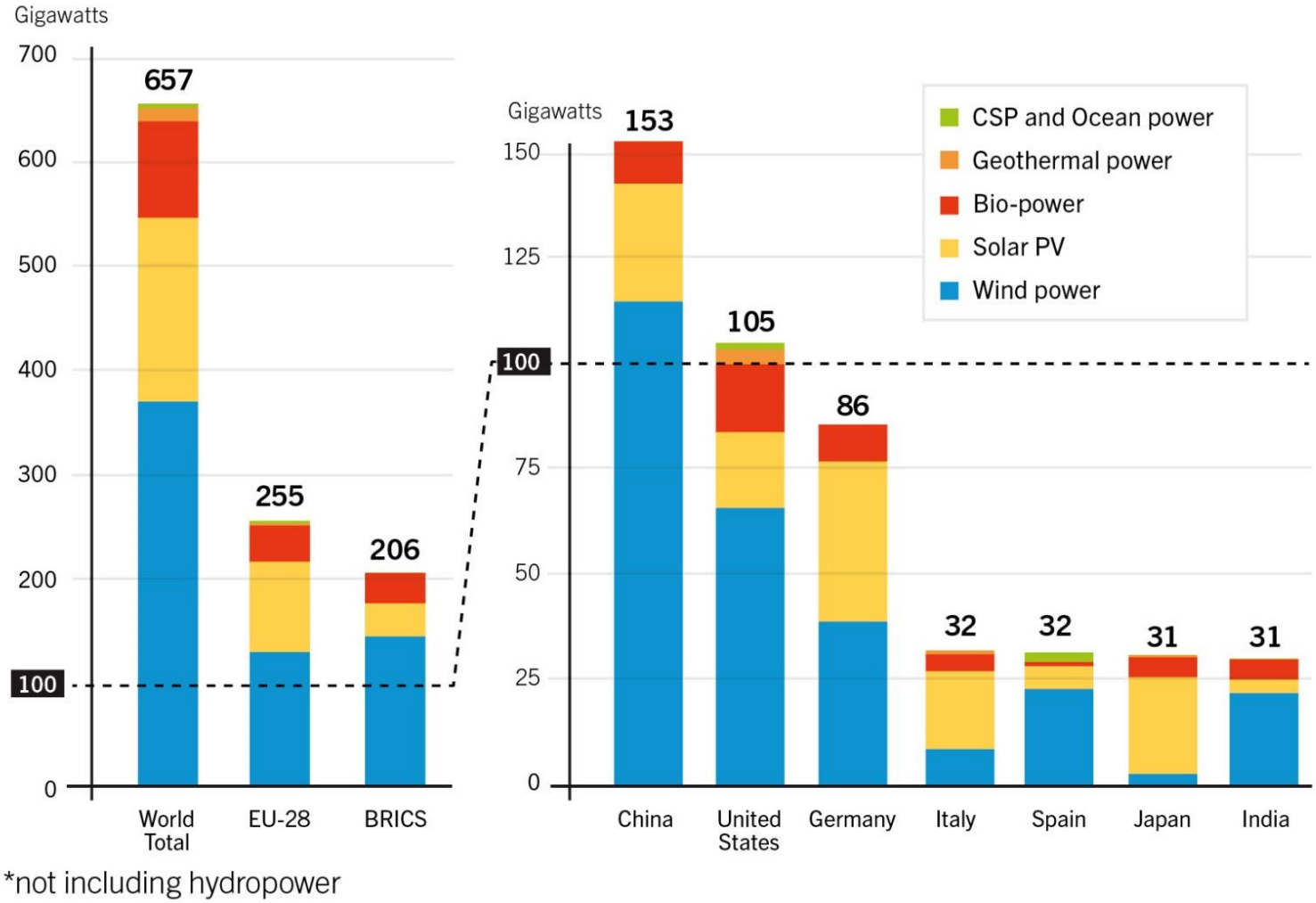






The technical potential for renewables is enormous.

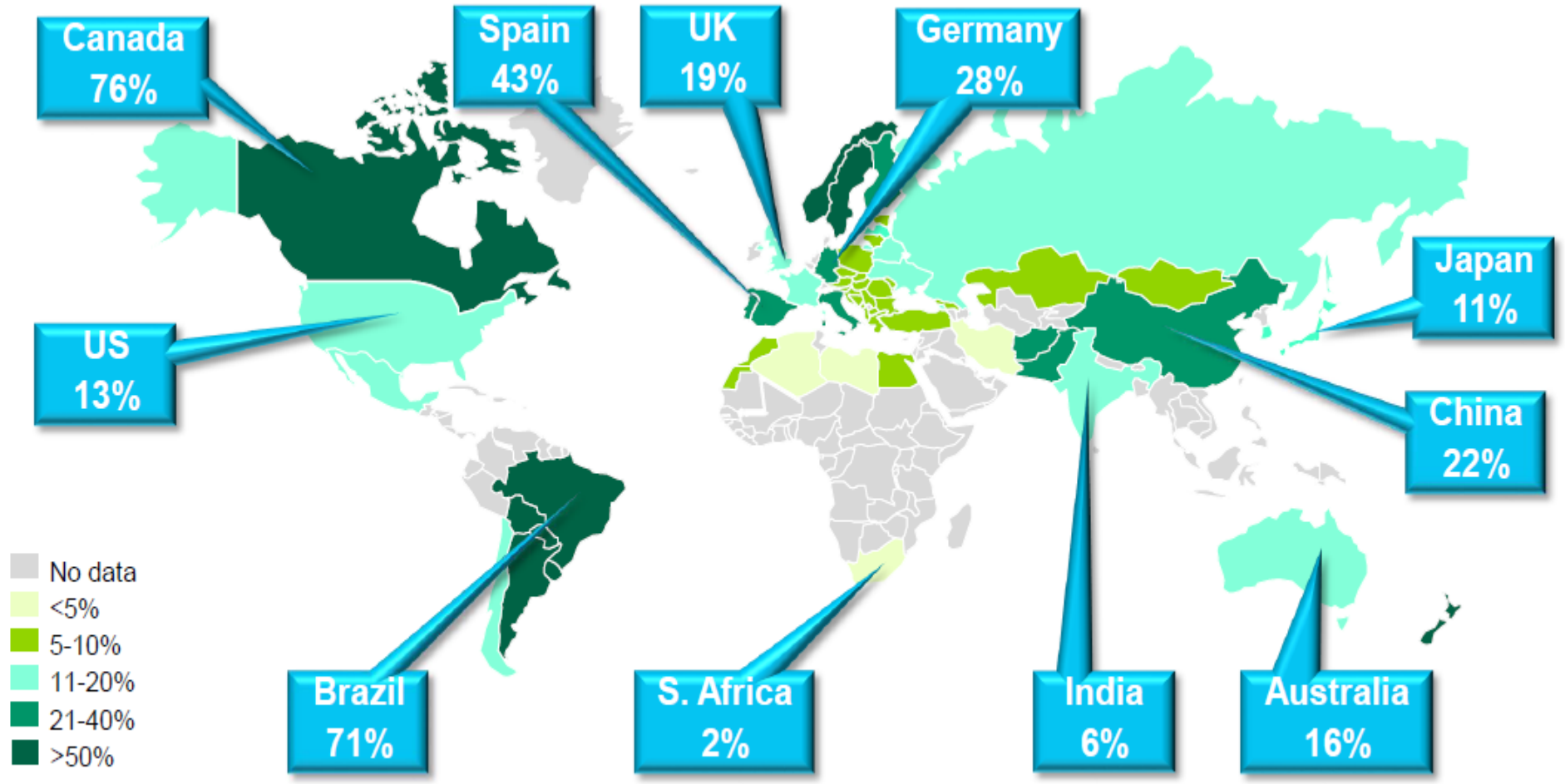
Renewable Power Capacities in World, EU-28, BRICS, and Top Seven Countries, 2015



REN21 *Renewables 2015 Global Status Report*

REN21 Renewable Energy Policy Network for the 21st Century

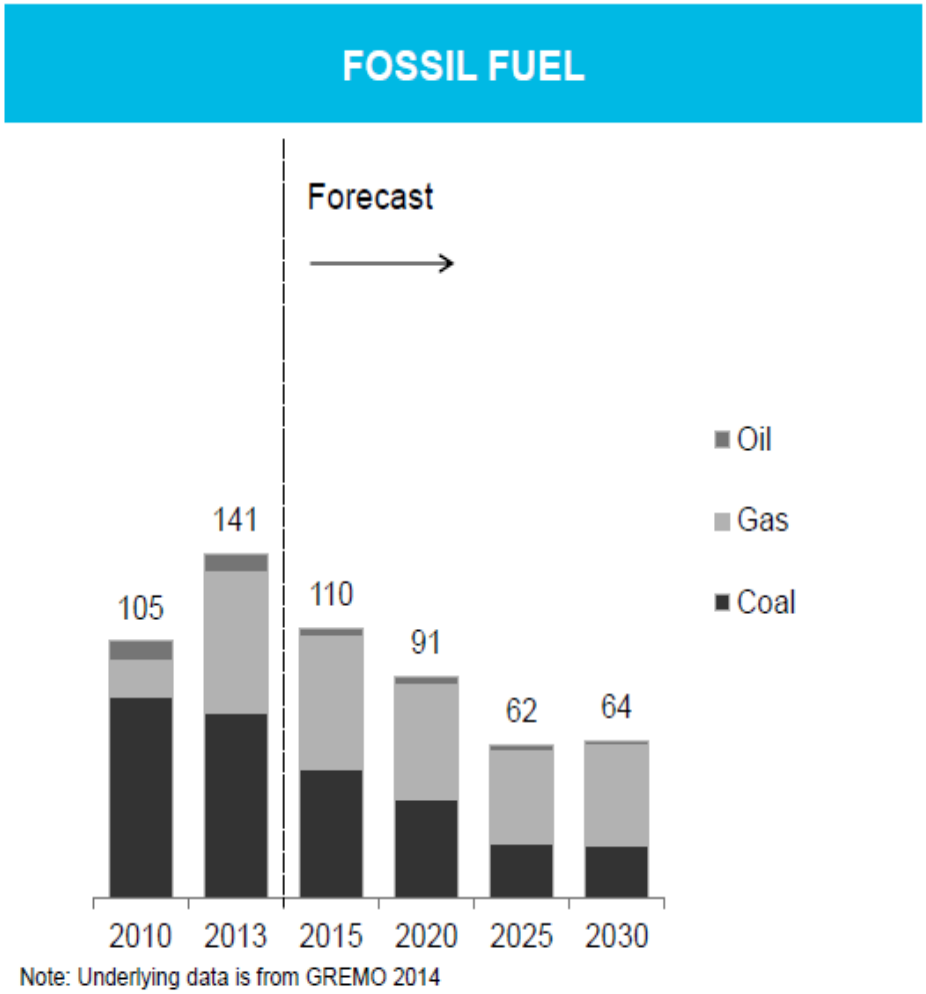
Global Renewable Energy Proportion of Power Generation



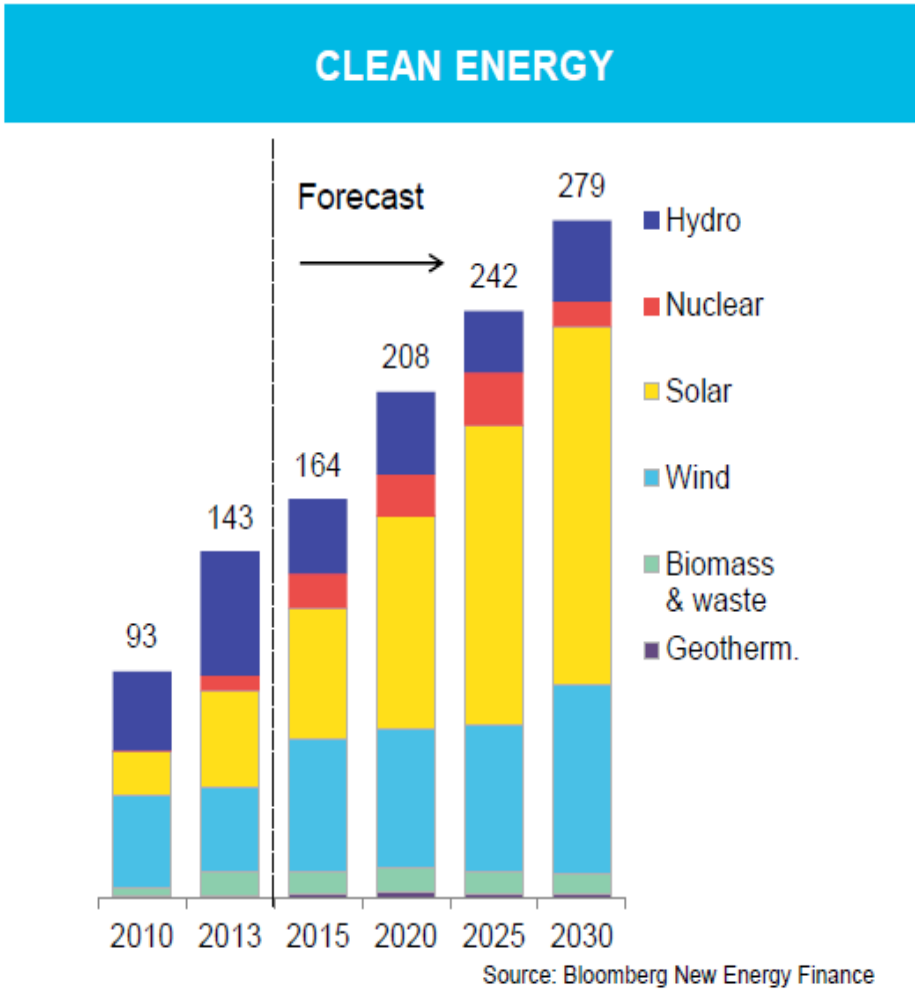
Source: Oxford Energy, China Electricity Council, BDEW, UK Govt, REE, NRCAN, EIA, USEA, Bloomberg New Energy Finance

2013/2014—Creating the Environment for Systems Integration

Global Gross Power Generation Capacity Additions 2010-2013 (GW)



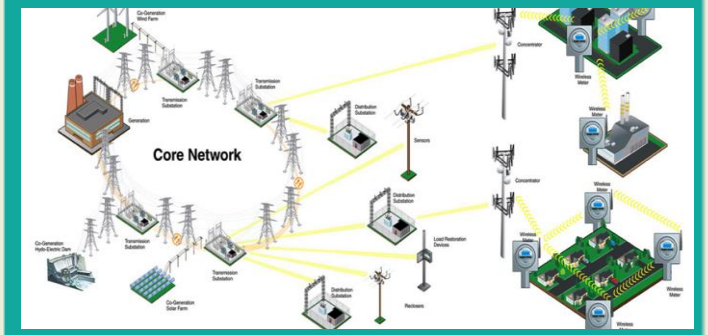
Note: Underlying data is from GREMO 2014



Source: Bloomberg New Energy Finance

2015—Managing Dimensions Required for Transformation

- Disruptive technologies
- Differentiated energy services
- Disintermediation of the value chain
- Distributed resources

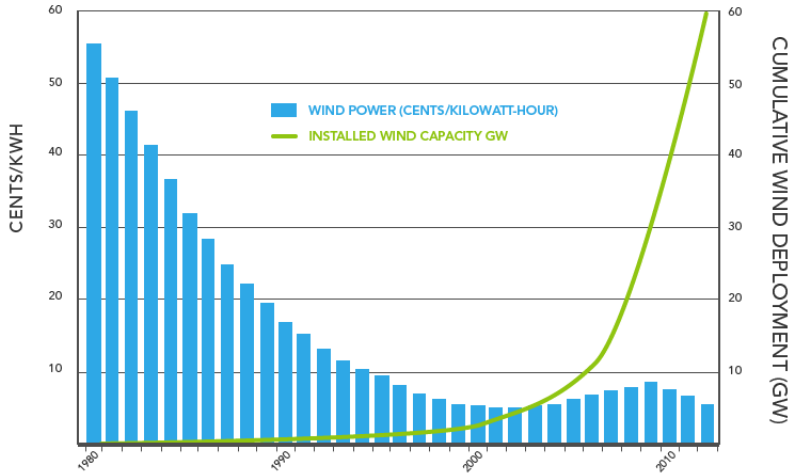


Updated 6/18/2015

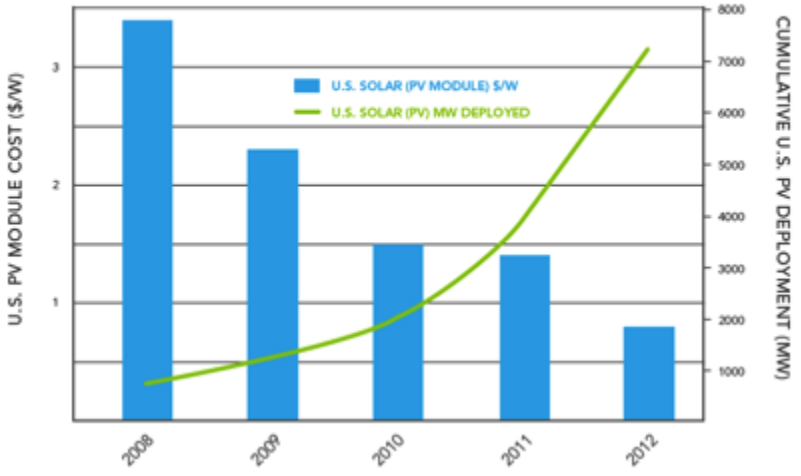
Disruptive Technologies

Disruptive Technologies

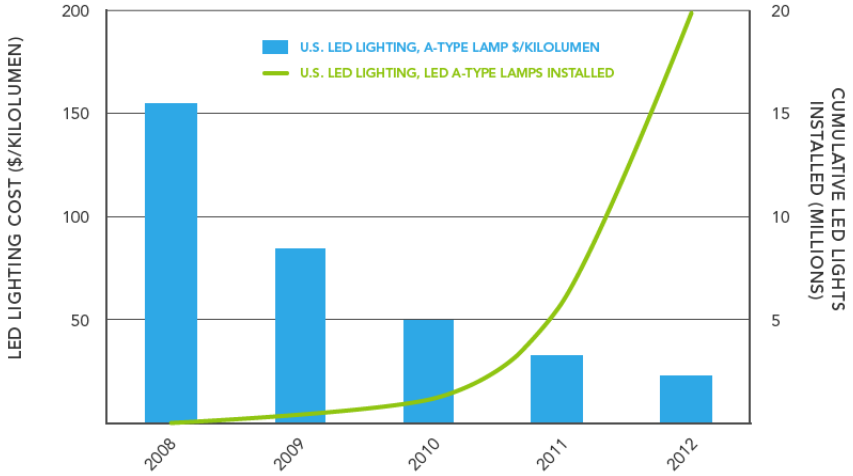
Deployment and Cost for U.S. Land-Based Wind
1980-2012



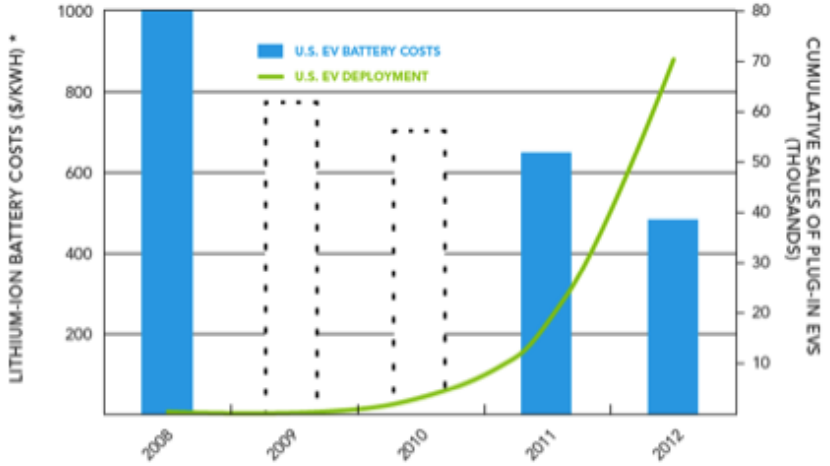
U.S. Deployment and Cost for Solar PV Modules
2008-2012



Deployment and Cost for A-Type LED Lights
2008-2012



Deployment and Cost for Electric Vehicles and Batteries*
2008-2012



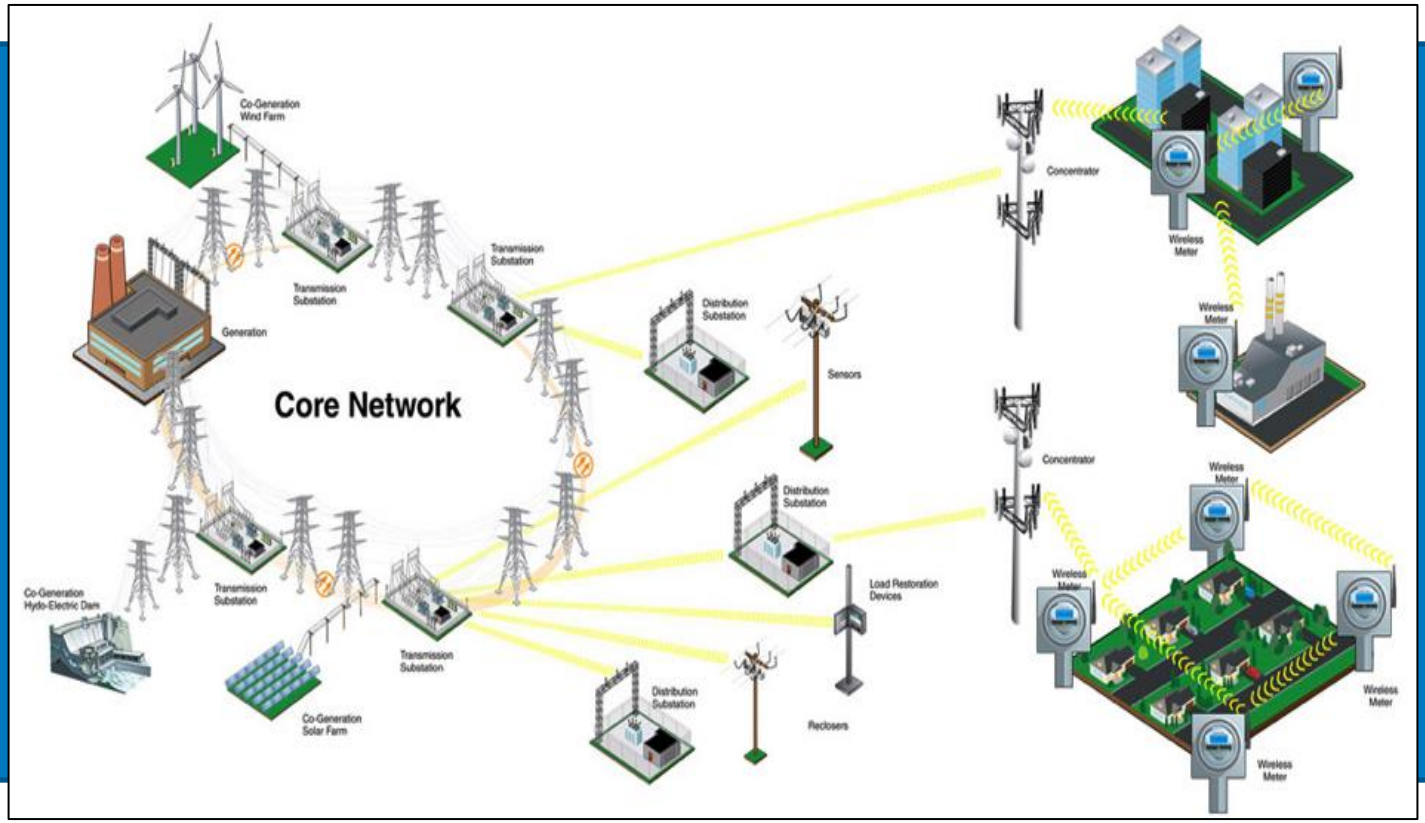
Source: "Revolution Now: The Future Arrives for Four Clean Energy Technologies", DOE, 2013

Differentiated Energy Services

Technologies Enabling Energy Services

Shelter & Comfort Low-cost storage Design control and sensors Microgrids and management Discretionary load efficiency Off-site construction and disaster Rebuilding/recovery	**Durable Goods** **Bio manufacturing** **High value roll-to-roll processing** **Sustainable advanced composites** **Advanced energy materials** **Kerfless Si wafering PV manufacturing**	**Feedstocks, Fuels and Chemicals** **Biomass catalytic conversion to specialty and commodity chemicals** **Synthetic biology conversion to specialty and commodity chemicals** **Process intensification/integration**
Information & Access **Intelligent, scalable energy systems and tools** **Networked grids/microgrids** **Intelligent energy aents and devices** **Energy ennabled personal services**	**Mobility** **Next gen electric vehicles** **Low-cost RE H2 techs** **Data; Management, connectivity & security** **Fuels/engine optimmization** **Bio-based materials**	**Safe Secure & Reliable Power Systems** **Secure and reliable microgrids** **Rapid response microgrids** **Reliable personal "nano-grids"**

Distributed Resources



Disintermediation of the Value Chain

Invent the Future We Desire

DISRUPTIONS

TECHNOLOGY
- Cyber-attacks with long/widespread outages
- Physical disruptions with long/widespread outages (e.g. weather, attacks)
- Improved flexibility management (technical aspects)
- Electrification of the transportation sector

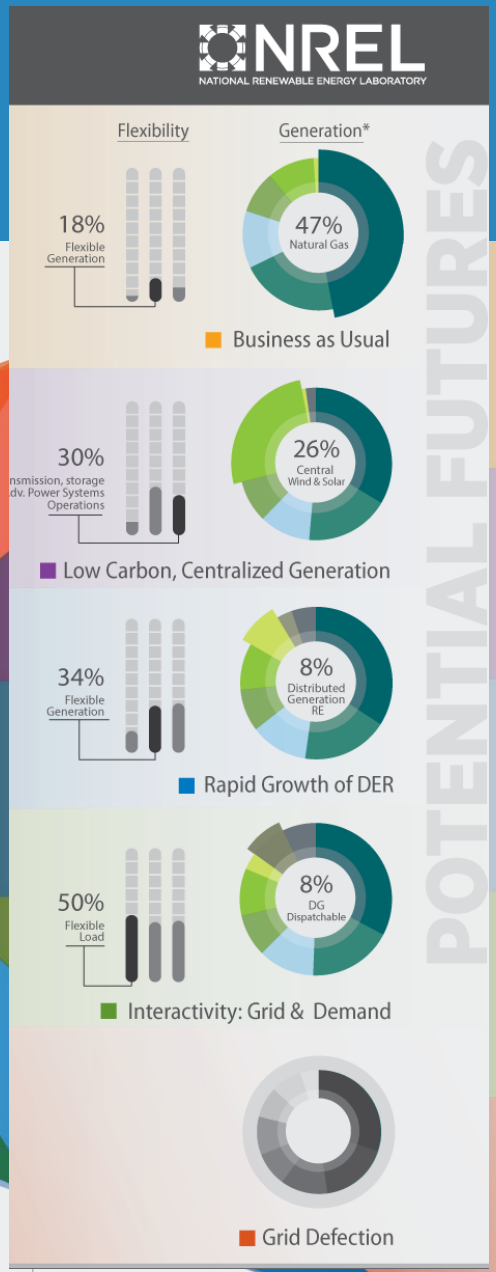
POLICY AND REGULATORY
- Final EPA Section 111 (d) rules
- National carbon market or carbon tax (policy)
- Policies to accelerate prevention of/recovery from cyber attacks
- Improved flexibility management (policies and regulations)
- Evolved regulations and policies focused on value of services
- Inability to, or high cost of interconnection
- Improved bulk system interconnections and sub-hourly markets

MARKET
- National carbon market or carbon tax (market)
- Improved flexibility management (market aspects)
- Evolved market rules focused on value of services
- Improved bulk system interconnections and sub-hourly markets

FINANCING
- Reduce capital uncertainties for clean generation (VRE, clean coal, nuclear), DG, bulk and distributed storage, value of services (flexibility, interactivity), and cyber-attack and physical disruption prevention
- Increased capital and financing for consumer-purchased resources
- Natural gas (NG) pipeline expansion limits, and NG fracking environmental restrictions

UTILITY BUSINESS MODELS
- Evolved business models focused on value of services
- Improved flexibility management (business aspects)
- Involvement of non-utilities (including third-party owners, customers) with different interests/business cases

POTENTIAL FUTURES



Partnerships More Important Than Ever


THE 21st NREL
INDUSTRY GROWTH FORUM
Denver, Colorado
October 28-30, 2008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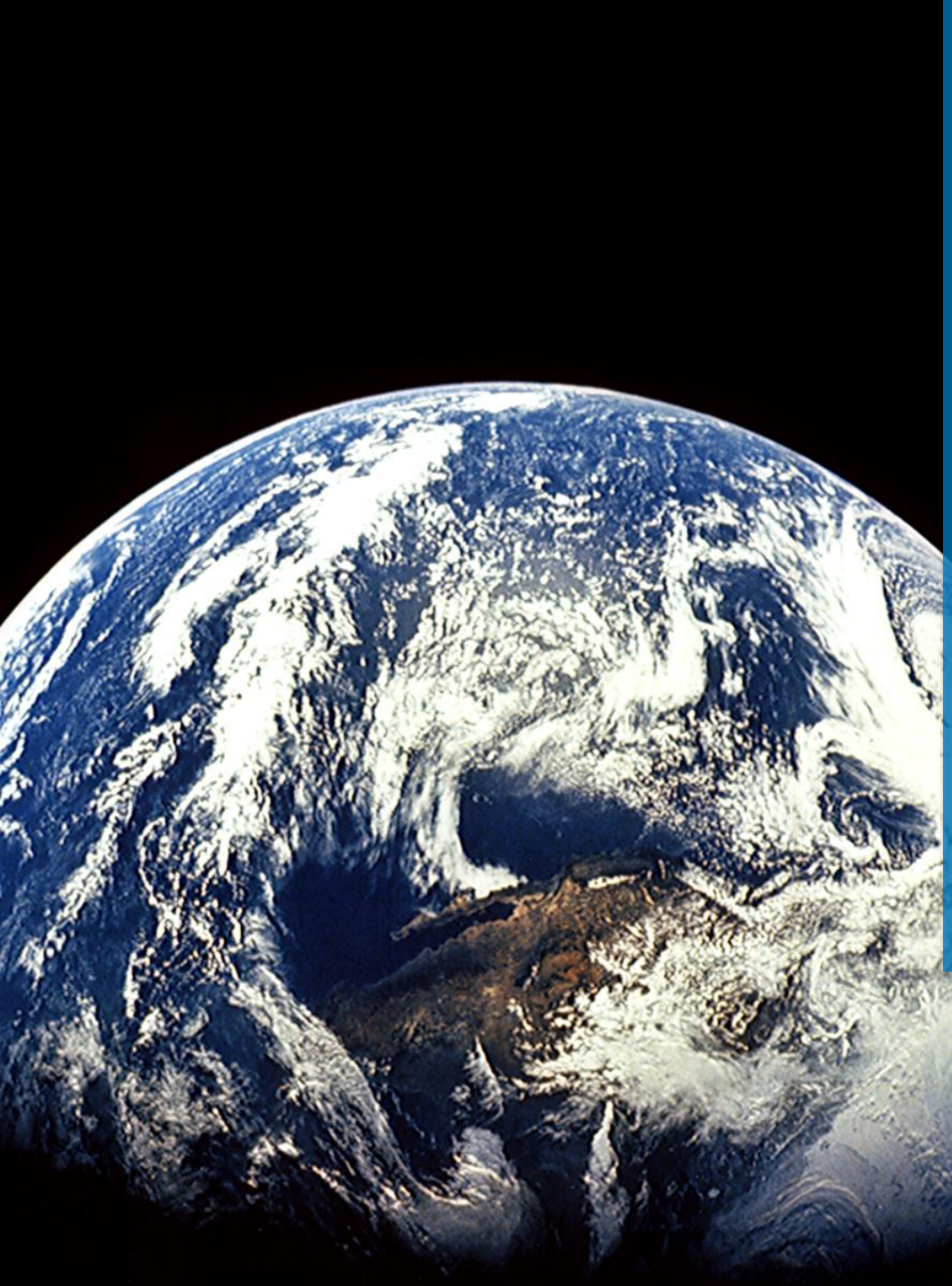

To achieve a clean energy vision, we must…

Invest in innovation

Invent the future we desire

Improve access to capital

Partner on a global scale

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For more than 35 years, NREL has delivered innovation impact enabling the emergence of the U.S. clean energy industry.

For more information, please visit our website at
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