ENERGY FUTURES INITIATIVE

Transforming the World's Energy Systems: the Intersection of Science, Technology and Policy

Presentation of Melanie Kenderdine

ANDEG Workshop

Bogota, Colombia

09/19/17

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Today's Discussion

- **Global and US Trends**
- **Four US Initiatives to Help Transform the World's Energy Systems**
  - Quadrennial Technology Review
  - Key Science/Technology Program
  - Quadrennial Energy Review
  - Mission Innovation
- **Discussion**

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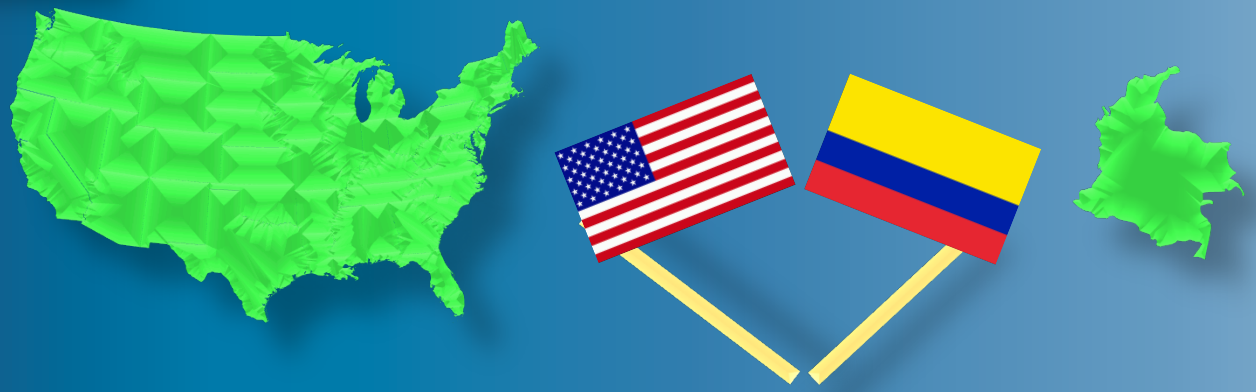
Similarities: U.S. and Colombia



- Successful revolutions against European monarchs!
- Major energy producers and exporters
- Increasing urbanization
- Coasts on two oceans
- Significant regional energy differences
- Robust research universities
- Energy infrastructure shared with other countries
- Climate/security policies suggest need for fuel diversification
- Until June 1, supporters of the Paris Climate agreement

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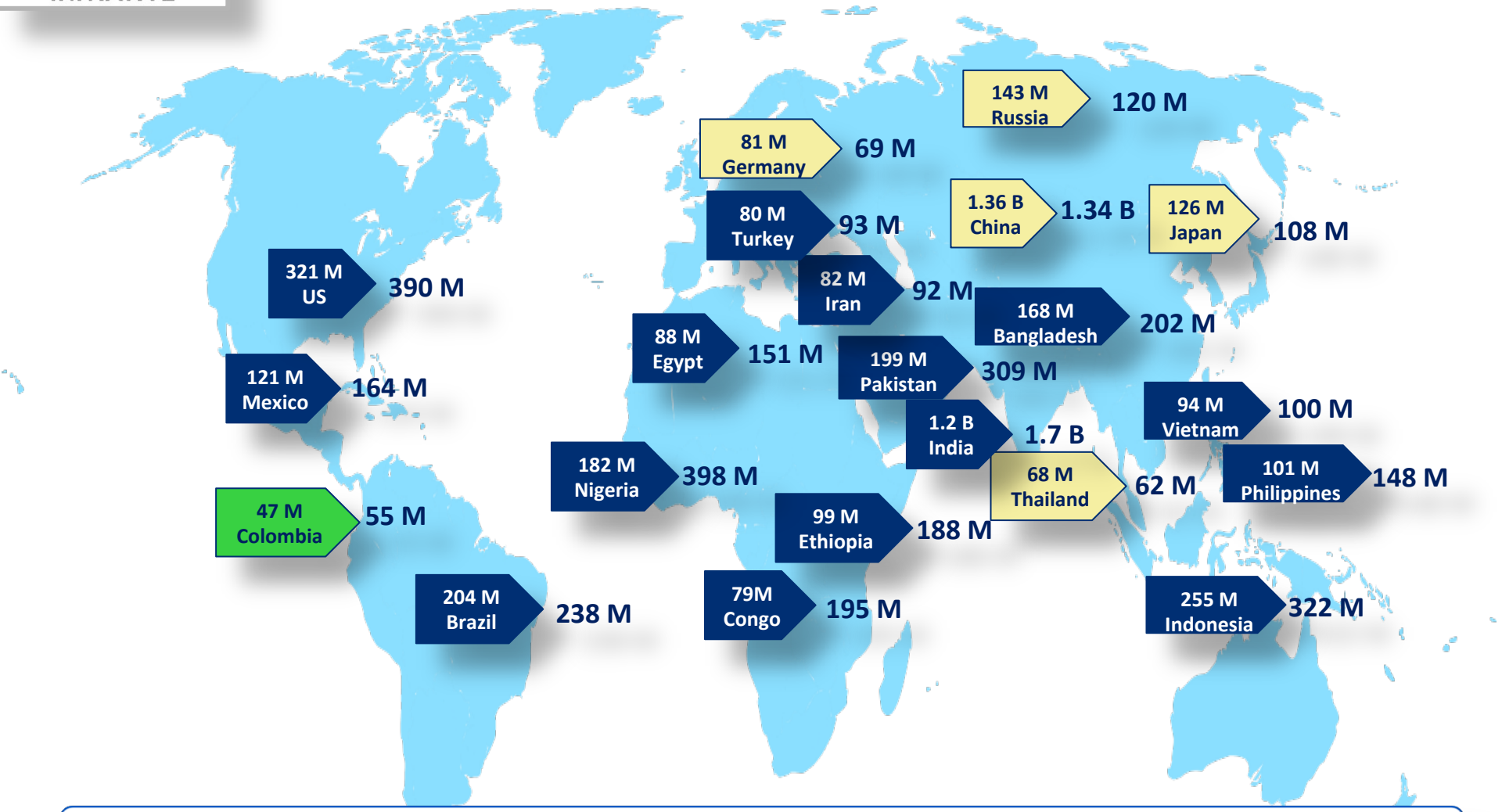
Top 20 Most Populous Countries, 2015/2050



Overall, these countries will see a 24 percent increase in population by 2050

Source: World Bank and CIA World Factbook

Significant Global LNG Volumes by 2020

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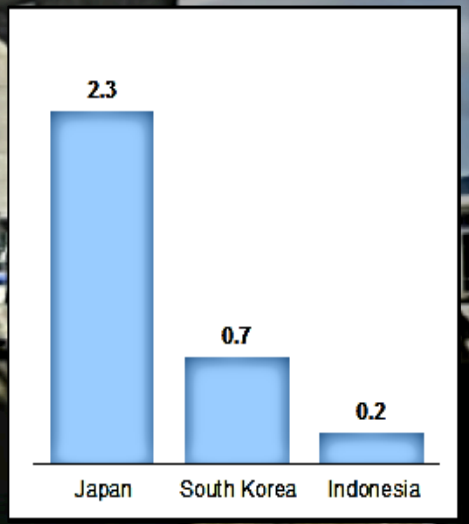
"Only 23 of the existing 421 LNG vessel fleet could pass through the canal. Now, nearly 90% of all LNG vessels can pass through the canal….a typical trip from Sabine Pass to Japan is roughly 16,000 nautical miles without the canal and 9,133 nautical miles using the canal. That's a saving of 42%.."

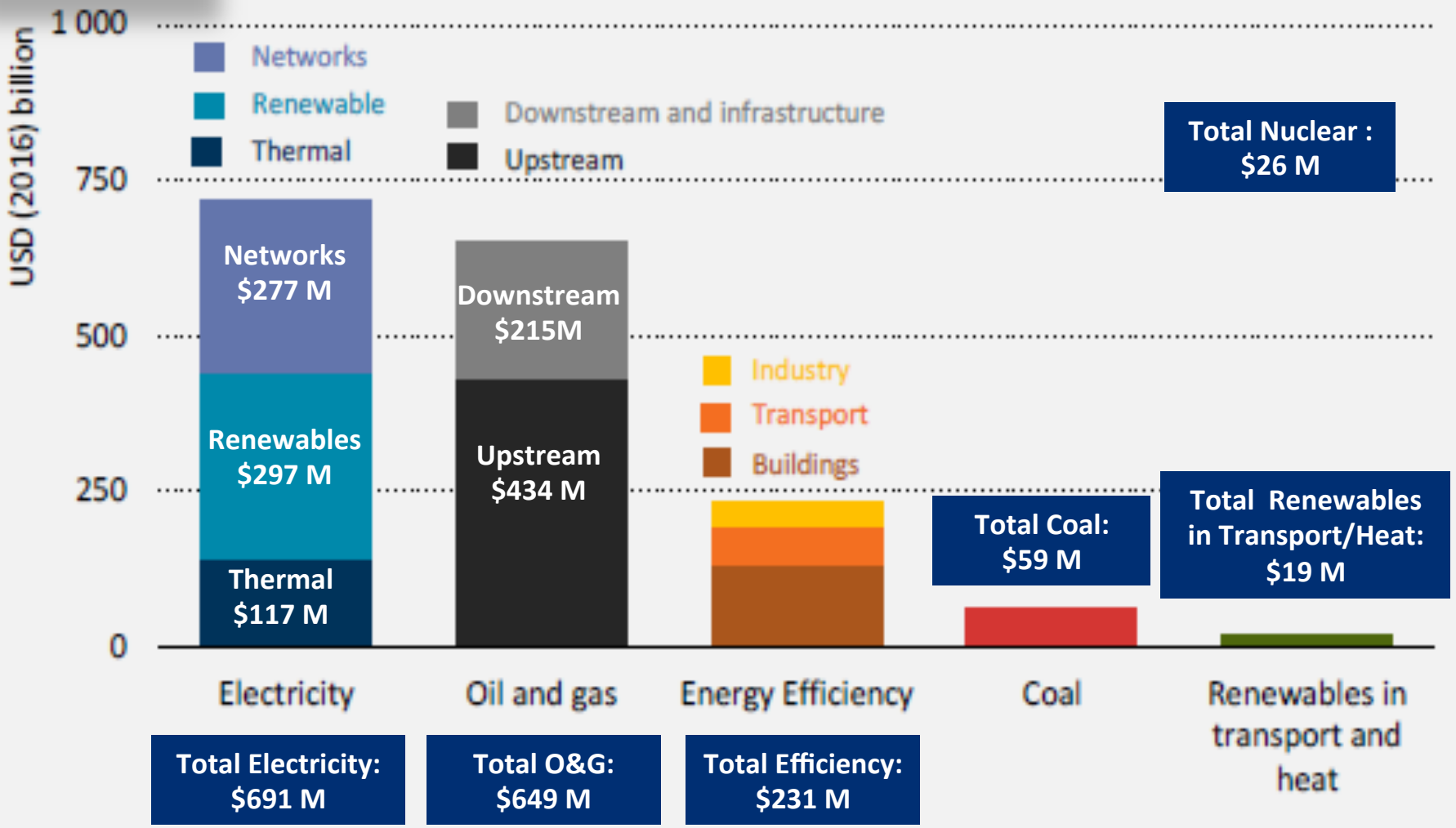
ADI Analytics



US LNG Volumes to Asia through Panama Canal by 2020 expected to exceed 3 bcf/d. EIA

*Plants under construction

Global Energy Investment



Global energy investment totalled USD 1.7 trillion in 2016, 12% down on 2015 due mainly to a fall of over one-quarter in oil and gas investment.

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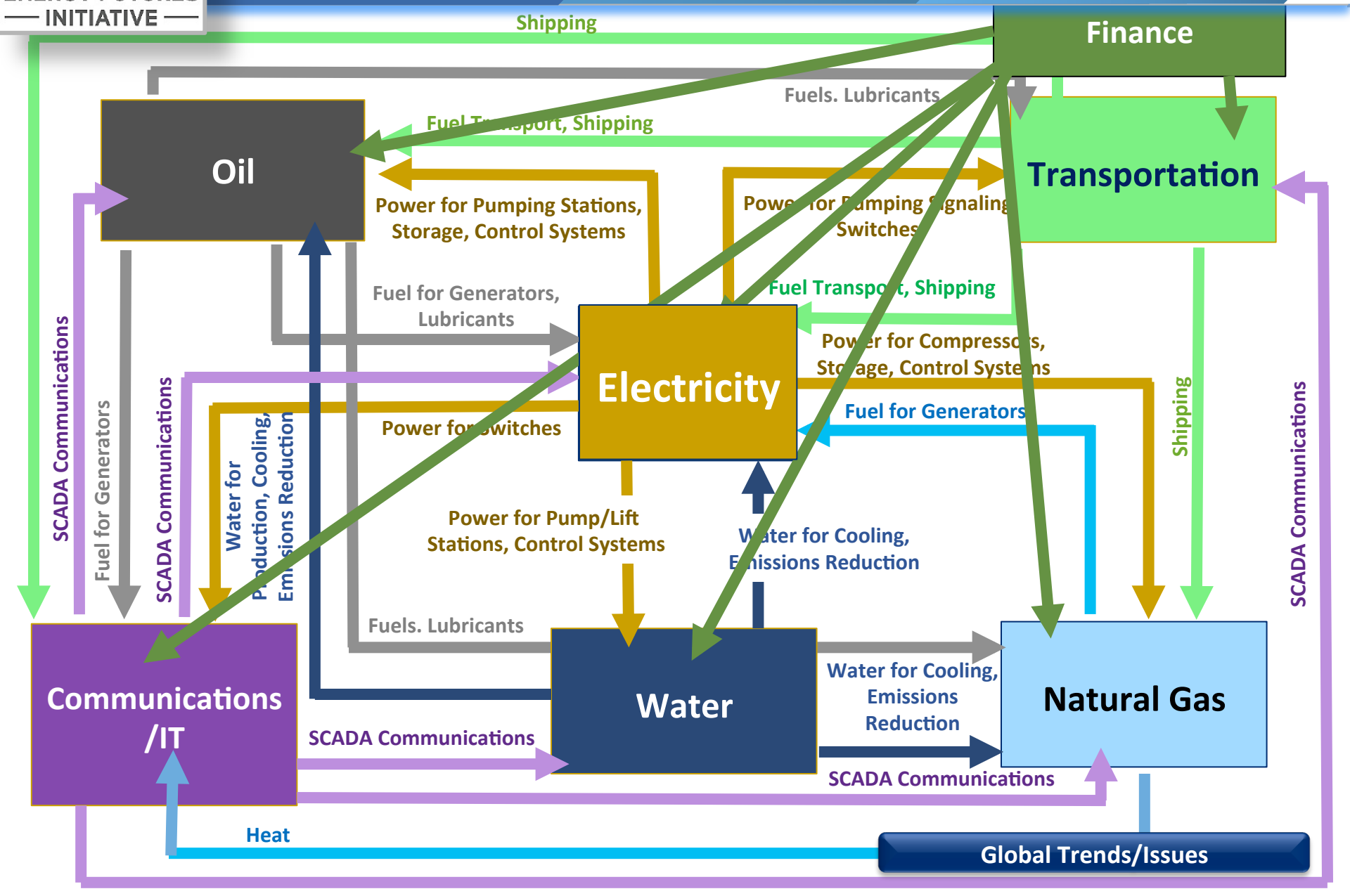
Lifeline Network Interdependencies



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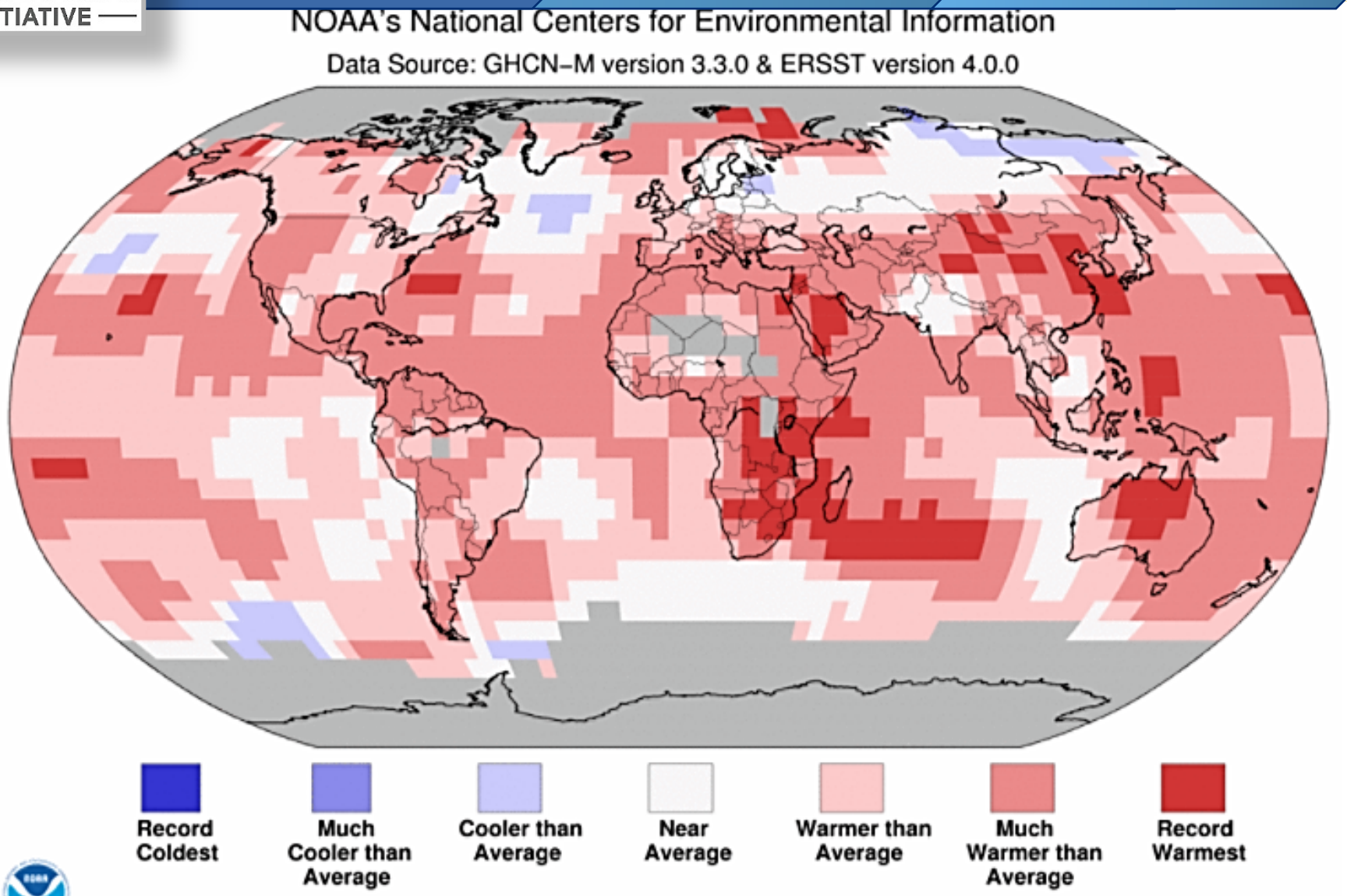
Land and Ocean Temperature Percentiles, 07/17



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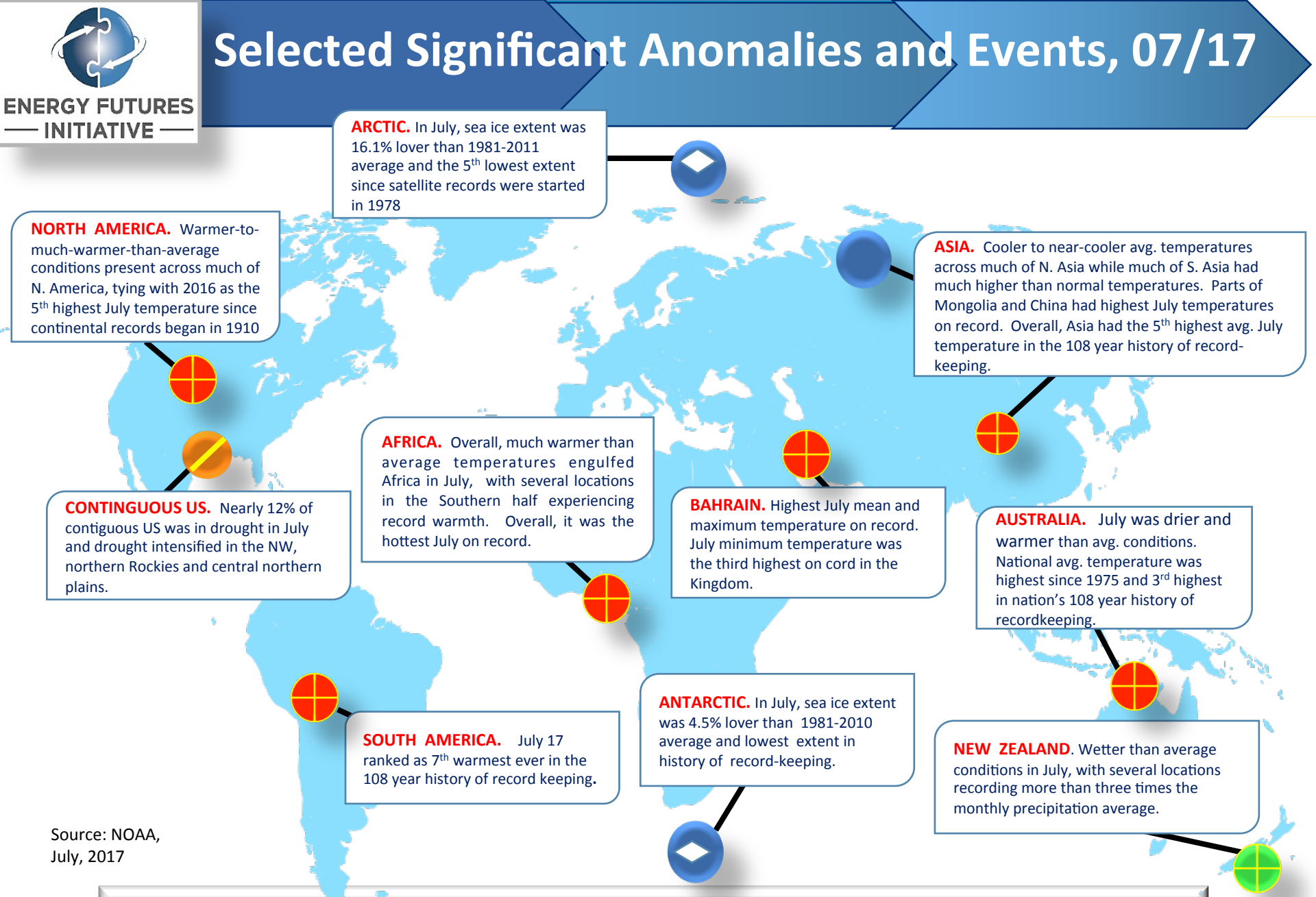
Selected Significant Anomalies and Events, 07/17



ARCTIC. In July, sea ice extent was 16.1% lover than 1981-2011 average and the 5th lowest extent since satellite records were started in 1978

NORTH AMERICA. Warmer-to-much-warmer-than-average conditions present across much of N. America, tying with 2016 as the 5th highest July temperature since continental records began in 1910

ASIA. Cooler to near-cooler avg. temperatures across much of N. Asia while much of S. Asia had much higher than normal temperatures. Parts of Mongolia and China had highest July temperatures on record. Overall, Asia had the 5th highest avg. July temperature in the 108 year history of record-keeping.

CONTINGUOUS US. Nearly 12% of contiguous US was in drought in July and drought intensified in the NW, northern Rockies and central northern plains.

AFRICA. Overall, much warmer than average temperatures engulfed Africa in July, with several locations in the Southern half experiencing record warmth. Overall, it was the hottest July on record.

BAHRAIN. Highest July mean and maximum temperature on record. July minimum temperature was the third highest on cord in the Kingdom.

AUSTRALIA. July was drier and warmer than avg. conditions. National avg. temperature was highest since 1975 and 3rd highest in nation's 108 year history of recordkeeping.

SOUTH AMERICA. July 17 ranked as 7th warmest ever in the 108 year history of record keeping.

ANTARCTIC. In July, sea ice extent was 4.5% lover than 1981-2010 average and lowest extent in history of record-keeping.

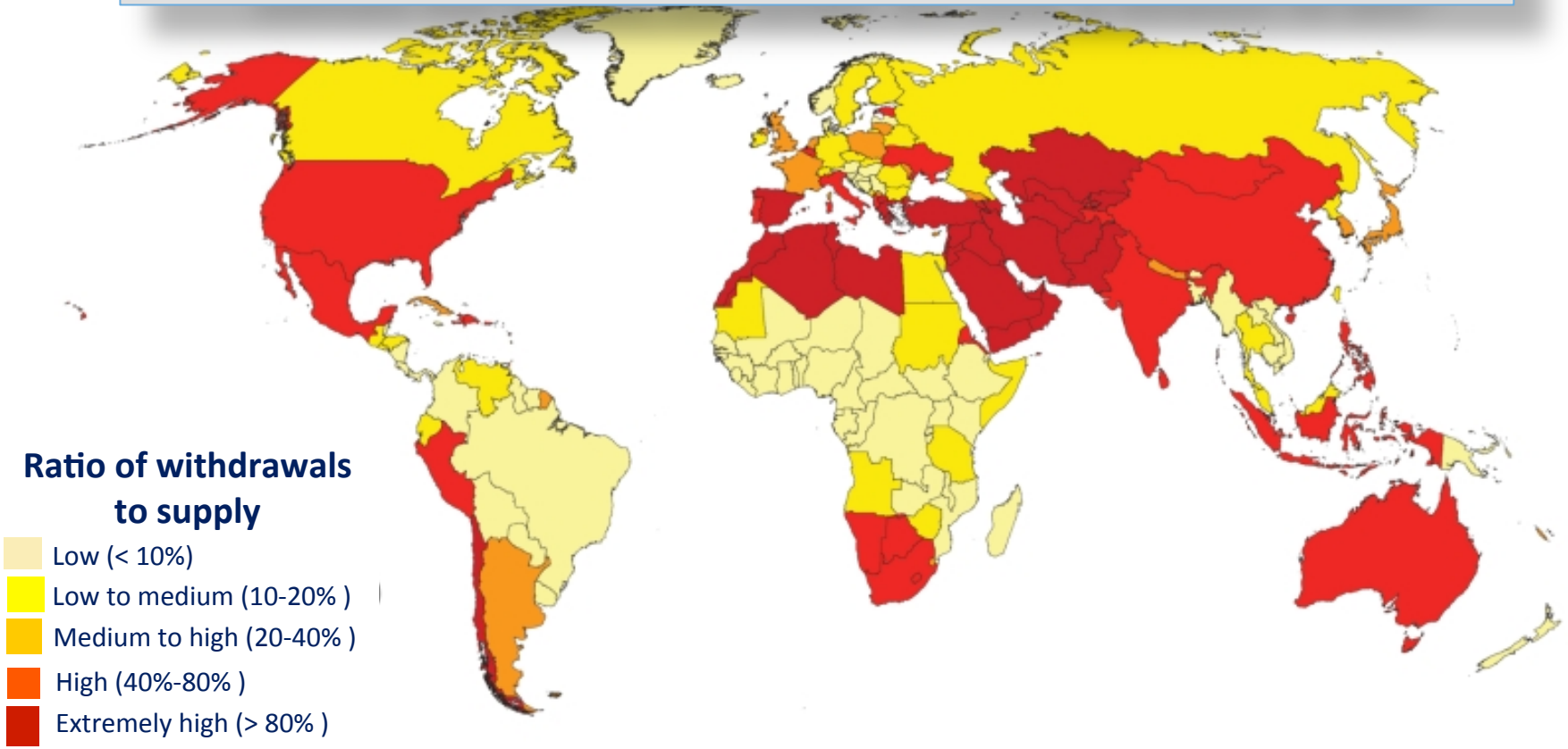
NEW ZEALAND. Wetter than average conditions in July, with several locations recording more than three times the monthly precipitation average.

Source: NOAA, July, 2017

Global average temperature: July, 2017 average land and ocean temperature was the second highest for July since recordkeeping began in 1880.

Global Water Stress, 2040

Currently, 28% of the world lives in water-scarce countries. Experts estimate that by 2080, this number will climb to between 43-50%*



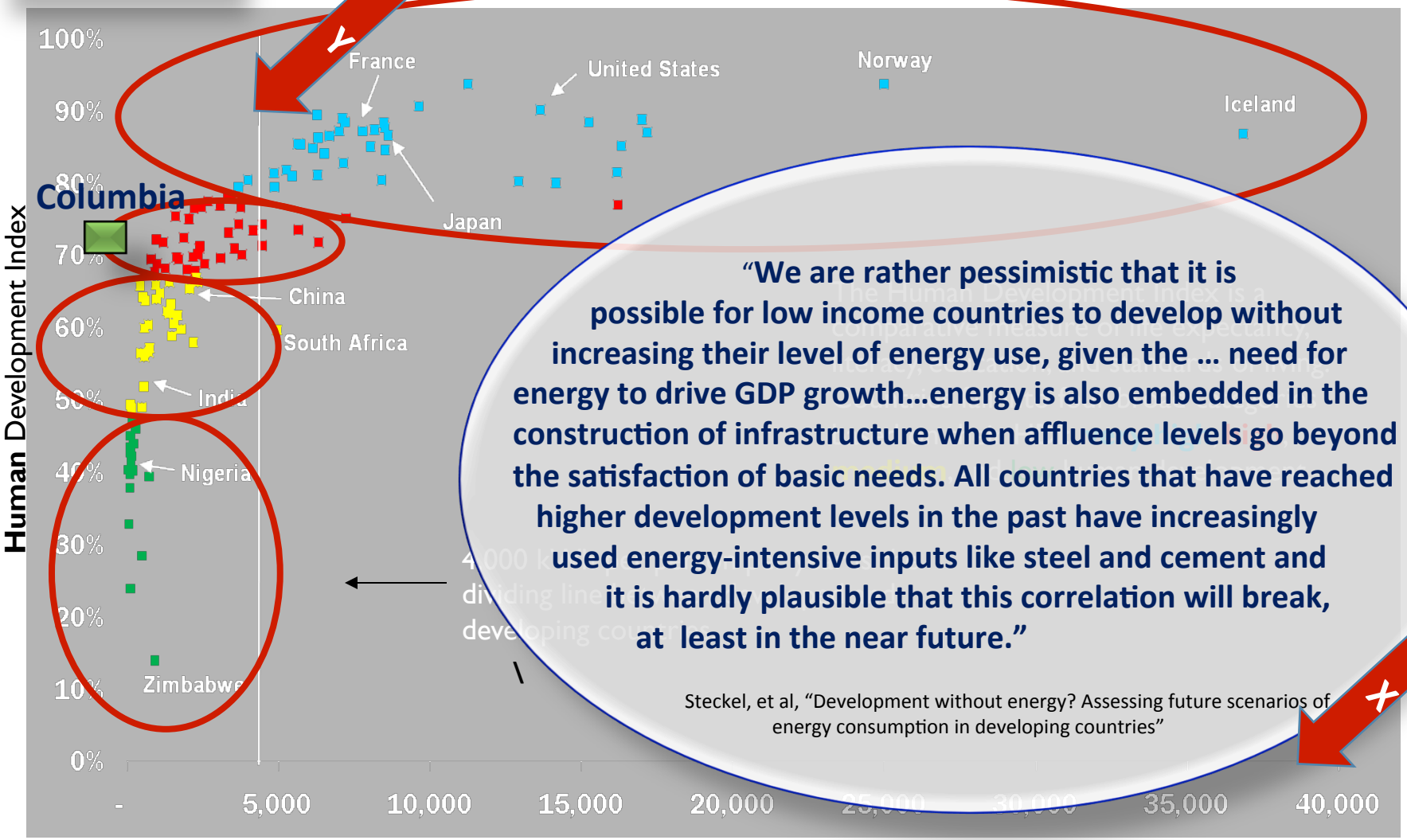
Water Stress by Country: 2040

Global Trends/Issues

For more: ow.ly/RiWop

* World Bank, 2014, Huffman

Human Development Index & Electricity Consumption



"We are rather pessimistic that it is possible for low income countries to develop without increasing their level of energy use, given the … need for energy to drive GDP growth…energy is also embedded in the construction of infrastructure when affluence levels go beyond the satisfaction of basic needs. All countries that have reached higher development levels in the past have increasingly used energy-intensive inputs like steel and cement and it is hardly plausible that this correlation will break, at least in the near future."

Steckel, et al, "Development without energy? Assessing future scenarios of energy consumption in developing countries"

Source: Human Development Index – 2010 data United Nations; Annual Per Capita Electricity Consumption (kWh) - 2007 data World Bank. Updated: 4/11

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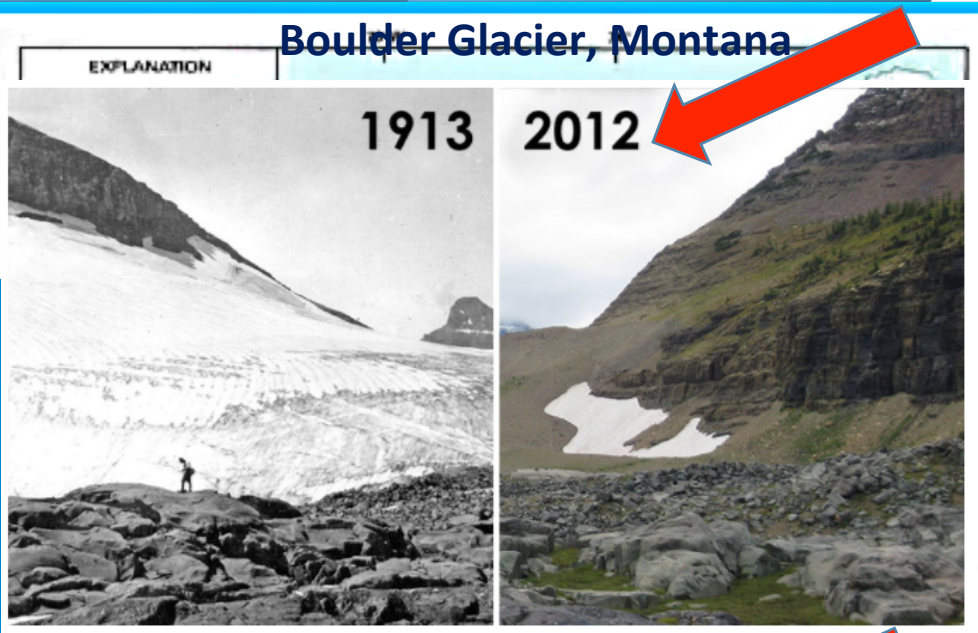
Colombia, El Nino, Glaciers, Climate Change

"The climate phenomenon known as El Niño has accelerated the melting of Colombian glaciers".

Hydrology, Meteorology and Environmental Studies Institute

"The Conejeras Glacier, located in Los Nevados National Natural Park in the Central Colombian Andes, lost 2.36 meters (7.8 feet) of its ice mass over the last five months as a result of El Niño"

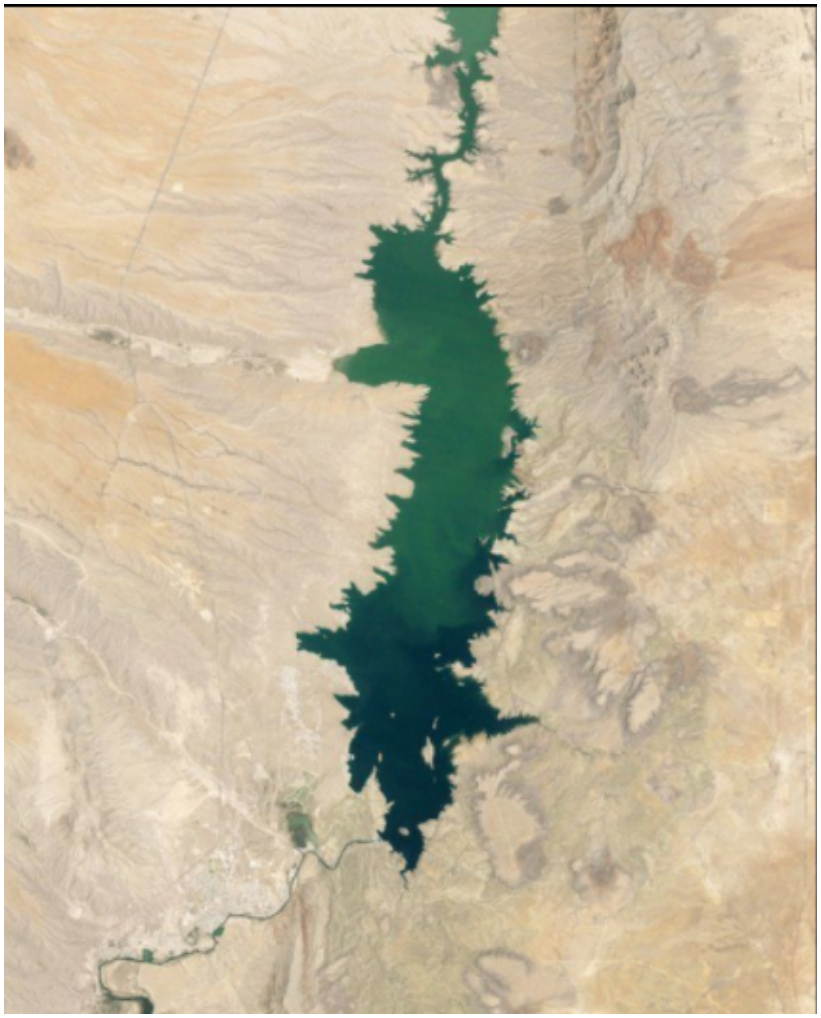
Boulder Glacier, Montana



Glacier in Peru

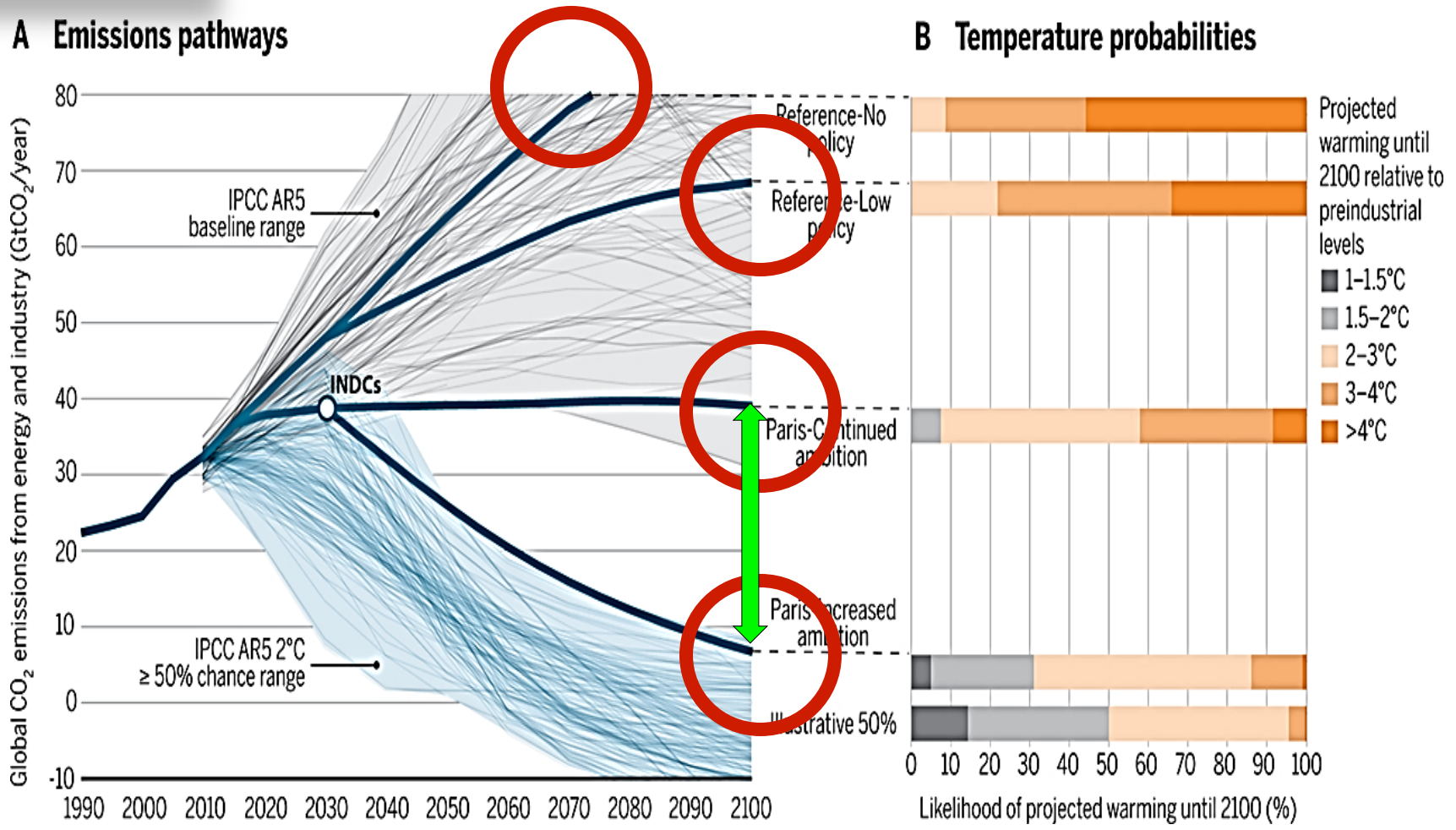
Closer to (My) Home: NASA Satellite Photos, Elephant Butte Reservoir, New Mexico

1994



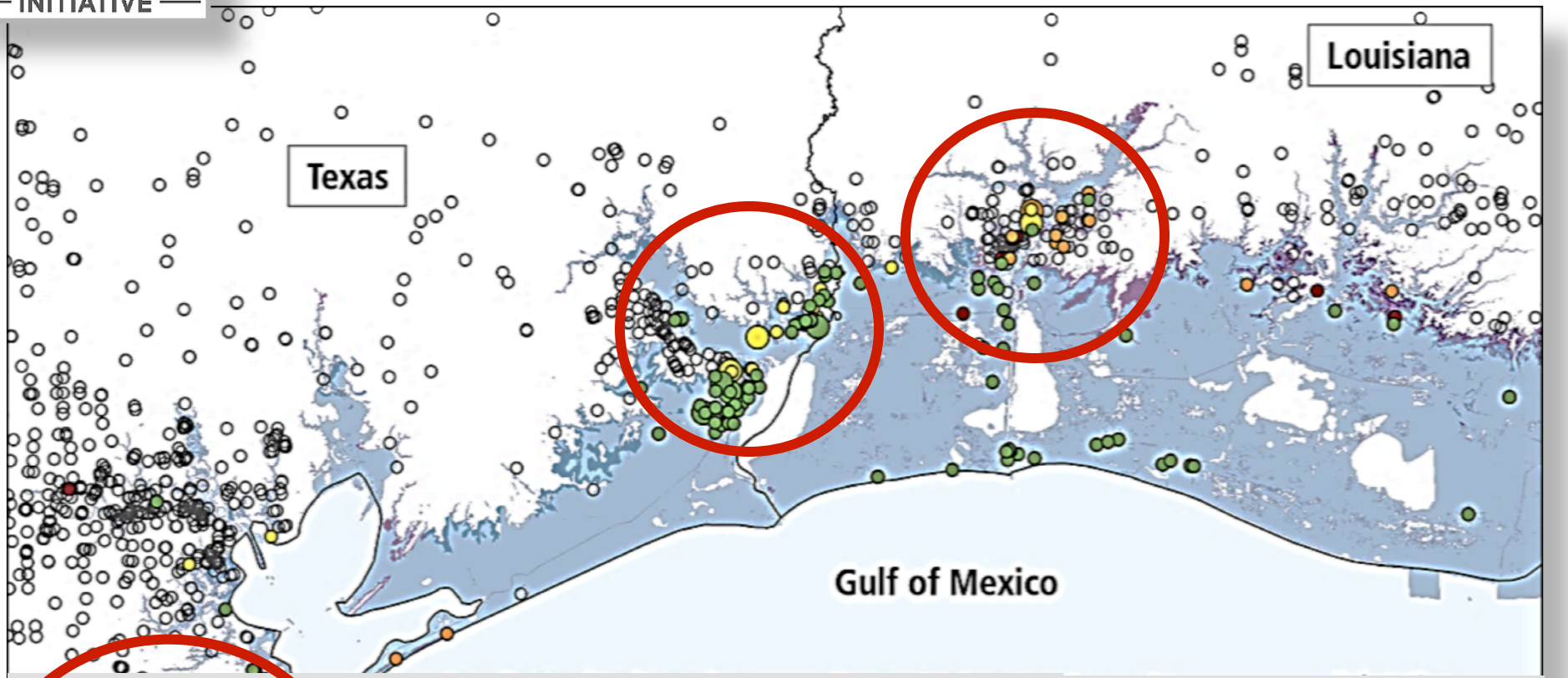
2013

Climate Goals/COP 21 Temperature Targets



Fawcett et al 2015

Gulf Coast Hurricanes: Increase in Storm Intensity Spells Trouble for Infrastructure



Petroleum:

- 42 refineries
- 8,225 MBbl/d
- 52% of national refining capacity
- 234 terminals

Natural Gas:

- 86 processing plants
- 31% of national gas processing capacity
- 291 compressors
- 13 transmission hubs

Propane:

- Mt. Belvieu storage complex and market hub
- ~35% of national propane stocks

Fuel Switching And US CO_2 Emissions Reductions

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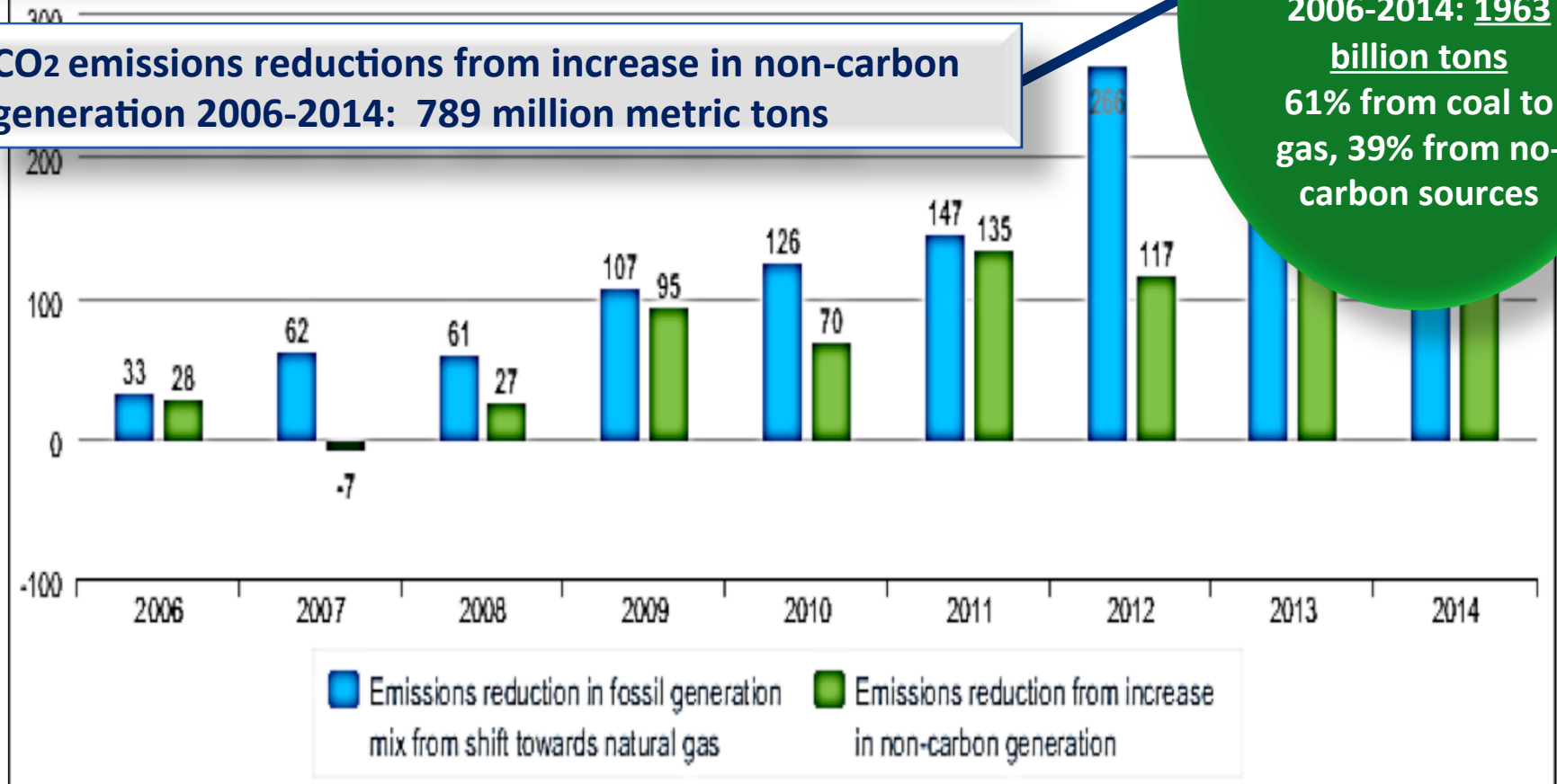
CO_2 emissions reductions in fossil fuel generation from shift to gas, 2006-2014: 1254 million metric tons

CO_2 emissions reductions from increase in non-carbon generation 2006-2014: 789 million metric tons

Total CO_2 emissions reductions from fuel switching 2006-2014: 1963 billion tons
61% from coal to gas, 39% from no-carbon sources



Source: EIA

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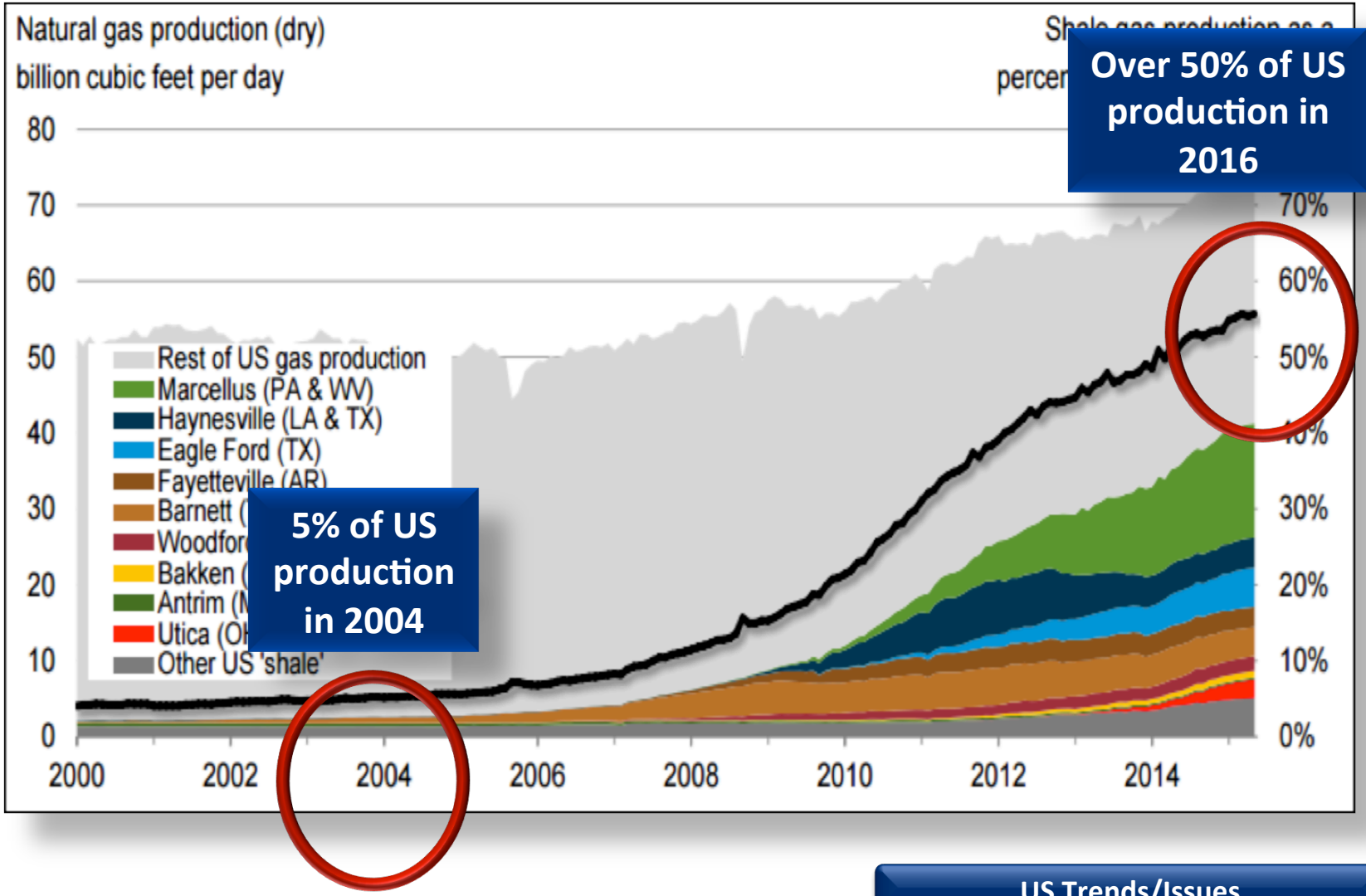
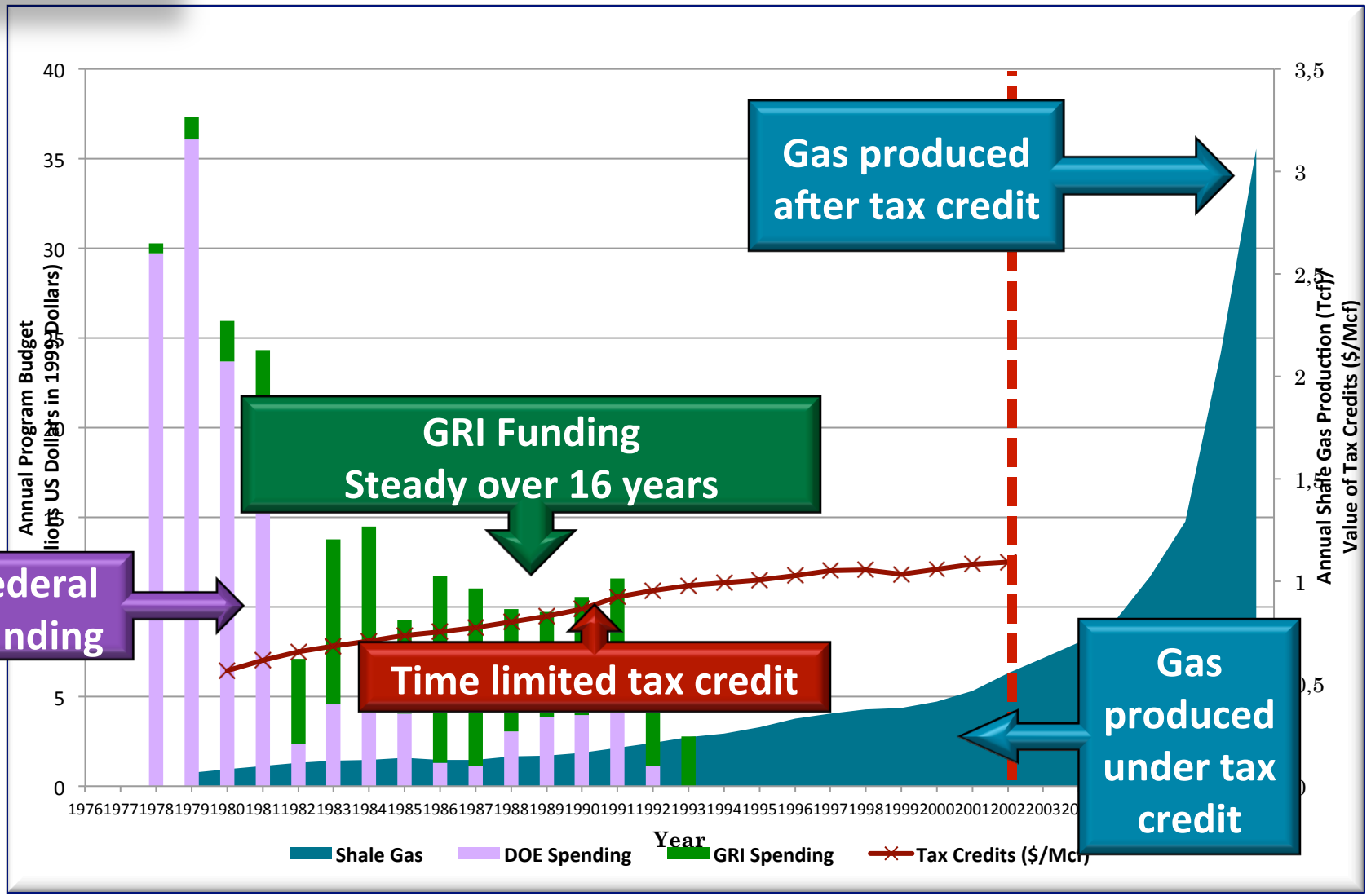
Shale Gas has Transformed US Energy Profile



Source: EIA

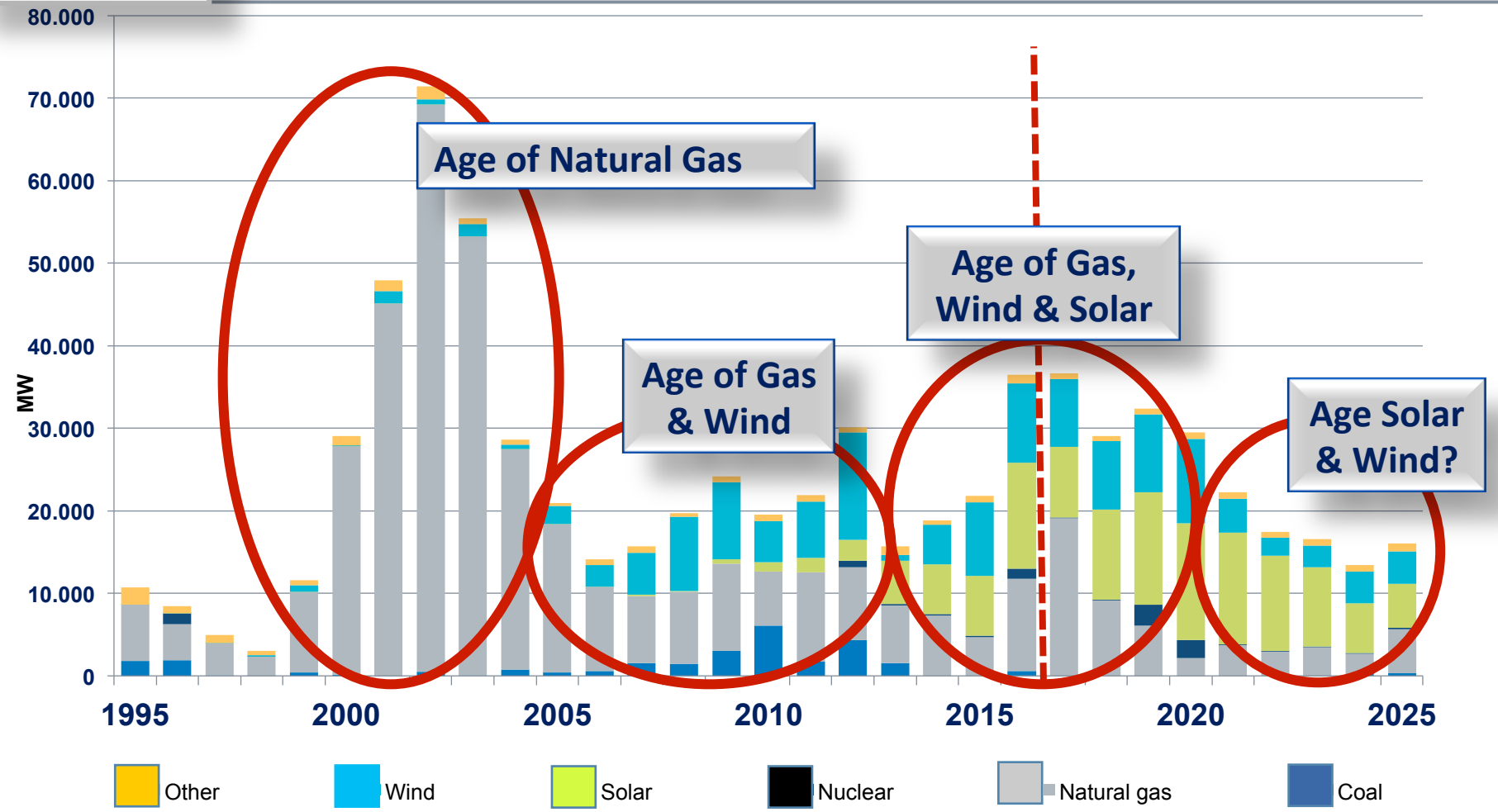
US Trends/Issues

Shale Gas Success: RD&D, Public/Private Partnerships, Policy Mechanisms



Source: MIT Future of Natural Gas Study

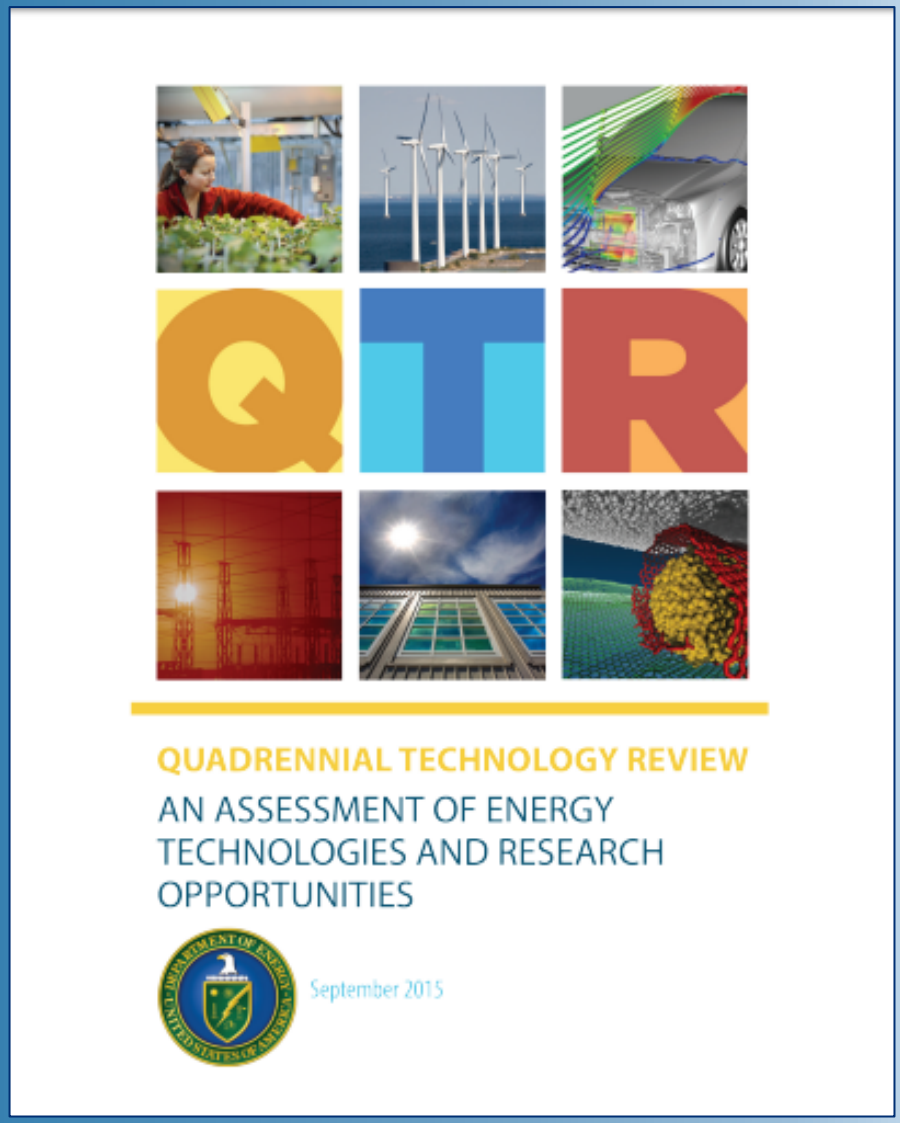
US Generation Capacity Additions



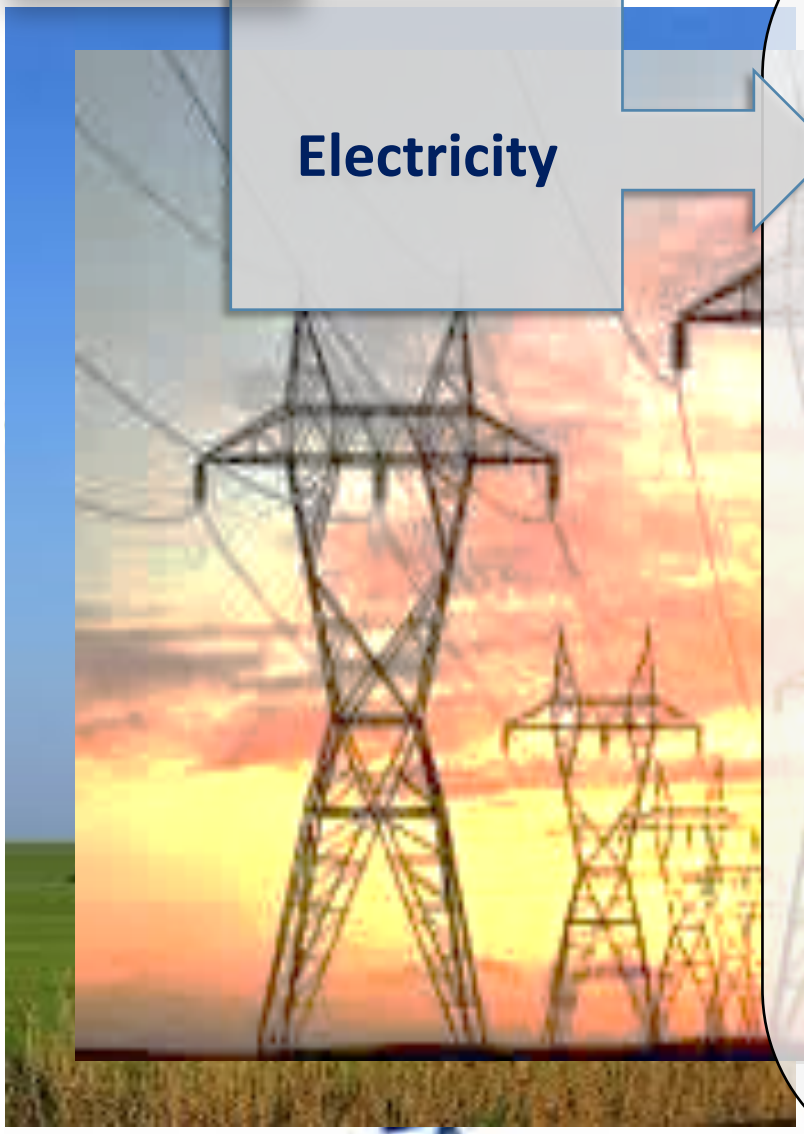
Notes: Additions exclude coal-to–natural gas or biomass conversions.
Source: IHS and ABB Velocity Suite

Quadrennial Technology Review

The 2015 Quadrennial Technology Review (QTR) examines the status of the science and technology that are the foundation of our energy system, together with the research, development, demonstration, and deployment (RDD&D) opportunities to advance them. It focuses primarily on technologies with commercialization potential in the midterm and beyond.



Key Transformational Technology Pathways: Electricity



Electricity

- **Fossil generation**
  - Turbine efficiency
  - Carbon capture, utilization, storage
- **Renewable generation**
  - On-shore wind
  - Off-shore wind
  - Grid scale solar
  - Distributed solar
  - Small hydro
- **Grid scale and distributed storage**
- **Small modular reactors and other advanced nuclear technologies**
- **Grid modernization**
  - Integration of variable renewables
  - Smart grid/meters
  - IT/OT integration
  - Internet of Things
  - Distribution system automations

Key Transformational Technology Pathways: Transportation

Transportation

- Electric Vehicle/Batteries
- Fuel Cell Vehicles
- Automated Vehicles
- Hybrids and Plug-ins
- Biofuels
- Light-weighting
- Heavy-duty vehicle efficiency and alternative fuels

Batteries: Key Clean Energy Enabler

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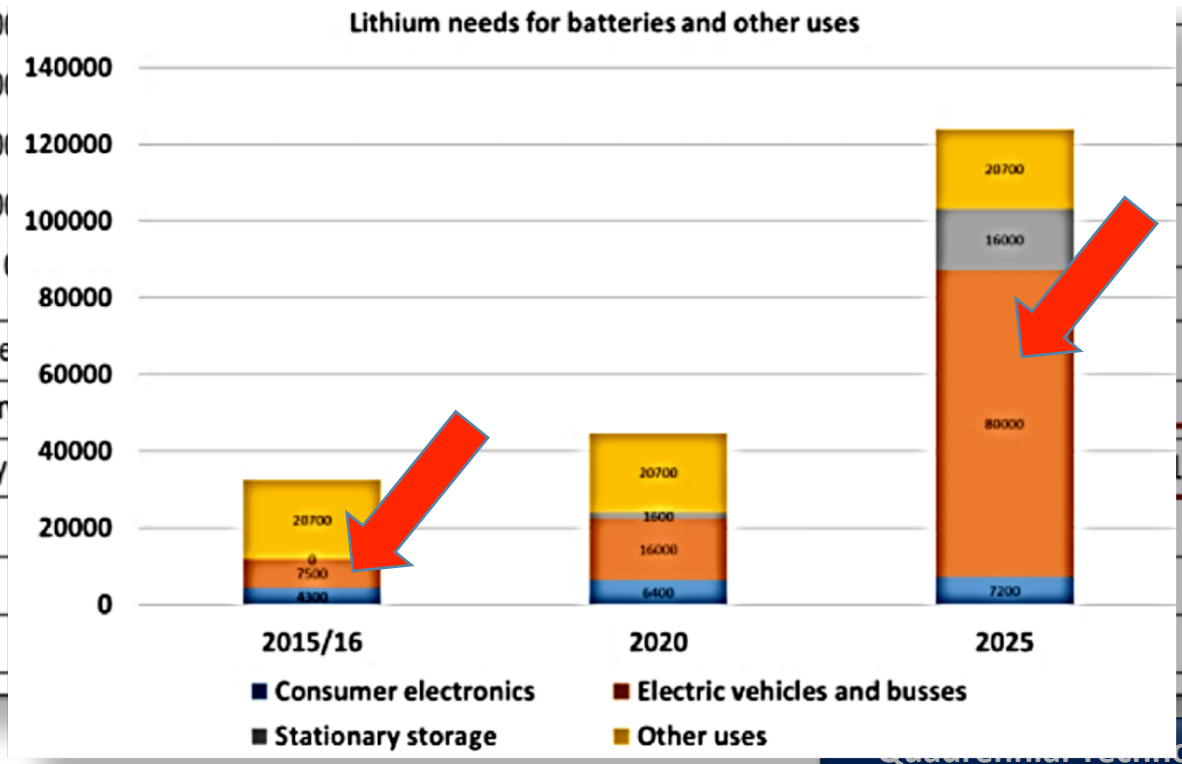
Table 1. Production, reserves, share of battery use and recycling rate of lithium and cobalt in 2015 (Jaskula, 2016) (CDI, 2016) (UNEP, 2011).

	Lithium	Cobalt
Annual production (Ton/a)	32.500	99.000
Useful reserves (million tons)	14	7.1
Global resources (million tons)	34	120
Share of battery use (%)	35	42
Main reserves	Chile, Argentina, Bolivia China, Australia	Democratic Republic of Congo
Recycling rate (%)	< 1	68



Rated Power kW

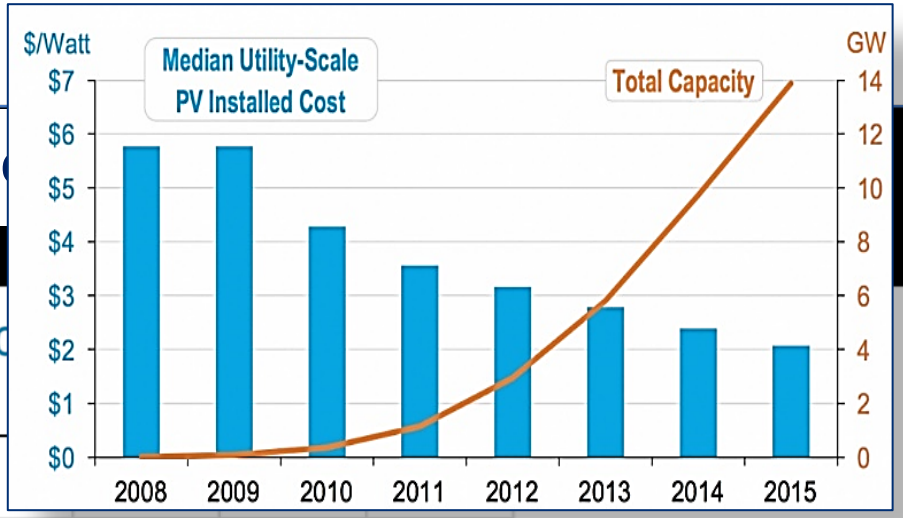
Sodium based Batte
Nickel based Batter
Lithium-ion Battery
Lead-acid Batter
Flow Battery
Electro-chemical

	2014	2015	2016
Sodium based Batte	600	470	25
Nickel based Batter			
Lithium-ion Battery	35016	145470	430
Lead-acid Batter	1100	6100	
Flow Battery	100	1270	
Electro-chemical		48	

ology Review

Source: DOE Global Energy Storage Database (energystorageexchange.org), April 6, 2016.

Significant Cost Reductions for Key Technologies



Advanced Research Projects Agency – Energy (ARPA-E)

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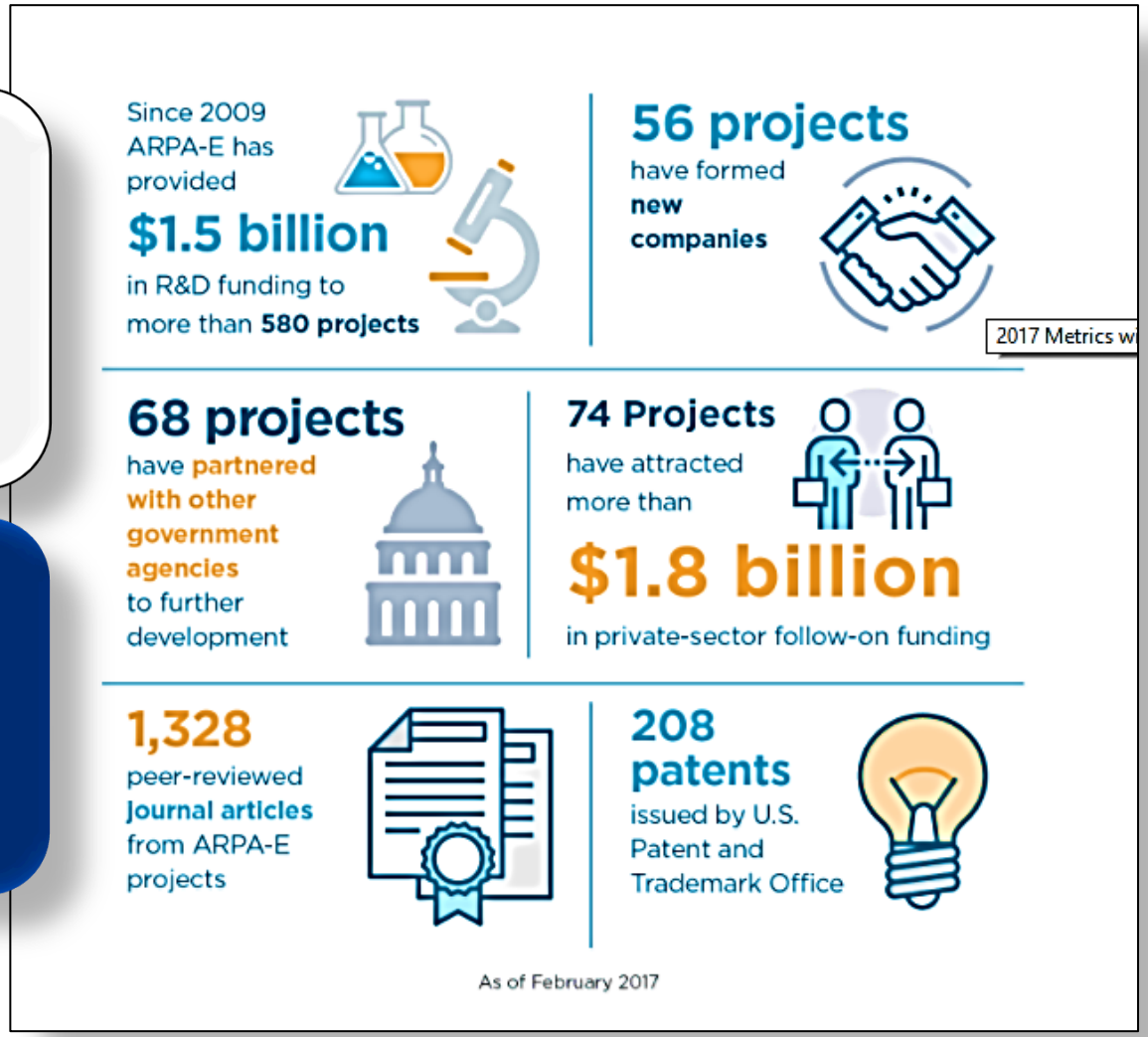
ARPA-E focuses on promoting transformational technologies with high risk, high payoff characteristics that may fall outside the path of conventional technology roadmaps

U.S. National Academy of Sciences recommended a funding path to an annual budget of $1 billion for ARPA-E



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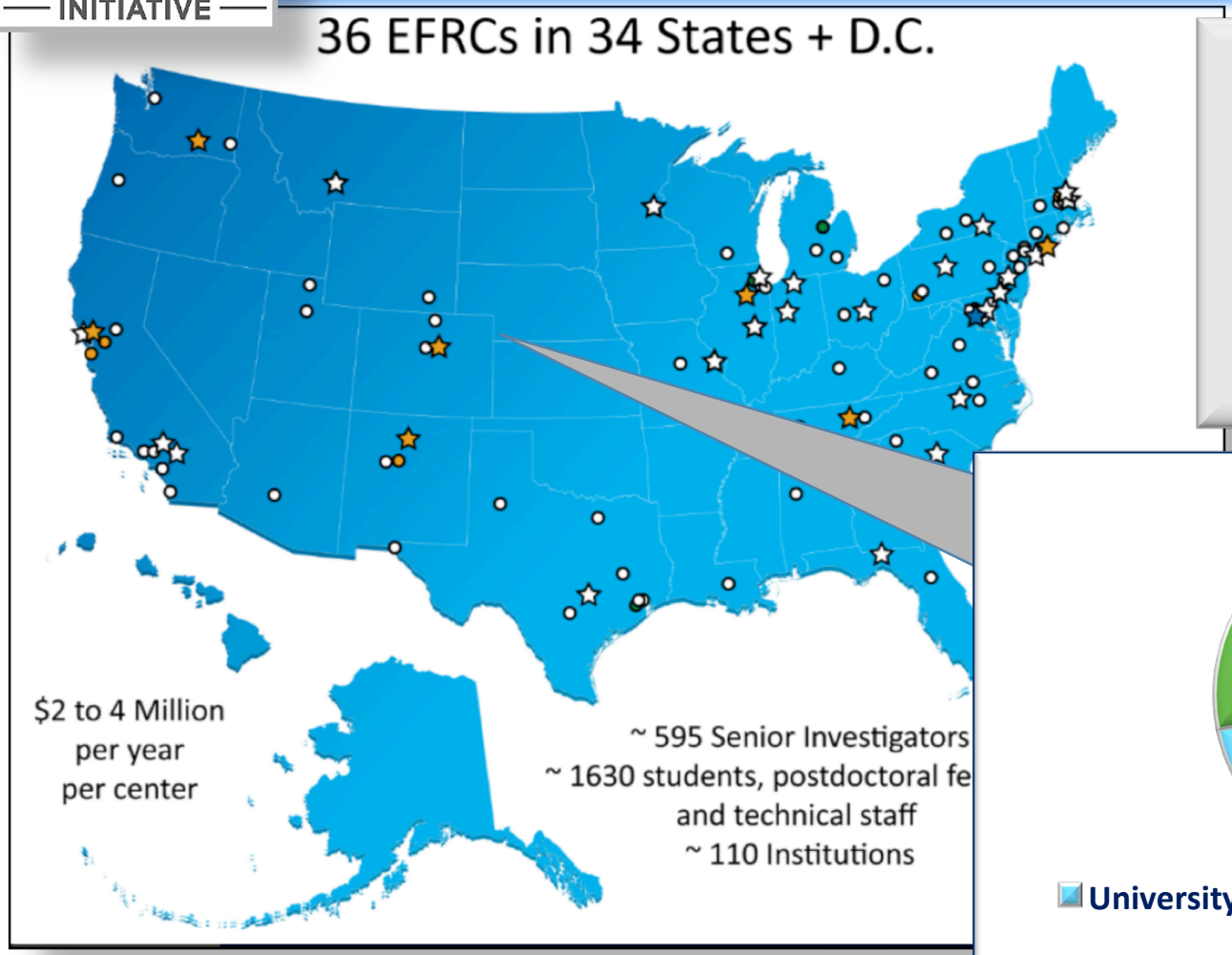
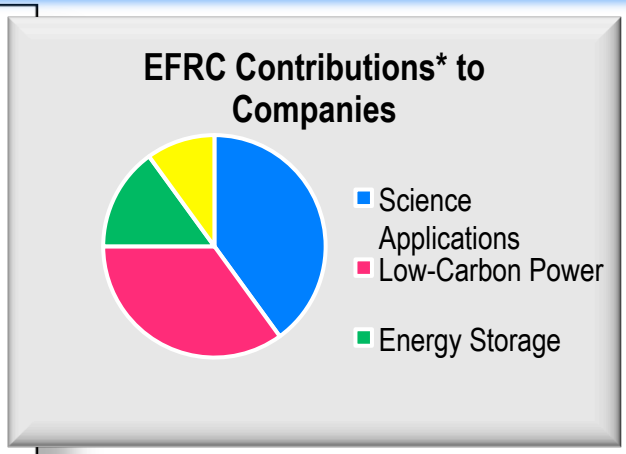
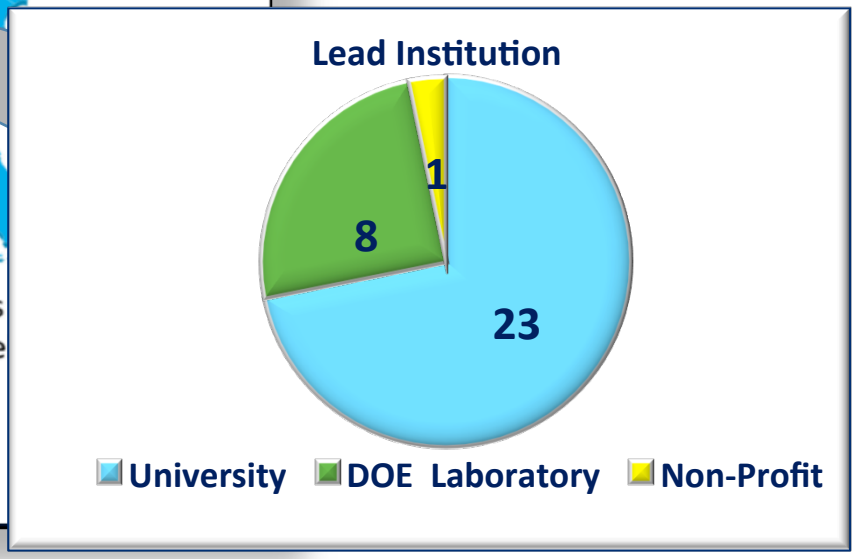
Energy Frontier Research Centers

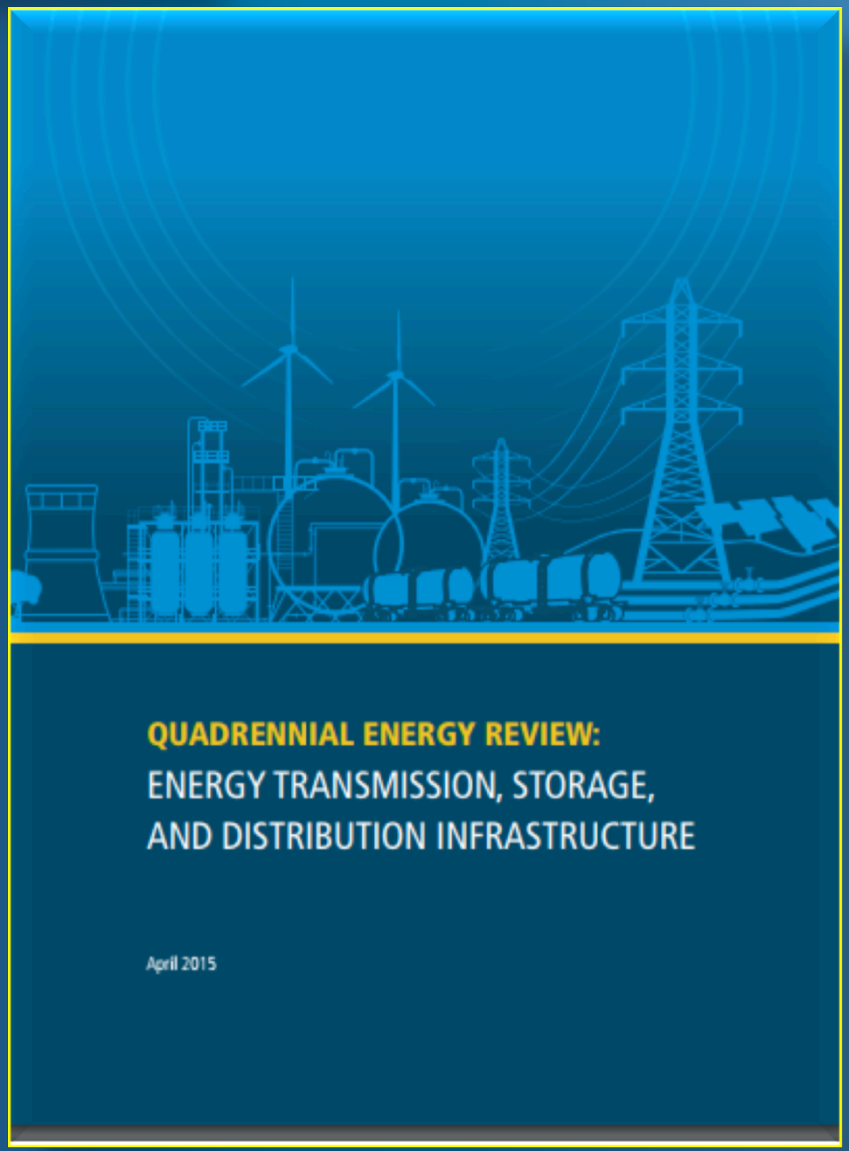


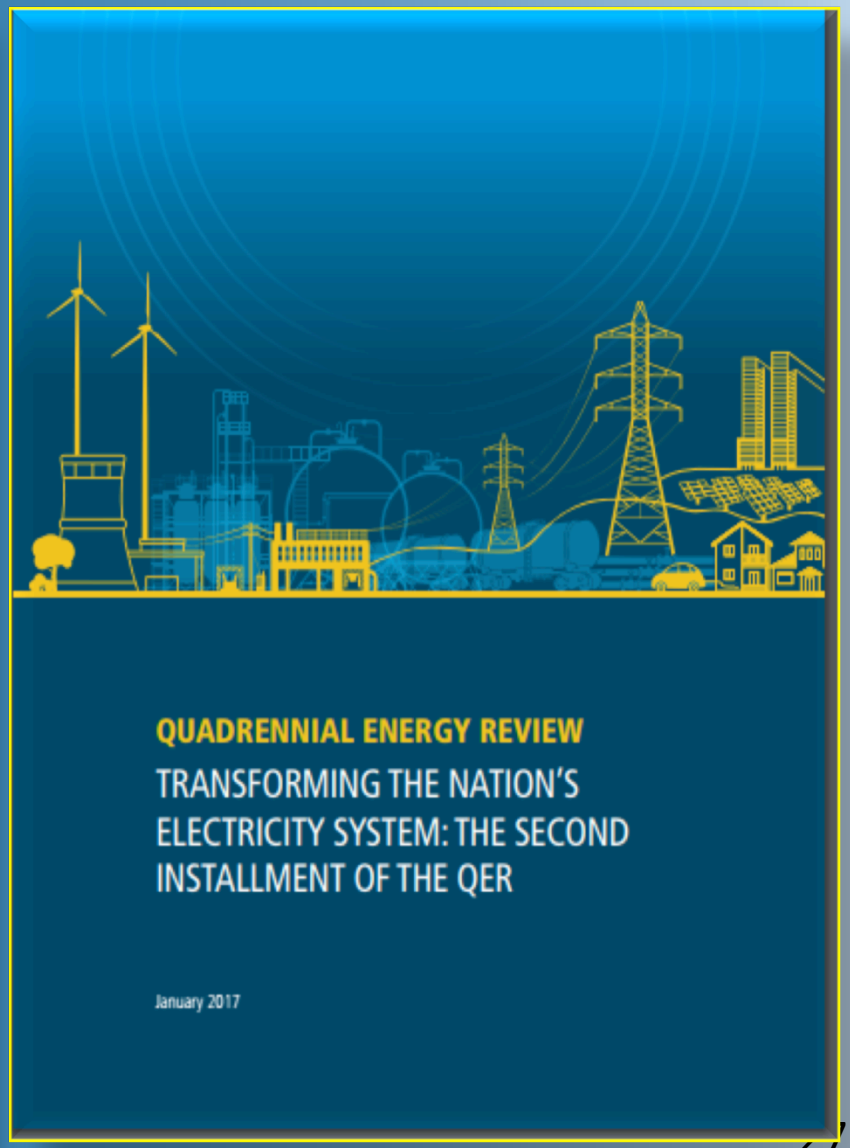




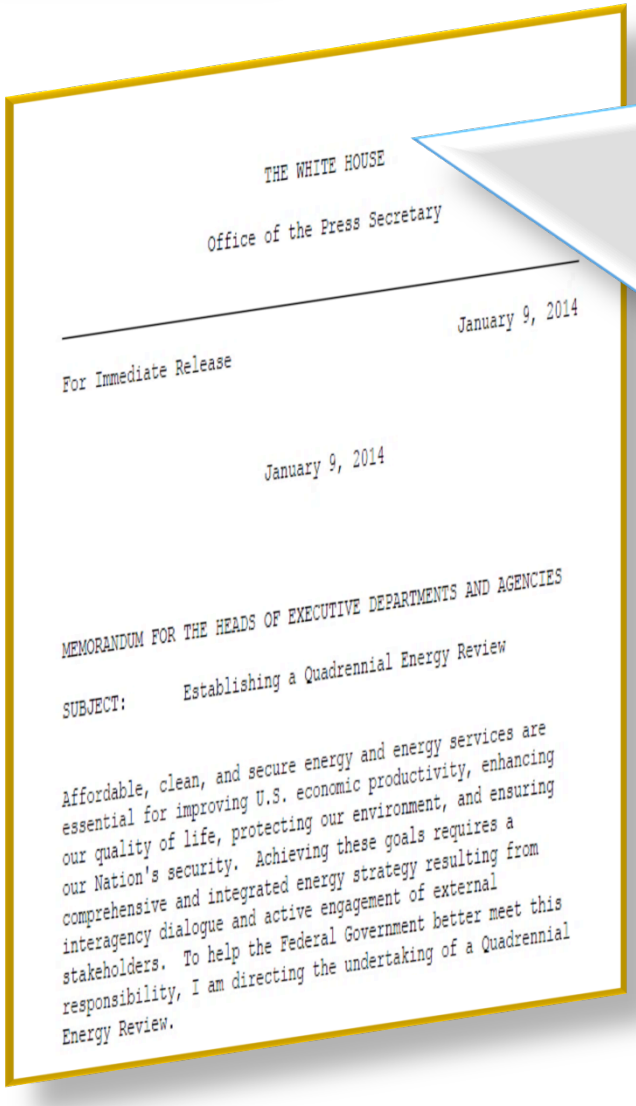
The EFRCs harness the most basic and advanced discovery research in a concerted effort to establish the scientific foundation for a fundamentally new U.S. energy economy.

Quadrennial Energy Review: Intallments One and Two





Quadrennial Energy Review



THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release

January 9, 2014

January 9, 2014

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

SUBJECT: Establishing a Quadrennial Energy Review

Affordable, clean, and secure energy and energy services are essential for improving U.S. economic productivity, enhancing our quality of life, protecting our environment, and ensuring our Nation's security. Achieving these goals requires a comprehensive and integrated energy strategy resulting from interagency dialogue and active engagement of external stakeholders. To help the Federal Government better meet this responsibility, I am directing the undertaking of a Quadrennial Energy Review.

- **Presidential Memorandum stated the Administration will conduct a Quadrennial Energy Review to be led by the White House Domestic Policy Council and Office of Science and Technology Policy**
- **Supported by a Secretariat established at the Department of Energy**
- **Process involves the robust engagement of federal agencies and outside stakeholders**
- **Enables the federal government to translate policy goals into a set of analytically based, integrated actions for proposed investments over a four-year planning horizon**

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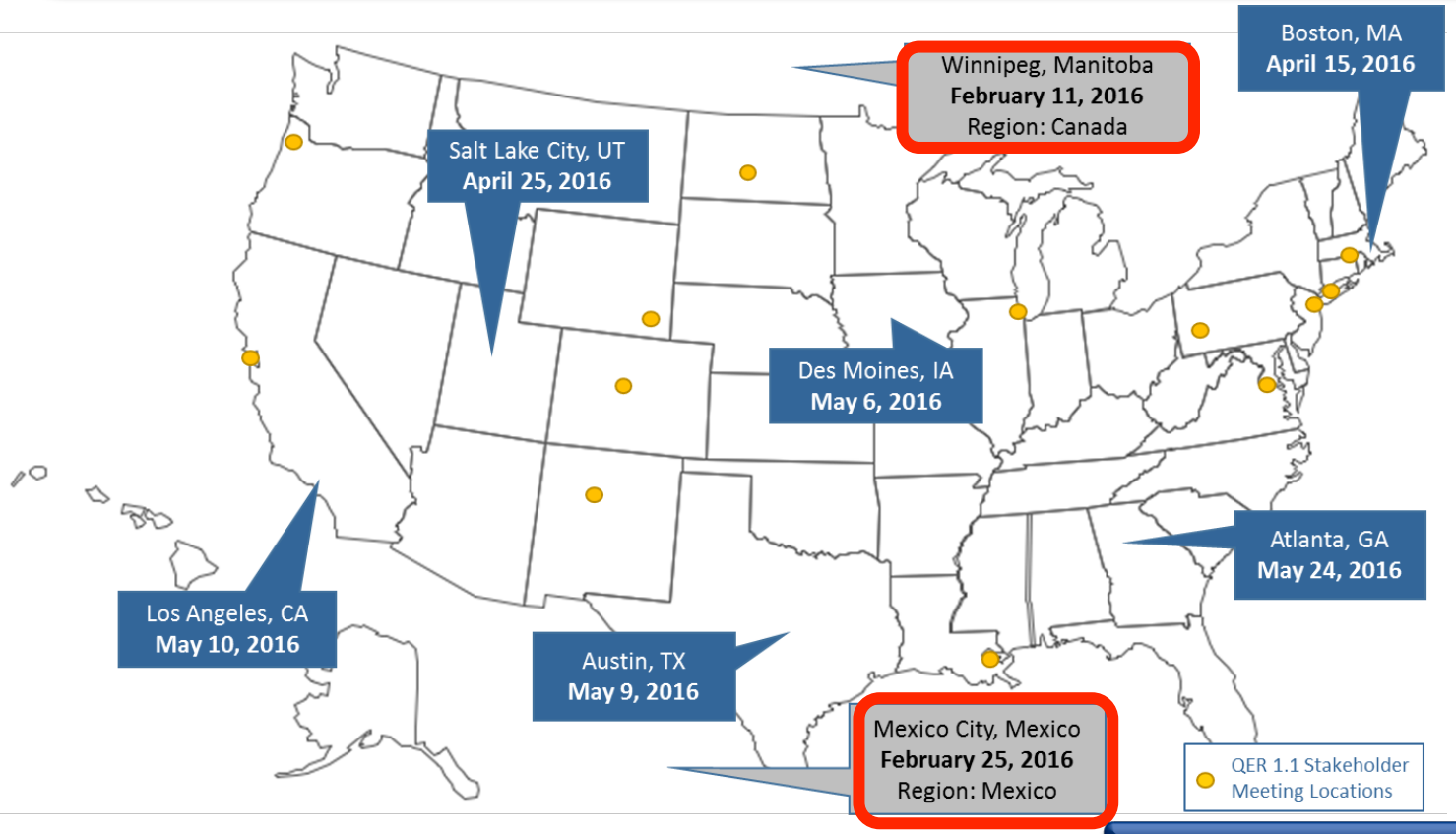
• QER Process - Interagency

- **Review and concurrence with the White House and over 20 Federal executive departments and agencies throughout process**
- **Additional analysis, including studies and data, provided from agencies for policy analysis and modeling consideration**

QER 1.1

• QER Process - Stakeholders

- Public meetings and technical workshops across the U.S.
- International meetings in Canada and Mexico
- Public comment portal available online



QER 1.1 Transmission, Storage, & Distribution Infrastructure

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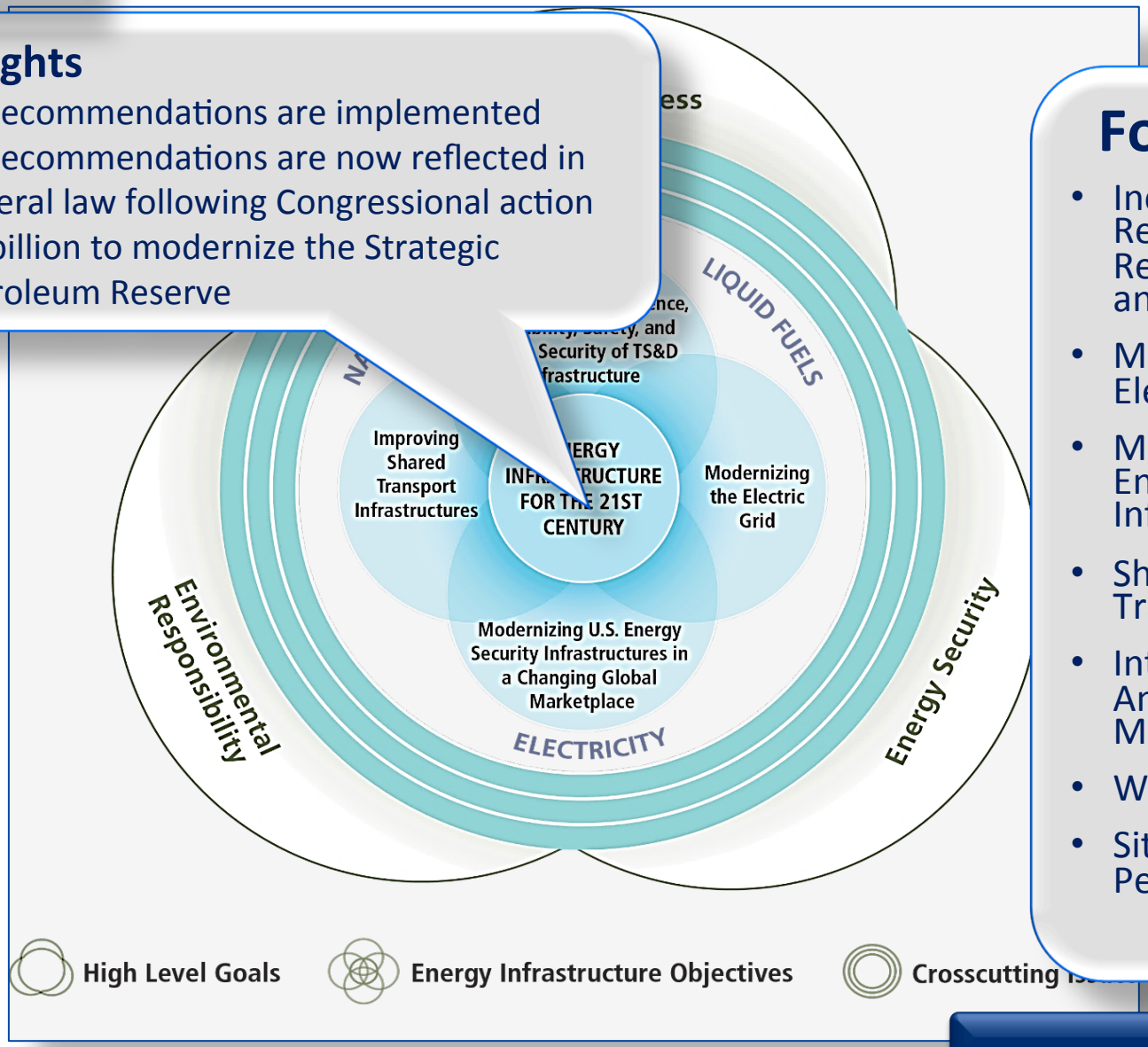
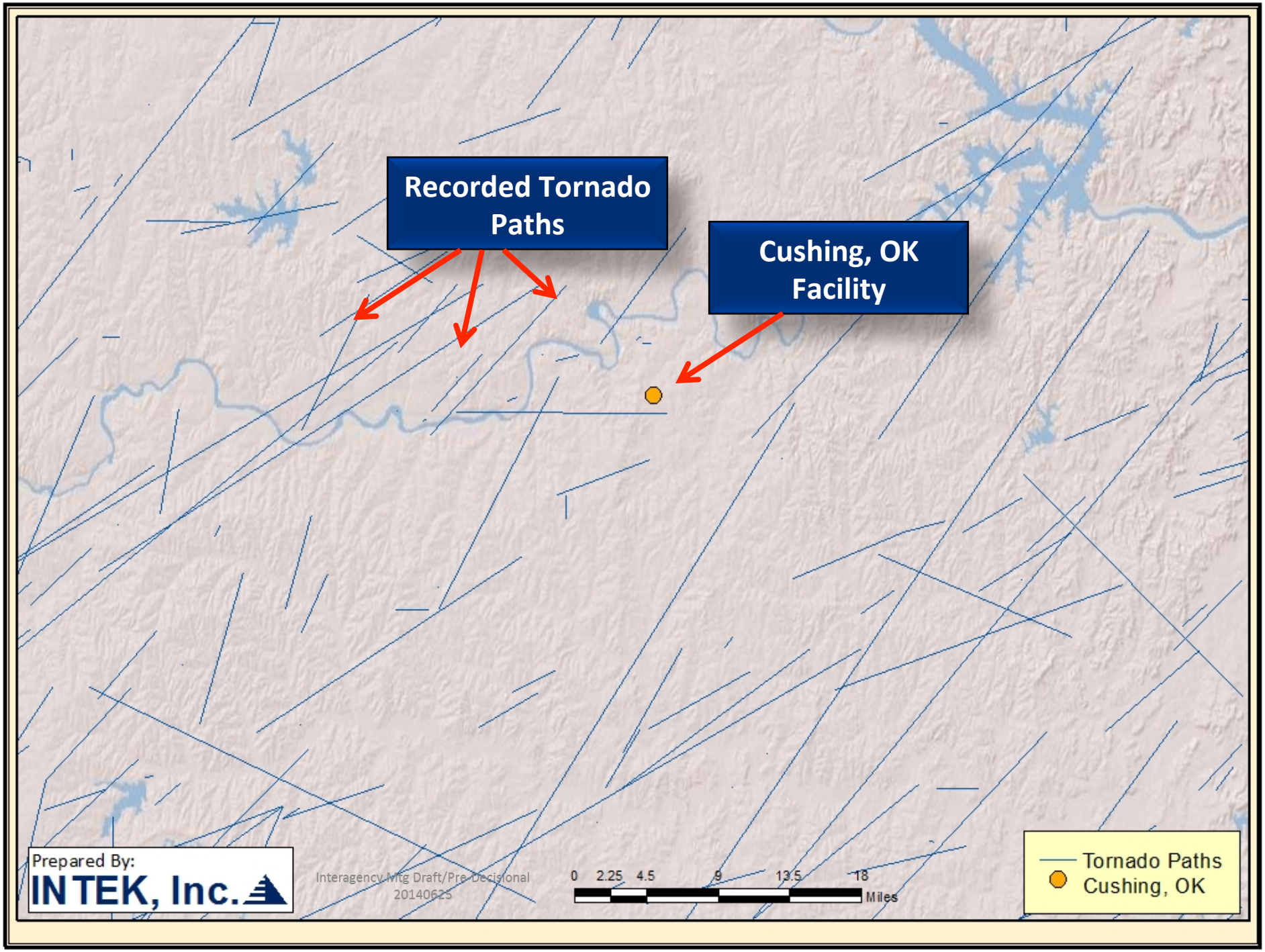
Highlights

- 12 recommendations are implemented
- 21 recommendations are now reflected in Federal law following Congressional action
- $2 billion to modernize the Strategic Petroleum Reserve

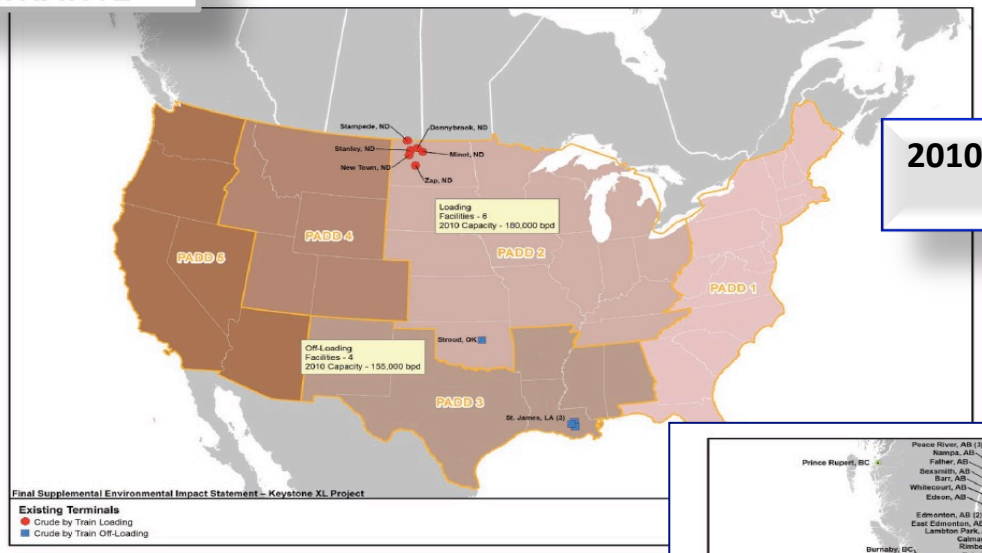


Focus Areas

- Increasing Resilience, Reliability, Safety and Asset Security
- Modernizing the Electric Grid
- Modernizing US Energy Security Infrastructure
- Shared Transportation
- Integrating N. American Energy Markets
- Workforce
- Siting and Permitting


Recorded Tornado Paths
Cushing, OK Facility
Prepared By:
INTEK, Inc.
Interagency Mtg Draft/Pre-Decisional
20140625
0 2.25 4.5 9 13.5 18
Miles
Tornado Paths
Cushing, OK

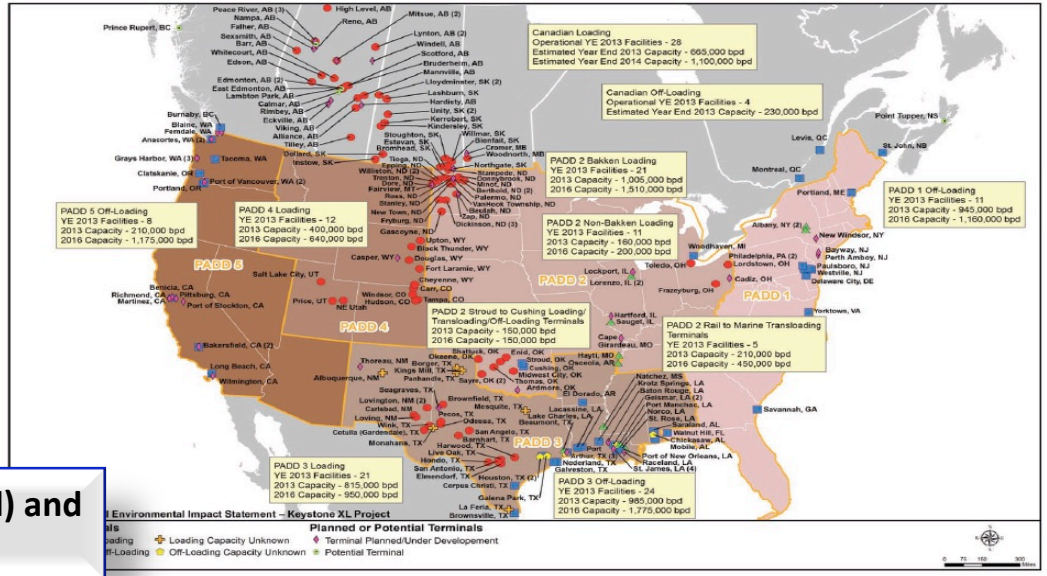
QER 1.1: Geography of Supply/Infrastructure Changing Rapidly



Source: Esri 2013; Walton 2010; Fielden 2013; NuStar Energy L.P. 2010; North Dakota Petroleum Council 2010; comp

Figure 1.4.3-11 Crude by Train Loading and Off-Loading Facilities

2010 Crude Oil by Train Loading (red) and Offloading (blue) Facilities

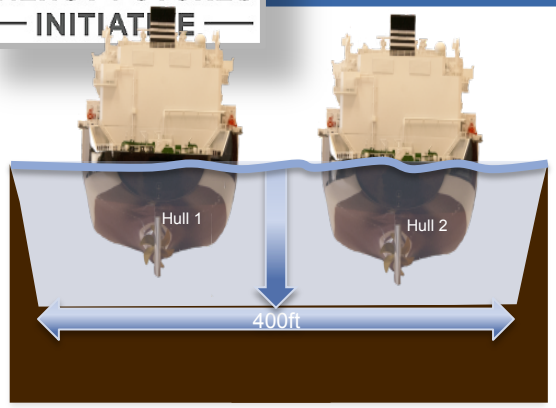


2013 Crude Oil by Train Loading (red) and Offloading (blue) Facilities

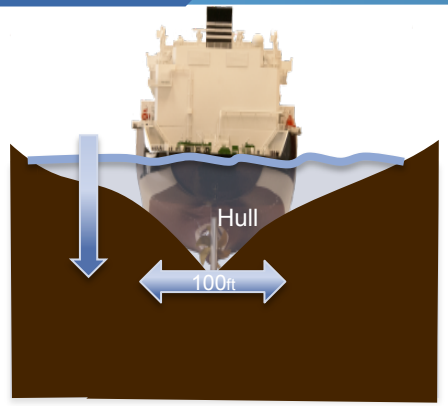
Source: Esri 2013; company and media reports. Sources for all facilities are presented in Appendix C, Supplemental Information to Market Analysis.

Figure 1.4.3-12 Crude by Train Loading and Off-Loading Facilities in 2013 (Current and Planned), Estimated Capacities

QER 1.1: Waterways of the U.S.



Lake Charles Ship Channel designed for two tankers to pass



Current channel conditions reduce cargos, idle until high-tide, or, be subject to one-way traffic restrictions

Port Channel System	Crude and Petroleum Products	Coal	Total Energy	Percent Energy Shipments
Lower Mississippi (LA)	161	47	208	48%
Houston/Galveston (TX)	200	3	203	69%
Beaumont/Port Arthur (TX)	115	-	115	89%
Port of NY/NJ	80	0	80	59%
Delaware River	62	-	62	82%
Corpus Christi (TX)	58	-	58	77%
Port of Virginia	2	50	52	66%
Lake Charles (LA)	49	-	50	88%
LA and Long Beach (CA)	46	2	47	33%
Huntington - Tristate (WV)	8	32	41	87%

- In 2012, crude oil, refined petroleum products, and coal were 55% of all U.S. waterborne cargo traffic by weight.
- Nearly 15 percent of all petroleum products consumed in the U.S. are shipped on inland waterways.
- DOT's *Beyond Traffic 2045* report concludes that "... several critical trends will have a major impact on the performance of critical marine links in our transportation systems. They include:
  - ✓ Increasing imports and exports and containerized freight will lead to greater congestion on America's coastal and inland ports.
  - ✓ Investment in ports, harbors and waterways will be essential to meet the demand of increased trade and competition."

ENERGY FUTURES INITIATIVE

Transporting Clean Energy Components on Shared Infrastructure

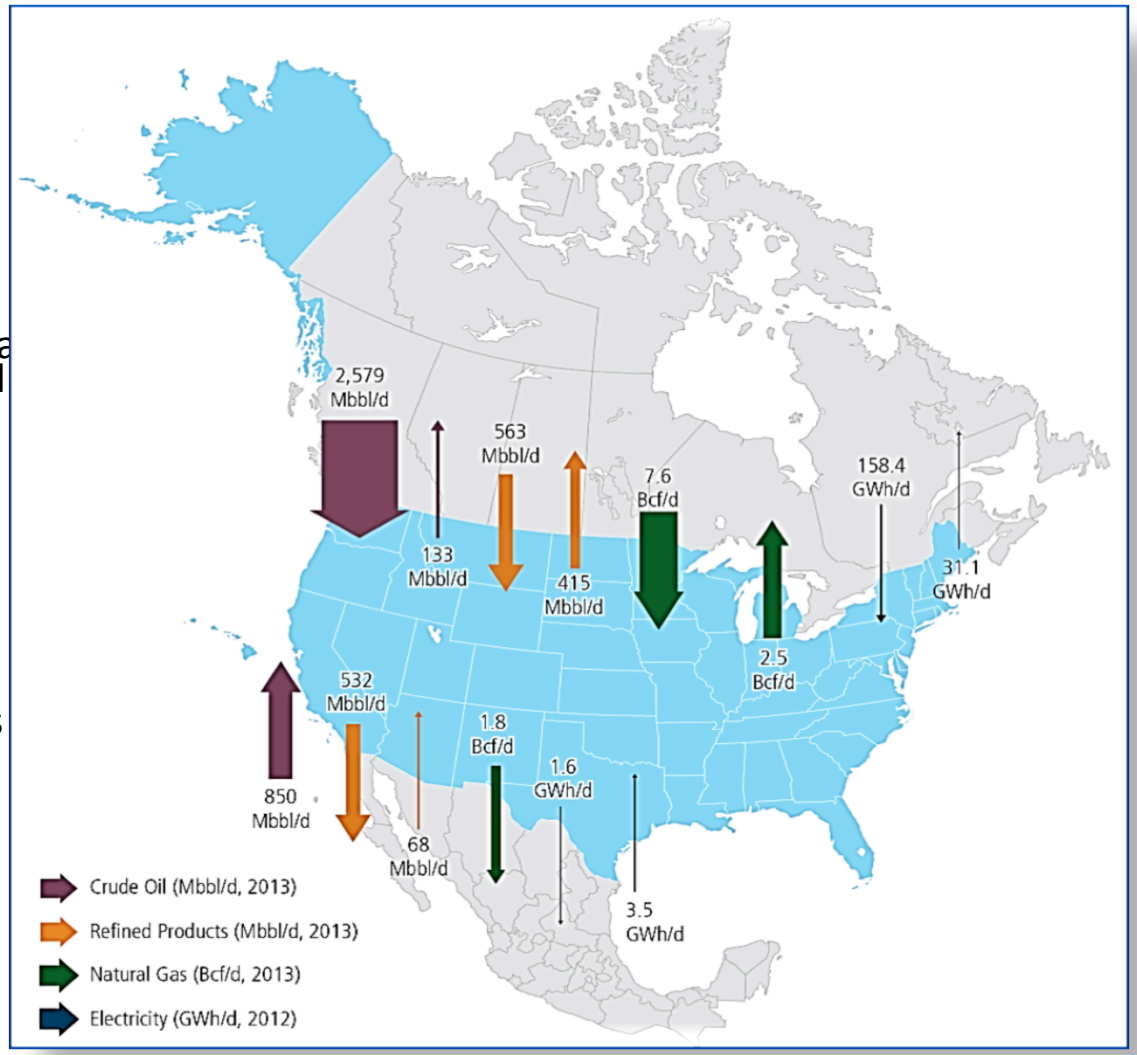
QER 1.1

QER 1.1: North American Findings/ Recommendations

Key Recommendations

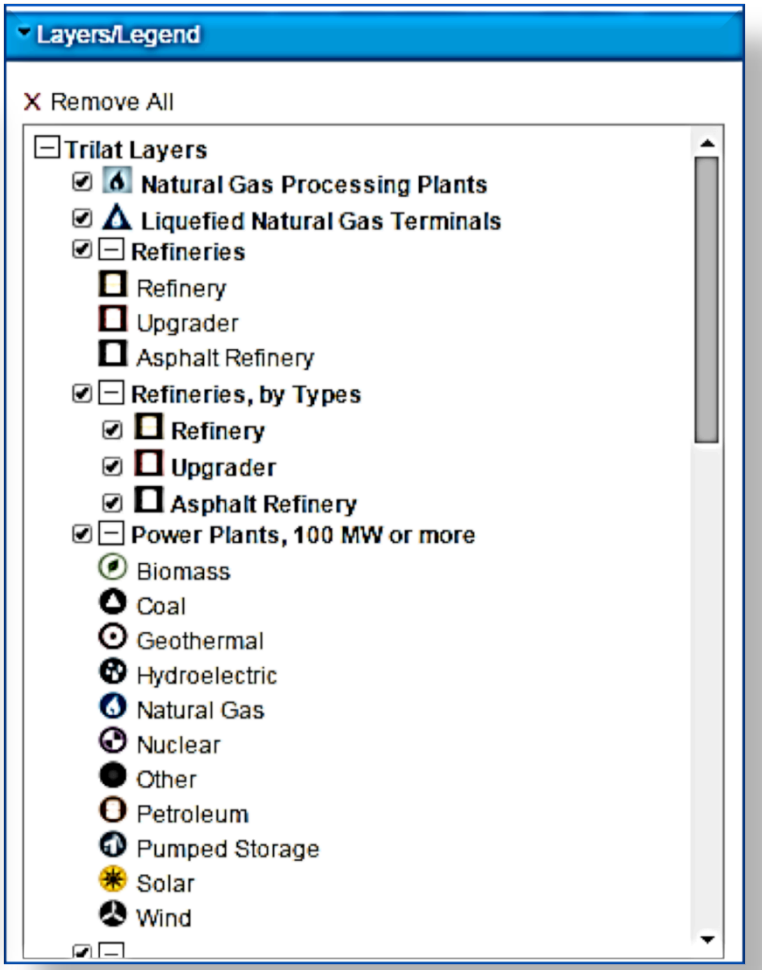
- Continue advances that have been made in the North American energy dialogue
- Increase the integration of energy data among the United States, Canada, and Mexico
- Undertake comparative and joint energy system modeling, planning, and forecasting
- Establish programs for academic institutions and not-for-profits to develop legal, regulatory, and policy roadmaps for harmonizing regulations across borders
- Coordinate training and encourage professional interactions

North American Energy Flows



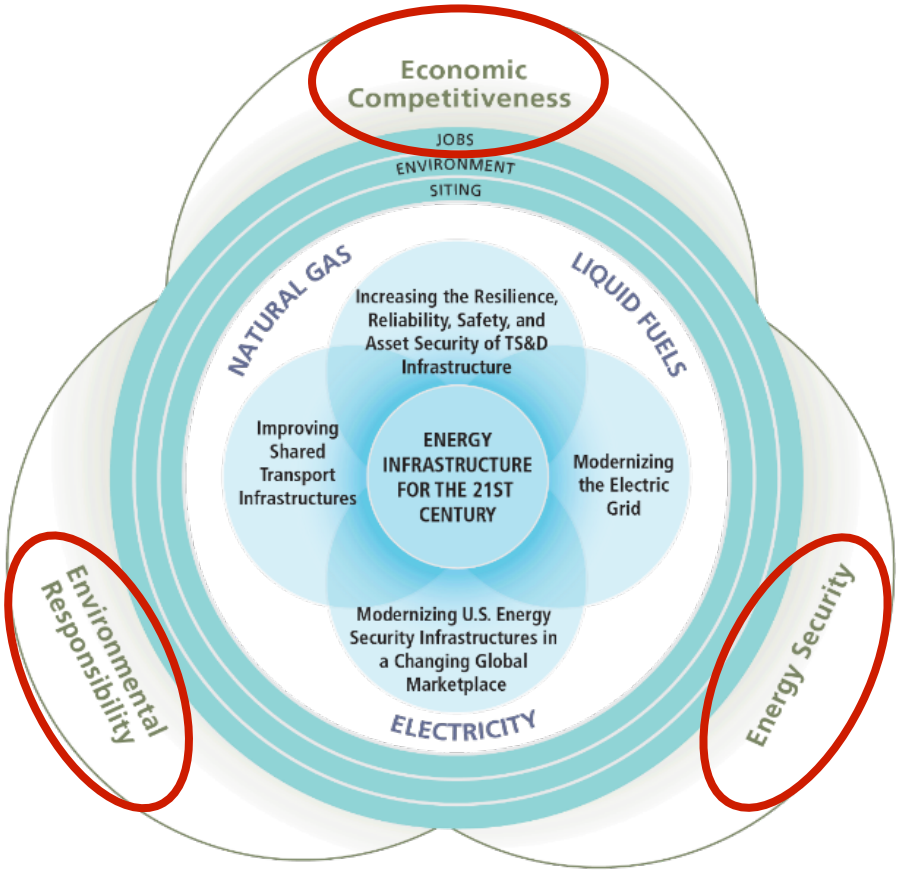
ENERGY FUTURES INITIATIVE

North American Mapping Effort

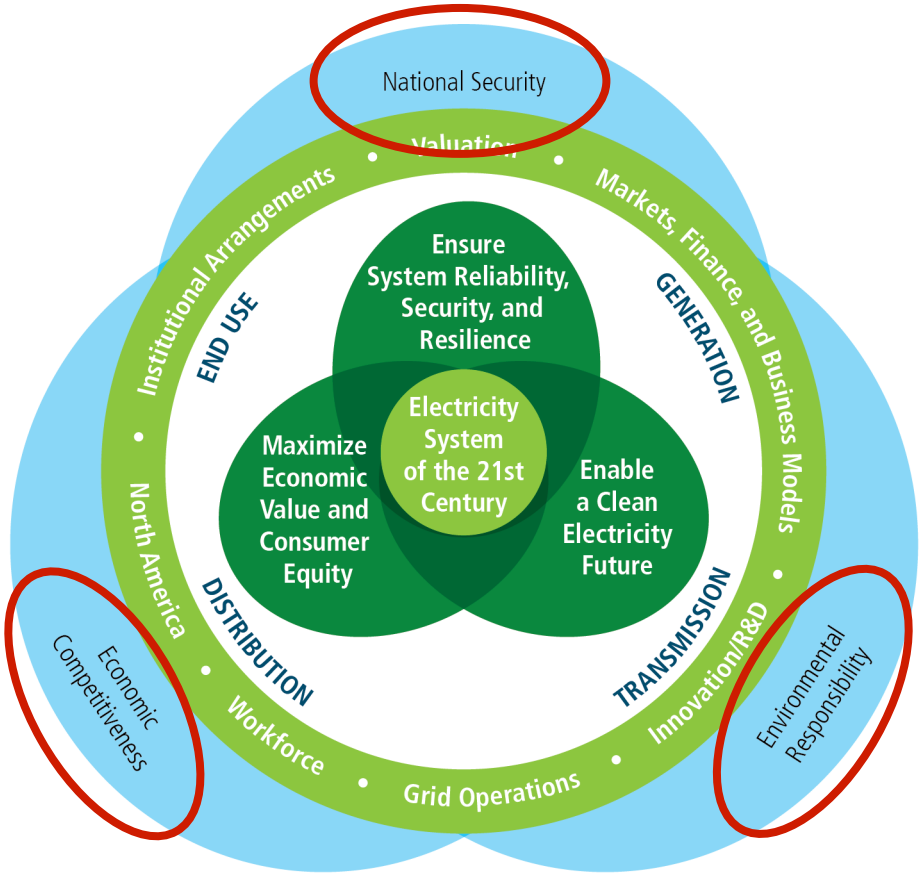


QER 1.2: Electricity from Generation to End Use

QER 1.1

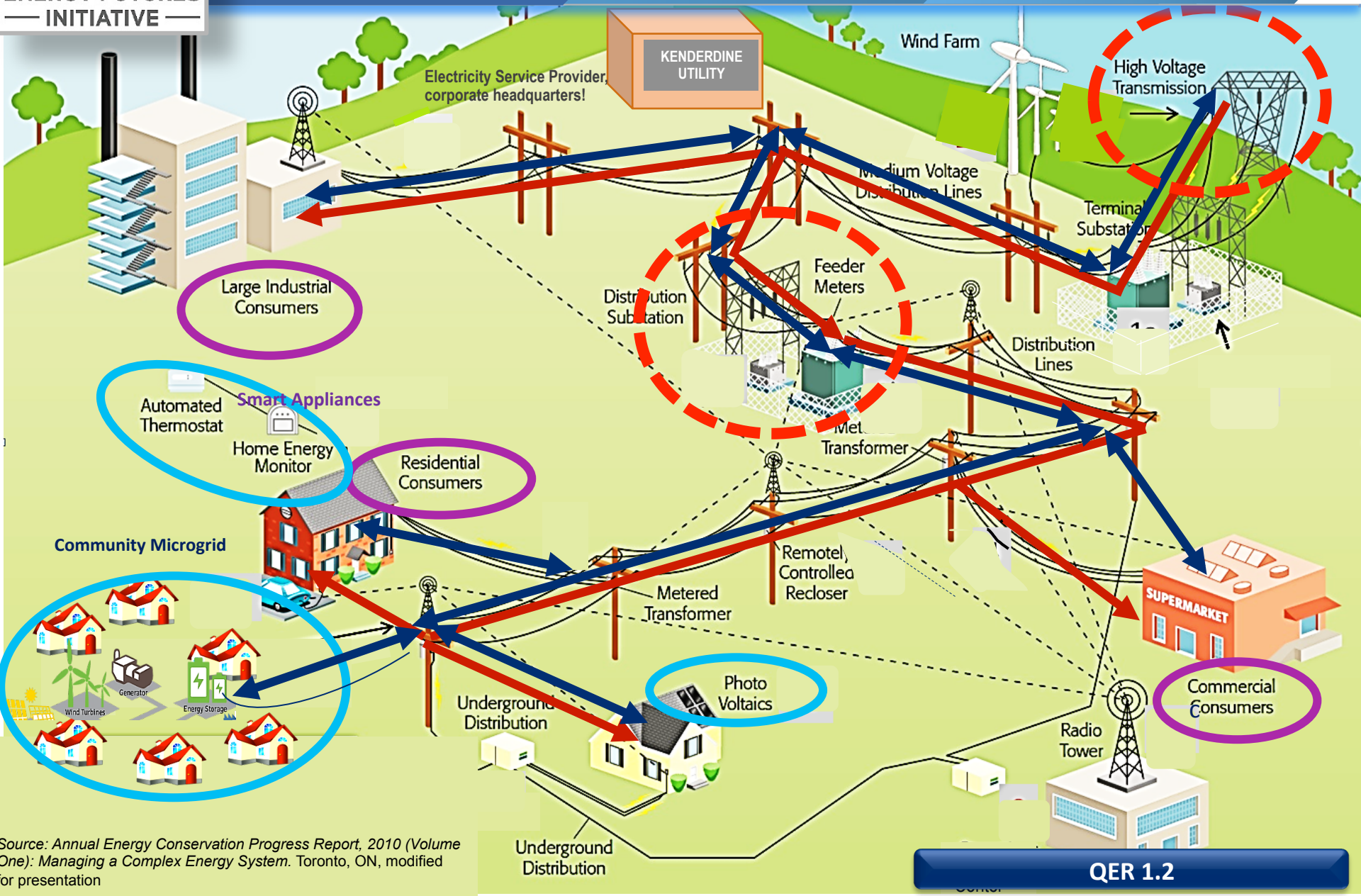


QER 1.2



ENERGY FUTURES INITIATIVE

Two Way Electricity Flows: Value Creation, Consumer Choice, Complex Grid Operations, Visibility Needs, Cyber Security



Source: Annual Energy Conservation Progress Report, 2010 (Volume One): Managing a Complex Energy System. Toronto, ON, modified for presentation

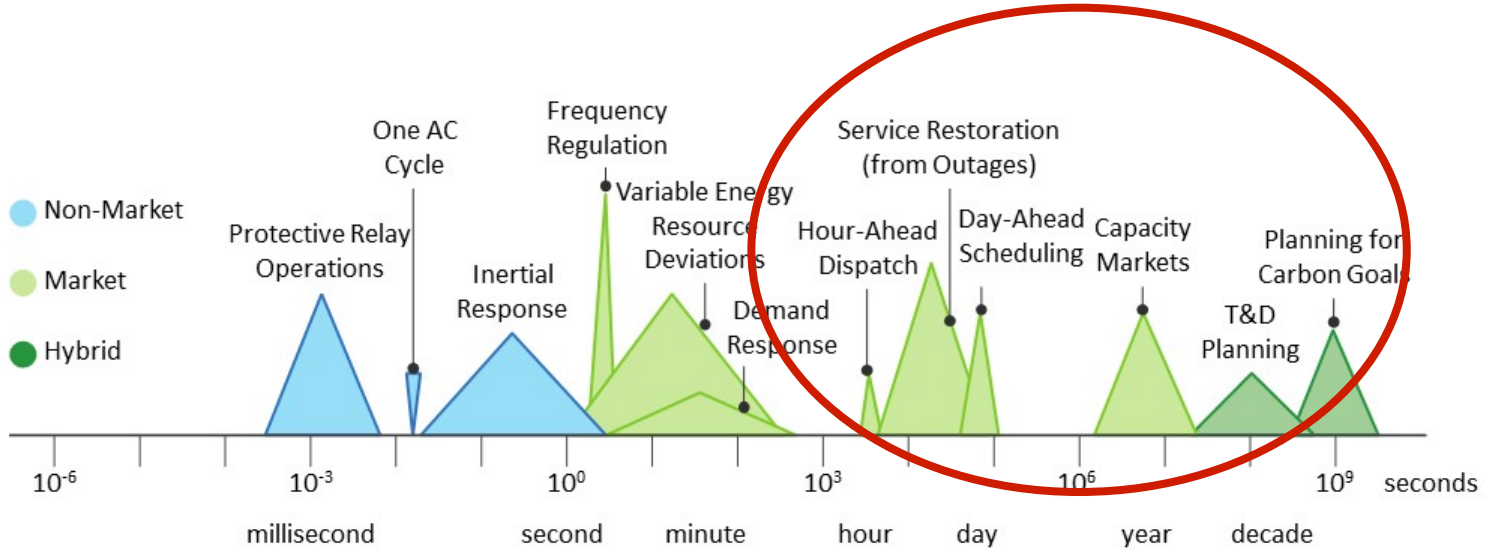
QER 1.2

Evolving Requirements for System Operations

Findings

- The widespread integration of VERs at both utility scale and distributed across all consumer segments significantly expands the time dimensions in which grid operators must function and complicates operations.
- Dispatch effectiveness will require the integration of automated grid management with continuing human oversight as well as an increase in the granularity, speed, and sophistication of operator analytics.

System Reliability Depends on Managing Multiple Event Speeds



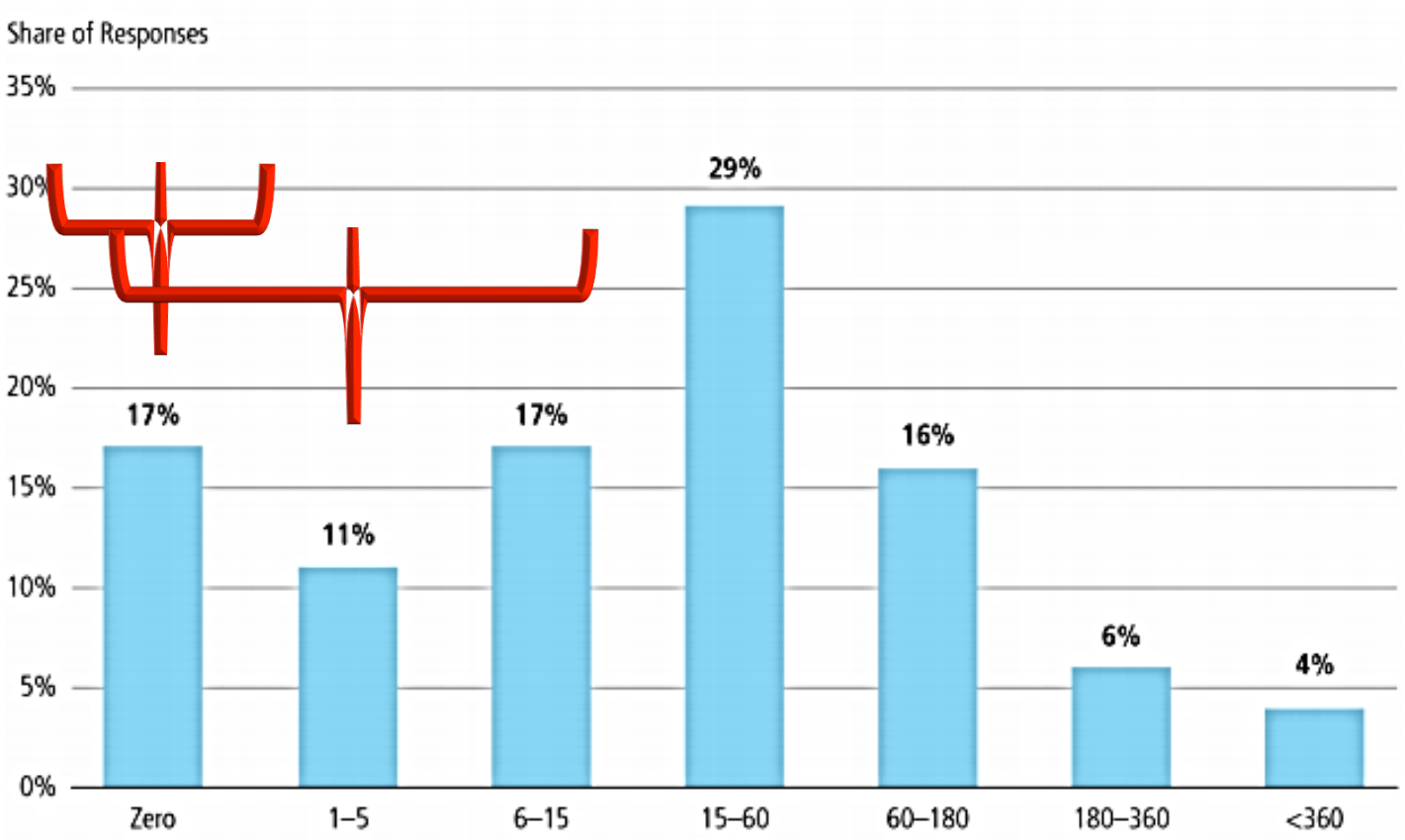
Source: von Meier, 2014

QER 1.2

ENERGY FUTURES INITIATIVE

Changing Needs for Electricity Reliability

Figure 1-3. Company Survey: Approximately How Many Minutes of IT Downtime Can Occur before Business Is Negatively Impacted?[44]



When the grid goes down, data centers face significant risks as backup power does not always work. The key is to try to minimize the likelihood of grid power outages. Local power grid reliability should be a factor considered when choosing data center locations.

Electricity Is a Critical and Essential Asset

Mirai Botnet Attack – October 21, 2016

"Assuring that we have reliable, accessible, sustainable, and affordable electric power is a national security imperative. Our increased reliance on electric power in every sector of our lives, including communications, commerce, transportation, health and emergency services, in addition to homeland and national defense, means that large-scale disruptions of electrical power will have immediate costs to our economy and can place our security at risk.

Whether it is the ability of first responders to answer the call to emergencies here in the United States, or the readiness and capability of our military service members to operate effectively in the U.S. or deployed in theater, these missions are directly linked to assured domestic electric power."

–Center for Naval Analyses, 2015

ENERGY FUTURES INITIATIVE

QER 1.2 Recommendations

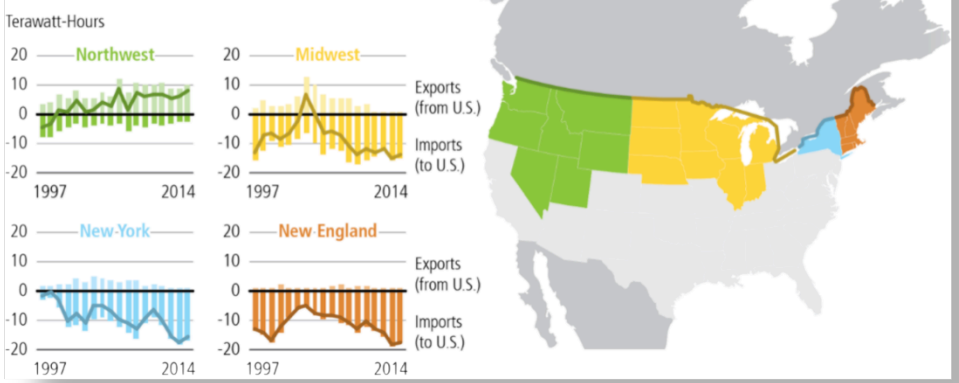
Protect the Electricity System as a National Security Asset.

- **Amend the *Federal Power Act* to:**
  - Clarify and affirm DOE's authority under the FAST Act to develop preparation and response capabilities that will ensure it is able to issue a grid-security emergency order to protect critical electric infrastructure from cyber attacks, physical incidents, EMPs, or geomagnetic storms. In this regard, DOE's authority should include the ability to address two-way flows that create vulnerabilities across the entire system; and
  - Authorize FERC to propose new reliability standards and to modify NERC-proposed reliability standards if FERC finds that expeditious action is needed to protect national security in the face of fast-developing new threats to the grid.
- **Collect information on security events to inform the President about emergency actions and imminent dangers.**
- **Adopt integrated electricity security planning and standards on a regional basis.**
- **Assess natural gas/electricity system infrastructure interdependencies for cybersecurity protections.**

North American Electricity Integration

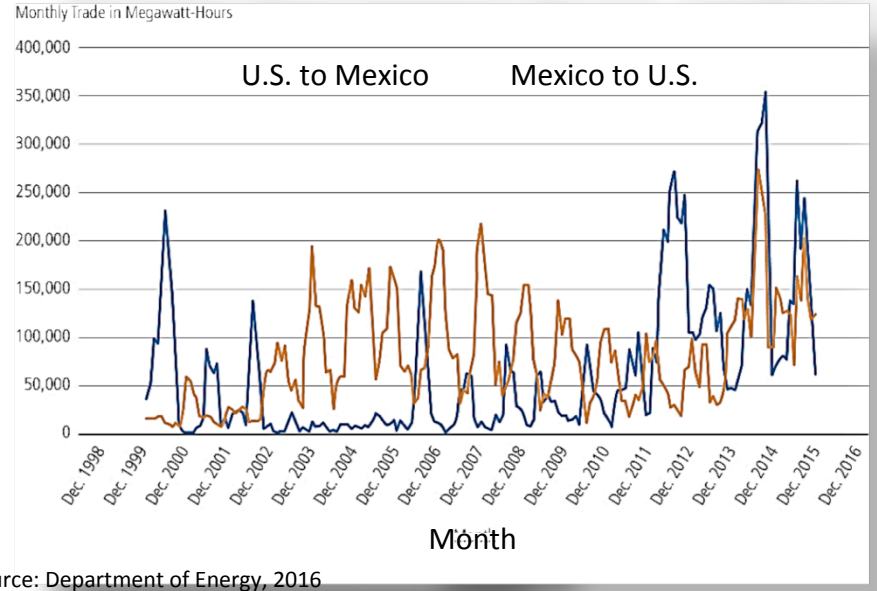
ENERGY FUTURES INITIATIVE

U.S. Electricity Trade with Canada in Four Regions



Source: Energy Information Administration, 2015

Electricity Flows between the U.S. and Mexico



Source: Department of Energy, 2016

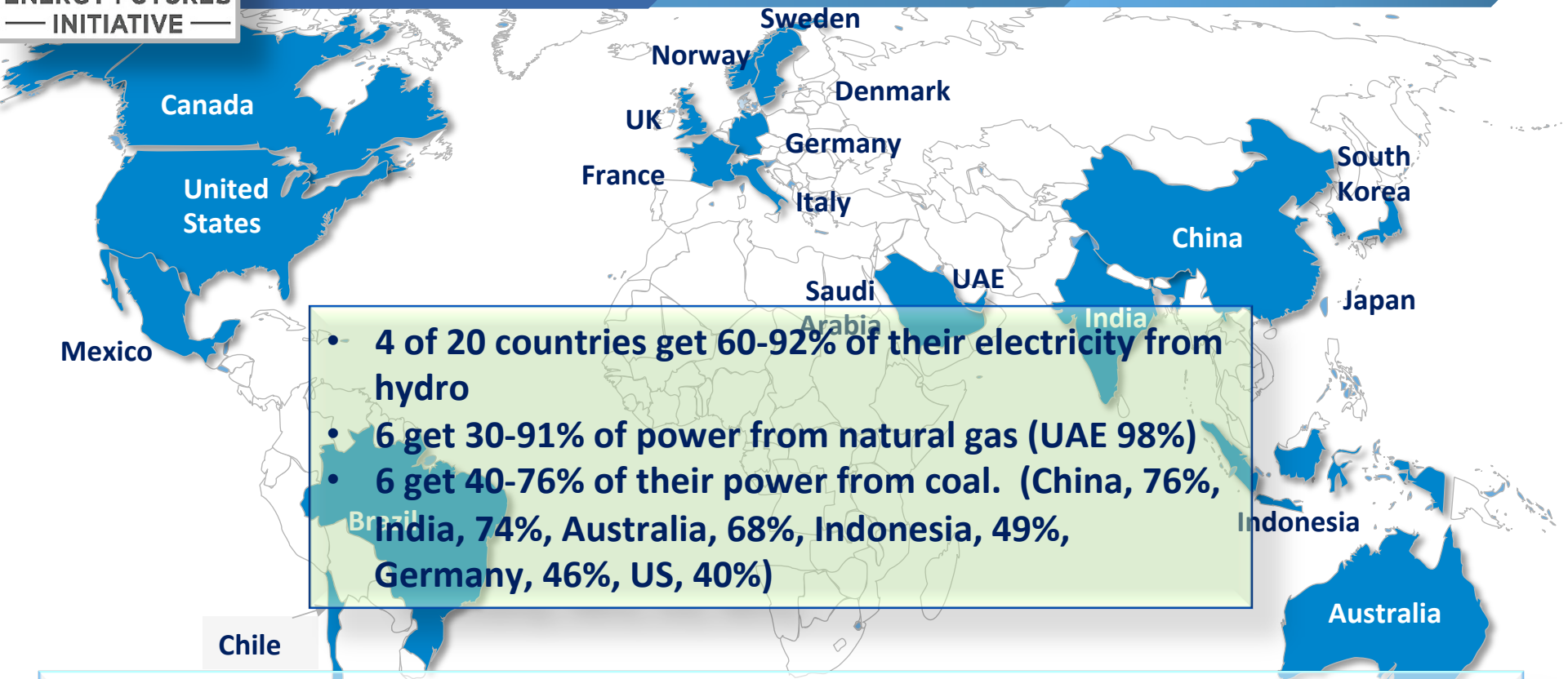
Findings

- Trade has been increasing across the North American bulk power system, but cross-border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.
- U.S.-Canada cross-border electricity trade and coordination of operations, policy, and regulatory planning are extensive, mature, and efficient, as evidenced by the December 2016 *Joint U.S.-Canada Electric Grid Security and Resilience Strategy*.
- One model for power-sector collaboration across national borders is demonstrated by the reliability planning under NERC, but this engagement has been limited to Canada, the U.S., and the Baja California region of Mexico. Notably, Mexico's ongoing electricity reform could have significant impacts on the future of cross-border integration.

Mission Innovation

- Leaders of 20 Countries Representing over 80 % of Global Clean Energy R&D Investment Agreed to Support a *Joint Statement* on Innovation
- Each Country Supported a Doubling of Governmental Clean Energy R&D Investment over Next Five Years (**www.mission-innovation.net**)
- Gov't Investment was Complemented by a Private Sector Initiative led by Bill Gates, the Breakthrough Energy Coalition (**www.breakthroughenergycoalition.com**)

Mission Innovation: Focus on Clean Energy Innovation



- 4 of 20 countries get 60-92% of their electricity from hydro
- 6 get 30-91% of power from natural gas (UAE 98%)
- 6 get 40-76% of their power from coal. (China, 76%, India, 74%, Australia, 68%, Indonesia, 49%, Germany, 46%, US, 40%)

- Mission Innovation partners span five continents
- They represent nearly 60% of the world's population and include the top five most populous countries in the world
- Coalition emits two-thirds of the world's total greenhouse gas emissions and nearly 3/4ths of the CO2 emissions from electricity
- GDP in these countries represents almost 70% of the global total
- Mission Innovation countries represent over 80% of all government investment in clean energy R&D

Mission Innovation

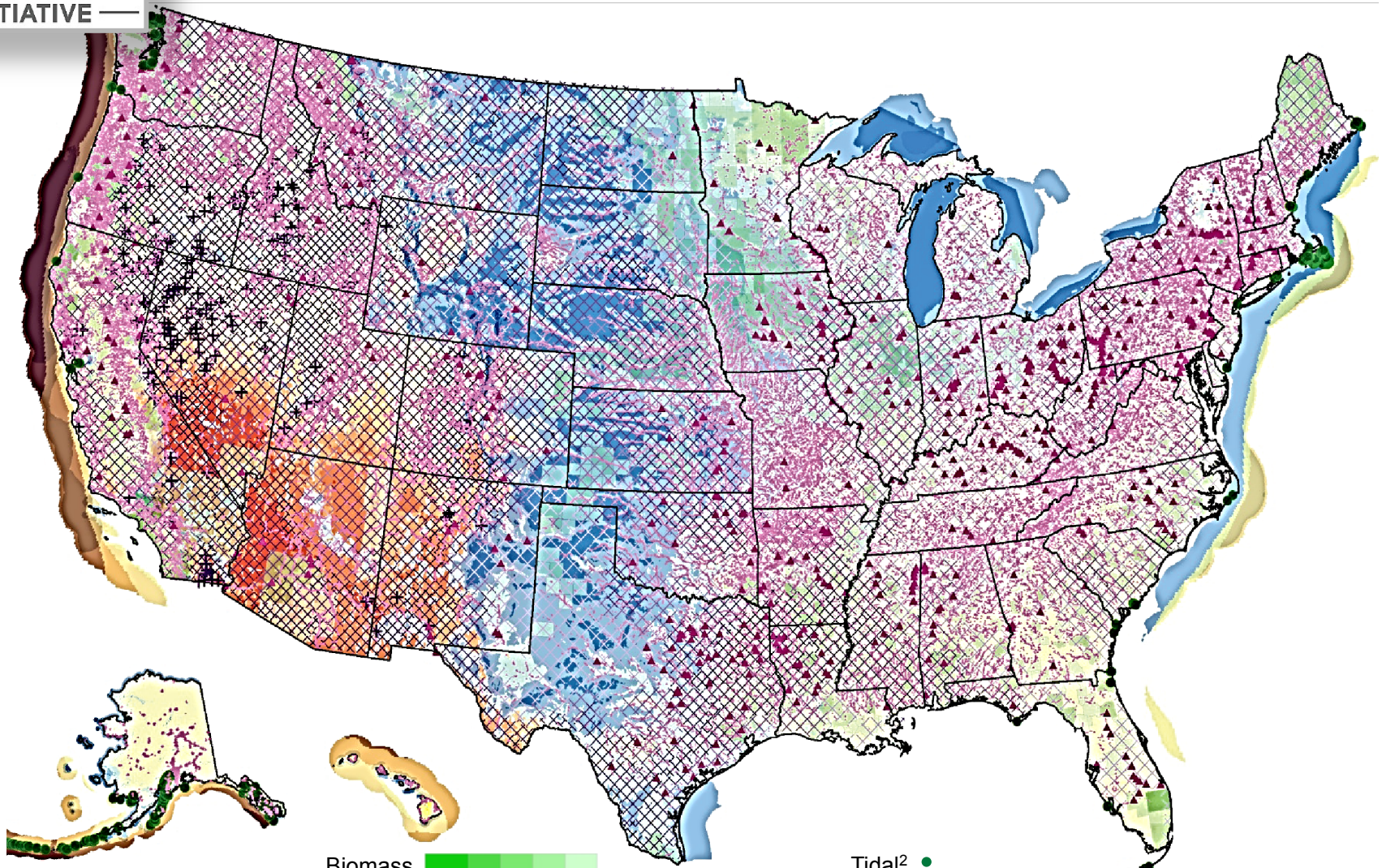
ENERGY FUTURES INITIATIVE

Mission Innovation R&D Doubling by Country

Country	Baseline(Million currency as declared, per year)	Baseline (Million US Dollars per year)	Five-Year Target Amount (Million US Dollars per year)
Australia	104 AUD	78	156
Brazil	600 BRL	150	300
Canada	387 CAD	295	590
Chile	4.1856 USD	4	9
China	25,000 RMB	3,800	7,600
Denmark	292 DKK	45	90
European Union	989 EUR	1,111	2,218
France	440 EUR	494	989
Germany	450 EUR	506	1,011
India	4700 INR	72	145
Indonesia	16.7 USD	17	150
Italy	222.6 EUR	250	500
Japan	45,000 JPY	410	820
Kingdom of Saudi Arabia	281.3 SAR	75	150
Mexico	20.71 USD	21	62
Norway	1132 NOK	140	280
Republic of Korea	490 USD	490	980
Sweden	134 SEK	17	33
United Arab Emirates	10 USD	10	34
United Kingdom	200 GBP	290	580
United States	6415 USD	6,415	12,830
TOTAL		14,690	29,516

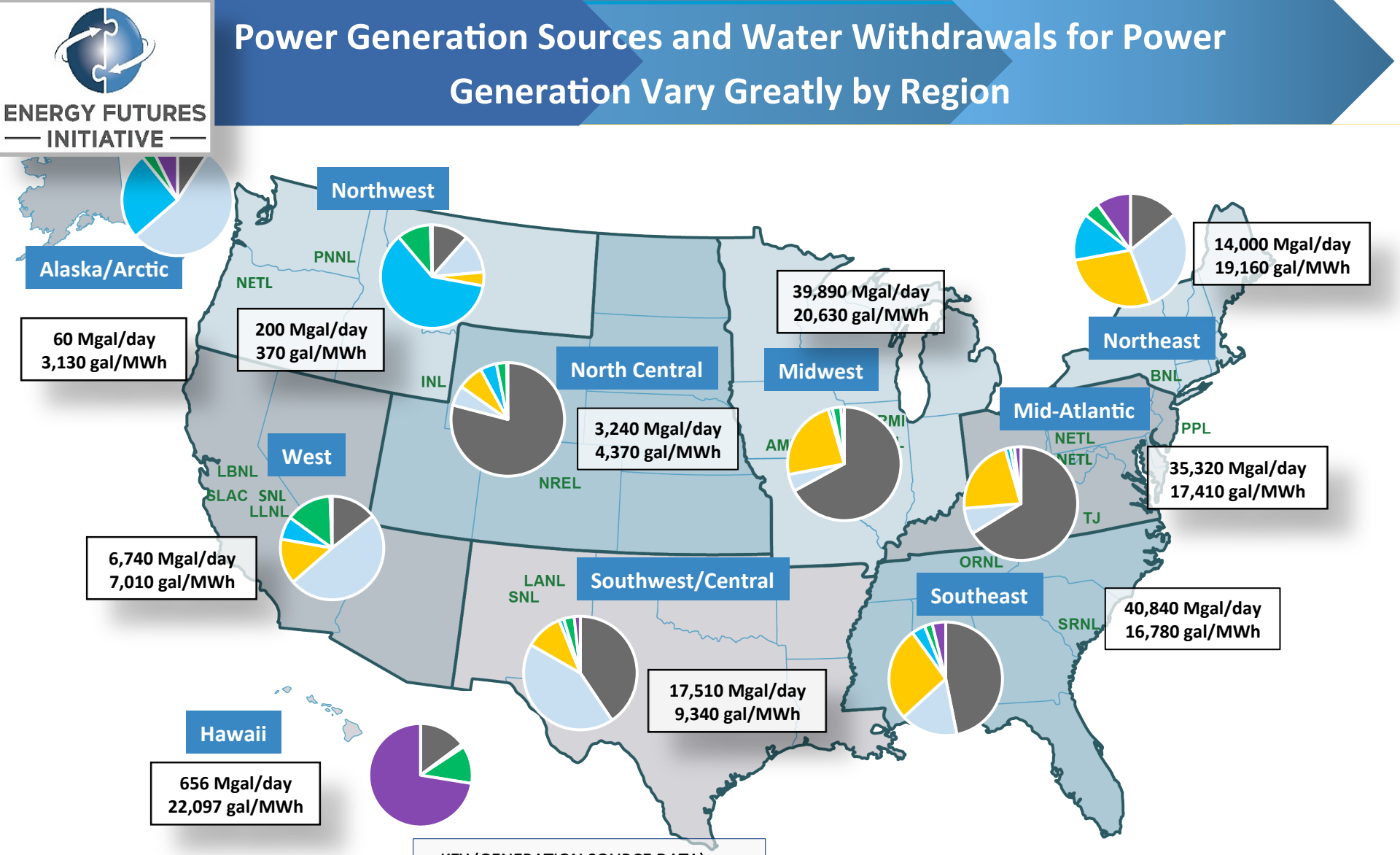
ENERGY FUTURES INITIATIVE

Mapping of U.S. Renewable Resources



Mission Innovation

Power Generation Sources and Water Withdrawals for Power Generation Vary Greatly by Region



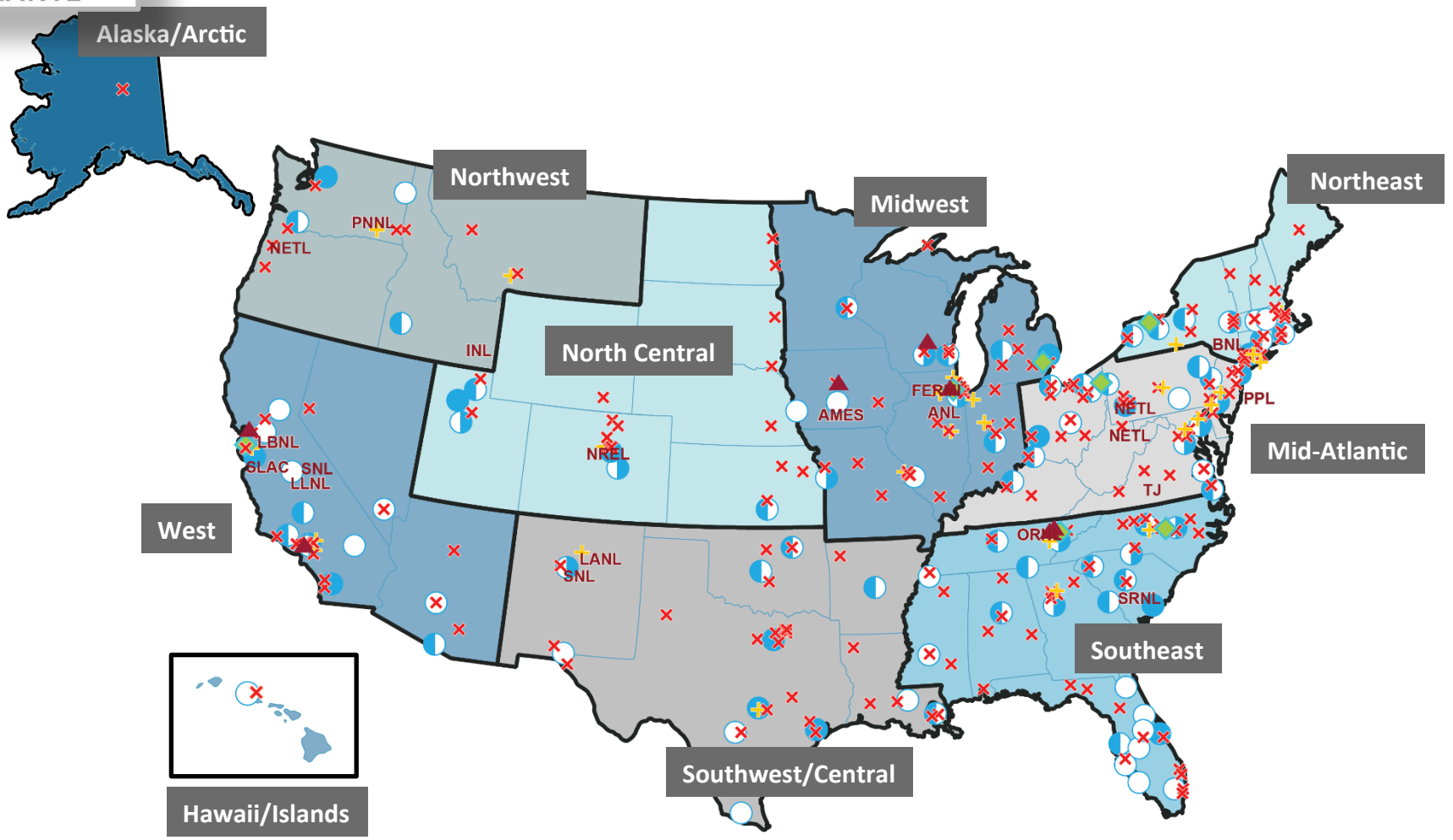
[1] Includes Wind, Solar, Biomass, Geothermal

[2] Includes Petroleum, Other Fossil Fuel Gases, Pumped Storage, Non-Biogenic Municipal Solid Waste, Batteries, Hydrogen, et al.

Sources: EIA, 2014 data from "Net Generation by State by Type of Producer by Energy Source (EIA-906, EIA-920, and EIA-923)," October 21, 20
USGS, EIA data via Maupin, M.A. et al., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405

ENERGY FUTURES INITIATIVE

Proposed US Mission Innovation Funding: Regional Clean Energy Innovation Partnerships



Metro Area - Advance Industry Base Characteristics[1]

- Manufacturing-Oriented
- Services-Oriented
- Both Manufacturing and Service-Oriented
- Not Specialized in Either
- Universities with highest and higher research activity[2]

Mission Innovation

ENERGY FUTURES INITIATIVE

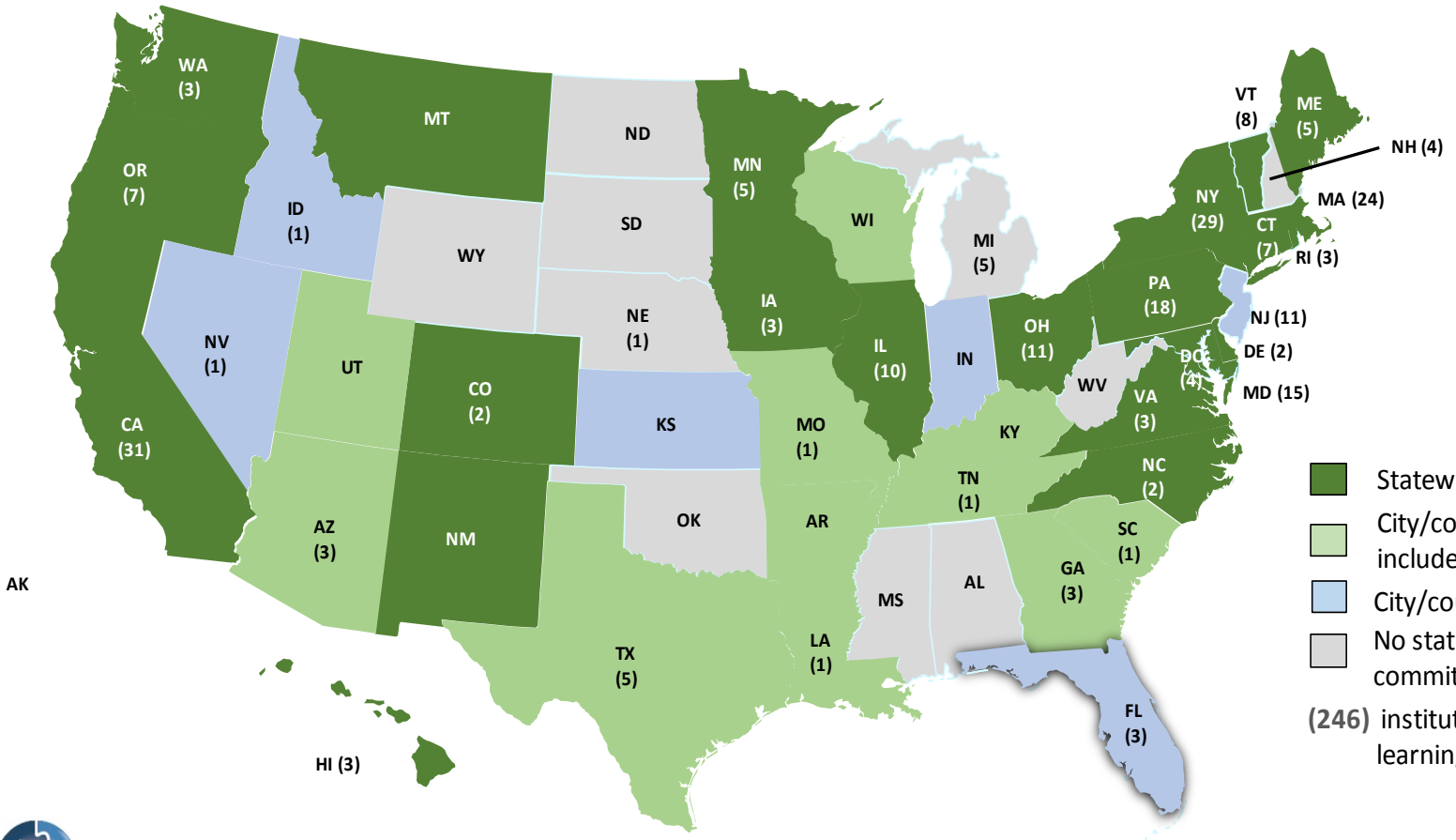
Potential Impacts of FY 2018 Trump Budget Reductions

- **Termination of Deployment Programs** – e.g. EV Everywhere, Better Buildings Challenge, Weatherization Grants, Clean Energy Manufacturing Institutes
- **Termination of Technology Demonstration Projects** – e.g. Offshore Wind Technology, SMR Licensing and Design assistance, ITER, Smart Grid Demonstrations
- **No re-proposal of FY 2017 new starts** – e.g. Desalination Hub, new CCUS pilot plant projects, FORGE Geothermal test facility, 5 new EFRCs, NGCC carbon capture pilot plant
- **Significant reductions to on-going applied R&D programs** – e.g. Sunshot, advanced reactor R&D, LWR sustainability research, upgrades to existing DOE test facilities (ATR, TREAT)
- **Termination of ARPA-E and Climate change research**
- **Closure of 2 of 4 SPR sites and the NE Gasoline Reserve**

Discussion

Paris Withdrawal Will Put Additional Pressure on Innovation Efforts

Initial Commitments to Meeting US NDC under Paris Agreement*

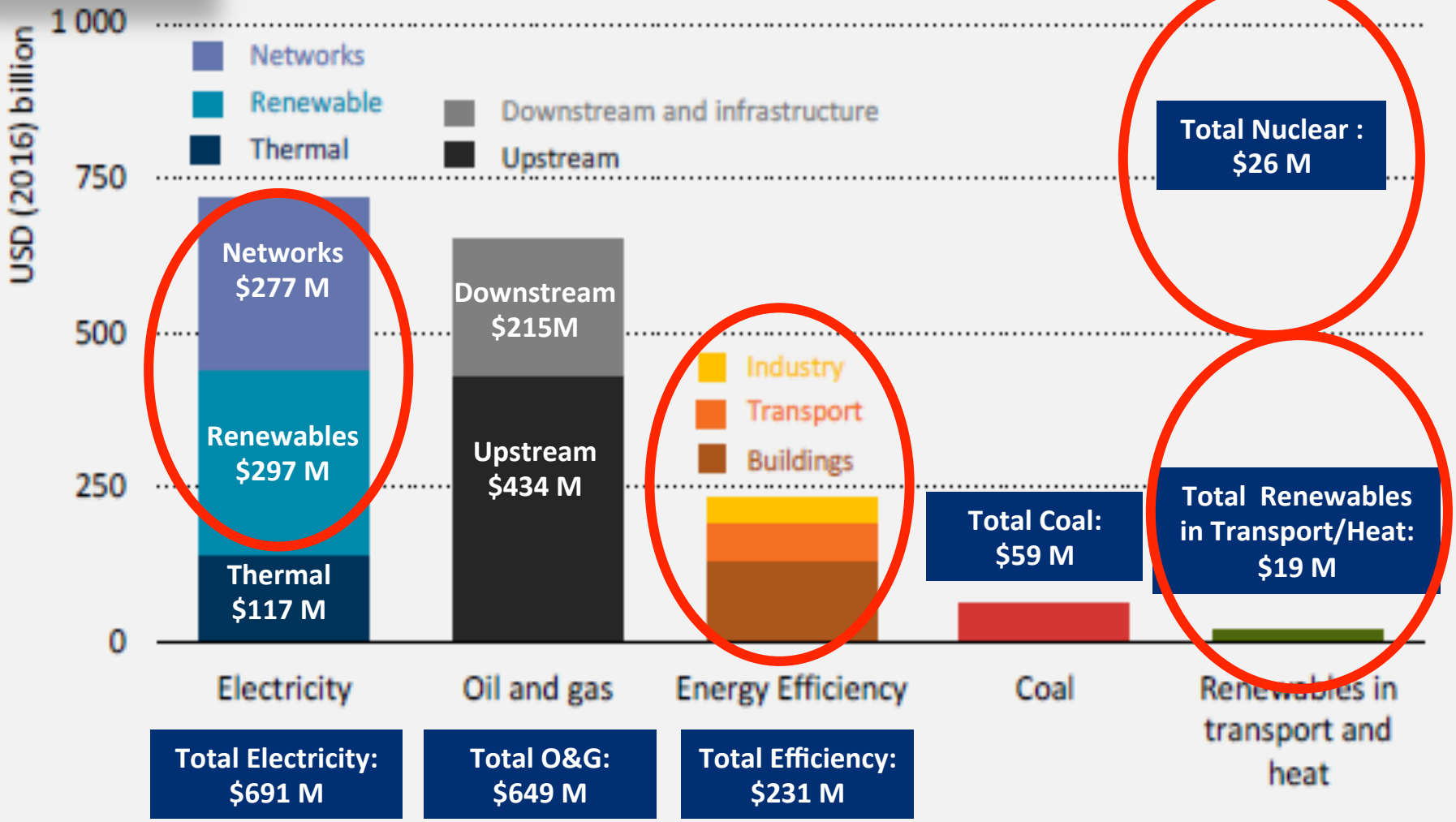


- Statewide commitments (22)
- City/county commitments, includes state's largest city (11)
- City/county commitments (6)
- No state/city/county commitments (11)

(246) institutions of higher learning

Discussion

Global Energy Investment



Global energy investment totalled USD 1.7 trillion in 2016, 12% down on 2015 due mainly to a fall of over one-quarter in oil and gas investment.

Discussion