Discussion

• US Trends
• Quadrennial Energy Review
• A Few Global Data Points
• Climate Change, Paris and Innovation
• Examples: Global Innovation Needs
• Analyzing the Emissions Reduction Value of Innovation
**Changing Energy Landscape in the United States**

**Supply/Demand**
- Natural gas production growth
- Oil production growth
- Intermittent renewables cost reductions
- Distributed generation/energy resources
- Increased efficiency
- Low electric load growth
- Natural gas generation growth

**Energy Security**
- Decreased N. American energy imports
- Climate change impacts
- Vulnerabilities more evident, including aging infrastructures, physical and cyber threats
- Increased interdependencies
- Broader more collective approach to energy security

**Policy Developments**
- CAFÉ
- Clean Air Act -111 (d), other
- Clean Water Act/other
- Oil and gas exports
- RPS (state)
- Extension PTC/ITC
- SPR modernization

**Technology Advances**
- Solar (central and rooftop)
- Wind
- Demand-side technologies
- CCS
- Hydraulic fracturing
- Storage

**US Energy Trends/Changes**
US on Pathway for Significant Reductions in Power Sector GHG Emissions

A continuation and acceleration of these trends, in addition to other existing policies and measures, will help the U.S. achieve the goals outlined in its nationally determined contribution to the UNFCCC process.
US on Pathway for Significant Reductions in Power Sector GHG Emissions

A continuation and acceleration of these trends, in addition to other existing policies and measures, will help the U.S. achieve the goals outlined in its nationally determined contribution to the UNFCCC process.
Fuel Switching And CO₂ Emissions Reductions

Source: EIA
CO₂ emissions reductions in fossil fuel generation from shift to gas, 2006-2014: 1254 million metric tons

CO₂ emissions reductions from increase in non-carbon generation 2006-2014: 789 million metric tons

Total CO₂ emissions reductions from fuel switching 2006-2014: 1963 billion tons
61% from coal to gas, 39% from no-carbon sources

Emissions reduction in fossil generation mix from shift towards natural gas
Emissions reduction from increase in non-carbon generation

Source: EIA
Renewables Capacity Increasing, Costs Declining, Electricity Demand Flat or Decreasing

Distributed Solar, 2008-2013: 769% increase in capacity

Utility Scale Solar, 2008-2013: 1200% increase in capacity

Utility Scale Wind, 2008-2013: 245% increase in capacity

Deployment and Cost for U.S. Solar PV 2008-2013

Sources: Department of Energy, Office of Energy Efficiency and Renewable Energy analysis, GTM, SEIA, LBNL, NREL

2020 goal: $0.5
Renewables Capacity Increasing, Costs Declining, Electricity Demand Flat or Decreasing

US Generation, 2014

- **Solar**: 0.4%
- **Wind**: 4.4%
- **Other**: 95.2%

Sources: Department of Energy, Office of Energy Efficiency and Renewable Energy analysis, GTM, SEIA, LBNL, NREL
US Shale Gas Production Has Changed Energy Profile

Source: EIA
Significant New LNG Export Capacity By 2020
(Billion Cubic Feet)

Source: BP

New LNG capacity by 2020: 7939 bcf
(only includes capacity already under construction)
Installed Smart Meters: 50 Million US Homes
Installed Smart Meters: 50 Million US Homes
Admiral Mike Rogers, NSA Director, before the House Select
Intelligence Committee, 11/14, Cyber-threats: The Way Forward —

“There shouldn’t be any doubt in our minds that there are groups
out there that have the capability to shut down, forestall our
ability to operate our basic infrastructure whether it’s generating
power, or moving water or fuel.”

The Center for Naval Analysis, in November, 2015 --

“Reliable electricity underpins every facet of our lives. The design
of the grid and its inherent vulnerabilities, are known to our
enemies, foreign and domestic.”
President Obama Directs the QER

- January 2014 Presidential Memorandum established the Quadrennial Energy Review
- White House Domestic Policy Council and Office of Science and Technology Policy co-chair a QER Task Force comprised of 22 Federal agencies
- The Department of Energy serves as the Secretariat of the Task Force
- Enables the Federal government to translate policy goals into a set of analytically based, integrated actions
- First installment released by Vice President Biden and Secretary Moniz in April 2015
The first installment of the QER analyzed transmission, storage, and distribution infrastructure (TS&D) and focused on eight topic areas:

- Increasing resilience, reliability, safety, and asset security
- Modernizing the electric grid
- Modernizing U.S. energy security infrastructures
- Improving shared transport infrastructures
- Integrating North American energy markets
- Addressing environmental aspects of TS&D infrastructure
- Enhancing employment and workforce training
- Siting and permitting of TS&D infrastructure
QER 1.2: Electricity from Generation to End Use

High Level Goals

Electric System Policy Objectives

Crosscutting Means and Issues

Elements of the Electricity System
These countries will see a 24 percent increase in population by 2050.
The Human Development Index is a comparative measure of life expectancy, literacy, education, and standards of living. Countries fall into four broad categories based on their HDI: very high, high, medium, and low human development.

4,000 kWh per person per year is the dividing line between developed and developing countries.

Source: Human Development Index – 2010 data United Nations; Annual Per Capita Electricity Consumption (kWh) - 2007 data World Bank. Updated: 4/11
The Human Development Index is a comparative measure of life expectancy, literacy, education, and standards of living. Countries fall into four broad categories based on their HDI: very high, high, medium, and low human development.

4,000 kWh per person per year is the dividing line between developed and developing countries.

"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."


Source: Human Development Index – 2010 data United Nations; Annual Per Capita Electricity Consumption (kWh) - 2007 data World Bank. Updated: 4/11
Populations Growing in Countries with Limited Access to Electricity

% of Population Growth, Year-on-Year

% of Population with Access to Electricity

Source: World Bank, 2012 data
Electricity Generation, Select Countries, 2013

Share of Generation Mix

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Gen. (Billion kWh)</th>
<th>Coal</th>
<th>Natural Gas</th>
<th>Hydro</th>
<th>Renewables and Other</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>4048</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Canada</td>
<td>616</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Germany</td>
<td>585</td>
<td></td>
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<tr>
<td>Japan</td>
<td>966</td>
<td></td>
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<td></td>
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<tr>
<td>India</td>
<td>1052</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>4768</td>
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Avg. Electricity Prices cents/kWh

<table>
<thead>
<tr>
<th>Country</th>
<th>Avg. Electricity Prices cents/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td></td>
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<tr>
<td>Canada</td>
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<tr>
<td>Germany</td>
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<td>Japan</td>
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<tr>
<td>India</td>
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<tr>
<td>China</td>
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</tbody>
</table>

Source: LHS: Data from EIA and IEA for 2013; RHS: EIA 2014 (for United States) Eurostat 2014 (for Germany), IEFFA.org 2011 (for India, China, Japan), Electricity.ca 2011 (for Canada)
Decommissioning of Nuclear Plants in Europe: Significant Loss of Carbon-free Generation

Source: IEA

* Scheduled decommissioning, may be life extensions
India has pledged it would **target 40 percent cumulative installed power capacity from non-fossil fuel sources by 2030** cut the intensity of its carbon emissions by 33 to 35 percent by 2030 from 2005.

China aims to achieve a peaking of its CO₂ emissions in 2030. **China also aims to reduce its CO₂ emissions per unit of GDP by 60-65% on 2005 levels by 2030.**

Korea plans to reduce its greenhouse gas emissions by 37% from the business-as-usual (BAU, 850.6 MtCO₂eq) level by 2030 across all economic sectors.

Japan’s INDC, submitted in advance of COP-21 **aims for a 26% reduction of greenhouse gas emissions by 2030 relative to 2013 levels** (ie -18% compared to 1990).

The United States intends to achieve an economy-wide target of reducing its greenhouse gas emissions by 26-28 per cent below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%.

The EU and its Member States are committed to a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990, to be fulfilled jointly...
Climate Goals/COP 21 Temperature Targets

A. Emissions pathways

B. Temperature probabilities

Fawcett et al. 2015
Mission Innovation Announced in Paris

- All on One Stage -- 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

Source: World Bank, EIA
Breakthrough Energy Coalition

- 27 investors & University of California; collective net worth: $300+ billion
- Commitment to invest in innovation emerging from Mission Innovation pipeline
- Long-term, patient, and risk-tolerant capital
Breakthrough Energy Coalition

What’s Special?

• 27 (of 28 total) investors pledging personal funds -- BEC says it is designing a new investment fund as its vehicle.
• Investments will be at earlier stage, be end-to-end (e.g. angel investment through commercial deployment) and be more patient.
• BEC committed to investing only in Mission Innovation partnership countries.

Interface with DOE?

• BEC’s efforts are separate from DOE and the federal government
• Existing platforms such as DOE programs, ARPA-E, Clean Energy Investment Center, and Office of Technology Transfers, will provide information about emerging technologies; no preferential access.

• Commitment to invest in innovation emerging from Mission Innovation pipeline
• Long-term, patient, and risk-tolerant capital
• 20 countries (80% of Global Clean Energy R&D,) will seek to double funding over 5 years

• U.S.: Double investment from $6.4B baseline in FY 2016 to $12.8B in 2021

• DOE: $1B (21%) increase from $4.8B to $5.9B in FY 2017

EU joins June 3, 2016
<table>
<thead>
<tr>
<th>Country</th>
<th>Baseline (Million currency as declared, per year)</th>
<th>Baseline (Million US Dollars per year)</th>
<th>Five-Year Target Amount (Million US Dollars per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>104 AUD</td>
<td>78</td>
<td>156</td>
</tr>
<tr>
<td>Brazil</td>
<td>600 BRL</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Canada</td>
<td>387 CAD</td>
<td>295</td>
<td>590</td>
</tr>
<tr>
<td>Chile</td>
<td>4.1856 USD</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>China</td>
<td>25,000 RMB</td>
<td>3,800</td>
<td>7,600</td>
</tr>
<tr>
<td>Denmark</td>
<td>292 DKK</td>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>European Union</td>
<td>989 EUR</td>
<td>1,111</td>
<td>2,218</td>
</tr>
<tr>
<td>France</td>
<td>440 EUR</td>
<td>494</td>
<td>989</td>
</tr>
<tr>
<td>Germany</td>
<td>450 EUR</td>
<td>506</td>
<td>1,011</td>
</tr>
<tr>
<td>India</td>
<td>4700 INR</td>
<td>72</td>
<td>145</td>
</tr>
<tr>
<td>Indonesia</td>
<td>16.7 USD</td>
<td>17</td>
<td>150</td>
</tr>
<tr>
<td>Italy</td>
<td>222.6 EUR</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Japan</td>
<td>45,000 JPY</td>
<td>410</td>
<td>820</td>
</tr>
<tr>
<td>Kingdom of Saudi Arabia</td>
<td>281.3 SAR</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Mexico</td>
<td>20.71 USD</td>
<td>21</td>
<td>62</td>
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<tr>
<td>Norway</td>
<td>1132 NOK</td>
<td>140</td>
<td>280</td>
</tr>
<tr>
<td>Republic of Korea</td>
<td>490 USD</td>
<td>490</td>
<td>980</td>
</tr>
<tr>
<td>Sweden</td>
<td>134 SEK</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>10 USD</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>200 GBP</td>
<td>290</td>
<td>580</td>
</tr>
<tr>
<td>United States</td>
<td>6415 USD</td>
<td>6,415</td>
<td>12,830</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>14,690</td>
<td>29,516</td>
</tr>
</tbody>
</table>
Currently, 28% of the world lives in water-scarce countries. Experts estimate that by 2080, this number will climb to between 43-50%*

* World Bank, 2014, Huffman
France is particularly vulnerable due to high power sector water dependency from nuclear generation and recurring heat waves.

Coal-rich but water poor, China is adopting direct and indirect measures to reduce water intensity in coal-fired power generation.

Hydrocarbon rich yet water poor Australia increasingly relies on desalinated water for drinking water. It is moving to power desalination with renewable power and waste heat.

India is highly reliant on inefficient coal-fired generation, and needs to power remaining 1/3rd of population. The country is improving coal-fired power generation efficiency and reclaiming waste water.

Global Generation Units with Water Stress
- yellow, orange, and red correspond with medium, high, to extremely high stress levels

Source: GE (2012)
Research in Dry Cooling

ARPA-E’s Advanced Research in Dry Cooling (ARID)

Water Stress by Country: 2040

Mission Innovation Countries

NOTE: Projections are based on a business-as-usual scenario using SSP2 and RCP6.5.

For more details:

World Resources Institute
Carbon Capture Technology

Depending on the technology, carbon capture can dramatically increase water requirements for thermoelectric cooling.

Mission Innovation Countries

Capture technology: monoethanolamine

Data source: Meldrum et al. (2013)
### Competition Between Policy Goals: Water Requirements, Energy Equity, Climate Mitigation

<table>
<thead>
<tr>
<th>Cooling System</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-through</td>
<td>Low water consumption</td>
<td>High water withdrawals</td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td>Impact on ecosystem</td>
</tr>
<tr>
<td></td>
<td>Lower capital cost</td>
<td>Exposure to thermal discharge limits</td>
</tr>
<tr>
<td>Wet tower</td>
<td>Significantly lower water withdrawal</td>
<td>Higher capital cost relative to once-through</td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td>Lower plant efficiency, especially when ambient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temperatures are high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large land area requirements</td>
</tr>
<tr>
<td>Dry</td>
<td>Zero or minimal water withdrawal or</td>
<td>Higher capital cost than wet tower or once through</td>
</tr>
<tr>
<td></td>
<td>consumption</td>
<td>Limited technology experience</td>
</tr>
</tbody>
</table>
Clean energy technology is any process, product or system of products and processes, that can be applied at any stage of the energy cycle from production to consumption, whose application will reduce net greenhouse gas emissions, and can meet one or more of the following characteristics:

- reduced demand for water resources
- reduced waste
- reduced emissions of other air pollutants
- or reduced concentrations of contaminants in wastewater discharges.

Mission Innovation consists of early-stage clean energy elements of existing programs that are research, development and demonstration (RD&D) – not deployment

FY 2016 U.S. government-wide baseline is $6.4 billion and, of this, the U.S. Department of Energy (DOE) baseline is $4.8 billion (75%)
Power Generation Sources and Water Withdrawals for Power Generation Vary Greatly by Region

**KEY (WATER DATA)**
- Water Withdrawal for Power Generation (Mgal/day)
- Water Withdrawal Intensity of Power Generation (gal/MWh)

**KEY (GENERATION SOURCE DATA)**
- Coal
- Natural Gas
- Nuclear
- Hydroelectric Conventional
- Non-Hydro Renewables
- Other

**Most**
- Water Withdrawal: Southeast, Midwest
- Water Intensity: Hawaii, Midwest

**Least**
- Water Withdrawal: Alaska/Arctic, Northwest
- Water Intensity: Northwest, Alaska/Arctic

**Sources:**
What greenhouse gas reductions would be achieved under current DOE program office goals, including cost and performance goals?

Energy program goals, most recently published in the FY17 budget, include cost and performance targets for future years. Program goals were translated into model inputs.

The Advanced Technology Case represents one potential version of a clean energy technology future based on current RDD&D funding levels and the “technology push” approach to significant GHG emissions reductions from the energy sector.
**Power Sector Emissions Under Advanced Tech Cases**

- **Historical**
- **EPSA Base Case**
- **EPSA Base Case, HOGR**
- **Advanced Tech 2016**
- **Advanced Tech HOGR 2016**
- **Advanced Tech 2016, CP10**

- **40% below 2005 levels**
- **70% below 2005 levels**
Unconventional Gas Development: Lessons Learned

Source: MIT Future of Natural Gas Study