Our Aging Energy Infrastructure –
A Precarious Future

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State Of Energy In America

“By 2025 aging and unreliable infrastructure will cost the American economy $7 trillion”

- American Society of Civil Engineers

Fortunately, aging infrastructure in the energy sector will only account for about $300 billion of that amount
## American Society of Civil Engineers Infrastructure Sector 2017 Grade

<table>
<thead>
<tr>
<th>Infrastructure Sector</th>
<th>2017 Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation</td>
<td>D</td>
</tr>
<tr>
<td>Bridges</td>
<td>C+</td>
</tr>
<tr>
<td>Dams</td>
<td>D</td>
</tr>
<tr>
<td>Drinking Water</td>
<td>D</td>
</tr>
<tr>
<td>Energy</td>
<td>D+</td>
</tr>
<tr>
<td>Hazardous Waste</td>
<td>D+</td>
</tr>
<tr>
<td>Inland Waterways</td>
<td>D</td>
</tr>
<tr>
<td>Levies</td>
<td>D</td>
</tr>
<tr>
<td>Ports</td>
<td>C+</td>
</tr>
<tr>
<td>Public Parks</td>
<td>D+</td>
</tr>
<tr>
<td>Rail</td>
<td>B</td>
</tr>
<tr>
<td>Roads</td>
<td>D</td>
</tr>
<tr>
<td>Schools</td>
<td>D+</td>
</tr>
<tr>
<td>Solid Waste</td>
<td>C+</td>
</tr>
<tr>
<td>Transit</td>
<td>D-</td>
</tr>
<tr>
<td>Wastewater</td>
<td>D+</td>
</tr>
</tbody>
</table>
State Of Energy In America

The United States is energy independent
- we now have more fossil fuel of all types than any country
- we have more renewable potential than any other country
- we choose for immediate economic reasons to import some fossil fuels and uranium

Overall, energy is cheaper than at any time in human history
- because of this, food is also cheaper than at any time

Energy has never been cheaper than it is now

Spending on energy did not fall below 20% of GDP until the middle of the 1800’s - the beginning of the fossil fuel age

In the preindustrial era, food was fuel for power as well as for life

Courtesy of Carey King, UT Austin
State Of Energy In America

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Climate Change
- significant changes and challenges will require adaptability
- need a diverse energy mix and a resilient infrastructure

The biggest challenge is our electrical infrastructure
- it’s old, it cost $5 trillion, it has depreciated about $2 trillion and will cost about $3 trillion more to meet this challenge

The U.S. electricity sector is worth about $5T

The Electricity Sector Value*:
- Replacement: $5 trillion
- Depreciated: $2 trillion

The electricity sector alone with require $Trillions in investment within 30 years*.

*Based on initial estimates from the Energy Institute of UT Austin
Gas infrastructure totals about $8T will require about $6 to meet this challenge.

From Joshua D. Rhodes PhD, UT Austin

State Of Energy In America

Most of the U.S. energy system predates the turn of the 21st century
- most electric T&D lines were constructed in the 1950s and 1960s with a 50-year life expectancy
- over 640,000 miles of high-voltage transmission lines in the lower 48 states’ power grids, most at full capacity
**History of U.S. Transmission Construction**

Significant recent and projected transmission additions are still well below additions made 40-50 years ago when much of the current grid was built.

**State Of Energy In America**

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Energy infrastructure is undergoing increased investment to ensure long-term capacity and sustainability, however:
- in 2015, 40% of additional power generation came from natural gas and renewable systems.
- without greater attention to aging equipment, capacity bottlenecks, and increased demand, as well as increasing storm and climate impacts, Americans will experience longer and more frequent power interruptions.
As a result of aging infrastructure, severe weather events, attacks and vandalism, in 2015 there were 3,571 total outages reported, with an average duration of 49 minutes.

For electricity – including generation facilities and T&D infrastructure – the cumulative investment gap between 2016 and 2025 is estimated to be $177 billion. 80% of interruptions are in the distribution system.
State Of Energy In America

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America’s 2.6 million miles of oil and gas pipelines connect sources such as wells and import/export terminals with processing facilities and consumers.
Nearly half of U.S. crude oil pipelines are over 50 years old
State Of Energy In America

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*Oil refineries have operated at capacity since 1996, with only one new addition.*

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Oil Refineries

- U.S. refines > 7 billion barrels of oil every year
- refineries engineered to process specific crudes, like sweet crude from New Mexico, tar sands from Canada or heavy oils from Venezuela
- average refinery age is 40 years - some are almost 90 - only one has been built in this century, this is a looming crisis
- half of our refineries have closed since 1996, but the **productivity** of the remaining has doubled
- In 1982, 301 refineries processed 6 billion barrels
- In 2014, 149 refineries processed 6 billion barrels
- In 2017, 149 refineries processed 8 billion barrels
- all refineries are now at capacity, some uprating
- expensive to build, low profit margin, difficult to permit, NIMBY, so all of them will run at capacity until they are dead
- Saudi Arabia has offered to double the size of our largest refinery which is in Port Arthur, Texas
State Of Energy In America

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Despite recent construction, a large percentage of higher-pressure natural gas transmission lines were installed before 1980.
Causes of Significant Onshore Hazardous Liquid Pipeline Incidents

Causes of Gas Transmission Pipeline Significant Incidents
What About The Weather?

Observed Outages to the Bulk Electric System, 1992-2012

<table>
<thead>
<tr>
<th>Events</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
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<tbody>
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<td>1992</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td>160</td>
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<tr>
<td>1996</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>110</td>
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<td>2000</td>
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<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
</tr>
<tr>
<td>2004</td>
<td>30</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>110</td>
<td>130</td>
<td>150</td>
<td>170</td>
<td>190</td>
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<tr>
<td>2008</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>2012</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>110</td>
<td>130</td>
<td>150</td>
<td>170</td>
<td>190</td>
<td>210</td>
</tr>
</tbody>
</table>

- Weather-Related
- Non-Weather Related
- Unclassified

EIA
Cause of Major Electricity Disturbances in the U.S. 2012 - 2016

<table>
<thead>
<tr>
<th>Cause</th>
<th>Share of total customer-hours disrupted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Severe Weather</td>
<td>64.5%</td>
</tr>
<tr>
<td>Hurricane Sandy</td>
<td>31.7%</td>
</tr>
<tr>
<td>Generation Inadequacy</td>
<td>0.00858%</td>
</tr>
<tr>
<td>Fuel Supply Emergencies</td>
<td>0.00007%</td>
</tr>
<tr>
<td>Other</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

Source: EIA and Rhodium Group analysis

Billion-Dollar Weather/Climate Disasters

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated Cost of Weather Related Outages (Billions 2012 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>$27 – $52</td>
</tr>
<tr>
<td>2011</td>
<td>$19 – $36</td>
</tr>
<tr>
<td>2010</td>
<td>$13 – $25</td>
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<tr>
<td>2009</td>
<td>$8 – $14</td>
</tr>
<tr>
<td>2008</td>
<td>$40 – $75</td>
</tr>
<tr>
<td>2007</td>
<td>$5 – $10</td>
</tr>
<tr>
<td>2006</td>
<td>$23 – $43</td>
</tr>
<tr>
<td>2005</td>
<td>$14 – $27</td>
</tr>
<tr>
<td>2004</td>
<td>$14 – $27</td>
</tr>
<tr>
<td>2003</td>
<td>$14 – $26</td>
</tr>
</tbody>
</table>
Since Gas & Renewables have been the fastest growing energy sources in the U.S. since 1990, more pipelines and transmission lines are needed to support them, especially as they replace premature coal and nuclear plant closings.

However, voters are balking at installing this infrastructure.

<table>
<thead>
<tr>
<th>New Generating Capacity: 1990 - 2015, MW</th>
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<tbody>
<tr>
<td>Coal</td>
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<tr>
<td>Gas</td>
</tr>
<tr>
<td>Nuclear</td>
</tr>
<tr>
<td>Oil</td>
</tr>
<tr>
<td>Renewables</td>
</tr>
<tr>
<td>Hydro</td>
</tr>
</tbody>
</table>

New England voters refuse to emplace new gas pipelines and new transmission lines as coal and nuclear close, thinking they can increase dependence on gas and new imported hydropower from Canada without them.

This has lead the grid operators to issue clear warnings

“Current trends are pushing the New England power system on a path toward greater fuel-security risks.”

- ISO NE

These trends include:

• increasing retirements of power plants with fuel stored onsite (nuclear, coal and oil); the

• growth in power plants dependent on natural gas, a fuel that’s delivered just in time

• growing demand for natural gas from local gas utilities in both New England and the Maritimes for heating/industry, leaving less for power plants

• increase in renewable resources with variable production and greater transmission needs
The Good News

• Building and construction energy codes and efficiency are working, and are bipartisan
• Energy will be cheap for the next two decades
• America is energy independent already – choice to import tied to local/temp costs/logistics
• Financing for retrofits and upgrades, usually a key barrier, now have market-based alternatives
• Easy to retrofit coal plants with gas turbines
• Easier and cheaper to supersize oil and gas pipelines than to build new ones - 26” to 42” pipe increases maximum flow 5-fold

RECOMMENDATIONS TO RAISE THE GRADE

• Adopt a federal energy policy to provide clear direction
• Streamline permitting processes for prompt construction of critical new transmission lines and pipelines - ensure safe routing.
• Develop a national ‘storm hardening’ plan that considers investment in T&D, refinery, and generation systems that withstand and recover quickly from storm events with increased minimum design loads for ice, wind, and temperature.
• Integrate new communications infrastructures, remote sensing and advanced information technologies to enable new distribution system capabilities and to recover rapidly from events.
• Implement performance-based regulations that mandate verification of pipeline integrity.
• Promote accepted engineering standards for all overhead T&D lines, pipelines, and support structures.
Questions?

Carbon Footprints

Future Energy Sources

and

New Infrastructure Needed
Climate Change is not a new phenomenon

Relative changes in global average temperature for the past 550 million years based on various methods from various researchers. The time scale is vastly different for each of the five general time segments, going from hundreds of millions of years per segment, to millions of years, to thousands of years. Note that the Earth has generally been warmer than it is today, and that we have been in a major cooling period for the last 10 million years, with glaciation the last 2.3 my.

Two scenarios for global temperature changes depending upon CO2 emissions reductions:

A2 - no reductions

B1 – significant reductions

Paris COP21 climate meeting was only about who would pay for implementing B1
Emissions pathways to limiting global warming to just 2° Celsius (3.6° Fahrenheit) above the temperatures of the 1800s.

What is the fastest growing energy source in the world?
U.S. Electric sector monthly CO2 emissions are at a 25-year low as natural gas overtakes coal’s share of power generation and we have implemented significant efficiency and conservation policies.

Huge shale gas production

<table>
<thead>
<tr>
<th>US Shale Gas Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billion Cubic Feet per Day</td>
</tr>
<tr>
<td>Antrim (MI, IN, &amp; OH)</td>
</tr>
<tr>
<td>Bakken (ND)</td>
</tr>
<tr>
<td>Woodford (OK)</td>
</tr>
<tr>
<td>Barnett (TX)</td>
</tr>
<tr>
<td>Fayetteville (AR)</td>
</tr>
<tr>
<td>Eagle Ford (TX)</td>
</tr>
<tr>
<td>Haynesville (LA &amp; TX)</td>
</tr>
<tr>
<td>Marcellus (PA &amp; WV)</td>
</tr>
<tr>
<td>Utica (OH, PA &amp; WV)</td>
</tr>
<tr>
<td>Rest of US ‘shale’</td>
</tr>
</tbody>
</table>

DOE Hydropower Vision includes
- 36 GWs of new pumped storage, 5 GWs of non-powered dams electrified, and 7 GWs of efficiency uprates at existing facilities
- advanced tech with special low-finance, fast permitting process
- $148 billion capital investment and operating expenses, 2017–2050
- mostly private investment with little government capital
Crude Oil Transport
Pick Your Poison – Pipeline, Truck, Rail or Ship
...depends on what you value most

For which is safest, the short answer is:
truck **worse** than train **worse** than pipeline **worse** than boat
But that’s only for human death and property destruction.

For the amount of oil spilled per billion-ton-miles it’s:
truck **worse** than pipeline **worse** than rail **worse** than boat

For environmental impact (dominated by aquatic habitat) it’s:
boat **worse** than pipeline **worse** than truck **worse** than rail
How much will it cost for an acceptable reliable energy system? Are costs among the various energy sources sufficiently different to justify unethical or illogical decisions?