Deep Decarbonization in the U.S.  
Implications for CPP & Near-term Decisions  

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CTAEE/EI  
Austin, Texas  
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Energy and Environmental Economics, Inc. (E3)

+ Electricity sector specialists, founded 1989
+ Rigorous analysis on a wide range of energy issues
+ Advise utilities, regulators, gov’t agencies, power producers, technology companies, and investors
+ Offices in San Francisco and Vancouver, international practice includes China and India
+ Key advisor to California state government on climate policy, electricity planning, energy efficiency
Deep Decarbonization Pathways Project

- National strategies to keep global warming below 2°C
- 15 countries, >70% of current global GHG emissions
  - OECD + China, India, Brazil, South Africa, Mexico, Indonesia
- July 2014 report to UN Secretary General Ban Ki-moon
- Nov 2014 US Report by E3, LBNL, PNNL team

US Report focus:
What would it take for US to achieve 80% GHG reduction below 1990 level by 2050?

Report available at http://unsdsn.org
DDPP modeling crates potential for comparisons & benchmarking similar metrics for low-carbon action across countries (rather than exclusively annual CO2)
Analysis explores implications of 80% reductions as long term target

- CO2 from energy in 2010 was 5405 MMT (17 tons/person)
- DDPP US 2050 target is 750 MMT (1.7 tons/person)

US GHG emissions by economic sector

Pathway A

Pathway B

2050 analysis is important for avoiding intermediate solutions that fall short of long term goals

750 MMT
+ E3’s climate policy modeling platform built in Analytica (US & CA versions)
+ Multi-sector model (80 demand; 20 supply) with sophisticated infrastructure stock representation to 2050
+ Hourly electricity dispatch model; sensitivity & uncertainty analysis
+ Conservative assumptions about economy, lifestyles (EIA Reference Case for population & economic growth)
+ 9 US Census regions separately modeled

+ Allows for a better understanding of impacts and differences in regional options for future energy systems
Electricity sector solutions

Hourly electricity supply and demand is balanced for three regions, approximates U.S. interconnections (excludes Canada)
- Western, Eastern, Texas

Electricity sector is of paramount importance and requires hourly representation
PATHWAYS Model: Physical Infrastructure Representation

+ 80 demand sectors, 20 supply sectors
+ Annual time steps with equipment lifetimes
+ Aligns with the structure of policymaker goals
+ Illustrates inertia of the physical energy system
+ Makes decarbonization pathways “real”

New Vehicles by Vintage

Total Stock by Year
KEY RESULTS: Decarbonizing U.S. economy depends on 4 energy transitions

1. Efficiency and Conservation
   - High efficiency residential & commercial buildings
   - Industrial efficiency
   - Transportation efficiency & smart growth

2. Fuel Switching
   - Electric heat pumps for HVAC, water heat in buildings
   - Electric and/or fuel cell vehicles in transportation

3. Decarbonize electricity
   - Increase in renewable generation, increase in nuclear and/or CCS electricity generation varies by scenario

4. Decarbonize fuels (liquid & gas)
   - Liquid biofuels in vehicles or biogas & synthetic decarbonized gas in pipeline for buildings & industry

Reduce energy use per capita (MMBtu/person)
Increase share of electricity & H₂ in total final energy (%)
Reduce emissions intensity (tCO₂e/MWh)
Reduce emissions intensity (tCO₂/EJ)
U.S. DDPP results consistent with U.S. 2025 climate pledge with China

China’s pledge
Plan to have carbon dioxide emissions peak “around 2030”

Multiple Pathways to Deeply Reduce U.S. Energy Emissions

Pathways to Deep Decarbonization in the United States
### Different Pathways to 80% Reduction

<table>
<thead>
<tr>
<th>Scenario</th>
<th>High Renewables</th>
<th>High Nuclear</th>
<th>High CCS</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric generation</strong></td>
<td>~ 70% wind, solar, geo by 2050</td>
<td>~40% nuclear by 2050</td>
<td>~55% CCS by 2050</td>
<td>Mix of nuclear, CCS, renewable</td>
</tr>
<tr>
<td><strong>Fuel strategy</strong></td>
<td>Decarbonize pipeline gas to replace liquid fuel</td>
<td>Hydrogen from electricity to</td>
<td>Limited fuel switching,</td>
<td>Decarbonize pipeline gas to replace</td>
</tr>
<tr>
<td></td>
<td></td>
<td>replace liquid fuel</td>
<td>some biofuels</td>
<td>liquid fuel</td>
</tr>
<tr>
<td><strong>Main transport fuel</strong></td>
<td>Electricity, pipeline gas, fossil diesel</td>
<td>Hydrogen, biofuel, fossil diesel</td>
<td>Electricity, biodiesel</td>
<td>Mix of hydrogen, electricity, fossil,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pipeline gas</td>
</tr>
<tr>
<td><strong>Light duty vehicle</strong></td>
<td>EV, PHEV</td>
<td>FCV</td>
<td>EV, PHEV</td>
<td>Mix of EV, PHEV, FCV</td>
</tr>
<tr>
<td><strong>Pipeline gas</strong></td>
<td>~60% biomass, 15% fossil NG, 15% synthetic NG</td>
<td>~60% fossil NG, 35% biomass</td>
<td>~80% fossil NG</td>
<td>~80% biomass, 7% hydrogen, 7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>synthetic NG</td>
</tr>
</tbody>
</table>
Current U.S. energy system in 2014

2014 Reference Case

- Geothermal
- Solar
- Wind
- Nuclear
- Hydro
- Biomass
- Natural Gas
- Coal
- Petroleum

Components:
- Electricity Generation
- Grid Electricity
- Biofuel Production
- Power-to-Gas SNG
- Hydrogen Production
- Pipeline Gas
- Combined Heat and Power
- Petroleum Refining
- Liquid Fuels
- Transportation

Energy + Environmental Economics
Decarbonized energy system in 2050

Electricity plays much larger role in low-carbon economy
Electricity Increasingly Dominated by Non-Dispatchable Generation

Mixed Case: Electricity Demand by Fuel Type

Pathways to Deep Decarbonization in the United States, Mixed case results
Electricity Supply: Regional Generation Mix by Decade (Mixed Case)
Technology Generation Share
Texas – High Renewables Case

Output Year

Generation Share by Technology (%)

Coal
Gas
Nuclear
Wind
Solar

All Generation Types
- CHP
- Subsector-Driven CHP
- Coal_All_Large
- Coal_All_Small
- Gas_CCGT_Large
- Gas_CCGT_Small
- Gas_CT_Large
- Gas_CT_Small
- Gas_ST
- Oil_All
- Nuclear
- CCGT with CCS
- Coal with CCS
- Conventional Hydro
- Biogas
- Biomass
- Geothermal
- Small Hydro
- Solar Thermal
- Utility PV
- Offshore Wind
- Distributed PV
- CSP with Storage
- International Imports
In High Renewables, High Nuclear and Mixed scenarios: flexible loads (esp production of hydrogen or methane) deployed to help balance intermittent renewable generation.

In High CCS scenario: natural gas with CCS is dispatchable, solving grid integration challenges.
Electricity used to produce hydrogen and synthetic methane → balance variable generation (wind, solar) & provide lower carbon fuel

Natural gas pipeline is partly decarbonized using gasified biomass and electricity-produced fuels with low lifecycle emissions

Decarbonized pipeline gas is used to replace liquid fossil fuels in industry, heavy duty transport

Biomass not used for ethanol because it is scarce and has better uses, such as biogas and biodiesel, while alternatives exist for LDV fuels
U.S. Cost Components

Cost mostly fixed costs, savings mostly fuel savings

Lower net cost if technology costs lower, fossil fuels higher

Pathways to Deep Decarbonization in the United States, High renewables case
Median 2050 net energy system cost $\sim 1\%$ of GDP ($40T$)
Uncertainty range $-0.2\%$ to $+1.8\%$

U.S. Net Energy System Cost by Sector

![Graph showing net energy system cost by sector from 2014 to 2050](image)

Pathways to Deep Decarbonization in the United States, Mixed case results
Incremental Average Household Spending in 2050 ($/Month)
Implications for near term planning

- Multiple pathways exist that are feasible to reach 80% reductions emphasizing different technologies
- Planning must take infrastructure inertia into account
- Important if plan to meet 111d can also set state up for ability to make further reductions
  - There are dead-ends that provide short-term GHG reductions but don’t lead to 80% by 2050
  - Other options set up the US (or ERCOT) to more easily make further emissions reductions post 2030.
- Coordination across sectors can help
  - Certain low-carbon options in other sectors – including hydrogen and synthetic methane production – could also help address electric sector balancing issues but must begin to consider carbon reduction plans across sectors (beyond electricity); Accounting for emissions reductions outside of electric sector needs to be clear.
Investments choices today will determine capacity to reduce emissions over the next 35 years.

A car purchased today, is likely to be replaced at most 2 times before 2050. A residential building constructed today, is likely to still be standing in 2050.

<table>
<thead>
<tr>
<th>Equipment/Infrastructure</th>
<th>2015 Lifetime</th>
<th>2030 Lifetime</th>
<th>2050 Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric lighting</td>
<td>5 years</td>
<td>20 years</td>
<td>24 years</td>
</tr>
<tr>
<td>Hot water heater</td>
<td>10 years</td>
<td>30 years</td>
<td>33 years</td>
</tr>
<tr>
<td>Space heater</td>
<td>15 years</td>
<td>35 years</td>
<td>38 years</td>
</tr>
<tr>
<td>Light duty vehicle</td>
<td>20 years</td>
<td>40 years</td>
<td>43 years</td>
</tr>
<tr>
<td>Heavy duty vehicle</td>
<td>25 years</td>
<td>50 years</td>
<td>53 years</td>
</tr>
<tr>
<td>Industrial boiler</td>
<td>30 years</td>
<td>60 years</td>
<td>63 years</td>
</tr>
<tr>
<td>Electricity power plant</td>
<td>35 years</td>
<td>70 years</td>
<td>73 years</td>
</tr>
<tr>
<td>Residential building</td>
<td>40 years</td>
<td>80 years</td>
<td>83 years</td>
</tr>
</tbody>
</table>

Average lifetimes, actual results will vary.
Thank You!

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ADDITIONAL SLIDES
Energy Supply and Demand
Transitions – All Scenarios

Mixed Case:

High Renewables Case:

High CCS Case:

High Nuclear Case:
Energy Demand by Sector

Residential

- Electricity
- Pipeline Gas
- Residual Fuel Oil
- LPG
- Kerosene
- Biomass

Commercial

- Electricity
- Pipeline Gas
- Residual Fuel Oil
- LPG
- Kerosene

Transportation

- Electricity
- Diesel Fuels
- Gasoline
- Jet Fuel
- Hydrogen
- Gas Fuels (CNG/LNG)

Industrial

- Asphalt & Road Oil
- Biomass
- Coal
- Coke
- Diesel
- Electricity
- Gasoline
- Pipeline Gas
Pipeline Gas Supply and Sectoral Demand (Mixed Case)

Final Energy in 2050 (EJ)

PIPELINE GAS SUPPLY SOURCES:
- Bio-SNG
- Natural Gas
- H2
- P2G

PIPELINE GAS DEMAND SECTORS:
- Industrial
- Transportation
- Commercial
- Residential

Legend:
- Natural Gas
- Power to Gas
- Natural Gas w/ End-Use Capture
- Commercial
- Industrial
- Hydrogen
- Biogas
- Residential
- Transportation
PATHWAYS Design Principles

+ Conservative assumptions about economy, lifestyles
+ Technology is commercial or near-commercial
+ Environmental sustainability (limits on biomass, hydro)
+ Infrastructure inertia
+ Electricity reliability

U.S. GDP (Trillion $2012)
- 166% increase

U.S. population (Millions)
- 40% increase

Comparison of 2030 Western Region Spring-time Generation Profile

+ Idealized dispatch across WECC with flexible fuel production loads allows renewable integration in both scenarios.

+ High Renewables Scenario requires reduction in base load generation during some hours to accommodate wind & solar

High Renewables Scenario

May 2030 (week 20), hours 1-24
Example of Daily Resource Balancing by Season: High Renewable Scenario

Western Interconnect High Renewables Case 2030

Early Spring
Low loads, high solar, wind & hydro, reductions in coal output

Spring
High loads, more reliance on gas

Summer
High wind, less solar

Fall
Low loads, high solar, wind & hydro, reductions in coal output

Winter
High loads, more reliance on gas
What would it take for US to achieve 80% GHG reduction below 1990 level by 2050?

- Is it technically feasible?
- What would it cost?
- What physical changes are required?
- What economic and policy changes are implied?

Report available at http://unsdsn.org
PATHWAYS Model Methodology: Bottom-Up Energy Demand

Infrastructure stock rollover model (keeps track of “stuff” e.g. Number of light bulbs by type)

Lighting Stock

Residential Demand (lumens/year)

Total Residential Final Energy for Lighting