Lessons from the Deep Decarbonization Pathways Project

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DDPP Director, SDSN

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Lessons from the DDPP

• Background
• US Pathways
• DDPP Pathways
• Research Agenda
Background
Deep Decarbonization Pathways Project

- National blueprints for limiting warming <2°C
- Independent research teams from 16 countries
- ¾ of current CO\textsubscript{2} emissions

Goal: change climate policy discussion

- From near-term to long-term
- From incremental to transformational
- From vague commitments to transparent plans

Research mirrors new policy architecture

- Reflects national conditions, development goals
- Each team determines own methods
- Bottom-up/hybrid modeling w sectoral detail
Paris Agreement, Article 4, Paragraph 19

“All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies...”
Why Long-Term Strategies? Avoiding Emissions Dead Ends

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

How to assess NDCs in the absence of a sectorally explicit mid-century strategy?
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.
Anticipating forks-in-the-road: Real examples from California

1. Electric vs. Fuel Cell Vehicles

- Zero Emissions Vehicles
  - Electric vehicles
  - Fuel cell vehicles
  - Electric charging infrastructure
  - H2 fuel production: grid electrolysis

2. Electrification vs. Low Carbon Gas in Buildings

- Building strategy
  - Biogas and low-carbon synthetic methane
  - Electric heat pumps, electrification
  - No building electrification, biogas in pipeline
  - Building electrification, no gas pipeline
US Pathways
U.S. Pathways Analysis

E3, UC, LBNL, PNNL team
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?*

Policy Report, Nov. 2015
• *What are the policy implications for the US?*

Reports available at [http://usddpp.org](http://usddpp.org)
PATHWAYS Used to Model Energy System

- Energy system model, user-defined scenarios
- 80 demand sectors, 20 supply sectors
- Annual rollover of equipment stock by vintage
- Mimics NEMS architecture
- 9 US census divisions separately modeled
- Hourly electricity dispatch

GCAM Used to Model Non-Energy/Non-\(\text{CO}_2\) GHGs

- Non-energy and non-CO\(2\) GHG mitigation
- Biomass production and indirect land use change emissions
- Sensitivity to terrestrial carbon sink assumptions
Scenario Design Constraints

- Infrastructure inertia
- Electric reliability
- Same energy services as EIA forecast
- Technology is commercial or near-commercial
- Environmental limits (biomass, hydro)

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

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

80% Reduction in CO$_2$e by 2050 is Achievable

Based on US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table 2-2
Multiple Feasible Technology Pathways Exist

Four distinct scenarios that reach per capita energy emissions of 1.7 t/person

- 2014: 5,153 Mt CO₂
- 2050 Reference: 5,639 Mt CO₂
- 2050 Mixed Renewables: 746 Mt CO₂
- 2050 High Renewables: 740 Mt CO₂
- 2050 High Nuclear: 747 Mt CO₂
- 2050 High CCS: 741 Mt CO₂

- Provide the same levels of energy service (VMT, EJ of heating and cooling demand, industrial output)
- Similar incremental costs: ~0.5%-1.5% of GDP
- Similar amounts of final energy demand
- Burden of proof should shift to those who say this can’t be done

Multiple pathways to achieving climate mitigation target in U.S.
Deep Decarbonization Cost is Affordable

Net energy system cost in 2050 ~ 0.8% GDP
(-0.2% − +1.8%)
( does not include economic benefits of avoided pollution or climate damage)
U.S. Results Summarized: Three Seeming Paradoxes

• Deeply decarbonized energy system
  • big change in physical energy system
  • little change in energy services

• Deeply decarbonized energy economy
  • big change in energy economy
  • little change in consumer cost

• Deeply decarbonized macro-economy
  • small net cost relative to GDP
  • significant benefits for macro-economy
Lessons for Energy System Transition
Three Pillars of Deep Decarbonization Required in All Cases

Pathways to Deep Decarbonization in the United States, Mixed case results
Interactions Among the 3 Pillars: LDV Transition Example

- Energy service demand (AEO)
- Annual LDV sales
- LDV stocks by type
- VMT by fuel type
- LDV final energy by fuel type
- GHG emissions by fuel type
### Sectoral Metrics: 2050 Benchmarks for US

<table>
<thead>
<tr>
<th>Sector</th>
<th>Current Energy System</th>
<th>Deep Decarbonized Energy System</th>
<th>Key Metrics in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Coal and natural gas dominated</td>
<td>Renewable, nuclear, or CCS</td>
<td>Double output while reducing CO₂/kWh 30x</td>
</tr>
<tr>
<td>Transportation</td>
<td>Oil dominated</td>
<td>Electricity, hydrogen, CNG, LNG, biodiesel</td>
<td>Fuel economy &gt;100 mpg equivalent</td>
</tr>
<tr>
<td>Buildings</td>
<td>Natural gas and oil dominate heating</td>
<td>Electrification, end use efficiency</td>
<td>Building energy use &gt;90% electrified</td>
</tr>
<tr>
<td>Industry</td>
<td>Fossil fuel dominated</td>
<td>Electrification, CCS, efficiency, low C fuels</td>
<td>Double efficiency, &gt;40% electrification</td>
</tr>
</tbody>
</table>
Five Interacting Elements of Deeply Decarbonized Energy Systems

- Electricity Mix
- Biomass Supply and Use
- CCS Availability
- Fuel Switching Strategy
- Electricity Balancing Strategy
Hourly Electricity Supply & Demand in WECC, High Renewables Case, Week in March 2050

WECC Electricity Generation 3/2/2050 - 3/8/2050:

WECC Electricity Load 3/2/2050 - 3/8/2050:
## Transformational Perspective Challenges
### Some Common Assumptions

<table>
<thead>
<tr>
<th>Common Assumption</th>
<th>US Pathways Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE is main demand-side strategy</td>
<td>Fuel switching is key demand strategy</td>
</tr>
<tr>
<td>Electric gen low growth due to EE</td>
<td>Electric gen ~2x due to electrification</td>
</tr>
<tr>
<td>Biomass used for ethanol in LDVs</td>
<td>Biomass used for pipeline gas /HDVs</td>
</tr>
<tr>
<td>Hydrogen is costly fuel</td>
<td>Hydrogen is balancing resource + fuel</td>
</tr>
<tr>
<td>Storage is key to RE intermittency</td>
<td>Storage has limited role in integration</td>
</tr>
<tr>
<td>Coal to NG is key gen transition</td>
<td>NG gen GHGs too high for later years</td>
</tr>
<tr>
<td>NG power plants will be stranded</td>
<td>NG plants valuable at low utilization</td>
</tr>
<tr>
<td>$/ton is key cost metric</td>
<td>Net system cost is key cost metric</td>
</tr>
</tbody>
</table>
Non-US Pathways
DDPP High Level Results: Aggregate, Per Capita, and Per $GDP CO_2 Emissions

DDPP aggregate result: 57% CO_2 reduction below present by 2050
### Three Pillars Results for China, India, UK

#### China

<table>
<thead>
<tr>
<th>Metric</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>402</td>
<td>110</td>
</tr>
<tr>
<td>Energy intensity of GDP, toe/M$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decarbonization of electricity</td>
<td>741</td>
<td>68</td>
</tr>
<tr>
<td>Electricity emissions intensity, gCO$_2$/kWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrification of end-uses</td>
<td>18%</td>
<td>34%</td>
</tr>
<tr>
<td>Share of electricity in total final energy, %</td>
<td>+17 pt</td>
<td>+17 pt</td>
</tr>
</tbody>
</table>

#### India

<table>
<thead>
<tr>
<th>Metric</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>12.96</td>
<td>3.08</td>
</tr>
<tr>
<td>Energy Intensity of GDP, MJ/$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decarbonization of electricity</td>
<td>771</td>
<td>66</td>
</tr>
<tr>
<td>Electricity Emissions Intensity, gCO$_2$/kWh</td>
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</tr>
<tr>
<td>Electrification of end-uses</td>
<td>14%</td>
<td>27%</td>
</tr>
<tr>
<td>Share of electricity in total final energy, %</td>
<td>+13 pt</td>
<td>+13 pt</td>
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</tbody>
</table>

#### UK

<table>
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<tr>
<th>Metric</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>2.87</td>
<td>0.91</td>
</tr>
<tr>
<td>Energy intensity of GDP, MJ/$</td>
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<td></td>
</tr>
<tr>
<td>Decarbonization of electricity</td>
<td>441</td>
<td>28</td>
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<tr>
<td>Electricity emissions intensity, gCO$_2$/kWh</td>
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<td></td>
</tr>
<tr>
<td>Electrification of end-uses</td>
<td>19%</td>
<td>40%</td>
</tr>
<tr>
<td>Share of electricity in total final energy, %</td>
<td>+22 pt</td>
<td>+22 pt</td>
</tr>
</tbody>
</table>
China Example: Infrastructure Inertia
India Example: Energy Access
DDPP Aggregate Clean Technology Market Potential and Its Effect on Costs

Decarbonized Electricity Generation

Decarbonized Fuel Production

Alternative Vehicles

Vertical axis: cost in $B
Deep decarbonization, global markets, and developing countries

• Low carbon infrastructure build-out is key to the extent and timing of emissions reductions
• Affordability is key to developing country build-out of low carbon infrastructure
• Large global markets to bring down costs is key to affordability
• High-income countries leading on low carbon technology is key to global market development
• Low-income country share in low carbon technology markets is key to sustainable development
Policy Challenges of Deep Decarbonization: A Research Agenda
The Policy Landscape

• Energy markets are fragmented and imperfect
• “Energy policy” is divided across national, state, and local jurisdictions
• Energy systems have strong regional identities
• Sector characteristics determine the suitability of policy instruments
• Carbon price alone is not enough, need to think through sector by sector, policy by policy
• Policy research must start with question “what does policy need to accomplish?”
How to incorporate future carbon consequences in current purchasing decisions?

- 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.

### Equipment/Infrastructure Lifetime (Years)

- Electric lighting: 2 replacements
- Hot water heater: 3 replacements
- Space heater: 2 replacements
- Light duty vehicle: 2 replacements
- Heavy duty vehicle: 1 replacement
- Industrial boiler: 1 replacement
- Electricity power plant: 1 replacement
- Residential building: 0 replacements
1. Electric vs. Fuel Cell Vehicles

- Electric vehicles
- Fuel cell vehicles

2. Electrification vs. Low Carbon Gas in Buildings

- Building electrification, no gas pipeline
- Building electrification, biogas in pipeline
- No building electrification, biogas in pipeline
- Biogas and low-carbon synthetic methane
- Electric heat pumps, electrification

How to coordinate across sectors when the institutions don’t currently exist?
How to drive investment flows into low carbon equipment and infrastructure?
How to drive rapid consumer adoption?

Light-Duty Vehicle Adoption:
vehicles

New Vehicle Sales

Total Vehicle Stock

ICE
BEV & PHEV
Hydrogen FCV

2016 2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050
How to reform wholesale electricity markets?

WECC Electricity Generation 3/2/2050 - 3/8/2050:

WECC Electricity Load 3/2/2050 - 3/8/2050:
Sustainable business model for network energy suppliers (utilities)?

Are utilities about to be obsolete?
How to drive electrification of buildings?
How can governments adjust to declining fossil fuel tax revenues?
How to address distributional effects of low carbon transition?

<table>
<thead>
<tr>
<th></th>
<th>Distribution</th>
<th>Transmission</th>
<th>Renewables</th>
<th>Variable and Fuel</th>
<th>Conventional Fixed</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td><strong>DDPP Reference Case</strong></td>
<td>3.9c</td>
<td>2.0c</td>
<td>2.7c</td>
<td>4.3c</td>
<td>3.9c</td>
<td>16.7c</td>
</tr>
<tr>
<td><strong>DDPP Mixed Case</strong></td>
<td>2.8c</td>
<td>2.6c</td>
<td>6.6c</td>
<td>1.8c</td>
<td>5.2c</td>
<td>19.1c</td>
</tr>
<tr>
<td><strong>DDPP CCS Case</strong></td>
<td>3.7c</td>
<td>2.0c</td>
<td>3.9c</td>
<td>4.6c</td>
<td>7.6c</td>
<td>21.8c</td>
</tr>
<tr>
<td><strong>DDPP High Renewables Case</strong></td>
<td>2.8c</td>
<td>4.5c</td>
<td>10.0c</td>
<td>0.4c</td>
<td>2.0c</td>
<td>19.5c</td>
</tr>
<tr>
<td><strong>DDPP Nuclear Case</strong></td>
<td>2.6c</td>
<td>2.6c</td>
<td>6.7c</td>
<td>0.8c</td>
<td>4.7c</td>
<td>17.4c</td>
</tr>
</tbody>
</table>

Average Electric Rate:
2012 cents/kWh

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*Note: The chart illustrates the distribution of costs across different cases, with green, red, and grey circles representing different components of the total cost.*
Ongoing Research

• Pathways analysis at different scales
  • State level: New York & Washington; Under2MOU
  • Regional: Pacific coast partnership
  • Continental: US-Canada-Mexico
• Linking deep decarbonization to co-benefits
  • Air quality: Pathways-INMAP (U.Washington)
  • Land use/siting: Pathways-ORB (U.C. Berkeley)
• Sectoral implementing strategies
  • Carbon sink: DOE C sink (LBNL & Nat. Labs)
  • Regional grid integration: WECC (CAISO)
  • Low carbon gas pilots: SoCal Gas
Ongoing Research

• Improving DDPP-type analyses
  • Open source EnergyPathways model
  • Common template for visualizing pathways
  • Community standards for national modeling
  • Harmonizing boundary conditions for bottom-up
  • Interface with integrated assessment models

• Policy/Research initiatives (DDPP/SDSN/IDDRI)
  • IPCC 1.5 C report
  • Intergovernmental Platform & G20
  • Low Emissions Solutions Conference
  • Sustainable Development Goals
  • Country teams engaged in mid-century strategies
THANK YOU

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www.deepdecarbonization.org

DEEP DECARBONIZATION PATHWAYS PROJECT