A Transformative Climate Action Framework:
Putting People at the Center of Our Nation’s Clean Energy Transition

Union of Concerned Scientists
www.ucsusa.org/resources/clean-energy-transformation

Supplemental Modeling Results and Key Modeling Assumptions

This document provides additional details on the US deep decarbonization modeling conducted by Evolved Energy Research (EER) for the Union of Concerned Scientists (UCS). A subset of these results were included in a report prepared by UCS and an expert advisory committee entitled: A Transformative Climate Action Framework: Putting People at the Center of Our Nation’s Clean Energy Transition.

Table 1 provides a summary of the main scenarios used in the report (“Reference,” “Zero CO₂ 2050,” and “Low Energy Demand” cases) as well as two additional scenarios that achieve the same level of emission reductions under different assumptions. The scenarios were designed to explore the effects of possible societal shifts and resource or technological constraints on decarbonization strategies and outcomes.

Table 2 compares CO₂ emissions, energy use in different sectors, costs, and other results for the decarbonization cases to a business-as-usual reference case based on the Energy Information Administration’s (EIA) Annual Energy Outlook (AEO) 2019 for the years 2030 and 2050. The results were generated by Evolved Energy Research using the EnergyPATHWAYS and RIO models.

Table 3 describes some of the key technology assumptions for different sectors, including the deployment of rooftop and distributed solar photovoltaics and air source heat pumps for space heating and cooling in the buildings sector and the increase in sales and stock shares for electric vehicles in the transportation sector. For more details on the scenarios, assumptions, and modeling approach, see the technical appendix.

Table 1. Summary of Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>Business as usual case based on EIA’s Annual Energy Outlook 2019</td>
</tr>
<tr>
<td><strong>Deep Decarbonizations Scenarios:</strong> All scenarios below assume reductions in U.S. heat-trapping emissions of more than 50% below 2005 levels by 2030 and net zero by 2050*</td>
<td></td>
</tr>
<tr>
<td>Zero CO₂ 2050</td>
<td>Least cost pathway to achieve U.S. emission reduction targets</td>
</tr>
<tr>
<td>Low Energy Demand</td>
<td>High conservation, efficiency, and societal shifts enabling demand reductions 20-40% below AEO levels</td>
</tr>
<tr>
<td>50% Biomass Supply</td>
<td>Assumes half the biomass supply from 2016 DOE billion-ton study</td>
</tr>
<tr>
<td>Renewable Build Limits</td>
<td>Wind and utility solar PV annual builds limited to 1.5-2 times record levels</td>
</tr>
</tbody>
</table>

*All decarbonization scenarios also include significant increases in energy efficiency and electrification of buildings, industry, and transportation. Outside of the energy modeling framework, we also make assumptions about deep cuts in non-carbon dioxide (CO₂) heat-trapping emissions and that the land sink continues to absorb CO₂ at current levels. See technical appendix for more details.
Table 2. Emissions, Energy, and Cost Results for Reference Case and Deep Decarbonization Scenarios in 2030 and 2050

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units</th>
<th>2050 Low Energy Demand</th>
<th>2050 50% Biomass</th>
<th>2050 RE Build Limits</th>
<th>2030 Low Energy Demand</th>
<th>2030 50% Biomass</th>
<th>2030 RE Build Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>36.5</td>
<td>34.6 32.0 29.0 32.0 31.9</td>
<td>36.1 8.2 5.6 9.7 8.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>28.6</td>
<td>30.8 26.2 28.8 26.2 26.4</td>
<td>28.1 7.6 5.5 6.7 9.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>15.4</td>
<td>10.5 0.9 1.1 0.9 0.9</td>
<td>10.0 0.4 0.3 0.4 0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>8.1</td>
<td>7.0 7.1 7.0 7.1 7.1</td>
<td>5.9 5.9 6.0 5.9 5.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar</td>
<td>0.5</td>
<td>1.5 2.8 2.1 2.8 3.3</td>
<td>5.4 14.7 9.7 15.6 10.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>1.2</td>
<td>1.6 5.5 2.9 5.5 4.9</td>
<td>3.3 14.3 10.1 15.3 15.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydro</td>
<td>1.0</td>
<td>1.0 1.0 1.0 1.0 1.0</td>
<td>1.0 1.0 1.0 1.0 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.0</td>
<td>0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>5.2</td>
<td>4.9 4.8 4.4 4.8 5.0</td>
<td>4.6 12.8 10.4 12.2 13.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>96.6</td>
<td>91.9 80.3 76.2 80.3 80.4</td>
<td>94.4 64.8 48.5 64.7 64.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Energy Supply Quads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5,300 4,683 3,366 3,344 3,366 3,377</td>
<td>4,444 1 3 0 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Energy Demand Quads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>66.2</td>
<td>65.5 62.3 56.8 62.3 62.3</td>
<td>70.8 48.8 35.0 48.8 48.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity Share of Final Demand %</td>
<td>19.7</td>
<td>21.1 23.4 23.0 23.4 23.6 22.2</td>
<td>20.7 58.9% 59.6% 59.2% 57.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Generation TWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9,525 2,863 9,525 2,863 9,525 2,863</td>
<td>9,525 2,863 9,525 2,863</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Capacity GW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1,186 1,185 1,535 1,326 1,442 1,591</td>
<td>1,186 1,185 1,535 1,326 1,442 1,591</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation Energy Quads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27.2</td>
<td>24.5 23.0 20.8 23.0 23.0</td>
<td>24.9 13.4 10.1 13.4 13.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Electricity</td>
<td>0.1</td>
<td>0.2 0.7 0.6 0.7 0.7</td>
<td>0.4 5.6 3.7 5.6 5.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Hydogen</td>
<td>0.0</td>
<td>0.0 0.1 0.1 0.1 0.1</td>
<td>0.0 2.6 1.8 2.6 2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Liquid Fuels (total)</td>
<td>26.3</td>
<td>23.1 21.0 19.2 21.0 21.0</td>
<td>23.1 4.1 3.8 4.1 4.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Gasoline</td>
<td>16.8</td>
<td>13.9 12.4 11.0 12.4 12.4</td>
<td>12.9 0.5 0.6 0.5 0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Diesel</td>
<td>6.4</td>
<td>5.9 5.7 5.4 5.7 5.7</td>
<td>6.2 0.9 1.0 0.9 0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From Jet Fuel</td>
<td>3.0</td>
<td>3.3 3.0 2.8 3.0 3.0</td>
<td>4.0 2.7 2.7 2.7 2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Key Technology Assumptions for Deep Decarbonization Scenarios

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooftop/Distributed PV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>GW</td>
<td>27</td>
<td>56</td>
<td>111</td>
<td>194</td>
<td>290</td>
<td>391</td>
<td>500</td>
</tr>
<tr>
<td>Residential Systems Million</td>
<td></td>
<td>2.7</td>
<td>5.8</td>
<td>11.4</td>
<td>19.9</td>
<td>29.7</td>
<td>40.1</td>
<td>51.2</td>
</tr>
<tr>
<td>Commercial Systems Million</td>
<td></td>
<td>0.2</td>
<td>0.5</td>
<td>0.9</td>
<td>1.6</td>
<td>2.4</td>
<td>3.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Residential Air Source Heat Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales Share</td>
<td>%</td>
<td>14%</td>
<td>30%</td>
<td>56%</td>
<td>75%</td>
<td>81%</td>
<td>82%</td>
<td>82%</td>
</tr>
<tr>
<td>Stock Share</td>
<td>%</td>
<td>11%</td>
<td>14%</td>
<td>23%</td>
<td>37%</td>
<td>52%</td>
<td>64%</td>
<td>72%</td>
</tr>
<tr>
<td>Systems Million</td>
<td></td>
<td>13.1</td>
<td>17.8</td>
<td>29.8</td>
<td>50.1</td>
<td>73.0</td>
<td>92.5</td>
<td>107.5</td>
</tr>
<tr>
<td>Commercial Air Source Heat Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales Share</td>
<td>%</td>
<td>3%</td>
<td>9%</td>
<td>33%</td>
<td>61%</td>
<td>72%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Stock Share</td>
<td>%</td>
<td>5%</td>
<td>5%</td>
<td>10%</td>
<td>24%</td>
<td>41%</td>
<td>55%</td>
<td>63%</td>
</tr>
<tr>
<td>Electric Vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales Share of ZEV in vehicle fleet (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars BEV</td>
<td>%</td>
<td>6.0%</td>
<td>17%</td>
<td>45%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Light-duty trucks</td>
<td>%</td>
<td>0.8%</td>
<td>10%</td>
<td>35%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Medium duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>4%</td>
<td>30%</td>
<td>59%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Heavy duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>3%</td>
<td>30%</td>
<td>55%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Stock/Fleet Share of ZEV (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>%</td>
<td>1.1%</td>
<td>5%</td>
<td>16%</td>
<td>40%</td>
<td>68%</td>
<td>87%</td>
<td>96%</td>
</tr>
<tr>
<td>Light-duty trucks</td>
<td>%</td>
<td>0.1%</td>
<td>2%</td>
<td>10%</td>
<td>32%</td>
<td>60%</td>
<td>82%</td>
<td>95%</td>
</tr>
<tr>
<td>Medium duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>1%</td>
<td>6%</td>
<td>19%</td>
<td>44%</td>
<td>69%</td>
<td>88%</td>
</tr>
<tr>
<td>Heavy duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>1%</td>
<td>7%</td>
<td>21%</td>
<td>45%</td>
<td>71%</td>
<td>88%</td>
</tr>
<tr>
<td>BEV Sales Share of ZEV (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>%</td>
<td>98.5%</td>
<td>100%</td>
<td>99%</td>
<td>97%</td>
<td>96%</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Light-duty trucks</td>
<td>%</td>
<td>85.4%</td>
<td>98%</td>
<td>98%</td>
<td>95%</td>
<td>92%</td>
<td>91%</td>
<td>91%</td>
</tr>
<tr>
<td>Medium duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>94%</td>
<td>93%</td>
<td>86%</td>
<td>75%</td>
<td>71%</td>
<td>70%</td>
</tr>
<tr>
<td>Heavy duty trucks</td>
<td>%</td>
<td>0.0%</td>
<td>62%</td>
<td>62%</td>
<td>62%</td>
<td>62%</td>
<td>62%</td>
<td>62%</td>
</tr>
</tbody>
</table>

Notes:
(1) The sales share of all zero-emission vehicles (ZEV) relative to all vehicle sales for that type of vehicle (which include other technologies such as plug-in hybrids, internal combustion engines). ZEV refers to the sum of battery electric (BEV) and fuel-cell (FC) vehicles. Ex. 100% of cars in 2050 are ZEV.
(2) The share of the number of vehicles that are ZEV relative to the entire vehicle fleet. Ex. 96% of the fleet of cars in 2050 are zero-emission.
(3) The sales share of BEV vehicles relative to the sales of ZEV vehicles. The remainder refers to FC vehicles. Ex. 95% of the sales of ZEV cars in 2050 are BEV, while 5% of the sales are FC.