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

Union of Concerned Scientists
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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 CO_2 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 CO_2 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

Scenario	Description
Reference	Business as usual case based on EIA's *Annual Energy Outlook 2019*
Deep Decarbonizations Scenarios: 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*	
Zero CO_2 2050	Least cost pathway to achieve U.S. emission reduction targets
Low Energy Demand	High conservation, efficiency, and societal shifts enabling demand reductions 20-40% below AEO levels
50% Biomass Supply	Assumes half the biomass supply from 2016 DOE billion-ton study
Renewable Build Limits	Wind and utility solar PV annual builds limited to 1.5-2 times record levels

*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 (CO_2) heat-trapping emissions and that the land sink continues to absorb CO_2 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

		2020	2030					2050				
Indicator	**Units**		**Reference**	**Zero CO2 2050**	**Low Energy Demand**	**50% Biomass**	**RE Build Limits**	**Reference**	**Zero CO2 2050**	**Low Energy Demand**	**50% Biomass**	**RE Build Limits**
Emissions	MMT CO2											
Commercial		258	263	241	225	241	241	309	36	27	35	36
Residential		340	284	255	242	255	255	243	22	18	22	22
Industrial		881	959	855	781	855	855	1,089	253	175	260	232
Transportation		1,942	1,707	1,536	1,403	1,536	1,533	1,704	32	36	104	56
Electricity		1,879	1,470	478	693	478	493	1,098	98	89	67	116
Biofuels with CCS (BECCS)		0	0	0	0	0	0	0	-439	-347	-363	-461
Direct Air Capture		0	0	0	0	0	0	0	-0.1	-0.1	-125	0
Total		5,300	4,683	3,366	3,344	3,366	3,377	4,444	1	-3	0	1
Primary Energy Supply	Quads											
Petroleum		36.5	34.6	32.0	29.0	32.0	31.9	36.1	8.2	5.6	9.7	8.0
Natural Gas		28.6	30.8	26.2	28.8	26.2	26.4	28.1	7.6	5.5	6.7	9.0
Coal		15.4	10.5	0.9	1.1	0.9	0.9	10.0	0.4	0.3	0.4	0.4
Nuclear		8.1	7.0	7.1	7.0	7.1	7.1	5.9	5.9	6.0	5.9	5.9
Solar		0.5	1.5	2.8	2.1	2.8	3.3	5.4	14.7	9.7	15.6	10.9
Wind		1.2	1.6	5.5	2.9	5.5	4.7	3.3	14.3	10.1	15.3	15.8
Hydro		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Geothermal		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass		5.2	4.9	4.8	4.4	4.8	5.0	4.6	12.8	10.4	10.2	13.7
Total		96.6	91.9	80.3	76.2	80.3	80.4	94.4	64.8	48.5	64.7	64.8
Final Energy Demand	Quads											
Commercial		8.6	8.9	8.4	7.9	8.4	8.4	10.3	6.8	5.5	6.8	6.8
Industrial		19.1	21.7	20.9	18.7	20.9	20.9	24.9	22.1	14.5	22.1	22.1
Residential		11.3	10.5	9.9	9.3	9.9	9.9	10.6	6.1	4.9	6.1	6.1
Transportation		27.2	24.5	23.1	20.8	23.1	23.1	24.9	13.8	10.1	13.8	13.8
Total		66.2	65.5	62.3	56.8	62.3	62.3	70.8	48.8	35.0	48.8	48.8
Electricity Share of Final Demand	%	19.7%	21.1%	23.4%	23.0%	23.4%	23.2%	22.7%	58.9%	59.6%	59.2%	57.6%
Electric Generation	TWh											
Coal		1,343	876	0	0	0	0	816	0	0	0	0
Gas		1,236	1,577	1,192	1,669	1,190	1,224	1,067	296	256	197	354
Gas with CCS		0	0	0	0	0	0	0	0	0	0	60
Nuclear		777	671	684	671	684	684	568	567	576	569	568
Other		18	18	18	18	18	18	6	4	4	4	4
Hydro		286	289	288	289	288	288	279	274	274	273	275
Offshore wind		0	12	118	114	118	120	48	837	499	863	1,301
Onshore wind		342	459	1,448	727	1,451	1,232	893	3,122	2,300	3,333	3,133
Solar PV		136	438	797	601	797	943	1,514	4,042	2,654	4,236	3,066
Geothermal		10	10	10	10	10	10	10	9	9	9	9
Biomass		43	43	54	43	53	58	43	43	43	43	43
Total		4,192	4,393	4,609	4,142	4,609	4,577	5,245	9,194	6,615	9,525	8,813
Electric Capacity	GW											
Coal		221	144	0	0	0	0	144	0	0	0	0
Gas CCGT & steam		354	305	344	327	343	370	382	385	279	375	401
Gas CT		148	116	116	115	116	108	80	89	63	88	79
Gas with CCS		0	0	0	0	0	0	0	0	0	0	11
Nuclear		95	82	84	82	84	84	70	70	71	70	70
Other		63	40	43	43	43	43	40	42	41	42	42
Hydro		84	85	85	85	85	85	79	79	79	79	79
Offshore wind		0	3	30	30	30	30	11	186	113	194	290
Onshore wind		111	138	391	204	392	335	195	750	542	806	743
Solar PV		71	231	400	400	307	490	861	2,145	2,040	1,389	1,550
Biomass		14	14	14	14	14	14	12	12	12	12	12
Storage		25	26	28	26	28	32	100	320	187	348	222
Total		1,186	1,185	1,535	1,326	1,442	1,591	1,973	4,077	3,427	3,403	3,499
Transportation Energy	Quads											
Total		27.2	24.5	23.0	20.8	23.0	23.0	24.9	13.4	10.1	13.4	13.4
From Electricity		0.1	0.2	0.7	0.6	0.7	0.7	0.4	5.6	3.7	5.6	5.6
From Hydogen		0.0	0.0	0.1	0.1	0.1	0.1	0.0	2.6	1.8	2.6	2.6
From Liquid Fuels (total)		26.3	23.1	21.0	19.2	21.0	21.0	23.1	4.1	3.8	4.1	4.1
From Gasoline		16.8	13.9	12.4	11.0	12.4	12.4	12.9	0.5	0.6	0.5	0.5
From Diesel		6.4	5.9	5.7	5.4	5.7	5.7	6.2	0.9	1.0	0.9	0.9
From Jet Fuel		3.0	3.3	3.0	2.8	3.0	3.0	4.0	2.7	2.2	2.7	2.7

Indicator	Units	2020	2030					2050				
			Reference	Zero CO2 2050	Low Energy Demand	50% Biomass	RE Build Limits	Reference	Zero CO2 2050	Low Energy Demand	50% Biomass	RE Build Limits
Carbon Capture Utilization & Sequestration (CCUS)												
CO2 captured	Mt CO2	0	0.0	25.6	18.4	25.6	33.5	0.2	620.3	464.8	677.9	674.8
CO2 utilized	Mt CO2	0	0.0	0.0	0.0	0.0	0.0	0.2	38.7	30.8	38.3	31.0
CO2 sequestered	Mt CO2	0	0.0	25.5	18.4	25.6	33.5	0.0	581.7	434.0	639.6	643.8
Costs												
U.S. GDP	Trillion $	22.2	26.6	26.6	N/A	26.6	26.6	38.4	38.4	N/A	38.4	38.4
Net Energy System Cost (NPV)	Billion $	N/A	N/A	200	N/A	210	200	N/A	1,770	N/A	1,790	1,850
Net Energy System Cost (Annual)	Billion $	N/A	N/A	44.9	N/A	45.4	43.1	N/A	154.9	N/A	166.6	161.4
Net Cost Share of GDP	%	N/A	N/A	0.17%	N/A	0.17%	0.16%	N/A	0.40%	N/A	0.43%	0.42%
Other Indicators												
U.S. Population	Millions	333	358	358	358	358	358	406	406	406	406	406
Interstate Transmission Capacity	GW-kmile	145	148	156	145	156	155	159	310	216	320	290
Per Capita Energy Use	MMBtu/person	199	183	174	159	174	174	174	120	86	120	120
Per Capita Emissions	Mt CO2/person	15.9	13.1	9.4	9.3	9.4	9.4	10.9	0.0	0.0	0.0	0.0
Economic Emissions Intensity	Mt CO2/K$ GDP	0.24	0.18	0.13	N/A	0.13	0.13	0.12	0.00	N/A	(0.00)	0.00
Electric Emission Intensity	lbs CO2/MWh	988	738	229	369	229	238	462	24	30	16	29

Table 3. Key Technology Assumptions for Deep Decarbonization Scenarios

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

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.