Supplementary Information

A Deep Decarbonization Scenario for the United States Economy – a Sector, Sub-Sector, and End-use based approach

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Table SI-1: Data for Figure 2, reference case economy-wide GHG emissions by sector, million metric tons $CO2_e$ per year.

	Transportation	Industrial	Waste	Commercial	Residential	Agriculture	LULUCF	Net Economy-Wide
2020	1,720	1,819	164	822	996	713	(790)	5,444
2021	1,824	1,831	164	864	1,024	718	(790)	5,635
2022	1,868	1,861	164	882	1,040	724	(790)	5,750
2023	1,875	1,862	164	855	994	724	(790)	5,683
2024	1,875	1,860	164	826	949	723	(790)	5,606
2025	1,871	1,872	164	814	924	723	(790)	5,577
2026	1,862	1,896	164	825	935	725	(790)	5,615
2027	1,851	1,897	164	816	926	726	(790)	5,589
2028	1,843	1,904	164	814	924	727	(790)	5,585
2029	1,834	1,912	164	813	923	728	(790)	5,584
2030	1,828	1,916	164	803	915	729	(790)	5,565
2031	1,821	1,923	164	799	911	730	(790)	5,556
2032	1,816	1,925	164	794	907	731	(790)	5,547
2033	1,814	1,930	164	794	907	732	(790)	5,550
2034	1,813	1,939	164	794	907	733	(790)	5,559
2035	1,813	1,941	164	786	899	734	(790)	5,547
2036	1,813	1,948	164	786	900	735	(790)	5,556
2037	1,813	1,954	164	786	900	736	(790)	5,563
2038	1,815	1,959	164	784	899	737	(790)	5,567
2039	1,818	1,967	164	786	901	738	(790)	5,584
2040	1,821	1,974	164	790	905	740	(790)	5,604
2041	1,827	1,981	164	791	906	741	(790)	5,619
2042	1,834	1,994	164	794	909	742	(790)	5,648
2043	1,843	2,008	164	797	912	744	(790)	5,676
2044	1,852	2,017	164	799	914	745	(790)	5,701
2045	1,861	2,023	164	799	912	746	(790)	5,715
2046	1,870	2,032	164	801	913	747	(790)	5,736
2047	1,878	2,041	164	804	914	748	(790)	5,759
2048	1,887	2,052	164	809	919	750	(790)	5,791
2049	1,897	2,064	164	814	923	751	(790)	5,822
2050	1,906	2,077	164	819	926	753	(790)	5,854

Table SI-2: Data for Figure 3, decarbonization scenario economy-wide GHG emissions by sector, million metric tons $CO2_e$ per year.

	Transportation	Industrial	Waste	Commercial	Residential	Agriculture	LULUCF	Net Economy-Wide
2020	1,600	1,839	164	836	1,017	711	(790)	5,376
2021	1,696	1,872	164	902	1,075	702	(797)	5,614
2022	1,740	1,833	164	803	960	686	(804)	5,382
2023	1,746	1,822	164	752	892	670	(811)	5,234
2024	1,747	1,814	164	713	839	653	(817)	5,113
2025	1,739	1,796	164	659	769	636	(824)	4,938
2026	1,723	1,759	164	586	683	617	(831)	4,702
2027	1,703	1,707	164	511	592	598	(838)	4,438
2028	1,679	1,654	152	437	500	578	(844)	4,157
2029	1,642	1,598	133	365	408	558	(851)	3,853
2030	1,597	1,549	104	310	336	539	(858)	3,578
2031	1,543	1,526	78	302	321	524	(860)	3,433
2032	1,471	1,484	78	293	306	509	(845)	3,297
2033	1,378	1,430	78	284	290	493	(837)	3,116
2034	1,261	1,365	79	270	273	476	(844)	2,880
2035	1,148	1,300	80	257	251	460	(852)	2,645
2036	1,034	1,237	81	252	237	445	(854)	2,432
2037	934	1,172	77	247	224	429	(850)	2,233
2038	837	1,110	72	243	212	414	(847)	2,041
2039	749	1,088	66	239	203	398	(871)	1,872
2040	670	1,047	60	236	198	382	(874)	1,720
2041	596	1,009	51	232	193	367	(875)	1,573
2042	528	981	50	230	189	351	(878)	1,452
2043	472	957	50	227	181	335	(885)	1,339
2044	414	930	49	225	174	319	(891)	1,220
2045	358	904	52	221	168	303	(898)	1,108
2046	311	877	50	217	161	286	(906)	998
2047	268	803	52	213	155	267	(870)	889
2048	264	789	52	210	149	252	(885)	831
2049	259	774	51	206	142	237	(897)	773
2050	256	762	51	202	137	222	(905)	725

Table SI-3: Data for Figure 5, GHG reduction contributions from electric power decarbonization, million metric tons $CO2_e$ per year.

	Transportation	Industrial	Commercial	Residential	Agriculture
2020	(0.2)	(14.0)	(21.9)	(25.4)	(1.2)
2021	(0.5)	(29.8)	(48.3)	(55.6)	(2.8)
2022	0.6	37.0	59.1	66.7	3.5
2023	0.8	46.2	73.2	81.6	4.4
2024	0.9	47.6	75.3	83.0	4.5
2025	1.5	71.0	111.8	121.7	6.7
2026	2.8	123.0	192.1	209.7	11.8
2027	4.1	165.9	257.7	281.9	16.0
2028	5.7	212.5	329.4	361.4	20.7
2029	7.4	259.8	401.8	442.1	25.6
2030	8.9	289.9	445.6	492.6	28.7
2031	9.6	289.3	442.7	491.3	28.9
2032	10.4	287.0	439.7	489.5	28.9
2033	11.3	287.3	440.9	492.3	29.3
2034	12.3	288.8	443.0	496.2	29.7
2035	13.2	287.7	442.0	496.4	29.9
2036	14.3	287.3	442.6	498.5	30.1
2037	15.4	286.1	442.2	499.4	30.3
2038	16.5	284.6	440.9	499.1	30.4
2039	17.8	285.1	442.9	502.3	30.7
2040	19.2	285.9	446.6	507.1	31.1
2041	20.6	285.8	447.8	508.7	31.3
2042	22.0	288.0	451.1	512.7	31.7
2043	23.4	289.3	453.7	515.4	32.0
2044	24.9	289.8	456.3	518.2	32.3
2045	26.1	288.1	456.1	517.4	32.4
2046	27.4	287.3	457.6	518.4	32.5
2047	28.8	287.2	460.7	520.8	32.8
2048	30.4	288.6	466.2	525.8	33.2
2049	32.0	290.1	471.8	530.6	33.7
2050	33.5	291.1	476.7	534.5	34.0

Table SI-4: Data for Figure 5, GHG reduction contributions from biofuels-based decarbonization, million metric tons $CO2_e$ per year.

	Transportation	Industrial	Waste	Commercial	Residential	Agriculture	LULUCF
2020	49.4	(3.4)	-	8.1	4.2	3.5	-
2021	56.9	(3.7)	-	10.1	5.3	4.3	-
2022	55.1	(3.4)	-	10.0	5.1	4.2	-
2023	56.9	(3.4)	-	10.4	5.0	4.3	-
2024	58.0	(3.5)	-	10.4	4.7	4.2	-
2025	59.7	(3.7)	-	10.3	4.3	4.1	-
2026	61.4	(4.0)	-	10.3	4.0	4.0	-
2027	63.6	(4.6)	-	10.2	3.8	3.8	-
2028	66.6	(5.4)	6.4	10.0	3.5	3.7	-
2029	71.0	(6.8)	17.3	9.8	3.2	3.5	-
2030	77.8	(9.0)	33.1	9.6	2.9	3.3	-
2031	89.3	(10.0)	47.6	9.4	2.7	3.2	(4.3)
2032	112.5	(4.6)	47.5	10.1	2.6	3.4	(26.5)
2033	153.2	5.1	47.2	11.1	2.7	3.8	(41.0)
2034	216.5	17.2	46.9	15.1	3.3	5.2	(40.6)
2035	272.4	17.7	46.5	15.6	3.1	5.5	(40.1)
2036	320.4	11.9	46.0	16.0	2.8	5.8	(44.7)
2037	352.8	10.5	47.8	16.4	2.5	6.0	(54.9)
2038	382.6	9.9	50.6	17.0	2.3	6.2	(65.4)
2039	407.3	(20.6)	54.0	17.5	2.0	6.4	(47.6)
2040	426.3	(24.3)	57.4	18.0	1.9	6.6	(52.1)
2041	441.5	(24.5)	62.6	18.6	1.9	7.0	(58.0)
2042	453.4	(27.7)	62.7	18.9	1.8	7.3	(61.5)
2043	460.5	(30.4)	62.7	19.2	1.8	7.7	(61.5)
2044	465.4	(31.6)	63.3	19.5	1.7	8.4	(61.9)
2045	467.7	(33.4)	61.6	19.7	1.6	9.6	(61.1)
2046	467.6	(32.2)	62.7	20.1	1.5	11.2	(60.8)
2047	463.9	16.1	61.9	20.3	1.4	14.6	(104.3)
2048	455.3	21.1	61.7	20.5	1.2	19.8	(104.2)
2049	438.5	30.6	62.5	20.9	1.0	29.3	(104.7)
2050	427.2	37.9	62.1	21.1	0.8	36.1	(106.0)

TableSI-5: List of correspondence files used for Decarbonization Model development.

File Name	Sheet name	Description
corr_EF_GREET.xlsx	corr_EF_GREET	Mapping Decarbonization Model's sector, subsector, energy carrier, energy carrier type, end use application, and scope to GREET Pathway
corr_EF_GREET_SUPPLY_CHAIN.csv	-	Similar to corr_EF_GREET, this maps supply chain emissions data
corr_EERE_SCOUT.xlsx	Mapping EIA_to_Scout	Mapping EIA data classifications as per sector, subsector, end use application, energy carrier, energy carrier type to SCOUT's types and to SCOUT based mitigation case names
corr_ghgi_emissions_categories.csv	-	Categorizing EPA GHGI emission types to four primary categories: CO2, N2O, CH4, and fluorinated gases
corr_ghgi_sources_EERE.csv	-	Mapping between EPA GHGI sector, and subsector to Decarbonization Model's sector, subsector and end use application
corr_carbon_content_biofuels.csv	-	Mapping biofuel energy carriers to their carbon content, in units of MMmt CO2 per MMBtu
corr_EIA_EERE.csv	-	Mapping EIA data classifications as per sector, subsector, and end use application to Decarbonization Model conventions
corr_EIA_energy_carrier.csv	-	Mapping EIA data classifications as per energy carrier and energy carrier type to Decarbonization Model conventions
corr_fuel_pool.csv	-	Mapping EIA data classifications as per energy carrier to new category classification, fuel pool, in Decarbonization Model
corr_elec_gen.csv	-	Mapping electric power as sector and electricity as energy carrier type to electricity generation types
corr_vision.csv	-	Mapping VISION model's data classification as per sector, subsector, category end use application, powertrain, energy carrier, energy carrier type to Decarbonization Model's sector, subsector, end use application, energy carrier, and energy carrier type
corr_ghgi.csv	-	Correspondence table tracking EPA GHGI data file name to corresponding EPA GHGI report table number, inventory sector, category, chapter, and description
corr_EF_GREET_EIA.csv	-	Mapping EIA energy carrier and energy carrier type to GREET's fuel and fuel type

Table SI-6: List of Economic Sectors, Economic Subsectors, Mitigation case names and their descriptions.

Mitigation Case	Economic Sector	Economic Sub-sector	Description
Biofuels, Changes in Above C stock	LULUCF	Changes in Aboveground C stock	Change in aboveground carbon based on the type of biofuel in use
Biofuels, Diesel	Agriculture	-	Fractional replacement of conventional fossil fuel-based diesel using biofuels for the various sectors and subsectors
	Commercial	-	
	Industrial	Aluminum Industry	
	Industrial	Bulk Chemical Industry	
	Industrial	Cement and Lime Industry	
	Industrial	Food Industry	
	Industrial	Glass Industry	
	Industrial	Iron and Steel Industry	
	Industrial	Metal Based Durables Industry	
	Industrial	Nonmanufacturing Sector	
	Industrial	Other Manufacturing Industry	
	Industrial	Paper Industry	
	Industrial	Refining Industry	
	Residential	-	
	Transportation	Marine	
	Transportation	Military	
	Transportation	On Road	
	Transportation	Rail	
Biofuels, Gasoline	Agriculture	-	Fractional replacement of conventional fossil fuel-based gasoline using biofuels for the various sectors and subsectors
	Industrial	Nonmanufacturing Sector	
	Transportation	Marine	
	Transportation	On Road	
Biofuels, Reduction in Fugitive Methane Emissions from Landfills	Waste	Landfills	Fractional collection and use of landfills produced methane for methane mitigation
Biofuels, SAF	Transportation	Aviation	Biofuels used as sustainable aviation fuels, replacing fraction of conventional jet fuels
	Transportation	Military	
Biofuels, SOC Change	LULUCF	Cropland Remaining Cropland	Change in belowground soil carbon due to change in production of energy crops, those are converted to biofuels
Bulk Chemical Industry, efficiency improvements	Industrial	Bulk Chemical Industry	Efficiency improvement in existing infrastructures applied annually over time for bulk

			chemical industries
Bulk Chemical Industry, fuel switching for low quality heat to Electricity	Industrial	Bulk Chemical Industry	Fraction of all fuels used for producing low quality heat is converted to electricity use over time for the bulk chemical industry
Bulk Chemical Industry, fuel switching Steam Coal to Natural Gas	Industrial	Bulk Chemical Industry	Fraction of steam coal used in the bulk chemical industry is converted to the use of natural gas
Bulk Chemical Industry, Green Ammonia	Industrial	Bulk Chemical Industry	Fraction of conventional ammonia production is converted to green ammonia production over time
Cement and Lime Industry, cement chemistry	Industrial	Cement and Lime Industry	Improvement in efficiency in the cement production process by improving the production chemistry is implemented by fraction over time
Cement and Lime Industry, efficiency improvements	Industrial	Cement and Lime Industry	Efficiency improvement in conventional cement production methodology, applied as a fraction improvement over time
Cement and Lime Industry, fuel switching Fossil H2 to renewable H2	Industrial	Cement and Lime Industry	Fraction of fossil based H2 used in the cement industry is now replaced with renewable H2 use over time
Cement and Lime Industry, fuel switching Natural Gas to Hydrogen	Industrial	Cement and Lime Industry	Fraction of natural gas used in the cement industry is now replaced with H2 use over time
Cement and Lime Industry, fuel switching Steam Coal to Natural Gas	Industrial	Cement and Lime Industry	Fraction of steam coal used in the cement and lime industry is converted to the use of natural gas
Commercial: Energy efficiency	Commercial	-	Improvement in energy efficiency over time in the commercial sector
Commercial: Energy efficiency of Fuel switching	Commercial	-	Improvement of efficiency in existing technologies over time in the commercial sector
Commercial: Fuel switching	Commercial	-	Improvement in the energy and GHG emissions performance of the commercial sector due to fuel switching mitigation implementation
Food Industry, efficiency improvements	Industrial	Food Industry	Improvement in energy efficiency over time in the food sector
Food Industry, fuel switching Fossil H2 to renewable H2	Industrial	Food Industry	Fraction of natural gas use converted to the use of

			conventional H2 as a fuel switching mitigation measure
Food Industry, fuel switching Natural Gas to Hydrogen	Industrial	Food Industry	Fraction of conventional H2 replaced by green H2
Food Industry, fuel switching Steam Coal to Natural Gas	Industrial	Food Industry	Fraction of steam coal use replaced with natural gas as a fuel switching mitigation measure
Global, fuel switching Fossil H2 to renewable H2	Agriculture	-	Implementing economy-wide fuel switching of converting fraction of conventional H2 to renewable H2 across the different sectors and sub-sectors
	Commercial	-	
	Industrial	Aluminum Industry	
	Industrial	Glass Industry	
	Industrial	Metal Based Durables Industry	
	Industrial	Nonmanufacturing Sector	
	Industrial	Other Manufacturing Industry	
	Residential	-	
	Transportation	On Road	
	Transportation	Other	
Global, fuel switching Natural Gas to Hydrogen	Agriculture	-	Implementing economy wide fuel switching of converting fraction of natural gas use to hydrogen across the different sectors and sub-sectors
	Commercial	-	
	Industrial	Aluminum Industry	
	Industrial	Glass Industry	
	Industrial	Metal Based Durables Industry	
	Industrial	Nonmanufacturing Sector	
	Industrial	Other Manufacturing Industry	
	Residential	-	
	Transportation	Other	
Global, fuel switching Steam Coal to Natural Gas	Agriculture	-	Implement economy wide fuel switching of converting fraction of steam coal to natural gas across the different sectors and sub-sectors
	Industrial	Aluminum Industry	
	Industrial	Glass Industry	
	Industrial	Metal Based Durables Industry	
	Industrial	Nonmanufacturing Sector	
	Industrial	Other Manufacturing Industry	
Industrial, CCS implementation	Industrial	Bulk Chemical Industry	Implementing fraction of CO2 reduction through carbon capture and sequestration for certain sub-sectors of the industrial sector
	Industrial	Cement and Lime Industry	
	Industrial	Refining Industry	
Iron and Steel Industry, efficiency	Industrial	Iron and Steel	Improvement in energy

improvements		Industry	efficiency over time in the iron and steel industry
Iron and Steel Industry, fuel switching Fossil H2 to renewable H2	Industrial	Iron and Steel Industry	Implementing fuel switching of converting fraction of conventional H2 to renewable H2 for the iron and steel industry
Iron and Steel Industry, fuel switching Natural Gas to Hydrogen	Industrial	Iron and Steel Industry	Fraction of natural gas used in the iron and steel industry is now replaced with H2 use
LULUCF: Sustainable Farming	LULUCF	Cropland remaining cropland	Improving carbon sequestration by croplands and forests by sustainable implementing several sustainable farming practices
Manure Management, linear reduction	Agriculture	Manure Management	Linear reduction of N2O emissions in agriculture by improvement manure application techniques and management
NREL Electric Power Decarb	Agriculture	-	Transformation of using conventional electricity generation feedstocks towards renewable and low-carbon alternative feedstocks for the electrical grid, across all economic sectors needing electricity
	Commercial	-	
	Industrial	Aluminum Industry	
	Industrial	Bulk Chemical Industry	
	Industrial	Cement and Lime Industry	
	Industrial	Food Industry	
	Industrial	Glass Industry	
	Industrial	Iron and Steel Industry	
	Industrial	Metal Based Durables Industry	
	Industrial	Nonmanufacturing Sector	
	Industrial	Other Manufacturing Industry	
	Industrial	Paper Industry	
	Industrial	Refining Industry	
	Residential	-	
	Transportation	On Road	
	Transportation	Rail	
On-Farm Mitigation	Agriculture	-	Implementing on-farm mitigation to reduce CO2 emissions
Paper Industry, efficiency improvements	Industrial	Paper Industry	Improvement in energy efficiency over time in the commercial sector
Paper Industry, fuel switching Fossil H2 to renewable H2	Industrial	Paper Industry	Implementing fuel switching of converting fraction of

			conventional H2 to renewable H2 for the paper industry
Paper Industry, fuel switching Natural Gas to Electricity	Industrial	Paper Industry	Fractional change in natural gas use replace with electricity
Paper Industry, fuel switching Natural Gas to Hydrogen	Industrial	Paper Industry	Fraction of natural gas used in the paper industry is now replaced with H2 use
Paper Industry, fuel switching Steam Coal to Electricity	Industrial	Paper Industry	Implement fuel switching of converting fraction of steam coal to natural gas for paper industry
Reduction in Fugitive Methane emissions from Abandoned Wells	Industrial	Abandoned Oil and Gas Wells	Fractional reduction of methane emissions through implementation of mitigation measures at the abandoned wells
Reduction in Fugitive Methane emissions from O&G	Industrial	Natural Gas Systems	Fractional reduction of methane emissions at oil and gas industries
	Industrial	Petroleum Systems	
Refinery Industry, fuel switching Natural Gas to Hydrogen	Industrial	Refining Industry	Fraction of natural gas used in the refinery industry is now replaced with H2 use
Refining Industry, efficiency improvements	Industrial	Refining Industry	Fractional improvement in energy efficiency for the refining industry
Refining Industry, fuel switching Fossil H2 to renewable H2	Industrial	Refining Industry	Implementing fuel switching of converting fraction of conventional H2 to renewable H2 for the refining industry
Residential: Energy efficiency	Residential	-	Improvement in energy efficiency over time in the residential sector
Residential: Energy efficiency of Fuel switching	Residential	-	Improvement of efficiency in existing technologies over time in the residential sector
Residential: Fuel switching	Residential	-	Improvement in the energy and GHG emissions performance of the residential sector due to fuel switching mitigation implementation
Rice Cultivation, linear reduction	Agriculture	Rice Cultivation	Implementing mitigation measures in rice cultivation to obtain linear reduction in carbon emissions through improved water and residue management
Soil N2O emissions, linear reduction	Agriculture	N2O from Agricultural Soil Management	Implementation of mitigation measures to reduce soil N2O emissions from agricultural soil
Transportation, VISION scenarios	Transportation	On Road	Improvement of GHG emissions from the transportation industry

			through implementation of several mitigation measures

Table SI-7: List of input parameters for the Decarbonization Model

Parameter Name	Description	Value
LCIA_Method	Specifying the GWP factor calculation methodology	AR4
lcia_timeframe	Specifying the GWP calculation timeframe	100
EIA_AEO_case_option	EIA AEO data projection case declaration	Reference case
D2E_mtg_2050	Targeted diesel to electricity use ratio	1.0
D2E_relative_eff	Relative efficiency of directly using diesel compared to directly using electricity in machineries	=0.4/0.9
manure_mgmt	Target of reducing GHG emissions from manure management activities	1.0
soil_N2O	Target percentage of reducing N2O emissions from soil based on precision farming activities	1.0
rice_cultv	Target percentage of reducing GHG emissions from rice cultivation through improved water and residue management	1.0
mtg_paper	Target efficiency improvement across all activities of the paper industry	0.32
mtg_food	Target efficiency improvement across all activities of the food industry	0.37
mtg_bulk_chemicals	Target efficiency improvement across all activities of the bulk chemicals industry	0.13
mtg_clinker_new_tech	Target technological improvement across all activities of the cement industry	0.30
mtg_cement_lime	Target efficiency improvement across all activities of the cement and lime industry	0.10
mtg_refinery	Target efficiency improvement of the lime industry	0.13
mtg_ironandsteel	Target efficiency improvement of activities of the iron and steel industry	0.13
mtg_NG_to_H2	Target switching ratio from natural gas use to conventional H2 use	0.3
mtg_NG_to_H2_refineries	Target switching of natural gas use to H2 use in the refineries industry	0.7
mtg_NG_to_H2_ironandsteel	Target switching of natural gas to H2 in the iron and steel industry	0.3
mtg_fossilH2_to_renewableH2	Target switching of fossil H2 to	1.0

	renewable H2	
ammonia_ng_frac_for_heatandpower	Fraction of natural gas used for heat and power, in the ammonia producing industry	0.283

Figure SI-1: A simplified model flow diagram representing the Python model scripts for implementing BAU and reference case calculations. The **main_2.py** script acts as the primary execution script, while supportive scripts are called. The TO_dashboard.py script is stand-alone script that's run to write model output data to the Excel dashboard.