The Clean Energy Future: Technical Appendix

Explanation and documentation of "The Clean Energy Future: Protecting the Climate, Creating Jobs, Saving Money", a report from Synapse Energy Economics, Labor Network for Sustainability, and 350.org

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1. INTRODUCTION

The "Clean Energy Future" report from Synapse Energy Economics and Labor Network for Sustainability presents a series of calculations showing that a clean energy scenario can slash carbon emissions, save money, and create hundreds of thousands of new jobs. This appendix explains and documents the calculations used in the report.

We begin with the reference case or business as usual scenario, then contrast it to the Clean Energy Future case. Emission reductions described in the report are based on the Clean Energy Future case emissions in 2050, compared to actual emissions in 1990. Most of the other calculations and results in the report, including costs and employment impacts, are based on the differences between the Clean Energy Future and Reference cases. In particular, the scenario differences in expenditures are the principal inputs into the analysis of job impacts, which we calculate with the IMPLAN model.

Because Synapse has produced other "clean energy future" studies with similar but not identical assumptions (and perhaps confusingly similar terminology), we conclude by contrasting this study with other related Synapse reports.

2. REFERENCE CASE

The Reference case reflects policies that were in place, visible trends and assumptions that seemed reasonable as of summer 2015, concerning the evolution of the US energy system in the absence of major new initiatives.

Federal policies that were adopted before the Clean Power Plan, such as environmental standards and vehicle fuel economy standards, are assumed to continue. The Clean Power Plan and any later standards are not included. Existing state-level Renewable Portfolio Standards (RPS), expressing state requirements to achieve specified percentages of renewable energy, are assumed to be met on schedule, but no new state regulations are adopted.

Retirements of coal and nuclear plants that were announced by June 2015 occur as scheduled; other existing plants remain available to supply electricity. Nuclear plants that are under construction or proposed are assumed to be built and used. While there is no prohibition on building additional nuclear plants, they are so expensive that they are never selected as part of the optimal plan for energy supply. All nuclear plants are assumed to retire after 60 years of operation, leading to a steep decline in nuclear capacity after 2030.

Future energy demand and price trends are based on the reference case from the federal Energy Information Administration's *Annual Energy Outlook* (AEO). Since the AEO projections end in 2040, their growth rates in the 2030s are extrapolated to apply to the 2040s as well. Consistent with those projections, we assume virtually no new movement toward electric vehicles or electric heating, but ongoing, gradual increases in vehicle fuel efficiency and other energy efficiency.

Costs of electric generating technologies are based on prior Synapse research, and on studies from the National Renewable Energy Laboratory (NREL). The Reference case assumes modest reductions in the price of wind and solar energy, gradually making them somewhat competitive – especially toward the end of the forecast period.

We modeled the electricity system that would be built under these assumptions, using NREL's Renewable Energy Development System (ReEDS) model. ReEDS is a long-term capacity expansion and dispatch model of the continental U.S. electric power system.[1] The model projects capacity, generation, and costs for each resource type for every even-numbered year through 2050. For distributed – mainly residential – photovoltaics (PV), which are not included in the ReEDS model, we used a rate of adoption based on solar power scenarios from NREL.[2]

Subject to these constraints, the ReEDS projection for the Reference case electricity system includes investment in any needed upgrades and pollution controls to keep existing coal and nuclear plants operating, while meeting new demand primarily though not exclusively with new gas plants. Some new investment occurs in renewable energy, both to meet state RPS requirements and because, in the later years of the projection, renewable energy becomes cost-competitive in many parts of the country. Demand reduction programs – offering customers reduced rates for interruptible power, which the utility can turn off at times of peak demand – also play an important part in avoiding new capacity.

In addition to formal modeling of the energy system, we assume that ongoing trends in waste management, which have already reduced emissions by one-third since 1990, will lead to zero carbon emissions by 2050. Carbon emissions from waste management consist almost entirely of methane from landfills. The progress of waste reduction, recycling and composting programs, combined with better management and methane capture at existing landfills, will continue to reduce emissions even further. This meets our criteria for the Reference case, since it is based on visible, existing trends. The assumption of zero emissions from waste by 2050 is common to both of our cases, and hence does not appear in the differences between them. It does, however, play a part in emission reduction from 1990 to 2050.

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[1] For ReEDS model documentation see Short et al. 2010. *Regional Energy Deployment System* (ReEDS). Available at: http://www.nrel.gov/docs/fy12osti/46534.pdf

[2] In the Reference case we assume the price of PV installations drops by 40% from 2010 to 2020, then remains constant. We assume adoption is 80 percent as fast as in the NREL "Sunshot 50" scenario, in which prices drop by 50% from 2010 to 2020.

3. Clean Energy Future case

3.1. Scenario assumptions

Our Clean Energy Future case rests on many of the same assumptions and inputs as the Reference case. The Clean Energy Future case differs in two major respects: it models a more aggressive strategy for emission reduction and renewable energy adoption in ReEDS; and it extends those results to allow 100 percent of gasoline used in light vehicles and 80 percent of fossil fuels used in space heating and water heating to be replaced by renewable electricity.

To model policies aimed at rapid reduction of carbon emissions in ReEDS, we added or changed the following Reference case assumptions:

- Energy efficiency programs expand nationwide to match the performance of the most successful existing state programs.
- A national RPS is adopted, requiring that 70 percent of electricity is generated from renewable sources by 2040.
- The cost of solar PV installations drops by 75% from 2010 to 2020, compared to only 40% in the Reference case, driving more rapid and widespread adoption. Costs of other energy technologies are unchanged from the Reference case.
- Coal plants are scheduled for retirement, beginning with the oldest ones; half the capacity is gone by 2030 and almost all are gone by 2040. The handful of newest coal plants are assumed to operate for 35 years and then close, ensuring that coal is entirely phased out by 2050.
- No new nuclear plants can be built; plants that are planned, but not yet under construction, are assumed to be cancelled. This is the only change from Reference case assumptions about nuclear power, leading to slightly lower nuclear capacity. As in the Reference case, retirement of existing plants after 60 years of operation leads to a steep decline in nuclear capacity after 2030.
- Based on the NREL *Renewable Electricity Futures Study*, we initially assume that electric vehicles will account for 40 percent of the light vehicles (cars and light trucks) on the road in 2050.[3] (See below for revised assumption.) In combination with the other assumptions of the Clean Energy Future case, the expanded use of electric vehicles drives a rapid expansion in renewable generation.

These assumptions alone lead to a significant reduction in carbon emissions and increase in employment, at a net savings to the nation. They do not, however, approach the target of 80 percent

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[3] National Renewable Energy Laboratory (NREL). 2012. Renewable Electricity Futures Study. Hand, M.M., S. Baldwin, E. DeMeo, J.M. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek, D. Sandor eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures

reduction in emissions by 2050. Most scenarios that reach or approach 80 percent emission reduction assume widespread adoption of electric vehicles, and sometimes heating, powered by renewable electricity.[4] Therefore, we modified the ReEDS model results to accommodate additional electrification of vehicles and heating, as follows:

- We scaled up the NREL assumptions about the expanded use of electric vehicles, to reach 100 percent electrification of gasoline-powered light vehicles by 2050.
- We assumed a linear rate of expansion of electrification of gas- and oil-fired space heating and water heating, starting from zero in 2015 and reaching 80 percent electrification in 2050.
- For each year, we calculated the percentage increase in wind and solar power (above the ReEDS model results) that would be needed to meet the additional demand from electric vehicles and heating. We assumed the needed percentage increase in wind and solar power would occur, at the same costs per unit as in the ReEDS model.
- For electric vehicles, we assumed that the total cost to consumers, i.e. vehicle purchases plus fuel, would be unchanged from gasoline vehicles through 2030. After 2030 we assumed a net savings to consumers, starting at 1 percent of fuel savings in 2031, rising linearly to 20 percent in 2050.
- For electric space and water heating, we assumed that the cost to consumers of furnaces and water heaters would be unchanged, so that the fuel savings from electrification flow through directly to consumers.

3.2. Emission reductions

Our study compares the greenhouse gas (GHG) emissions in 2050 under the Clean Energy Future case to actual U.S. emissions for the same sectors in 1990, from EPA's GHG inventory.[5] Those 1990 emissions include 1821 million metric tons (MMT) from electricity, 950 MMT from light-duty vehicles, and 206 MMT from waste management. As explained below, we estimate 314 MMT of carbon emissions in 1990 from residential heating and 135 MMT from commercial heating. Upstream fuel supply activities – coal mining, natural gas production and distribution, oil drilling and refining, and electricity transmission and distribution – together account for 374 MMT of emissions.[6] All activities included in this study emitted an estimated 3,800 MMT.

The derivation of 1990 emissions from residential and commercial fossil fuel heating is shown in Table 1. The GHG Inventory provided emissions from residential and commercial by fuel type. However, it did

[4] For example, a study of options for California concluded that reaching 80 percent emission reduction by 2050 is impossible without widespread electrification of vehicles and other sectors, supplied by renewable energy. J.H. Williams et al. 2012. "The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity", *Science* 335, 53-59.

[5] US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2013. April 15, 2015

[6] Id. Tables ES-2, ES-4 and 2-13. "Light-duty vehicles" includes passenger cars and light-duty trucks.

not isolate fuel emissions by end-use. Data on residential space and water heating by fuel type were provided by the Energy Information Administration (EIA) Residential Energy Consumption Survey.[7] Data on commercial space and water heating by fuel type was provided by the EIA Commercial Building Survey.[8] For both sectors, the share of each fuel type used for heating was applied to the GHG Inventory's estimate of emissions from each fuel.[9] Emissions from electric heating were attributed to the power sector rather than residential and commercial heating.

Table 1: Carbon Emissions from Residential and Commercial Space and Water Heating in 1990 (Million metric tons of CO_2)

Sector and End-Use	Fuel Oil emissions (CO_2 MMT)	Natural Gas emissions (CO_2 MMT)	*Potential emission reductions (CO_2 MMT)*
Residential			
All uses	97	238	
Space and Water Heating only	*92*	*222*	***314***
Commercial			
All uses	63	142	
Space and Water Heating only	*17*	*119*	***135***

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2013 (emissions from all uses); EIA 1990 Residential Energy Consumption Survey (space and water heating fuel usage); EIA 1992 Commercial Building Survey (space and water heating fuel usage)

Clean Energy Future CO_2 emissions from the electric power sector in 2050 match the results of the Synapse EF study, discussed below (297 MMT). Additional electric load to serve electric heating and vehicles all comes from energy efficiency and renewable energy. Therefore, although significant electric load is being added to the system, it results in no additional carbon emissions. Reference case U.S. 2050 CO_2 emissions were based on EIA AEO projections of each sector's emissions by fuel type and end-use. As with other AEO projections used in this study, we extrapolated the AEO 2040 data to 2050 using the average annual growth rate from 2030 to 2040. This provided a baseline with which to reduce 2050 emissions under the clean scenario for heating and light-vehicle transportation. The percentage of 2050

7 EIA, Household Energy Consumption and Expenditures 1990: Tables 31, 32, 39 and 40. Available at: http://www.eia.gov/consumption/residential/data/archive/pdf/DOE%20EIA-0321(90).pdf

8 EIA, 1992 Commercial Building Survey: End-Use Consumption Tables 3 and 5. Available at: http://www.eia.gov/consumption/commercial/data/1992/pdf/eui92.pdf

9 The only exception was commercial fuel oil usage for heating which was not specified in the Commercial Building Survey. As an estimate, we used the EIA's report share of all commercial fuel oil used for heating purposes in 2012 (26%).

adoption of electric heating (80% of 2050 residential oil and gas heating) and electric vehicles (97% of the 2050 light-duty fleet)[10] result in a commensurate reductions in the reference scenario emissions.

Table 2: Carbon Emissions Reductions from Electricity, Transportation, and Heating (Million metric tons of CO2)

Sector	1990 emissions (CO_2 MMT)	Reference Scenario 2050 emissions (CO_2 MMT)	Clean Scenario 2050 emissions (CO_2 MMT)	Clean Scenario % reduction from 1990 emissions	Clean Scenario % reduction from 2050 Ref Scenario
Electricity	1,821	2,212	297	84%	87%
Light-duty transportation	950	737	26	97%	97%
Residential heating	314	212	42	86%	80%
Commercial heating	135	103	21	85%	80%

4. THE TWO CASES COMPARED

4.1. Electricity Sector

The electricity sector modeling in ReEDS builds new capacity in both the Clean Energy Future and Reference cases in order to meet regional reserve margin requirements (i.e. additional capacity above peak load). The Clean Energy Future results in more coal retirements (see Figure 1), fewer new natural gas plants being built (see Figure 2) and much more renewable capacity (see Figure 3 and Figure 4) and efficiency. For this study, we extrapolated the renewable, efficiency and transmission requirements to meet additional load from electric vehicles and electric heating.

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[10] This does not represent 100% of light-duty vehicle emissions because only gasoline emissions are displaced. We assume that light-duty diesel vehicles--and by extension their emissions--still exist in 2050.

Figure 1. Coal generation capacity

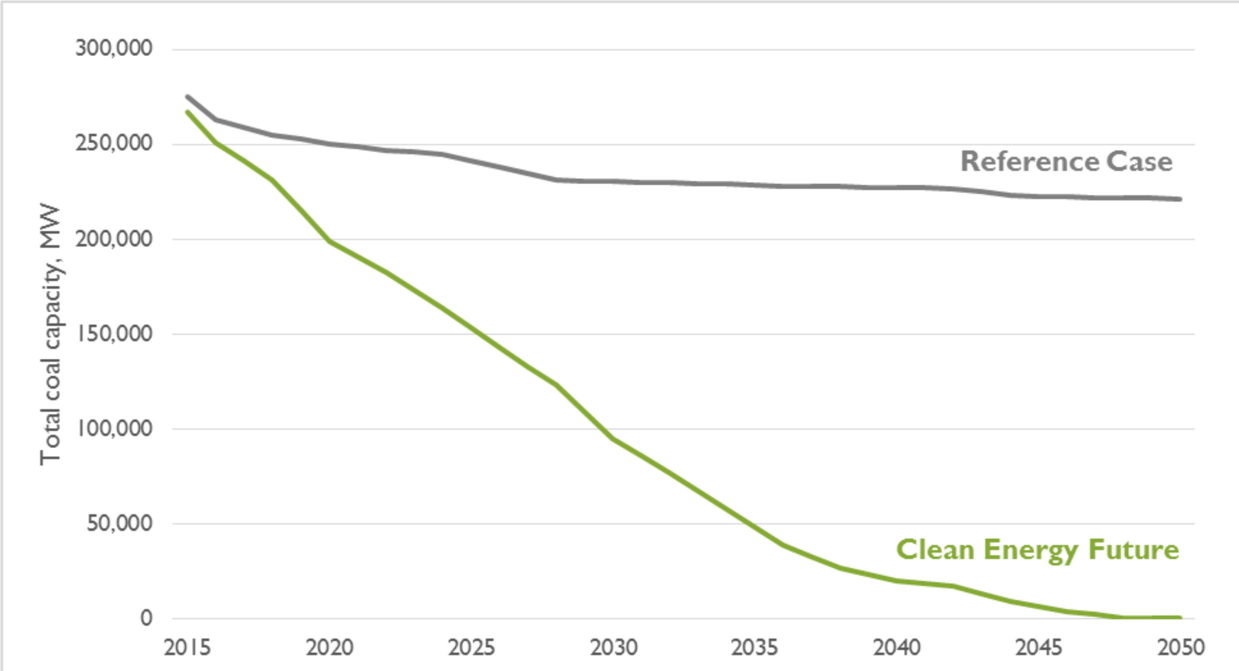

Figure 2. Gas generation capacity

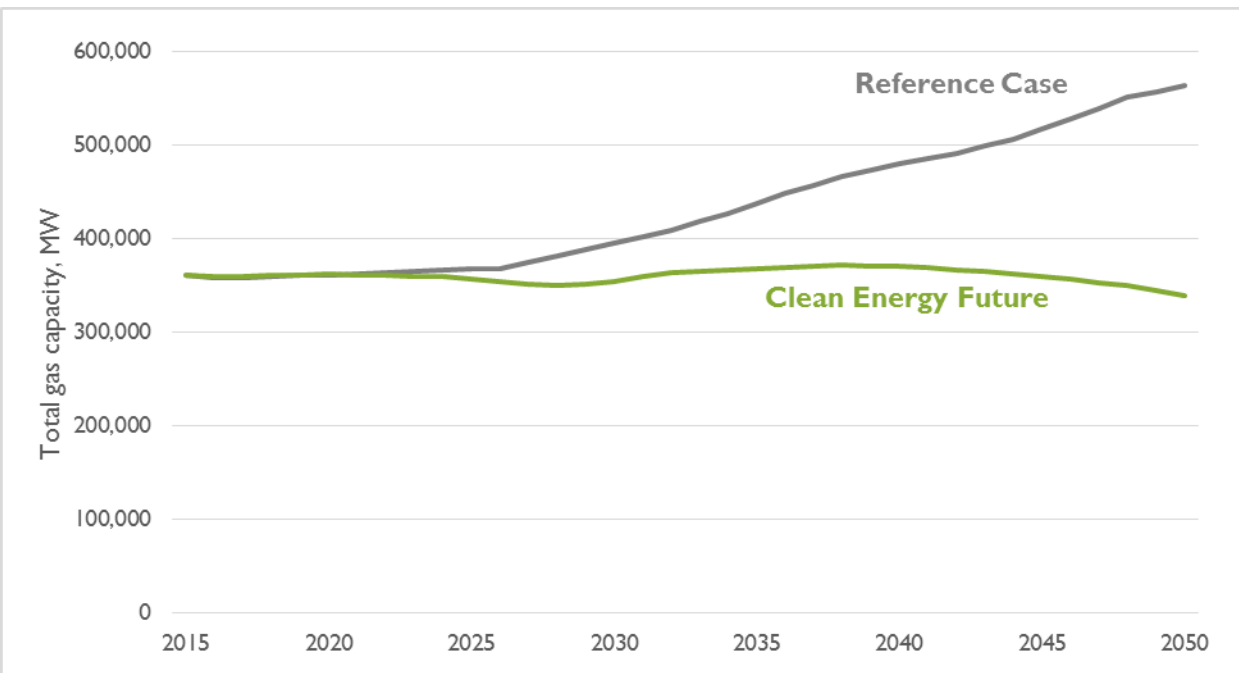

Figure 3. Wind generation capacity

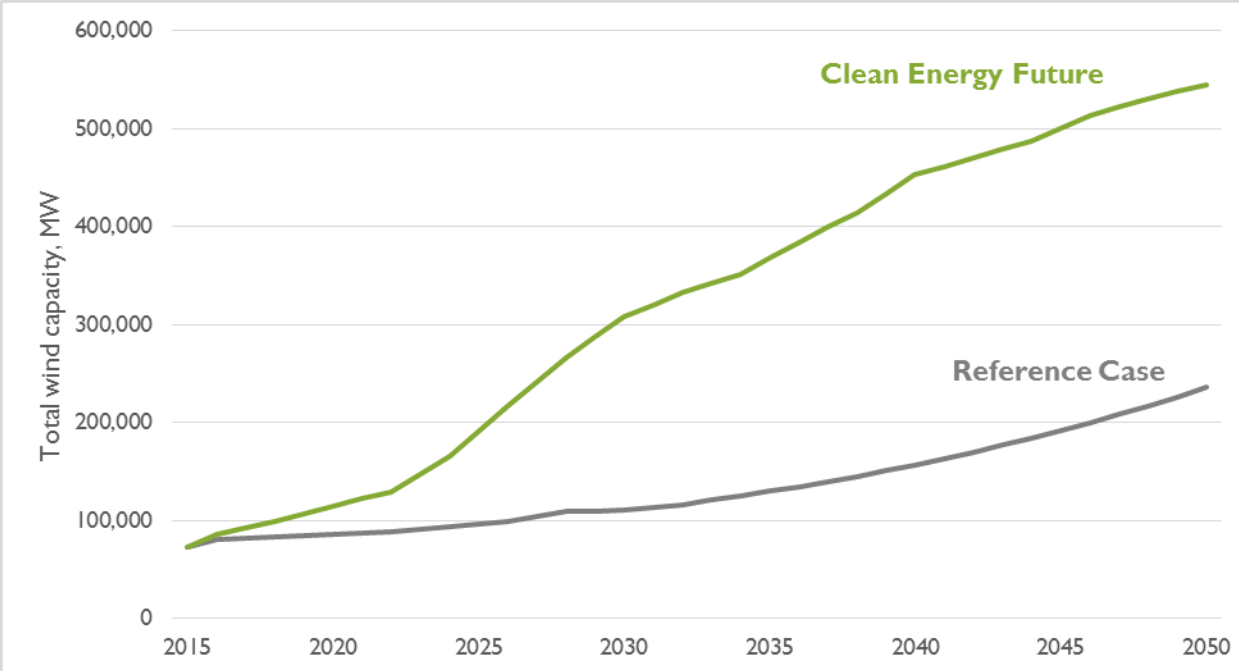

Figure 4. Solar generation capacity

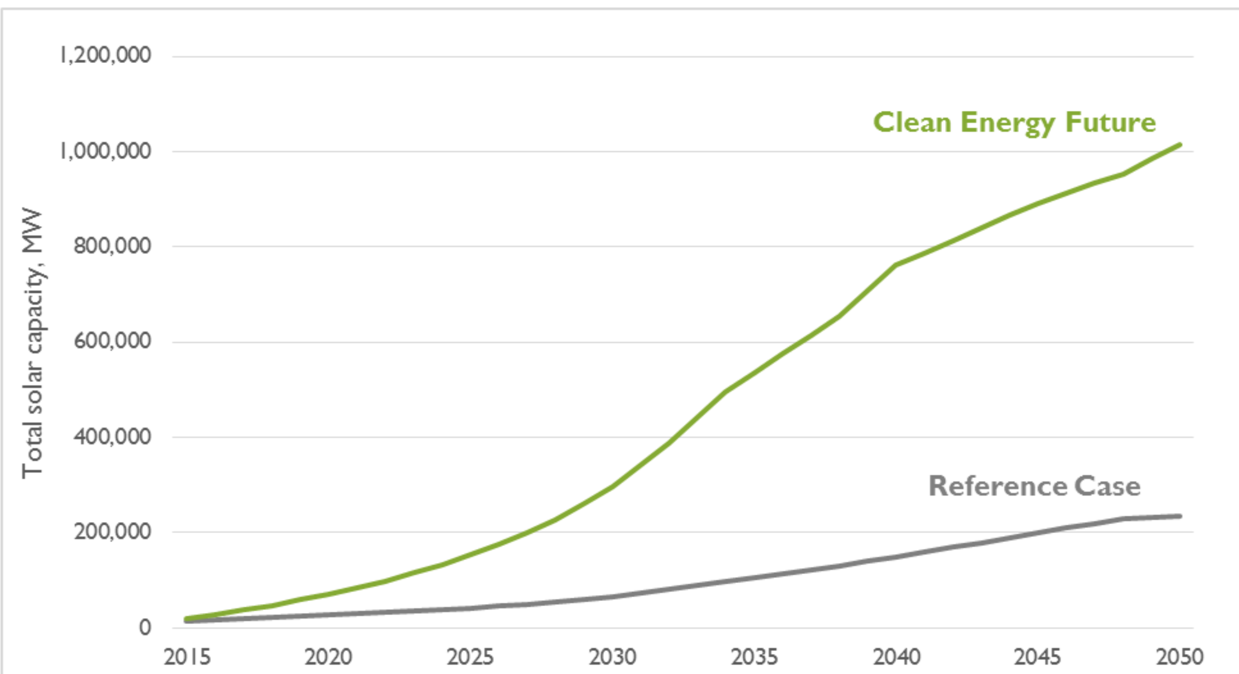

Table 3 below shows the difference in capital costs between the two scenarios (Clean Energy Future costs minus Reference costs). These costs are used in developing economic impacts from construction, as explained in the next section. Even when the avoided cost of constructing new fossil fuel plants is subtracted, the Clean Energy Future requires a net annual average increase of $80 billion in capital spending, above the Reference case. A majority of the new spending ($48 billion per year) is on new energy efficiency which obviates the need for additional generating resources. For new renewable sources, over $18 billion per year is spent on solar photovoltaics (small-scale and utility-scale combined) and nearly the same amount on new wind (including a small amount of off-shore)—in addition to what is spent in the Reference case.

Table 3: Incremental Electricity Sector Capital Costs by Resource ($2013 millions)

Resource type	2016-2020	2021-2030	2031-2040	2041-2050	Annual Average
Battery	$0	$0	$100	$100	$0
Biomass	$2,000	-$2,400	$3,300	$0	$100
Coal	$0	$0	$0	$0	$0
Coal Retrofits	-$18,300	-$21,700	-$140,300	-$73,200	-$7,200
Energy Efficiency	$142,900	$503,300	$532,500	$505,100	$48,100
Geothermal	-$2,200	$11,600	$37,100	$200	$1,300
Hydro	$600	$12,900	$51,100	$19,500	$2,400
Natural Gas CC	-$200	-$14,000	-$15,100	-$61,600	-$2,600
Natural Gas CT	-$200	-$26,300	-$49,800	-$45,400	-$3,500
Nuclear	-$11,900	-$8,600	-$21,500	-$15,800	-$1,700
Off-shore wind	$300	$2,300	$2,700	$6,400	$300
On-shore wind	$11,200	$282,400	$214,500	$105,800	$17,500
Pipeline	-$24,500	-$49,000	-$49,000	-$49,000	-$4,900
Solar CSP	$0	$6,900	$97,000	$177,900	$8,100
Solar PV (small scale)	$43,000	$103,500	$115,300	$53,300	$9,000
Solar PV (utility scale)	-$300	$102,500	$260,000	-$21,600	$9,700
Transmission	$2,400	$23,800	$39,500	$54,100	$3,400
TOTAL	**$144,800**	**$927,200**	**$1,077,400**	**$655,800**	**$80,000**

The electricity sector modeling in ReEDS dispatches resources in both scenarios in order to meet energy requirements for different times of day, throughout the year. Again, the energy required for electric vehicles and electric heating was extrapolated from renewable energy, energy efficiency and transmission. The costs of operating each generating resource are comprised of both variable and fixed costs—that is, costs that fluctuate with the level of output and costs that do not. (These costs are used in developing economic impacts from construction, as explained in the next section.)

Table 4 below shows the difference in operating costs between the two scenarios. Not surprisingly, the Clean Energy Future results in lower operating costs for coal, natural gas, and (to a lesser extent) nuclear resources. This is the result of more retirements of these resources, as lower-cost renewables and efficiency displace the need for energy from traditional resources. Increased operating costs for wind and solar power are small by comparison. Thus the Clean Energy Future results in a net annual average reduction in operating costs of $59 billion per year below the Reference case. Most of this decrease comes from coal generation and retrofit operations ($55 billion per year) and natural gas ($26 billion per year).

Table 4: Incremental Operations and Maintenance Costs by Resource ($2013 millions)

Resource type	2016-2020	2021-2030	2031-2040	2041-2050	Annual Average
Battery	$0	$0	$100	$0	$0
Biomass	$200	-$1,400	$500	$45,700	$1,300
Coal	-$28,900	-$265,100	-$618,900	-$739,900	-$47,200
Coal Retrofits	-$3,700	-$48,800	-$105,000	-$121,500	-$8,000
Energy Efficiency	$0	$0	$0	$0	$0
Geothermal	$300	$5,400	$17,500	$66,400	$2,600
Hydro	$2,300	$9,300	$18,000	$61,200	$2,600
Natural Gas CC	-$12,800	-$110,900	-$282,500	-$478,400	-$25,300
Natural Gas CT	-$300	-$1,300	-$6,500	-$12,100	-$600
Nuclear	-$300	-$4,900	-$20,200	-$42,500	-$1,900
Off-shore wind	$100	$900	$1,500	$3,000	$200
On-shore wind	$4,600	$58,600	$133,500	$165,900	$10,400
Pipeline	$0	$0	$0	$0	$0
Solar CSP	$100	$600	$6,900	$45,300	$1,500
Solar PV (small scale)	$2,300	$17,300	$34,300	$47,100	$2,900
Solar PV (utility scale)	$300	$6,600	$35,600	$50,300	$2,700
Transmission	$0	$0	$0	$0	$0
TOTAL	**-$35,800**	**-$333,700**	**-$785,200**	**-$909,500**	**-$58,800**

4.2. Transportation

Additional electric vehicles add load to the electrical system and displace the emissions and costs of gasoline use—shown in Table 5. The additional electrical load (to meet our projected expansion of electric vehicles above NREL's adoption level) is assumed to be met with renewable energy. Our Reference case projections of gasoline usage come from the Energy Information Administration's (EIA) Annual Energy Outlook 2015 (AEO 2015). These projections account for regulations that have been finalized, such as the corporate average fuel economy (CAFE) standards for model years 2017 through

2025.[11] As shown in the table, this means that the Clean Energy Future does not count savings from the latest fuel economy standards—only *incremental* savings from measures beyond the Reference case, such as electrification.

Table 5: Gasoline Savings in Clean Energy Future[12]

	2020	2030	2040	2050
Average miles per gallon (Reference case)	24	31	36	41
Avoided consumption (million gallons)	5,288	19,847	51,474	88,682
Avoided consumption (% of Reference case)	4%	20%	55%	100%
Price per gallon ($2013)	$2.74	$3.20	$3.90	$4.75
Avoided gasoline spending ($2013 millions)	$14,469	$63,472	$200,679	$421,489

We assume that most of the gasoline savings is not passed on to the consumer. Between 2016 and 2030, we assume that the fuel savings from transportation (= avoided gasoline spending minus additional cost of electricity for charging) is exactly matched by the cost of electric vehicles. In 2031, we assume that 1% of net fuel savings flows to customers, an amount that increases by 1% per year to reach 20% of net savings passing through directly to the consumer in 2050.

4.3. Heating

Similar to our treatment of transportation, for space and water heating we assume substantial movement from burning fossil fuels to using clean electricity. The Clean Energy Future assumes that 80% of residential and commercial heating with natural gas and fuel oil is replaced with electricity by 2050. As shown in Table 6 and Table 7 below, this results in combined savings of nearly $90 billion on fossil fuel heating.

[11] See AEO 2015 Transportation Demand Module: http://www.eia.gov/forecasts/aeo/assumptions/pdf/transportation.pdf

[12] Reference case projections through 2040 are from EIA's AEO 2015. Data from 2041-2050 was extrapolated based on the average annual growth rate from 2031-2040. Available here: http://www.eia.gov/forecasts/aeo/data.cfm. AEO 2015 Tables: *Transportation Sector Energy Use by Fuel Type Within a Mode, Reference case*; *Transportation Sector Key Indicators and Delivered Energy Consumption, Reference case*; *Petroleum and Other Liquids Prices, Reference case*

Table 6: Natural Gas Heating Savings in Clean Energy Future[13]

	2020	2030	2040	2050
Avoided residential NG consumption (tcf)	388	1,164	1,940	2,716
Avoided commercial NG consumption (tcf)	200	600	1,000	1,400
Avoided consumption (% of Reference case)	10%	29%	52%	80%
Avoided natural gas spending ($2013 millions)	$6,590	$21,713	$43,818	$74,278

Table 7: Fuel Oil Heating Savings in Clean Energy Future Scenario[14]

	2020	2030	2040	2050
Avoided residential fuel oil consumption (mil. barrels)	8.8	26.5	44.1	61.8
Avoided commercial fuel oil consumption (mil. barrels)	2.4	7.1	11.8	16.5
Avoided consumption (% of reference scenario)	7%	27%	56%	80%
Avoided fuel oil spending ($2013 millions)	$1,189	$4,233	$8,630	$14,914

As with EVs, the electrical load to provide heating is assumed to be met with additional renewable energy. All of the net fuel savings from heating is assumed to pass through to consumers.

5. EMPLOYMENT CALCULATIONS

In all sectors, we account for both the economic gains and losses that come with investing in clean energy. This study estimates the "net" jobs from the clean energy future, that is: the jobs created by the Clean Energy Future *minus* the jobs created in the Reference case. For the electricity sector, the net jobs depend on the differences in capital and operating costs between scenarios. We account for the increased activity and job creation from new resources in the Clean Energy Future, and also the avoided activity (i.e., decrease in spending and loss of jobs) from resources that exist only in the Reference case. Similarly, heating and transportation sectors generate economic impacts resulting from new electricity service and electric vehicles but also include losses from the fossil fuel industry.

We estimated the net employment impacts from the following activities – that is, increases or decreases in employment in the Clean Energy Future relative to the Reference case:

- Construction of generating resources, transmission and energy efficiency installations

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13 *Id.* AEO 2015 Tables: *Energy Consumption by Sector and Source, United States, Reference case; Residential Sector Key Indicators and Consumption, Reference case; Commercial Sector Key Indicators and Consumption, Reference case; Natural Gas Supply, Disposition, and Prices, Reference case*

14 Id. AEO 2015 Tables: Energy Consumption by Sector and Source, United States, Reference case; Residential Sector Key Indicators and Consumption, Reference case; Commercial Sector Key Indicators and Consumption, Reference case; Petroleum and Other Liquids Prices, Reference case

- Operations of energy resources
- Electric vehicle manufacturing from new electric vehicle demand
- Avoided petroleum refining from reductions in gasoline usage caused by electric vehicles
- Avoided natural gas and petroleum extraction from reductions caused by electric heating

For the electric sector, we developed customized inputs for the IMPLAN model using spending patterns produced for NREL's JEDI model.[15] For each resource, we estimated the portion of the investment spent on materials versus labor based on data provided from the JEDI model. Impacts from electric vehicles, petroleum refining and natural gas and oil extraction were more straightforward since these industries directly correspond to IMPLAN industries.[16] IMPLAN captures the relationships between industries and institutions in order estimate the multiplier impacts from each direct activity. The types of employment impacts are defined as follows:

- **Direct impacts** are comprised of jobs for contractors, construction workers, plant operators and automobile manufacturers. We developed these estimates using the amount of investment, the share of that investment spent on labor for each resource, and industry-specific wages.

- **Indirect impacts** are jobs that support the direct activities. For instance, an investment in a new wind farm not only creates jobs at the wind farm, but also down the supply chain, increasing jobs for turbine and other component manufacturers. We adjusted the IMPLAN model's base resource spending allocation assumptions for the entire electric industry based on NREL data on requirements for each individual resource.

- **Induced Impacts** result from employees in newly created direct and indirect jobs spending their paychecks locally on restaurants, car repairs, and countless other consumer goods and services. Induced impacts also come from customer savings on energy spending, which are spent on the same broad range of goods and services.

Table 8 shows the breakdown of employment impacts by direct, indirect and induced jobs. (The annual employment impacts are presented in Figure 2 of the report.) Importantly, most of the new job activity comes from direct employment in construction and operation of energy resources.

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[15] NREL Jobs and Economic Development Impact (JEDI): http://www.nrel.gov/analysis/jedi/about_jedi.html. Information on IMPLAN is available at http://implan.com/

Table 8: Net Direct, Indirect and Induced Employment Impacts (cumulative job-years)[17]

Impact Type	Total Job-Years	Average Annual Jobs
Direct	10,692,400	305,500
Indirect	1,464,300	41,800
Induced	7,141,200	204,000
TOTAL	**19,298,000**	**551,400**

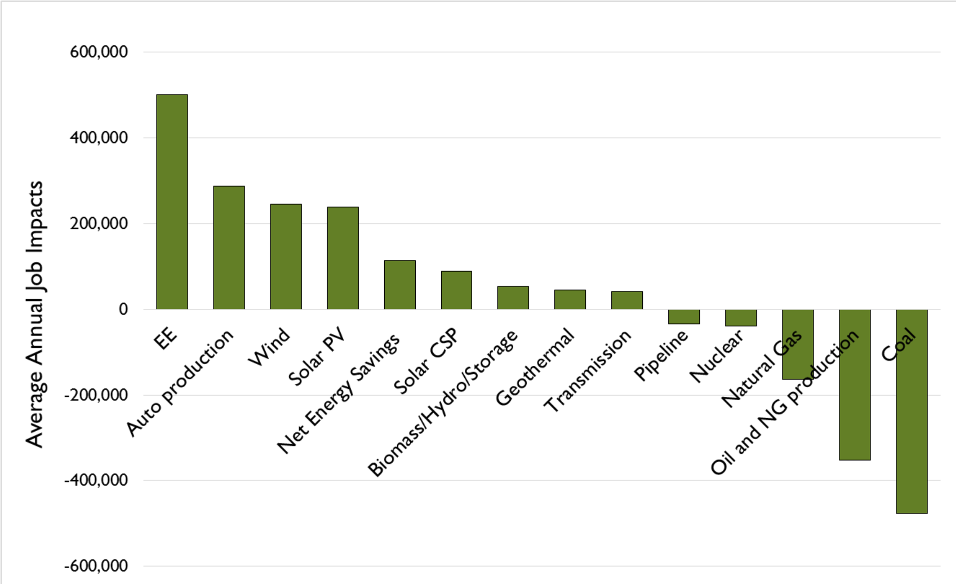
Table 9 shows the breakdown of employment impacts by the source of impact through 2050. The highest amount of job activity comes from energy efficiency (over 500,000 average jobs per year) followed by automobile production, wind and solar. The largest reduction in jobs comes from coal (-476,000 average jobs per year) followed by oil and natural gas production, and natural gas-fired generation. Figure 5 shows the results for average annual job impacts ranked from highest to lowest.

Table 9: Net Job Impacts by Resource (cumulative job-years)

Resource type	2016-2020	2021-2030	2031-2040	2041-2050	Total Job-Years	Average Annual Jobs
Auto production	172,300	1,084,100	2,980,100	5,809,100	10,045,600	287,000
Biomass/Hydro/Storage	67,800	149,000	573,900	1,106,800	1,897,500	54,200
Coal	-549,700	-2,861,600	-6,925,500	-6,334,500	-16,671,300	-476,300
Energy Efficiency	1,790,700	5,751,100	5,428,400	4,569,200	17,539,400	501,100
Geothermal	-23,200	215,800	600,000	771,200	1,563,800	44,700
Net Energy Savings (+)	-785,300	-1,560,200	515,600	5,802,100	3,972,200	113,500
NG	-72,100	-981,900	-1,866,400	-2,792,500	-5,712,900	-163,200
Nuclear	-190,700	-174,600	-465,600	-541,500	-1,372,400	-39,200
Oil and Natural Gas	-198,700	-1,369,600	-3,563,400	-7,202,700	-12,334,400	-352,400
Pipelines	-197,700	-361,800	-321,100	-285,000	-1,165,600	-33,300
Solar CSP	1,400	80,900	1,011,600	2,023,200	3,117,100	89,100
Solar PV	516,100	2,375,800	4,217,100	1,261,100	8,370,100	239,100
Transmission	36,800	330,600	487,200	614,300	1,468,900	42,000
Wind	167,600	3,154,000	3,030,900	2,227,300	8,579,800	245,100
TOTAL	**735,400**	**5,831,500**	**5,702,900**	**7,028,300**	**19,298,000**	**551,400**

[17] All jobs in this report are in terms of full-time equivalents (FTE's). IMPLAN data for each industry was used to translate number of workers into FTE's. We also assumed annual productivity gains across all industries which cause job impacts per dollar spent to decrease over time. The productivity assumption is based on the 1.2% average annual gains over the past 30 years from the Bureau of Labor Statistics (BLS).

Figure 5: Average Annual Net Job Impacts by Resource



Renewable energy and energy efficiency typically create more jobs for the same amount of capacity provided by coal and natural gas generation. This is partly because more of the cost of clean energy is spent on labor rather than on capital and fuel. The electrification of heating and transportation also displaces fossil fuels previously used for those purposes. Thus the clean energy scenario leads to a shift from extractive industries to more labor-intensive industries. Table 10 shows that much of the job creation is in the construction and manufacturing industries while the largest losses come from mining and extraction. (The percentages are also reported in Table 2 of the main report.)

Table 10: Net Job Impacts on Major Sectors (cumulative job-years)

	Construction	Manufacturing	Mining/Extraction	All Sectors
Net job-years (2016-2050)	8,404,424	6,563,119	(3,564,627)	**19,297,974**
% of all net jobs	44%	34%	-18%	

6. Comparison to other Synapse studies

The electricity sector scenarios relied heavily on previous electricity modeling that Synapse performed for the Energy Foundation (EF) that focused on the impact of a clean energy scenario on customers' electricity bills.[18] That study used the Renewable Energy Development System (ReEDS) model designed

[18] Knight, Patrick et al. *Bill Savings in a Clean Energy Future*. July 23, 2015.

by the National Renewable Energy Laboratory (NREL). ReEDS is a long-term capacity expansion and dispatch model of the continental U.S. electric power system.[19] The model projects capacity, generation, and costs for each resource type for every even-numbered year through 2050.

Key differences between this and the EF study include:

- **Extension of analysis past 2040.** The EF report analyzed a clean energy future through 2040. For this study, we have extended the analysis to 2050 in order to match up with many nations' climate goals.

- **Incorporating participant costs for solar PV and energy efficiency.** The most significant change from the EF study was the incorporation of additional electric vehicle and electric heating loads. Synapse's previous study was not intended to address the transformation of transportation and heating. As a result of the transfer of energy between sectors, we also have to capture the full costs to customers, including those paid out-of-pocket by participants for installing solar PV systems and efficiency measures. The previous study for EF was intended only to address costs that would appear on customers' electricity bill (i.e. utility system costs).

- **Investments in natural gas pipeline were developed for both the Clean Energy Future and Reference cases**. In this study, we assumed that pipelines would be needed for natural gas distribution in the clean scenario due to local gas constraints. We used the same methodology as the EF reference scenario to develop pipeline investment assumptions for the clean energy scenario.

- **More electric vehicle adoption**. For this study the Clean Energy Future assumes that 100% of light-duty, gasoline powered vehicles are replaced with electric vehicles (EVs) by 2050. For the EF study the level of EV adoption was from an NREL study which projected that EVs would be 40% of light-duty vehicle stock by 2050.[20]

- **Additional renewable energy and energy efficiency to serve new load from EVs and heating.** We scaled up the buildout and costs for renewables and efficiency to meet this additional load while maintaining the same share of each resource's contribution to total renewable generation. We also assumed that transmission investments were increased to accommodate the integration of more renewables.

Available at: http://synapse-energy.com/sites/default/files/Bill-Savings-in-a-Clean-Energy-Future.pdf

[19] *Id*, p.12. ReEDS model documentation: Short et al. 2010. *Regional Energy Deployment System* (ReEDS). Available at: http://www.nrel.gov/docs/fy12osti/46534.pdf

[20] National Renewable Energy Laboratory (NREL). 2012. Renewable Electricity Futures Study. Hand, M.M., S. Baldwin, E. DeMeo, J.M. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek, D. Sandor eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures