Cost of Electrification:
A State-by-State Analysis and Results

Thomas Tanton

President, T² and Associates

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Contents

Executive Summary

The purpose of this analysis is to report the capital cost associated with "electrification" for states and the nation. For the context of this report, electrification is converting the entire economy to use electricity as a fuel. This includes all appliances in residential and commercial buildings, as well as every transport vehicle. Electrifying the entire nation, with a goal of eliminating the direct consumption of fuel would cost between *$18 trillion and $29 trillion* in first costs. In addition, constructing and implementing an "all-electric" nation will require consideration of two other significant costs: stranded assets[1] and deadweight losses[2]. The cost per ton of reduced carbon emissions was also determined through this analysis. In no instance are the costs of universal electrification less than the benefits as "estimated" by the social cost of carbon. *Electrification is not a cost-effective means of reducing carbon emissions from commercial or residential buildings nor from transportation. There are more efficient and less costly means to reduce atmospheric carbon, including a range of carbon capture approaches.*

Two scenarios were assumed to calculate the cost estimates:

1. 100% of the existing and new demand for electricity is met with renewables plus storage.
2. Traditional dispatchable generation technologies are used.

To ensure no bias is inadvertently input into the analysis, data come from the Energy Information Administration (EIA). This includes the consumption by state per fuel type, as well as technology costs. It should be noted that in the scenarios, costs are calculated to electrify the transportation sector and residential and commercial buildings. Also calculated are estimates to satisfy peak loads that may occur in a weather event or other emergency. In the recent past, during a hurricane or a polar vortex, natural gas was the fuel used to meet higher demand levels.

It should be noted, great care was taken to calculate costs due to comprehensive electrification, meaning calculations include moving to 100% renewable electricity for anticipated load, not just existing load. Non-energy elements that have been a part of other proposals were not included in this analysis. The assumptions in this study can be justified. However, if different capital costs may be warranted, the workbook used in the calculations is available and the default capital cost for each technology can be modified by the user. Similarly if there is disagreement with the energy or demand for a sector or state, those values can also be changed. This capability is to hopefully allow policy makers and any public opportunity to see impacts of increased energy conservation due to proposed policies or more demand due to emergencies.

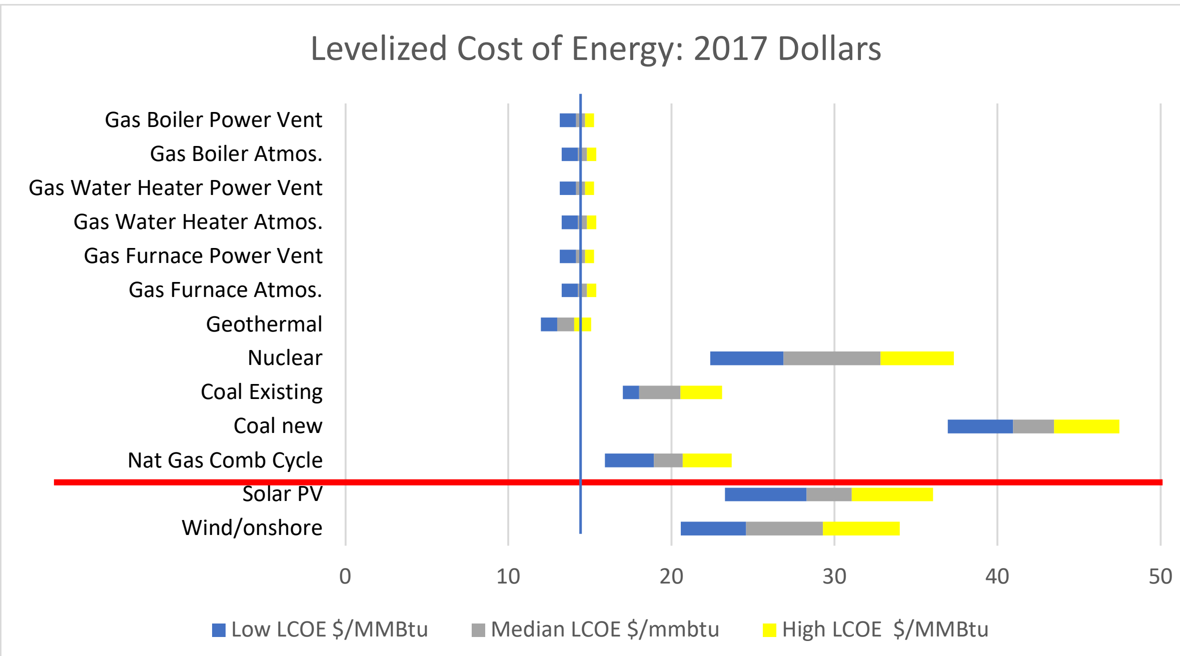
[1]Stranded assets are defined as the components of the natural gas system that are discarded before their useful life is over.

[2] Deadweight losses are losses that occur when a beneficial good or service is not fully realized because of artificial scarcity, a tax or subsidy, or other government action. They are costs imposed when one party transfers to another party something the second party doesn't value or views as a negative. One example is the intermittency of wind and solar, if the second party values on-demand energy.

Background

This analysis is a continuation of, “Levelized Cost of Energy: Expanding the Menu to Include Direct Use of Natural Gas,”[3] which compared the expense to use natural gas directly versus electricity, in a levelized form, referred to as the levelized cost of energy (LCOE). The cost of capacity and, importantly, the price of carbon emissions’ reductions were included in that initial analysis.

The previous effort found that natural gas has levelized costs significantly less than any electricity option, and often by a factor of two. See figure below. Options above the red line are commonly dispatchable. As seen by the median levelized cost, represented by the vertical blue line, natural gas direct use is less costly than electric options.



The following pages build off the 2017 work and present an overview of the updated results. Also, in Appendix B is an introduction on a simple-to-use calculator if policy makers or the public want to analyze further or modify the default values for technology cost, load values, population, or other factors given in the tool.

The US currently derives about 35% of its electricity from natural gas but have also nearly doubled their use of renewable fuels in the past decade, from 9% to 17%, according to the EIA. This growth however doesn’t account for the electricity generated from non-renewable sources during periods of peak electrical demand. Whether it is peak load or normal operating times, policy makers must understand how the variables in utility operation impact the fuel availability and cost. This analysis and the calculator aim to do just that.

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[3] https://higherlogicdownload.s3.amazonaws.com/APGA/1151c1f6-49e1-4598-badd-127e33da42cd/UploadedFiles/KyQ7jphQTGK6IWtFOD95_2017--Levelized-Cost-of-Energy-Study.pdf

As well, residential and commercial buildings account for about 12% of U.S. greenhouse gas (GHG) emissions, according to the Environmental Protection Agency (EPA)[4]. The following discussion will help frame the cost of CO_2 avoided, as the 8.45 trillion cubic feet direct natural gas consumption[5] in 2018 was more efficient and produced less GHG emissions, given the inefficiency of conversion of fuels into electricity.

Derivation of Cost Estimates

Each end use sector is described separately, but the following assumptions are applied in all:

1. Universal electrification is assumed implemented overnight in 2020. This simplifies calculations, avoiding forecasting future interest rates (charged during construction) and relative price escalation that occurs from now into the future.

2. Learning and mass production impacts on future costs of renewables, EVs, batteries, and efficiency technologies are subsumed within capital costs. These estimates are based on recent published data, some of which is from the Department of Energy (DOE).

Cost of Converting Electricity Grid To 100% Renewables

Electrical service is provided to Americans by a variety of public and private utilities and marketers. Nationally about 5% of all electricity currently comes from renewable sources. Other supply comes from natural gas (31%), nuclear (10%), large hydroelectric (4%), coal (18%), and other/unspecified sources of power (7%). Nationwide there are approximately 1 million megawatts (MW) of installed capacity representing over 21,000 generation units.[6] To move from the current resource mix to 100% renewable generation will require replacing 70% of the "fleet," and most likely, a significant amount of new transmission lines to reach distant locales. For context, approximately 30% of this electricity generated is used in residential applications, and 70% in commercial and industrial. The typical residential customer uses about 500 kilowatt-hours (kWh) per month.

In this analysis, the estimated total installed cost (overnight) is approximately **<u>$2.8 trillion</u>**, which accounts for converting the nation's electricity supply to 100% renewable, just to meet existing loads. The demand needed for electric vehicle charging, as well as electrifying buildings is not included in that value.

Cost to Convert to Electric Vehicles (EVs)

In 2018, about 143 billion gallons of gasoline were consumed in the United States, an average of about 391.40 million gallons per day[7]. In addition, approximately 61 billion gallons of diesel were consumed.[8] There are approximately 272 million motor vehicles in the US, and approximately 112 million of these

[4] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
[5] https://www.eia.gov/tools/faqs/faq.php?id=50&t=8
[6] https://www.eia.gov/electricity/annual/html/epa_04_03.html
[7] https://www.eia.gov/tools/faqs/faq.php?id=23&t=10
[8] Ibid.

are automobiles.[9] Various tax credits at the state and Federal level are available to buyers of electric vehicles (EVs). At the Federal level the tax credit varies between $2500 and $7500. For this analysis, the midpoint of the tax credit ($5,000) was used.

Taking all this into account, the transition to electric vehicles would be anywhere from **$560 billion to $1.4 trillion**. The additional consumer side costs of electric vehicles, such as replacing batteries, was not estimated.

Cost to Eliminate Natural Gas Use in Buildings

Natural gas is the fuel of choice of home and commercial building owners for a variety of reasons. Water heating, space heating, and cooking are a few preferred applications. In 2018, US residential consumers used an estimated 4,973,983 million cubic feet (mcf) of natural gas, and commercial buildings an additional 3,476,281 mcf, or 8,450,264 mcf total.[10]

The household level investment needed to replace natural gas use with electricity is **$1.6 trillion**. In the commercial sector, those buildings consumed 6,830 trillion Btu in 2012,[11] in 90 billion square feet.[12] Completing the deep energy retrofits (DER) on every existing commercial building that would be necessitated to meet environmental targets would cost about **$9 trillion**.

Costs to Convert Other Transportation

Off-Road Vehicles

For this report, off-road vehicles include construction and agriculture, as well as recreational vehicles, tractors, materials handling, loaders, railroad, and airport tow vehicles. Data regarding fuel, mostly diesel, consumption was obtained from EIA[13]. It does not include maritime nor aviation, both of which are dealt with separately below. For off-road vehicles, 11.3 billion gallons were used in 2017. This works out to **$415 billion** in first costs to provide just this amount of energy in the form of electricity, instead of fuel. This cost does not include the cost to convert vehicles from fuel to battery power.

Aviation

Aviation was also briefly analyzed. This sector uses different fuels (Jet fuel A-1, Jet B, Aviation gasoline, and Biokerosene) than construction and farm equipment. U.S. consumption of aviation fuels was 17.7 billion gallons in 2016[14]. To provide just this amount of energy in the form of electricity, instead of fuel, would initially cost about **$550 billion**. This estimate was made using the same basic approach as for automobiles' infrastructure requirements. It does not include any cost to convert airplanes themselves to use electricity, which would entail installing batteries and electric motors and removing jet or reciprocating engines.

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[9] https://www.fhwa.dot.gov/policyinformation/statistics/2017/mv1.cfm
[10] Daniel S. Bertoldi, "Deep Energy Retrofits Using the Integrative Design Process: Are they Worth the Cost," Master's Projects and Capstones, University of San Francisco, spring 2014, https://repository.usfca.edu/capstone/22.
[11] https://www.eia.gov/consumption/commercial/index.php accessed 8/21/2019
[12] Ibid.
[13] *http://www.eia.gov/dnav/pet/pet_cons_821dst_dcu_nus_a.htm*
[14] https://www.eia.gov/todayinenergy/detail.php?id=31512

Maritime

Maritime fuel use in cargo transport includes very low-grade petroleum, called “bunker fuel.” A global shift to diesel (distillate) is underway due to the United Nations’ (UN) International Maritime Organization (IMO) direction to significantly decrease sulfur emissions by 2020. That shift would not matter for this analysis, as liquified natural gas or liquid petroleum fuels won’t impact calculating the amount of electrical energy needed to move cargo and people. While it is unclear if shipping will ever change over to electric drive, there is a recent increase in ships are using electricity when in port resupplying. They shut off their own engines, no longer needing to use fuels.

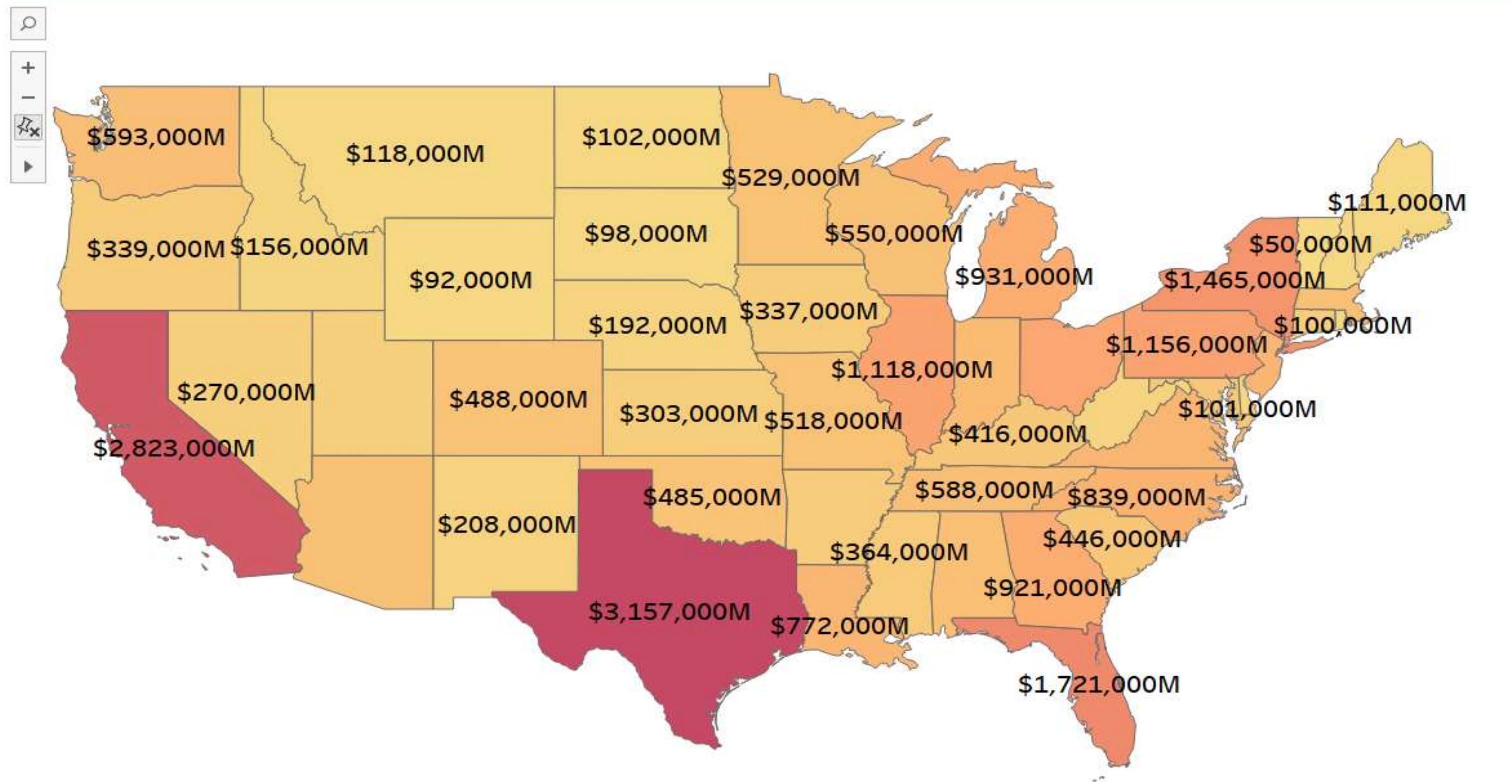
According to the Energy Information Administration[15] in 2017 there were 2,579,465,000 gallons of bunker fuel and 2,185,638,000 of diesel (distillate) sold in the U.S. Using this data, an infrastructure cost (generation capacity, storage, and transmission) of just under **$200 billion** is calculated. This figure does not include vessel engine change over.

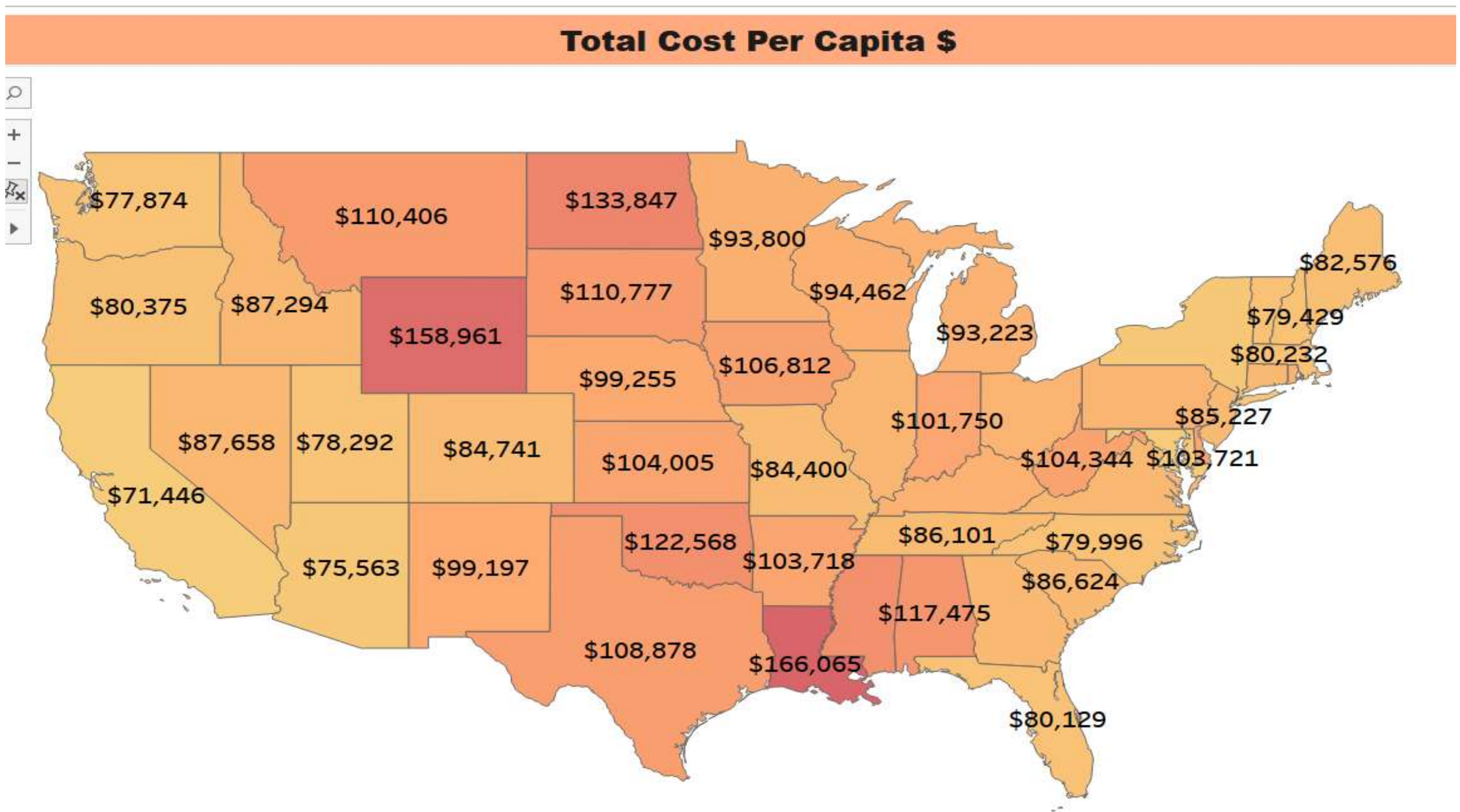
The sum of first cost for these three off-road customer types is approximately **$1.2 trillion.**

The next figure summaries the costs per state to electrify the economy. And the following figure shows the same but on a per capita basis

[15] https://www.eia.gov/dnav/pet/pet_cons_821rsd_a_EPPR_VVB_Mgal_a.htm

Total Cost to Electrify: Million Dollars



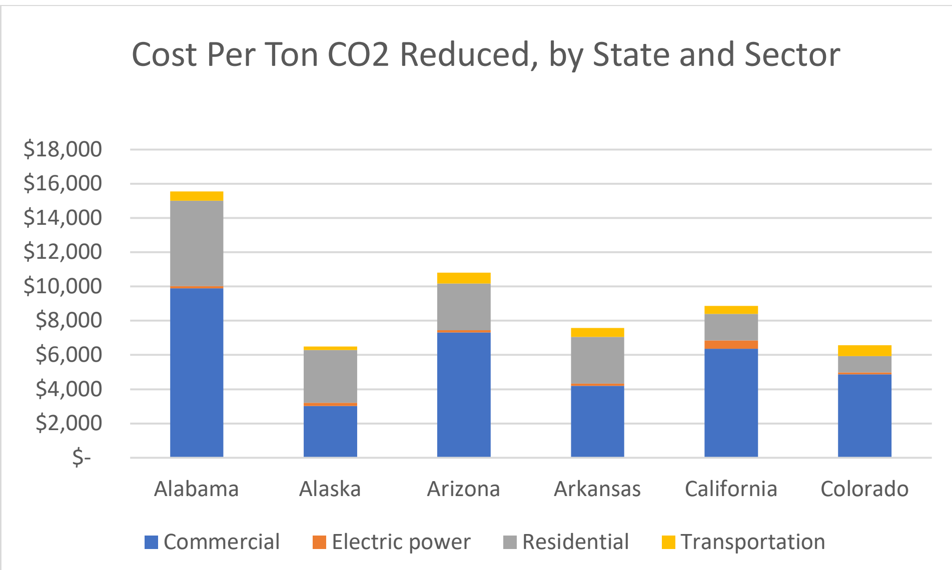

Total Cost Per Capita $
$77,874
$110,406
$133,847
$93,800
$82,576
$80,375
$87,294
$158,961
$110,777
$94,462
$79,429
$93,223
$80,232
$106,812
$99,255
$101,750
$85,227
$87,658
$78,292
$84,741
$104,005
$84,400
$104,344
$103,721
$71,446
$122,568
$86,101
$79,996
$103,718
$75,563
$99,197
$86,624
$117,475
$108,878
$166,065
$80,129

Cost per Avoided Ton of Emission

Figure 1 shows the wide disparity of costs per ton of reduced carbon within six (alphabetically selected) states by end use sector. For these states, **the cost per ton varies** from $116/ton (Colorado electric power) to nearly $10,000/ton (Alabama commercial buildings). Considering all states as shown in Appendix A, the range is even wider at $12/ton (Georgia electric power) to over $17,000/ton (Florida residential buildings). Commercial and residential buildings are most often the more costly to convert.

The cost per ton is calculated by dividing the annualized sectoral cost by state[16], by the emissions reported by EIA.[17]

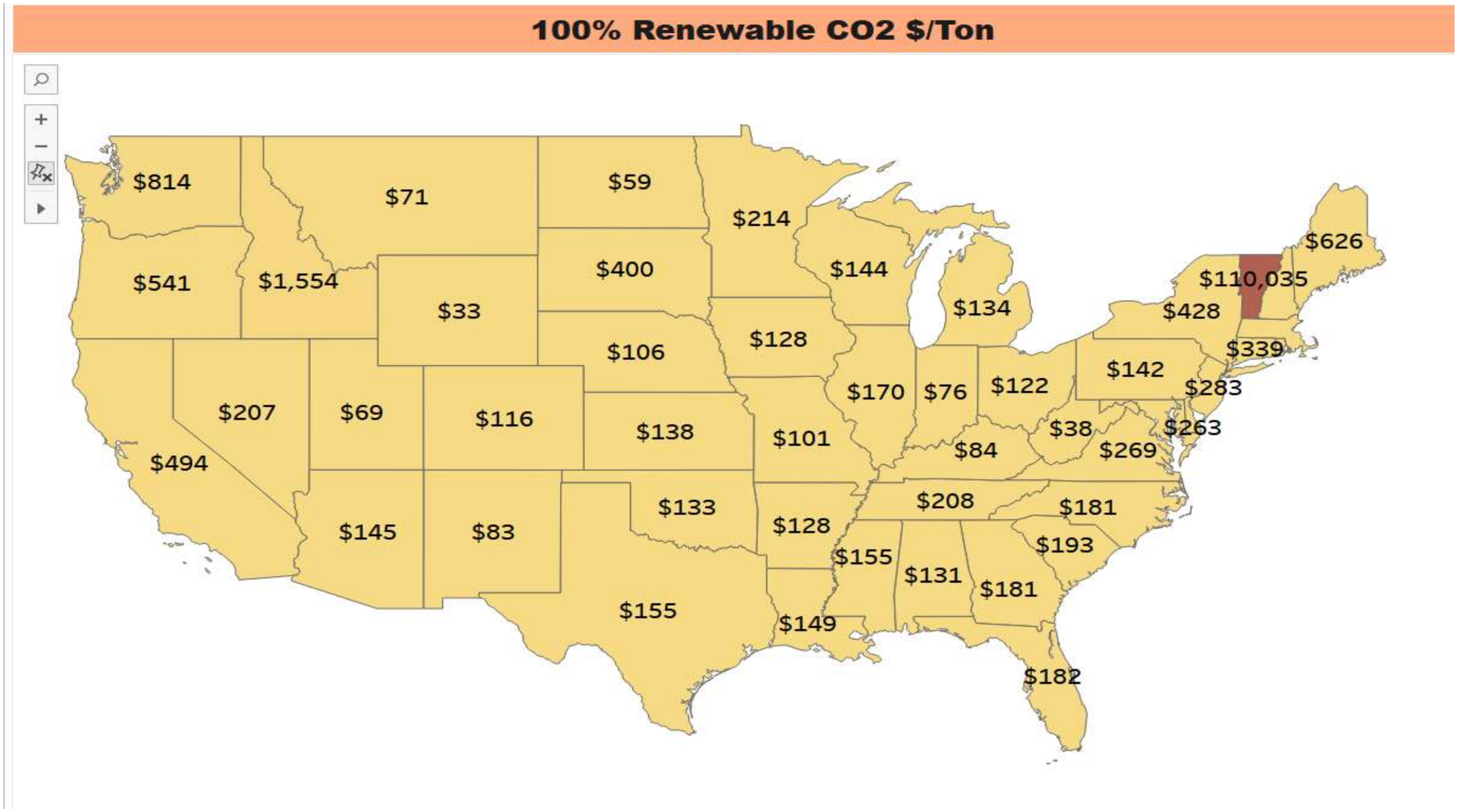
Figure 1



The maps on the following pages illustrates the cost per ton reduced by end use.

[16] The capital costs were converted to estimated annual costs by multiplying by an industry-standard fixed cost rate of 10 percent, which takes into account the cost of capital, time value of money, the depreciation of equipment, operations and maintenance, insurance and administrative costs.

[17] U.S. Energy Information Administration, State Energy Data System.


100% Renewable CO2 $/Ton
$814
$71
$59
$214
$541
$1,554
$400
$144
$626
$110,035
$33
$134
$428
$128
$106
$339
$142
$170
$76
$122
$283
$207
$69
$116
$138
$101
$38
$263
$494
$84
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$133
$181
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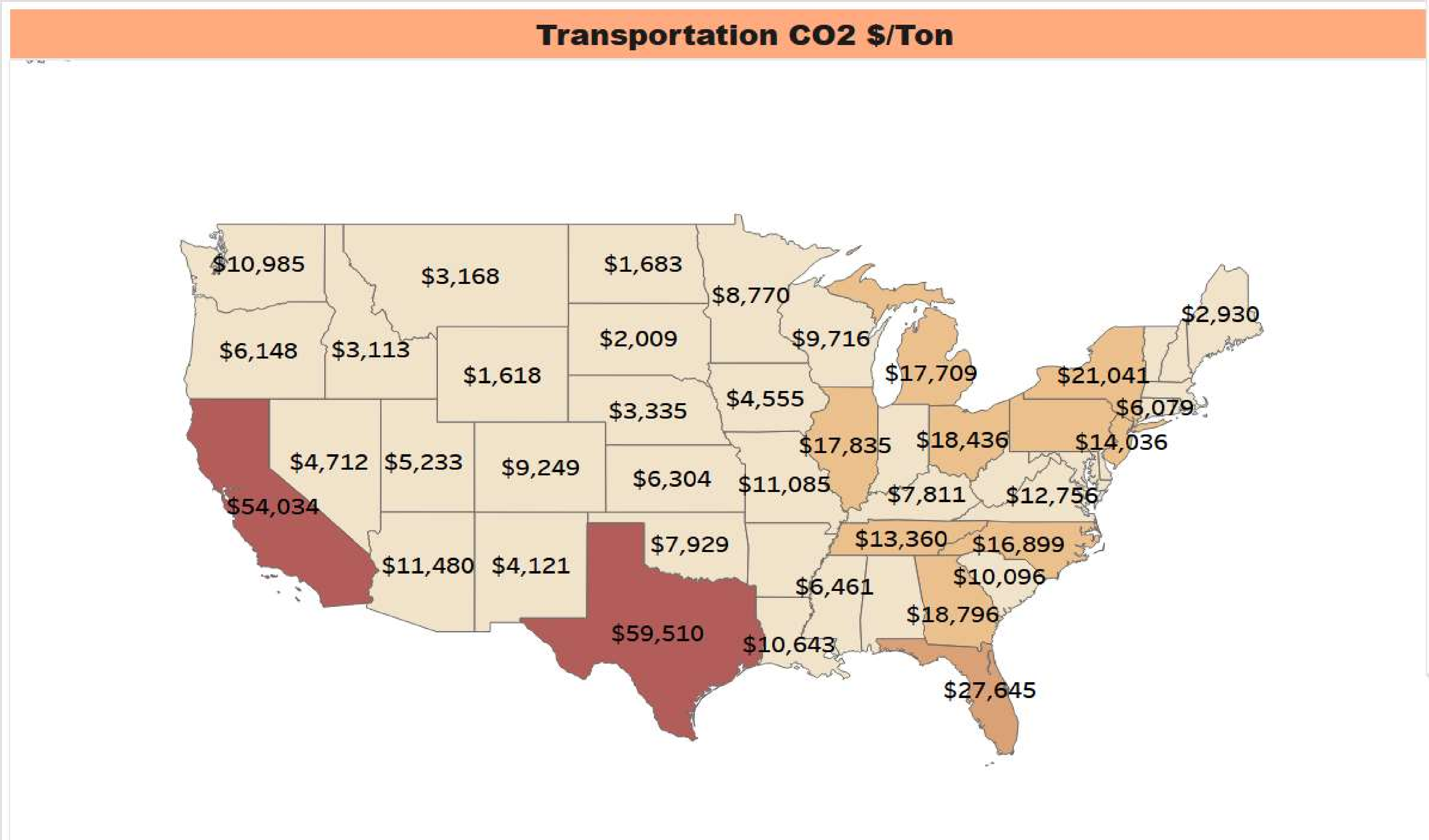
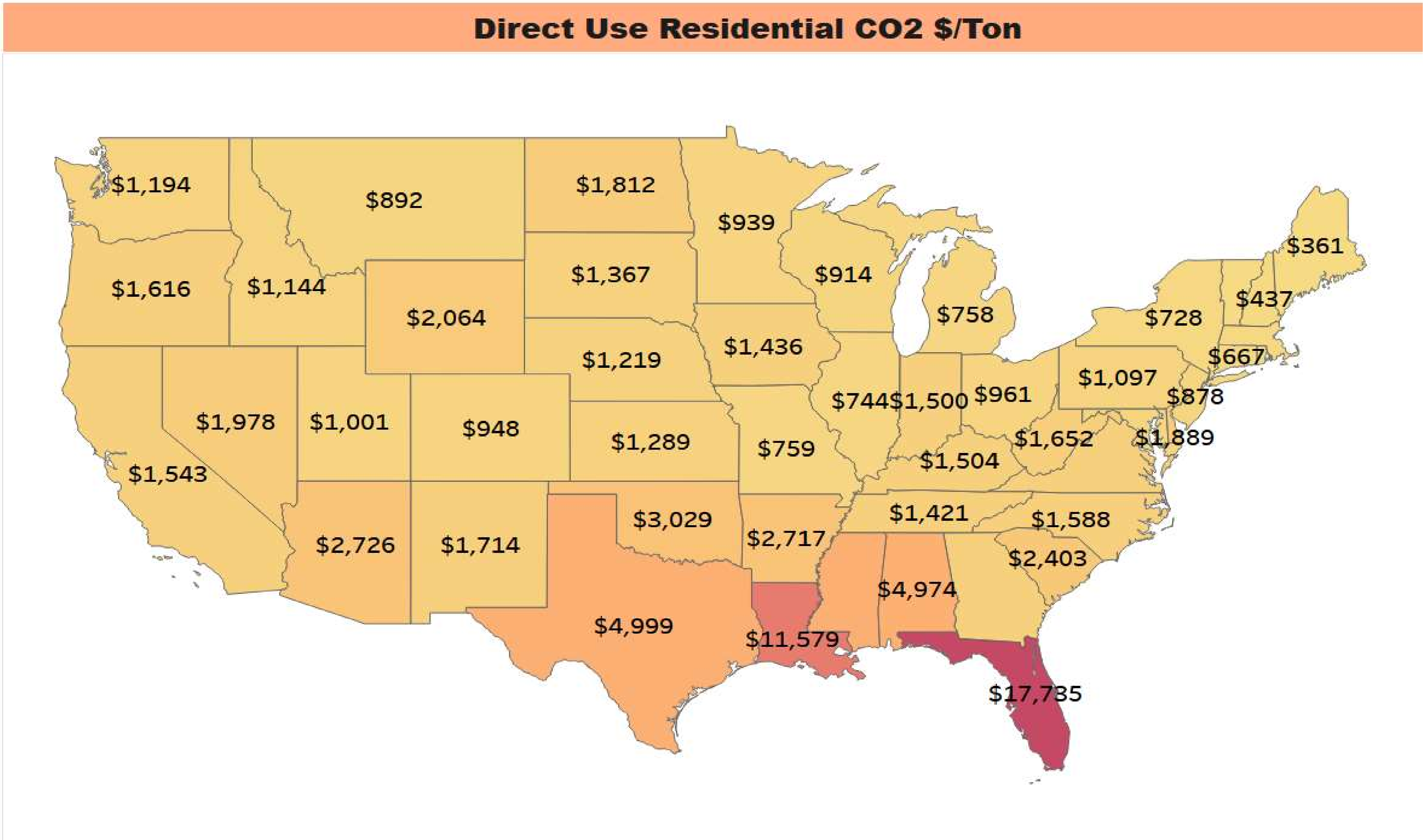
$145
$83
$193
$155
$131
$181
$155
$149
$182


Transportation CO2 $/Ton
$10,985
$3,168
$1,683
$8,770
$2,930
$6,148
$3,113
$2,009
$9,716
$1,618
$17,709
$21,041
$3,335
$4,555
$6,079
$17,835
$18,436
$14,036
$4,712
$5,233
$9,249
$6,304
$11,085
$7,811
$12,756
$54,034
$13,360
$16,899
$7,929
$11,480
$4,121
$6,461
$10,096
$18,796
$59,510
$10,643
$27,645


Direct Use Residential CO2 $/Ton
$1,194
$892
$1,812
$939
$1,367
$1,616
$1,144
$914
$2,064
$758
$361
$437
$728
$1,436
$1,219
$667
$1,097
$744
$1,500
$961
$878
$1,978
$1,001
$948
$1,289
$759
$1,652
$1,889
$1,543
$1,504
$3,029
$1,421
$1,588
$2,726
$1,714
$2,717
$2,403
$4,974
$4,999
$11,579
$17,735

Comparing The Cost Per Ton Avoided with The Social Cost of Carbon

To put these costs into context, a quick discussion of the governments' use of the social cost of carbon (SCC) follows. The US EPA has provided a guide to planners for assessing the benefit/cost ratio of specific plans to reduce such emissions. The current guidance is that the reduction of each ton of CO2 emissions should be valued at between $11 and $212, depending on year, discount rate, and how sensitive the climate actually is to carbon emissions.[18]. It is common practice to use $40/ton[19].

The SCC reflects the theoretical damages from climate change that are avoided by reducing, by one ton, emissions of carbon dioxide. Estimates of the social cost of carbon, according to Office of Management and Budget[20], should only include domestic costs, although some analysts use global SCC. When limited to domestic costs (avoided damages) the SCC is smaller and close to $11.

Using $11/ton (or even the higher $40/ton) and Inspecting Table A2 in the Appendix A, we note that only in very limited cases are the benefits (as measured by SCC) larger than the costs: electrification is generally not cost effective as a carbon control mechanism. It also raises an important, but infrequently asked, question: are there cheaper ways to reduce carbon emissions? One such approach that may be less costly is carbon capture and sequestration (aka CCS) where carbon dioxide is stripped out of industrial and power plant exhaust streams and separately disposed of, in some 'permanent' repository. This would reduce atmospheric carbon by reducing the emissions of carbon dioxide.

There are a number of physical and chemical approaches to CCS, and naturally each impose costs and energy penalties. Their effectiveness depends on the concentration of CO_2 in the gas stream, and the impacts on costs and efficiency increase dramatically at low concentrations. CCS applied to a modern conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80–90% compared to a plant without CCS, but capturing and compressing CO_2 and other system costs are estimated to increase the cost of energy produced by 21–91% for new fossil fuel power plants[21]. Applying the technology to existing plants is more expensive. As of 2017 there were 13 operating CCS electric power projects globally and approximately 102 industrial projects[22]

Another approach would remove carbon directly from the atmosphere, rather than reducing emissions. This can be accomplished by improving agricultural practice and enhancing the carbon storage of soil. A great deal of carbon, once in the soil, is now in the atmosphere. We have lost two thirds historical soil humus to the atmosphere, representing 476 gigatons of CO2 and for a sense of perspective – all of mankind's other activities since 1860 have released a total of just 250 gigatons of CO2[23]. A mere 2%

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[18] https://www.epa.gov/sites/production/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf
[19] https://www.edf.org/true-cost-carbon-pollution
[20] https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf
[21] [IPCC, 2005] *IPCC special report on Carbon Dioxide Capture and Storage*. Prepared by working group III of the Intergovernmental Panel on Climate Change. Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L.A. Meyer (eds.).
[22] https://www.thirdway.org/graphic/carbon-capture-projects-map
[23] https://blog.nutri-tech.com.au/humus-saves-the-world/

increase in the carbon content of the planet's soils could offset 100% of all greenhouse gas emissions going into the atmosphere[24].

[24] Dr. Rattan Lal: Ohio State University, Professor of Soil Science, Director, Carbon Management and Sequestration Center, President of International Union of Soil Sciences

Costs Beyond Capital Costs

Impacts on Other Prices

The impact on other goods and services of spending $18-29 trillion or more to electrify everything with renewables or otherwise is also reviewed. The estimate for annual energy expenses directly and indirectly paid by households will likely increase by **at least $5,000 per household**. Annual consumer expenditure for energy would roughly double. Of course, that amount and proportion would vary by state and consumer end use.

Stranded Assets

Stranded assets suffer from unanticipated or premature write-downs, devaluations, or conversion to liabilities, most often through government action. In the context of this analysis, stranded assets have become obsolete or non-performing but are recorded on the balance sheet as a loss of profit or undepreciated capital. This applies to both privately-owned and publicly-owned assets. In the case of publicly-owned assets, the concept includes infrastructure costs that are burdened with bonded indebtedness. In the case of natural gas being replaced with electricity, stranded assets include natural gas wells, transmission pipelines, and local distribution facilities.

Investments in shale gas, the dominant manner in which production has occurred recently period, total an estimated $195 billion.[25] These would become stranded in a future where everything is electric, with generation provided by renewables. If electric is used for direct use, but with generation provided by traditional sources, such as natural gas, much less of these assets become stranded. With balanced energy solutions for generation and direct use, there would be no stranded assets.[26]

In addition to production assets, there are pipelines used to transport and distribute natural gas to customers. Three major types of pipelines are found along the transportation route bringing natural gas from the point of production to the point of use. Gathering pipeline systems gather raw natural gas from production wells and transport it to large cross-country transmission pipelines. Transmission pipeline systems transport natural gas hundreds or thousands of miles from processing facilities across North America. Natural gas distribution pipeline systems can be found in thousands of communities from coast-to-coast and provide energy to homes and businesses. Including both onshore and offshore lines, there are over 300,000 miles of interstate and intrastate transmission pipelines, and 2.1 million miles of distribution pipeline.[27] The average cost to install distribution lines is $18/linear foot[28] or a national asset worth just under $200 billion in distribution line replacement cost alone. These all would become obsolete and stranded through electrification under a 100% renewables scenario.

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[25] https://www.api.org/~/media/Files/News/2018/18-May/2017_API_GHG_Investment_Study.pdf

[26] Recall that electrical generation requires 2 or 3 times the amount of natural gas to produce a Btu of useful energy as the direct use of that natural gas to satisfy an end use.

[27] https://pipeline101.com/Why-Do-We-Need-Pipelines/Natural-Gas-Pipelines

[28] https://homeguide.com/costs/gas-line-installation-cost

Deadweight Loss

Totally electrifying the US economy would likely cause massive deadweight losses, which is the reduction in overall benefit for reasons like taxes or subsidies, price ceilings or floors, and other non-market factors. For the natural gas industry, one analysis shows the deadweight losses expected from broad electrification would be $58 trillion for natural gas resource loss that results from leaving America's substantial energy resources in the ground. Further, there would be $1.06 trillion for the energy infrastructure loss, including natural gas wells, pipelines and distribution.[29]

Nonmonetized Costs

In addition to the quantifiable costs and benefits described above, the wholesale electrification would result in impacts that are not quantifiable in terms of dollars and jobs. Some of these are detailed below:

Consumer preference

The wholesale electrification would affect consumer preference and convenience. Many consumers prefer cooking with natural gas because it responds more quickly to changes in heating levels. Also, gas appliances have longer life than electric.[30] As well, gas dryers typically dry clothes faster, as they heat up much quicker.[31] More recently the California Restaurant Association filed suit against the City of Berkeley for imposing a ban on natural gas, claiming the cooking process would be irreparably harmed[32]

Strategic benefits and Energy Security

Natural gas can also provide strategic benefits, as the price of this fuel continues to fall. Based on reservoir estimates, at the very least, the price will remain stable, relative to alternatives. With this price advantage, the large capital investments needed under wholesale electrification are non-competitive in the sense that they ignore need for future flexibility. Maintaining flexibility and stewarding capital are significantly important, especially for the municipally-owned utilities whose costs are directly tied to a city budget.

In addition to price stability having a diverse energy mix improves energy security, especially if the resource is domestically produced as is the case for natural gas.

[29] https://www.therightinsight.org/Green-New-Deal-Deadweight-Loss
[30] Electric or Gas Appliances: Which Is Better? Consumer Affairs, June 6, 2012 https://www.consumeraffairs.com/news04/2012/06/electric-or-gas-appliances-which-is-better.
[31] Ibid.
[32] https://www.npr.org/2019/11/21/781874235/california-restaurant-industry-group-sues-berkeley-over-natural-gas-ban

Disaster response

A diverse energy supply provides greater resiliency in times of disaster. If all energy consumption relies on electricity, and the grid is knocked out, having natural gas available in homes and elsewhere would provide important health and safety benefits for consumers. DOE is actively investigating the resiliency of the grid and natural gas infrastructures.[33]

In addition, and perhaps most important, is the adequacy of the electric grid in times of extreme weather like artic blasts, 'bomb cyclone', 'polar vortex' or extended low temperatures. This is when the adequacy of the delivery mechanism is most critical to human health and safety.

The monthly average delivery of natural gas from 2015 through September 2015 has been 382 BCF to the residential sector and 271 BCF to the commercial sector. This average is what we have based our initial cost estimates on. However, in the colder months (typically January, February) the demand is understandably larger, with January 2018 seeing a demand of 980 BCF (also varying daily and diurnally) in the residential sector and 555 in the commercial sector[34]. The ratio of highest demand in January 2018 to the average demand was 2.5 to 1 in the residential sector and about 2 to 1 in commercial. In order to protect public health and safety then, the supply and delivery mechanism, were it to be electrified, would have to be over 2 times as large in the residential and commercial sector, assuming other sectors and end uses are less weather sensitive. This would add approximately **$7 Trillion to our estimates for a total of over $36 trillion.**

Costs to Wealth and Health

Electrification advocates assert that achieving the complete electrification, particularly with renewable energy, will reduce premature deaths by several thousand per year, largely from educd exposure to air pollution. EPA has developed a set of "values" that help state and local government policymakers and other stakeholders estimate the monetized public health benefits,[35] especially in consideration of investments in energy efficiency and renewable energy. Higher energy prices should be evaluated in coordination with EPA's values, as utility costs can impact life span. This is well documented. One document[36] explains that "regulations to promote health and safety that are exceptionally costly relative to the expected health benefits may actually worsen health and safety, since compliance reduces other spending, including private spending on health and safety." EPA also states: "people's wealth and health status, as measured by mortality, morbidity, and other metrics, are [directly] correlated. Hence, those who bear a regulation's compliance [such as electrification] costs may also suffer a decline in their health status, and if the costs are large enough, these increased risks might be greater than the direct risk-reduction benefits of the regulation."[37]

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[33] See Federal Register, July 9, 2019, page 32732, and page 32731

[34] http://www.eia.gov/oil_gas/natural_gas/data_publications/natural_gas_monthly/ngm.html

[35] U.S. EPA "Public Health Benefits per kWh of Energy Efficiency and Renewable Energy in the United States: A Technical Report" July 2019 https://www.epa.gov/sites/production/files/2019-07/documents/bpk-report-final-508.pdf

[36] https://link.springer.com/chapter/10.1007/978-94-011-1360-1_3

[37] https://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0311-1.pdf/%24file/EE-0311-1.pdf

Human Rights Issues with Renewable/Storage

Greatly expanding battery storage and renewables also raises human rights concerns. These technologies rely heavily special minerals, including rare earths such as lithium mined by China and cobalt from the Congo. Both of these, as well as other rare earths, are currently controlled by foreign monopolies and mined under horrendous conditions[38] with no respect for human rights. In fact, this technology has earned the sobriquet, "blood batteries" because of the extreme poverty of the miners, forced child labor, corruption and environmental pollution commonly associated with their extraction[39].

[38] https://www.washingtonpost.com/politics/2019/02/21/demand-congos-cobalt-is-rise-so-is-scrutiny-mining-practices/?utm_term=.cb7ca2a27d6f
[39] https://www.forbes.com/sites/jamesconca/2018/09/26/blood-batteries-cobalt-and-the-congo/#737e1ea4cc6e

About the Author

Mr. Tanton is President of T^2 & Associates, a firm providing consulting services to the energy and technology industries. T^2 & Associates are active primarily in the area of renewable energy and interconnected infrastructures, analyzing and providing advice on their impacts on energy prices, environmental quality and regional economic development. Mr. Tanton is also Director of Science and Technology at Energy and Environment Legal Institute a 501(c) 3 nonprofit involved in strategic litigation in the public interest. Mr. Tanton is a strong proponent of free market environmentalism and consumer choice, and frequently publishes and speaks against alarmist and reactionary policies and government failures.

Most recently, Mr. Tanton presented invited testimony to the House Energy and Commerce Committee, regarding energy technology focused Federal policies, provided expert testimony to various state legislatures, and provided Hill briefings on the critical nature of Rare Earths markets.

Mr. Tanton has 45 years direct and responsible experience in energy technology and legislative interface, having been central to many of the critical legislative changes that enable technology choice and economic development at the state and federal level.

As the General Manager at Electric Power Research Institute, from 2000 to 2003, Mr. Tanton was responsible for the overall management and direction of collaborative research and development programs in electric generation technologies, integrating technology, market infrastructure, and public policy. From 2003 through 2007, Mr. Tanton was Senior Fellow and Vice President of the Houston based Institute for Energy Research. Until 2000, Mr. Tanton was Principal Policy Advisor at the California Energy Commission, including serving on the Governor's Task force on Critical Infrastructure for the 21st Century.

Appendix A

Results

Table A1: Cost To Electrify Generation, Transportation and Buildings Using 100% Renewables: First Cost

	100% Renewable Electric	Transportation	Direct Use Infrastructure	Household Cost	Commercial Bldg Cost	Vehicle Cost	Off Road	TOTAL
Alabama	$73,000,000,000	$94,000,000,000	$171,000,000,000	$8,000,000,000	$134,000,000,000	$92,000,000,000	$5,000,000,000	$576,000,000,000
Alaska	$5,000,000,000	$9,000,000,000	$88,000,000,000	$2,000,000,000	$17,000,000,000	$16,000,000,000	$1,000,000,000	$139,000,000,000
Arizona	$64,000,000,000	$112,000,000,000	$82,000,000,000	$19,000,000,000	$169,000,000,000	$97,000,000,000	$7,000,000,000	$550,000,000,000
Arkansas	$39,000,000,000	$53,000,000,000	$81,000,000,000	$5,000,000,000	$83,000,000,000	$50,000,000,000	$3,000,000,000	$313,000,000,000
California	$181,000,000,000	$538,000,000,000	$538,000,000,000	$103,000,000,000	$931,000,000,000	$471,000,000,000	$61,000,000,000	$2,823,000,000,000
Colorado	$41,000,000,000	$89,000,000,000	$112,000,000,000	$15,000,000,000	$134,000,000,000	$90,000,000,000	$8,000,000,000	$488,000,000,000
Conn.	$24,000,000,000	$58,000,000,000	$61,000,000,000	$11,000,000,000	$99,000,000,000	$45,000,000,000	$5,000,000,000	$303,000,000,000
Delaware	$9,000,000,000	$18,000,000,000	$25,000,000,000	$3,000,000,000	$27,000,000,000	$16,000,000,000	$2,000,000,000	$101,000,000,000
Florida	$192,000,000,000	$274,000,000,000	$355,000,000,000	$33,000,000,000	$585,000,000,000	$260,000,000,000	$21,000,000,000	$1,721,000,000,000
Georgia	$104,000,000,000	$185,000,000,000	$177,000,000,000	$16,000,000,000	$289,000,000,000	$137,000,000,000	$12,000,000,000	$921,000,000,000
Hawaii	$7,000,000,000	$17,000,000,000	$1,000,000,000	$4,000,000,000	$33,000,000,000	$21,000,000,000	$2,000,000,000	$84,000,000,000
Idaho	$19,000,000,000	$28,000,000,000	$28,000,000,000	$5,000,000,000	$41,000,000,000	$33,000,000,000	$2,000,000,000	$156,000,000,000
Illinois	$113,000,000,000	$176,000,000,000	$253,000,000,000	$38,000,000,000	$353,000,000,000	$168,000,000,000	$18,000,000,000	$1,118,000,000,000
Indiana	$63,000,000,000	$115,000,000,000	$188,000,000,000	$20,000,000,000	$185,000,000,000	$105,000,000,000	$8,000,000,000	$685,000,000,000
Iowa	$32,000,000,000	$43,000,000,000	$99,000,000,000	$9,000,000,000	$87,000,000,000	$63,000,000,000	$4,000,000,000	$337,000,000,000
Kansas	$34,000,000,000	$61,000,000,000	$69,000,000,000	$9,000,000,000	$81,000,000,000	$46,000,000,000	$3,000,000,000	$303,000,000,000
Kentucky	$61,000,000,000	$76,000,000,000	$73,000,000,000	$7,000,000,000	$123,000,000,000	$72,000,000,000	$4,000,000,000	$416,000,000,000
Louisiana	$54,000,000,000	$105,000,000,000	$404,000,000,000	$7,000,000,000	$128,000,000,000	$69,000,000,000	$5,000,000,000	$772,000,000,000
Maine	$9,000,000,000	$27,000,000,000	$13,000,000,000	$4,000,000,000	$37,000,000,000	$19,000,000,000	$1,000,000,000	$111,000,000,000
Maryland	$48,000,000,000	$74,000,000,000	$57,000,000,000	$19,000,000,000	$167,000,000,000	$66,000,000,000	$8,000,000,000	$440,000,000,000
Mas.	$43,000,000,000	$89,000,000,000	$115,000,000,000	$22,000,000,000	$191,000,000,000	$81,000,000,000	$12,000,000,000	$553,000,000,000

Michigan	$74,000,000,000	$174,000,000,000	$223,000,000,000	$30,000,000,000	$277,000,000,000	$142,000,000,000	$11,000,000,000	$931,000,000,000
Minnesota	$57,000,000,000	$85,000,000,000	$118,000,000,000	$17,000,000,000	$155,000,000,000	$90,000,000,000	$8,000,000,000	$529,000,000,000
Mississippi	$40,000,000,000	$63,000,000,000	$136,000,000,000	$5,000,000,000	$82,000,000,000	$36,000,000,000	$3,000,000,000	$364,000,000,000
Missouri	$62,000,000,000	$108,000,000,000	$66,000,000,000	$9,000,000,000	$168,000,000,000	$97,000,000,000	$6,000,000,000	$518,000,000,000
Montana	$11,000,000,000	$28,000,000,000	$20,000,000,000	$3,000,000,000	$25,000,000,000	$30,000,000,000	$1,000,000,000	$118,000,000,000
Nebraska	$22,000,000,000	$31,000,000,000	$42,000,000,000	$6,000,000,000	$53,000,000,000	$35,000,000,000	$3,000,000,000	$192,000,000,000
Nevada	$29,000,000,000	$45,000,000,000	$75,000,000,000	$8,000,000,000	$71,000,000,000	$39,000,000,000	$3,000,000,000	$270,000,000,000
New Hampshire	$9,000,000,000	$21,000,000,000	$13,000,000,000	$4,000,000,000	$38,000,000,000	$22,000,000,000	$2,000,000,000	$108,000,000,000
New Jersey	$56,000,000,000	$139,000,000,000	$181,000,000,000	$29,000,000,000	$247,000,000,000	$94,000,000,000	$13,000,000,000	$757,000,000,000
New Mexico	$19,000,000,000	$39,000,000,000	$61,000,000,000	$5,000,000,000	$49,000,000,000	$32,000,000,000	$2,000,000,000	$208,000,000,000
New York	$119,000,000,000	$208,000,000,000	$320,000,000,000	$63,000,000,000	$541,000,000,000	$181,000,000,000	$34,000,000,000	$1,465,000,000,000
North Carolina	$92,000,000,000	$166,000,000,000	$130,000,000,000	$16,000,000,000	$285,000,000,000	$138,000,000,000	$12,000,000,000	$839,000,000,000
North Dakota	$17,000,000,000	$15,000,000,000	$29,000,000,000	$2,000,000,000	$21,000,000,000	$17,000,000,000	$1,000,000,000	$102,000,000,000
Ohio	$98,000,000,000	$182,000,000,000	$241,000,000,000	$35,000,000,000	$324,000,000,000	$173,000,000,000	$14,000,000,000	$1,066,000,000,000
Oklahoma	$47,000,000,000	$77,000,000,000	$171,000,000,000	$12,000,000,000	$109,000,000,000	$65,000,000,000	$4,000,000,000	$485,000,000,000
Oregon	$42,000,000,000	$58,000,000,000	$59,000,000,000	$11,000,000,000	$99,000,000,000	$65,000,000,000	$5,000,000,000	$339,000,000,000
Pen.	$117,000,000,000	$131,000,000,000	$322,000,000,000	$41,000,000,000	$355,000,000,000	$176,000,000,000	$16,000,000,000	$1,156,000,000,000
Rhode Island	$6,000,000,000	$25,000,000,000	$21,000,000,000	$3,000,000,000	$29,000,000,000	$13,000,000,000	$1,000,000,000	$100,000,000,000
South Carolina	$53,000,000,000	$99,000,000,000	$70,000,000,000	$8,000,000,000	$140,000,000,000	$72,000,000,000	$5,000,000,000	$446,000,000,000
South Dakota	$10,000,000,000	$17,000,000,000	$21,000,000,000	$3,000,000,000	$24,000,000,000	$22,000,000,000	$1,000,000,000	$98,000,000,000
Tennessee	$74,000,000,000	$131,000,000,000	$82,000,000,000	$10,000,000,000	$186,000,000,000	$96,000,000,000	$8,000,000,000	$588,000,000,000
Texas	$322,000,000,000	$593,000,000,000	$990,000,000,000	$44,000,000,000	$789,000,000,000	$382,000,000,000	$37,000,000,000	$3,157,000,000,000
Utah	$19,000,000,000	$50,000,000,000	$57,000,000,000	$8,000,000,000	$74,000,000,000	$39,000,000,000	$4,000,000,000	$251,000,000,000
Vermont	$4,000,000,000	$12,000,000,000	$3,000,000,000	$2,000,000,000	$17,000,000,000	$10,000,000,000	$1,000,000,000	$50,000,000,000
Virginia	$90,000,000,000	$125,000,000,000	$148,000,000,000	$13,000,000,000	$234,000,000,000	$119,000,000,000	$11,000,000,000	$741,000,000,000

Washington	$78,000,000,000	$107,000,000,000	$82,000,000,000	$20,000,000,000	$177,000,000,000	$117,000,000,000	$12,000,000,000	$593,000,000,000
West Virginia	$26,000,000,000	$28,000,000,000	$48,000,000,000	$3,000,000,000	$50,000,000,000	$30,000,000,000	$2,000,000,000	$187,000,000,000
Wisconsin	$55,000,000,000	$94,000,000,000	$123,000,000,000	$17,000,000,000	$161,000,000,000	$92,000,000,000	$7,000,000,000	$550,000,000,000
Wyoming	$13,000,000,000	$14,000,000,000	$32,000,000,000	$2,000,000,000	$14,000,000,000	$17,000,000,000	$1,000,000,000	$92,000,000,000
Grand Total	**$2,876,000,000,000**	**$5,106,000,000,000**	**$6,874,000,000,000**	**$788,000,000,000**	**$8,688,000,000,000**	**$4,458,000,000,000**	**$420,000,000,000**	**$29,210,000,000,000**

Table A2: Cost Per Ton of Reduced Carbon Emissions

State	Commercial	Electric power	Residential	Transportation
Alabama	$9,896	$131	$4,974	$538
Alaska	$3,023	$188	$3,074	$210
Arizona	$7,308	$145	$2,726	$632
Arkansas	$4,199	$128	$2,717	$535
California	$6,359	$494	$1,543	$474
Colorado	$4,861	$116	$948	$636
Connecticut	$3,306	$339	$667	$671
Delaware	$4,260	$263	$1,889	$744
Florida	$10,392	$98	$17,735	$516
Georgia	$8,222	$12	$1,534	$597
Hawaii	$10,306	$296	$9,264	$374
Idaho	$4,055	$9,023	$1,144	$568
Illinois	$3,601	$96	$744	$503
Indiana	$5,338	$38	$1,500	$507
Iowa	$3,930	$139	$1,436	$495
Kansas	$4,822	$246	$1,289	$570
Kentucky	$5,845	$74	$1,504	$458
Louisiana	$15,092	$26	$11,579	$367
Maine	$2,678	$3,222	$361	$517
Maryland	$3,797	$250	$873	$506
Massachusetts	$3,543	$689	$700	$537
Michigan	$3,790	$103	$758	$631
Minnesota	$3,376	$152	$939	$559
Mississippi	$9,616	$239	$5,092	$332
Missouri	$4,751	$18	$759	$541
Montana	$2,553	$141	$892	$733
Nebraska	$4,091	$136	$1,219	$473
Nevada	$4,807	$65	$1,978	$558

New Hampshire	$3,187	$2,351	$437	$630
New Jersey	$3,357	$97	$878	$401
New Mexico	$4,703	$516	$1,714	$501
New York	$3,238	$332	$728	$516
North Carolina	$6,664	$34	$1,588	$620
North Dakota	$3,537	$340	$1,812	$379
Ohio	$4,042	$58	$961	$562
Oklahoma	$6,511	$119	$3,029	$436
Oregon	$6,034	$1,500	$1,616	$603
Pennsylvania	$4,843	$8	$1,097	$505
Rhode Island	$4,628	$2,067	$766	$1,004
South Carolina	$8,068	$38	$2,403	$523
South Dakota	$4,726	$2,853	$1,367	$565
Tennessee	$6,160	$897	$1,421	$521
Texas	$10,164	$9	$4,999	$434
Utah	$3,915	$16	$1,001	$503
Vermont	$2,207	$2,207,489	$271	$652
Virginia	$5,358	$231	$1,528	$515
Washington	$4,998	$276	$1,194	$459
West Virginia	$4,393	$81	$1,652	$476
Wisconsin	$3,777	$35	$914	$630
Wyoming	$2,680	$7,418	$2,064	$393

Appendix B

Process for Estimating Costs to Convert 100% of Electricity to Renewables

The following summarizes the steps used in calculating the cost to convert the existing grid to 100% renewables. The reader should note that the estimated capacity of wind and solar is three times the calculated average capacity. Reputable literature currently assumes these renewable sources will likely replace existing generation resources[40] and operate at this reduced capacity. Essentially, three times as much of wind and solar is needed to provide the equivalent energy.[41]

1. Determine existing Annual Electricity from non-renewables in gigawatt (GW) hours. For the US in 2018 that was 3 billion MW-hours.

2.Convert to kW by multiplying by 1,000,000 and dividing by 8760 (hours in a year). This gives average capacity (a.c.).

3. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference earlier discussion to learn more on reasoning for this reduced capacity.

4. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 3. The solar/wind value was determined using EIA data[42] and averaging on-shore wind and utility-scale solar photovoltaic (PV) expenses.

5. Determine the cost for storage using $1,850/kW multiplied by a.c. This number is the cost to install dispatchable and capable battery storage and was calculated using EIA cost estimates.

6. Find the cost for transmission, which is $572/kW multiplied by the a.c. This transmission number is derived from the National Renewable Energy Laboratory's Eastern Wind Integration and Transmission Study (EWITS).[43]

7. The total is the addition of values calculated in Steps 4, 5, and 6.

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[40] This is essence requires 3x the installed capcity of wind and solar compared to more traditional sources.

[41] U.S. Energy Information Administration, Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2019

[42] U.S. Energy Information Administration, *Cost and Performance Characteristics of New Generating Technologies*, Annual Energy Outlook 2019

[43] Tanton and Taylor "Hidden Cost of Wind Energy" American Tradition Institute, December 2012

Process for Estimating Costs for Vehicle Fuel Conversion

1. Determine annual fuel sales in gallons of gasoline and diesel.
2. Adjust for higher energy content of diesel, and calculate weighted average gasoline equivalent. Diesel contains approximately 14% more energy than gasoline, so for the purposes of this analysis, a gasoline equivalent of 216 billion gallons was used.
3. Calculate current annual electrical energy equivalent in GW-hours for vehicle fuel purchased using 3412 Btu/kWh.
4. Convert to kW by multiplying by 1,000,000 and dividing by 8760, which is hours in a year. This will give average capacity (a.c.).
5. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference discussion in Appendix A to learn more on reasoning for this reduced capacity.
6. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 5. Reference discussion in Appendix A to learn more on determining this cost.
7. Determine the cost for storage using $1,850/kW multiplied by a.c. Reference discussion in Appendix A to learn more on determining this cost.
8. Find the cost for transmission, which is $572/kW multiplied by the a.c. Reference discussion in Appendix A to learn more on determining this cost.
9. **Total (Step 6+7+8)**

Process to Estimate Cost to Eliminate Natural Gas Use in Buildings

1. Determine sales of natural gas in 2018 in million therms. A therm is a unit of heat equivalent to 100,000 Btu.
2. Determine equivalent electrical energy, divide by 29.3 kWh/therm. Provides kWh.
3. Convert to kW by multiplying by 1,000,000 and dividing by 8760, which is hours in a year. This will give average capacity (a.c.).
4. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference discussion in Appendix A to learn more on reasoning for this reduced capacity.
5. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 4. Reference discussion in Appendix A to learn more on determining this cost.
6. Determine the cost for storage using $1,850/kW multiplied by a.c. Reference discussion in Appendix A to learn more on determining this cost.
7. Find the cost for transmission, which is $572/kW multiplied by the a.c. Reference discussion in Appendix A to learn more on determining this cost.
8. **Subtotal (Step 5+6+7). This represents the infrastructure costs.**
9. Determine number of households by dividing population by 2.3, which is a commonly used value for this calculation.
10. To find the number of household candidates for fuel switching, multiply the value from Step 9 by percentage not yet all electric. There are residential consumers in each state who already use electricity for end uses, such as water heating and space heating. DOE provides this information. In California, for example, 18% of people use electricity for space heat and 14% for water heating while in Alabama 57% use electricity. [44]

[44] Department of Energy, Residential Energy Consumption Survey, 2001.

11. Find the cost of converting households by multiplying by $10,000 initially. This represents individual consumer costs. The cost per household is based on a 2018 study led by the American Gas Association (AGA).[45] **Subtotal. This represents the individual household costs.**
12. Ascertain the cost to convert commercial buildings by multiplying 90 billion square feet by $100/square foot. There is estimated 87 billion square feet nationally. The analysis includes this value, as well as the breakdown of commercial building by state. Note that commercial building electrification is often coupled with energy efficiency measures. These are known as “deep energy retrofits” (DERs). The cost can vary considerably, given varying climates, building ages, uses, sizes, and other factors. Reliable average cost of a DER for commercial buildings is estimated at $75 per square foot. However, $100/square foot is used in this calculation to account for inflation occurring since the research completed. As well, many measures have already been implemented. More challenging retrofits that will cost more money are now all that remains further increasing the average cost. **Subtotal. This represents the commercial building costs.**
13. **Total Cost, add line 8, 12 and 13**

Process to Estimate Costs to Convert Other Transportation

Off Road

1. Determine annual fuel sales in gallons of diesel.
2. Adjust for higher energy content of diesel, and calculate weighted average gasoline equivalent. Diesel contains approximately 14% more energy than gasoline, so for the purposes of this analysis, a gasoline equivalent of 216 billion gallons was used.
3. Calculate current annual electrical energy equivalent in GW-hours for vehicle fuel purchased using 3412 Btu/kWh.
4. Convert to kW by multiplying by 1,000,000 and dividing by 8760, which is hours in a year. This will give average capacity (a.c.).
5. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference discussion in Appendix A to learn more on reasoning for this reduced capacity.
6. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 5. Reference discussion in Appendix A to learn more on determining this cost.
7. Determine the cost for storage using $1,850/kW multiplied by a.c. Reference discussion in Appendix A to learn more on determining this cost.
8. Find the cost for transmission, which is $572/kW multiplied by the a.c. Reference discussion in Appendix A to learn more on determining this cost.
9. **Total (Step 6+7+8).** The original data from FHWA did not allow for easy allocation to individual states, so the nation-wide total was allocated to each state based upon its’ percentage of national gross domestic product (GDP). The majority of off-road use is assumed to be in commercial endeavors, consequently, the amount of fuel used would reflect economic activity.

[45] *Implications of Policy-Driven Residential Electrification* An American Gas Association Study, prepared by ICF, July 2018 https://www.aga.org/globalassets/research--insights/reports/aga_study_on_residential_electrification.pdf

Aviation

1. Determine annual fuel sales in gallons. The U.S. aviation industry used an estimated 17.7 billion gallons in 2016 according to the U.S. Energy Information Administration.
2. Calculate current annual electrical energy equivalent in GW-hours for vehicle fuel purchased using 3412 Btu/kWh, or 644 x 10^3 GWh
3. Convert to kW by multiplying by 1,000,000 and dividing by 8760, which is hours in a year. This will give average capacity (a.c.) or 73,517,216 kw.
4. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference discussion above to learn more on reasoning for this reduced capacity.
5. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 5. Reference discussion above to learn more on determining this cost.
6. Determine the cost for storage using $1,850/kW multiplied by a.c. Reference discussion, again, above to learn more on determining this cost.
7. Find the cost for transmission, which is $572/kW multiplied by the a.c. Reference discussion above to learn more on determining this cost.
8. **Total (Step 5+6+7).** This total does not include any marginal costs for airplanes themselves.

Maritime

9. Determine annual fuel sales in gallons. The shipping industry uses an estimated 4 million barrels, or 168 million gallons, per day, or the energy equivalent of 231 GW.
10. Adjust for higher energy content of diesel and bunker fuel, and calculate weighted average gasoline equivalent. Diesel contains approximately 14% more energy than gasoline, so for the purposes of this analysis, a gasoline equivalent of 216 billion gallons was used.
11. Calculate current annual electrical energy equivalent in GW-hours for vehicle fuel purchased using 3412 Btu/kWh. Individual container ships use engines with over 35 MW of capacity, the largest over 80 MW.
12. Convert to kW by multiplying by 1,000,000 and dividing by 8760, which is hours in a year. This will give average capacity (a.c.).
13. Determine kW of solar and wind at 30% capacity factor by multiplying a.c. by 3. Reference discussion in Appendix A to learn more on reasoning for this reduced capacity.
14. Estimate cost for solar/wind using $1,694/kW multiplied by number calculated in step 5. Reference discussion in Appendix A to learn more on determining this cost.
15. Determine the cost for storage using $1,850/kW multiplied by a.c. Reference discussion in Appendix A to learn more on determining this cost.
16. Find the cost for transmission, which is $572/kW multiplied by the a.c. Reference discussion in Appendix A to learn more on determining this cost.
17. **Total (Step 6+7+8).** Increasingly, ports such as Long Beach are electrifying port connections and on-shore services like loading cranes,[46] at a cost of half a million dollars per crane. The Port Authority

[46] https://www.joc.com/port-news/us-ports/port-long-beach/long-beach-ssa-marine-launch-electrification-effort-meet-emission-goals_20180405.html

also plans to replace over 10,000 servicing trucks. In addition, some locales, like Seattle, are pushing to electrify ferry service.[47] Those costs were not included.

[47] https://patch.com/washington/seattle/washingtons-largest-ferries-will-be-converted-electric-power

Appendix B

Using the Workbook

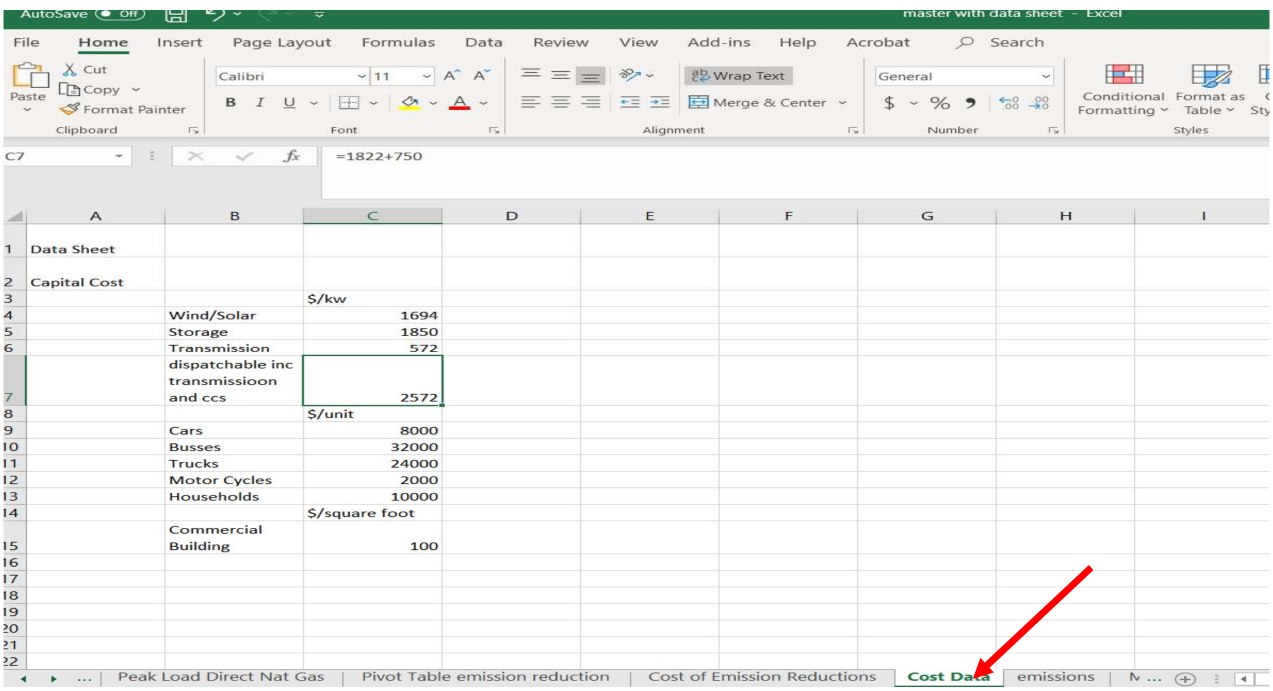
This section provides directions for the “Electrification Cost Workbook,” a simple Excel file designed and populated to calculate the first costs of electrifying all energy consuming end uses. The user should be:

- Generally familiar with and adept at using multi-sheet workbooks in Excel. The workbook was built in MS Office 365 (build 16) but should work with other versions. Some minor differences in commands may exist for older versions.
- Able to track cross-sheet relative and absolute cell references.
- Generally familiar with Pivot Tables and in selecting fields for display.

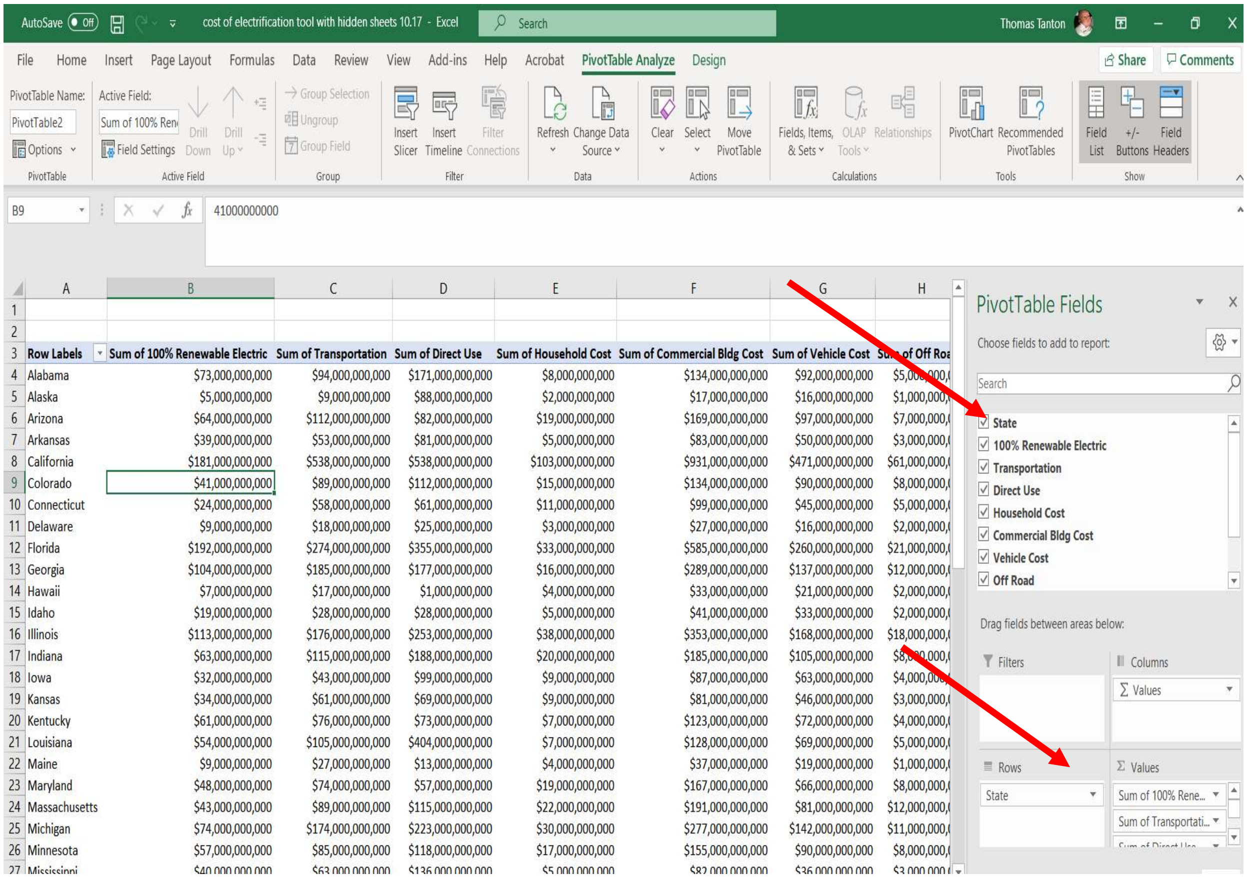
The workbook contains various hidden sheets that contain data representing usage, population, commercial square footage, number of households, and related information. These are viewable and editable if desired by right clicking on any worksheet tab and selecting “unhide.” For further directions on hiding or showing worksheets, search Excel’s Help function for “Hide of Show Worksheets.”

The workbook estimates first cost only and does not include running or operational costs, nor financing costs.

The tab “cost data” is editable, but the workbook should be refreshed after doing so. It is recommended that the workbook be saved with a different file name, if cost or other data is edited, in order to save the default values.



If cost estimated for only one or multiple states or end uses is desired, click on the appropriate Pivot Table and select the state (row) and end use (column) of interest. Check end uses under “show field list.” See below for more details.



	A	B	C	D	E	F	G	H
1								
2								
3	Row Labels	Sum of 100% Renewable Electric	Sum of Transportation	Sum of Direct Use	Sum of Household Cost	Sum of Commercial Bldg Cost	Sum of Vehicle Cost	Su[illegible] of Off Roa
4	Alabama	$73,000,000,000	$94,000,000,000	$171,000,000,000	$8,000,000,000	$134,000,000,000	$92,000,000,000	$5,0[illegible]000,
5	Alaska	$5,000,000,000	$9,000,000,000	$88,000,000,000	$2,000,000,000	$17,000,000,000	$16,000,000,000	$1,000,000,
6	Arizona	$64,000,000,000	$112,000,000,000	$82,000,000,000	$19,000,000,000	$169,000,000,000	$97,000,000,000	$7,000,000,
7	Arkansas	$39,000,000,000	$53,000,000,000	$81,000,000,000	$5,000,000,000	$83,000,000,000	$50,000,000,000	$3,000,000,
8	California	$181,000,000,000	$538,000,000,000	$538,000,000,000	$103,000,000,000	$931,000,000,000	$471,000,000,000	$61,000,000,
9	Colorado	$41,000,000,000	$89,000,000,000	$112,000,000,000	$15,000,000,000	$134,000,000,000	$90,000,000,000	$8,000,000,
10	Connecticut	$24,000,000,000	$58,000,000,000	$61,000,000,000	$11,000,000,000	$99,000,000,000	$45,000,000,000	$5,000,000,
11	Delaware	$9,000,000,000	$18,000,000,000	$25,000,000,000	$3,000,000,000	$27,000,000,000	$16,000,000,000	$2,000,000,
12	Florida	$192,000,000,000	$274,000,000,000	$355,000,000,000	$33,000,000,000	$585,000,000,000	$260,000,000,000	$21,000,000,
13	Georgia	$104,000,000,000	$185,000,000,000	$177,000,000,000	$16,000,000,000	$289,000,000,000	$137,000,000,000	$12,000,000,
14	Hawaii	$7,000,000,000	$17,000,000,000	$1,000,000,000	$4,000,000,000	$33,000,000,000	$21,000,000,000	$2,000,000,
15	Idaho	$19,000,000,000	$28,000,000,000	$28,000,000,000	$5,000,000,000	$41,000,000,000	$33,000,000,000	$2,000,000,
16	Illinois	$113,000,000,000	$176,000,000,000	$253,000,000,000	$38,000,000,000	$353,000,000,000	$168,000,000,000	$18,000,000,
17	Indiana	$63,000,000,000	$115,000,000,000	$188,000,000,000	$20,000,000,000	$185,000,000,000	$105,000,000,000	$8,[illegible]0,000,
18	Iowa	$32,000,000,000	$43,000,000,000	$99,000,000,000	$9,000,000,000	$87,000,000,000	$63,000,000,000	$4,000,00[illegible]
19	Kansas	$34,000,000,000	$61,000,000,000	$69,000,000,000	$9,000,000,000	$81,000,000,000	$46,000,000,000	$3,000,000,
20	Kentucky	$61,000,000,000	$76,000,000,000	$73,000,000,000	$7,000,000,000	$123,000,000,000	$72,000,000,000	$4,000,000,
21	Louisiana	$54,000,000,000	$105,000,000,000	$404,000,000,000	$7,000,000,000	$128,000,000,000	$69,000,000,000	$5,000,000,
22	Maine	$9,000,000,000	$27,000,000,000	$13,000,000,000	$4,000,000,000	$37,000,000,000	$19,000,000,000	$1,000,000,
23	Maryland	$48,000,000,000	$74,000,000,000	$57,000,000,000	$19,000,000,000	$167,000,000,000	$66,000,000,000	$8,000,000,
24	Massachusetts	$43,000,000,000	$89,000,000,000	$115,000,000,000	$22,000,000,000	$191,000,000,000	$81,000,000,000	$12,000,000,
25	Michigan	$74,000,000,000	$174,000,000,000	$223,000,000,000	$30,000,000,000	$277,000,000,000	$142,000,000,000	$11,000,000,
26	Minnesota	$57,000,000,000	$85,000,000,000	$118,000,000,000	$17,000,000,000	$155,000,000,000	$90,000,000,000	$8,000,000,
27	Mississippi	$40,000,000,000	$63,000,000,000	$136,000,000,000	$5,000,000,000	$82,000,000,000	$36,000,000,000	$3,000,000,