VALUATION OF U.S. INFRASTRUCTURE ASSETS RELATED TO LIQUID HYDROCARBONS AND TRANSPORTATION

With implications on the decarbonization of mobility and the grid as of Sept 2019

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Executive Summary

In this brief report, we summarize **existing asset values and investments for U.S. infrastructure related to liquid hydrocarbon transportation systems**. This includes primarily assets in the hydrocarbon fuel supply chain as well as the engines and equipment that consume hydrocarbon fuels. The motivation prompting this effort is generally stated as a desire to better understand near-, medium-, and long-term pathways to decarbonize transportation. As such, this particular effort was a part of a broader scoping effort in which researchers with Georgia Tech's Strategic Energy Institute sought to compare the economic viability of renewable hydrocarbons as a substitute for petroleum-derived fuels. This includes both biofuels and synthetically produced alternative fuels. Doing so is believed to help facilitate a more direct and holistic comparison of renewable fuels with other forms of sustainable transportation, such as electric vehicles (EVs).

The research team believes this topic will garner increasing attention, given that hydrocarbons (whether fossil-, alternative-, or bio-derived) and electricity represent the predominant "energy carriers" in our modern world. While studies exist that assess and forecast the near-term potential of EVs to mitigate CO2 emissions and the variable cost benefits of EVs, the research team found little to no data in the literature that develop a high-level asset valuation of associated public and private infrastructure for the extended hydrocarbon/transportation sector. Cost estimates of a fully-deployed domestic EV charging and grid support system over an extended time horizon are similarly lacking, or uncertain at best. The team believes such evaluations are valuable, if not essential, even as qualified engineering estimates and comparisons, to inform the long-term viability of alternate pathways for decarbonizing transportation. The notable contribution of this preliminary investigation is toward the asset implications of synthetic fuels derived from renewable resources that can be interchangeable (i.e., "drop-in") with currently approved liquid hydrocarbons, including those derived from petroleum or other fossil-fuels. In short, such "Renewable Hydrocarbons" (RHCs) can leverage largely existing and long-lived assets which should not be overlooked in their total cost of deployment.

Our high-level assessment of U.S. infrastructure has thus been conducted to develop a rough order of magnitude valuation of the extended hydrocarbon sector, situated in context with US infrastructure broadly, and compared to the US electric grid, specifically. **Our study finds:**

- **Approximate Total Valuation of US non-real estate Infrastructure:** \$37 Trillion[1] (as of 2015)

[1] Arcadis, 2017. https://gizmodo.com/heres-how-much-americas-infrastructure-is-worth-compar-1739382781

- **Hydrocarbon share**: 22.7% (based on definitions and estimates below)
- **Electric grid share**: 12.9% (based on definitions and estimates below)

Our study also estimates that US hydrocarbon and transportation infrastructure assets can be roughly characterized as follows:

- Estimated **total asset value** of US Hydrocarbon Infrastructure[2] as of 2018: **$8.4 Trillion**
  - Share that is upstream, or "Hydrocarbon Support" (est.): $3.4 T (40%)
  - Share that is downstream, or "Vehicles, Engines, & Equipment" (est.): $5.0 T (60%)
- Estimated **annual investments** into this sector in 2018: **$729 Billion**
  - Allocation: 80% private, 20% public
  - Estimated annual turnover (new annual investments/total assets): 8.7%/year

In short, the US hydrocarbon (HC) sector, broadly defined, comprises a large investment, upwards of 8.4 trillion dollars, out of a total U.S. infrastructure investment of about $37 trillion[3]. Our HC infrastructure estimate excludes the parts of the transportation system that could be used with other vehicle propulsion systems, such as roads, but includes the petroleum refining industry, as well as publicly and privately owned vehicles in the U.S. fleet that rely on internal combustion engines. So called "upstream" or "supply side assets" are defined to liquid hydrocarbon support infrastructure (e.g., refineries, pipelines, storage assets). These account for about 40% of the total. So called "downstream" or fuel consuming devices are defined to include engines and the broad category of equipment that uses them. This segment account for the remaining 60% of HC sector assets. Separately, initial estimates suggest that the **replacement value of the U.S. electric grid is about 4.8 trillion dollars**.

Together, these findings suggest two important challenges:

(1) replacement of HC infrastructure by expanding, for example, the delivery of electricity to enable EVs is likely to require substantial investment, on the order of trillions of dollars;
(2) the accelerated retirement of HC infrastructure may be difficult due to the vested interests in maintaining its economic use, and given the comparatively long useful lifespans.

Finally, it is the opinion of the authors that data and debate on the subject of the value of the existing infrastructure and the cost to replace it has been inadequate to this point in policy circles. There is significant economic inertia to be overcome to decarbonize U.S. transportation, with important implications on the viability of solutions. The implication of this is that although fossil-based hydrocarbons may not have a role in decarbonizing transportation, renewable-derived hydrocarbons may, and if so, they could leverage substantial legacy infrastructure.

Study authors:

[3] Real estate and property are excluded from this broad estimate of the value of U.S. "infrastructure." See also footnote 6. At the time of publication,estimates of all U.S. assets, including real estate and property, approach $70T.

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About the Energy, Policy, and Innovation Center

The Energy, Policy, and Innovation Center (EPICenter) was launched in the Fall of 2016 with the mission of conducting technical research, providing information on various contemporary topics in the energy field, and coordinating activities among leaders and innovators across industries and sectors. The Center operates within the Georgia Tech's Strategic Energy Institute and explores the intersection of policy and technology, while leveraging the extensive expertise present across firms, research institutions, policymakers, and other government and non-government organizations in the Southeastern United States.

The Center is the first known implementation of a regional partnership to focus on the interdependencies of energy policy and technology in developing and implementing significant, cost-effective, and market-based carbon reductions. EPICenter primary deliverables include original research studies and publications, events, educational outreach, and events. Through these outputs, the Center strives to help accelerate a variety of reliable, affordable, and low-carbon energy options in the Southeast. Please visit our website for a sampling of recent work products: https://epicenter.energy.gatech.edu/studies/

In executing its mission, EPICenter draws upon voluntary contributions from external organizations. The center is funded by an endowment and annual cash gifts to the Georgia Tech Foundation, and receives additional support in the form of personnel time and other in-kind contributions. Input from external entities that accompanies support, including recommendations related to center studies or operations, is subject to the discretion of EPICenter leadership. Similarly, no particular work product, findings, or implied results of center deliverables shall be linked, or give the perception of being linked, to a specific donation by any individual participant.

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The Value of U.S. Infrastructure Related to Liquid Hydrocarbon Fuels and Conventional Transportation

The value of a sector within the national economy can be measured most accurately by the benefits it provides to its users and investors. The transportation sector, for example, functions as a lynchpin of the U.S., providing crucial support for nearly every other industry, from agriculture to construction to trade. The infrastructure to support the transportation sector is in turn created through a combination of private and government investments. Broadly defined, one can understand this sector as having upstream and downstream segments loosely related to the delivery of hydrocarbon fuels and the consumption of those same fuels, respectively. While overlap naturally exists for large sectors like transportation, the private sector is generally the predominant investor of billions of dollars in railroads, vehicles, transit, and pipeline networks, whereas various levels of government are generally responsible for funding public assets, airports and equipment necessary for national defense. It is noteworthy that over the past decade, the two categories of U.S. infrastructure related to transportation and electricity have ranked #1 and #2 respectively[5].

As it relates to the present study, the research team performed a high-level analysis of the estimated value of public and private infrastructure that is linked directly to liquid hydrocarbon fuels used predominantly for transportation, and the vehicles, engines, and other assets that depend exclusively upon them. A reasonable approximation of the current value of these assets will facilitate meaningful techno-economic comparisons between the current baseline (or business as usual assumptions), and future alternative scenarios for transportation energy (e.g., synthetic hydrocarbons, electric vehicles, fuel cells, etc.) The infrastructure estimate, then, becomes a critical, if not complex, factor in establishing the viability of a substitute to today's incumbent technologies. For this reason, it is important to note that common infrastructure (not directly linked to a given energy source), such as roads, bridges, parking areas, ports, airports, and land dedicated to transportation has been excluded from the following analysis.

Within this framework, Table 1 indicates that the private and public sector witnessed $588.5 billion and $140.3 billion respectively in investments for the transportation sector in 2018 alone[6]. This means that about $728.8 billion in new private and government money was invested in the year 2018. It is notable that such large sums are being directed to what many consider conventional and mature technologies. To date however, a prevailing market aversion to technological, economic and political risk, along with a lack of economically competitive alternatives, and, not surprisingly, a lack of infrastructure to support alternatives, have created an inertia that is complicated to overcome, or at least overcome quickly.

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[5] Statista, "Value of infrastructure construction put in place in the U.S. between 2008 and 2018, by sector." https://www.statista.com/statistics/1009084/us-construction-value-for-infrastructure-by-sector/

[6] United States, Congress, Bureau of Economic Analysis. "Investment in Private Fixed Assets, Equipment, Structures, and Intellectual Property Products by Type." *Investment in Private Fixed Assets, Equipment, Structures, and Intellectual Property Products by Type*, Bureau of Economic Analysis, 2019. apps.bea.gov/iTable/iTable.cfm?ReqID=10&step=2.

United States, Congress, Bureau of Economic Analysis. "Investment in Government Fixed Assets." *Investment in Government Fixed Assets*, Bureau of Economic Analysis, 2019. apps.bea.gov/iTable/iTable.cfm?ReqID=10&step=2.

Table 1. Annual Investments in Private Fixed Assets, Equipment, Structures and Government Fixed Assets between 2011 and 2018 (Billions of Dollars)

	2011	2012	2013	2014	2015	2016	2017	2018
Private Fixed Assets								
Nonresidential equipment								
Engines and turbines	11.8	16.4	14.3	13.9	14.8	13.8	15.2	14.9
Transportation equipment								
Light trucks and autos	90.3	115.8	128.9	140.9	161.5	169.2	153.6	164.6
Heavy duty and other trucks	34	39.9	41.7	46.9	54.5	44.3	45.4	56.9
Aircraft	33	34.4	36.9	43.3	44.6	40.2	45.3	48.3
Ships and boats	5.9	6.5	8.1	8.2	9	7.1	7.5	6.6
Agricultural machinery	26.5	35.2	41.9	47.6	36.9	29.6	32.1	37.8
Construction machinery	40.5	44.1	41.1	46	39.6	38.7	43.2	48.5
Mining and oilfield machinery	25.8	35.2	34	36.4	24.9	17.9	22.9	22.2
Nonresidential structures								
Other commercial [1]	7.7	8.4	9.1	9.2	10.5	13.6	13.2	12.7
Non-electric power	14	17.4	26.9	28.2	24.4	20.4	20.7	23.3
Mining exploration, shafts, and wells								
Petroleum and natural gas	113.3	141.7	143.8	177.5	126.7	68.7	101.7	130.9
Mining	11.2	11	11.6	10.6	10	5.8	7.1	6.8
Air Transportation	0.6	1.1	1	1.1	1.1	2.2	3.8	6.2
Farm	5.9	7.7	9.5	11	9.3	8.3	8.5	8.8
Private Fixed Assets SubTotal	***420.6***	***514.8***	***548.8***	***620.8***	***567.8***	***479.8***	***520.2***	***588.5***
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Government Fixed Assets [2]								
Transportation	23.9	24.1	25.4	28.5	29.3	28.7	28.7	30.7
Federal								
National defense								
Aircraft	20.2	20.2	19.6	19.2	17.6	16.4	18.3	20.3
Ships	11.7	12	12.5	13.3	13.5	14.4	14.1	15.5
Vehicles	7.1	5.8	3.9	2.9	2.4	2.4	2.5	3
Other equipment	32.8	31.2	27	26.4	26.4	27.7	30.4	33
Nondefense								
Transportation	0.4	0.2	0.3	0.2	0.3	0.4	0.3	0.3
Power	1.3	1.2	1.1	1.1	1.6	1.3	0.7	0.6
State and local								
Transportation	23.5	23.9	25.1	28.3	29	28.2	28.5	30.4
Power	9.3	9.1	9.2	9.1	8.9	8.7	7.4	6.5
Government Fixed Assets SubTotal	***130.2***	***127.7***	***124.1***	***129***	***129***	***128.2***	***130.9***	***140.3***
Total Private and Government Fixed Assets, Annual							**TOTAL**	**728.8**

Table 1 Legends/Footnotes:

1. Includes buildings and structures used by the retail, wholesale and selected service industries. Consist of auto dealerships, garages, service stations, drug stores, restaurants, mobile structures, and other structures used for commercial purposes. Bus or truck garages are included in transportation.
2. Consists of the fixed assets of general government and government enterprises.

Of course, the substantial infrastructure investments into this sector in recent years represent merely a fraction of the cumulative asset value. Accordingly, the team has estimated the full replacement value of all subject assets currently in use. Accounting for these fixed assets, structures, equipment and associated products, the replacement cost of the current liquid-hydrocarbon fuel based transportation system would have a price tag of about $8.4 trillion in the U.S. economy. These findings do not, however, include the value of corresponding jobs, ancillary items, or intrinsic significance of the contemporary infrastructure[7]. A more complete accounting of the included assets of the hydrocarbon transportation sector can be found in *Table 2.*

Table 2. Full Valuation of the Hydrocarbon Economy Infrastructure, Cumulative asset value (in billions of dollars) at various years'-end, 2010-2019

Private Fixed Assets, Cum.	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Engines and turbines	113.5	121.8	126.9	132	135.9	137.6	138.7	147.5
Light trucks and autos	349.6	390.3	432.2	479.6	536.3	589.6	610.2	639.5
Heavy duty and other trucks	157.4	167.5	177.9	190.8	208.5	213.1	218.3	236.6
Aircraft	344.9	356.9	371.2	390.7	404.7	416	436.2	457.5
Ships and boats	82.3	82	85.8	89.5	93.4	94.8	97	100.1
Agricultural machinery	175.9	188.4	206.4	226.9	233.6	233.1	235.6	246.2
Construction machinery	203.5	220.1	223.9	233.7	232.4	232.8	236.1	250.4
Mining and oilfield machinery	94.1	114.3	129.2	144.1	143.8	138.2	139.9	141.8
Other commercial (transportation structures[3])	505.5	512.9	522.5	528.6	534.4	542.3	559.7	575.1
Power (not electric)	497.7	512.8	524.8	551.8	533.8	553.4	584.6	629.4
Petroleum and natural gas	1305.4	1401.8	1528	1762.3	1678.8	1590.6	1636.1	1630.3
Air Transportation	34.6	35.7	38	39.9	41.3	44.7	49.2	56.4
Private Assets SubTotal	***3864.4***	***4104.5***	***4366.8***	***4769.9***	***4776.9***	***4786.2***	***4941.6***	***5110.8***
Government Fixed Assets, Cum.	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Transportation	650	684.8	710.4	727.5	740.7	774.2	814.8	861.3
Power	321.2	332.5	343	357.3	366.7	378.4	387.3	403.8
National Defense								
Aircraft	148.8	151.6	158.6	160.1	158.5	164.2	167.6	176.9
Ships	142.1	141.9	144.5	147	149.5	152.2	155.4	160.5
Vehicles	35.5	36.3	32.6	36.6	33.8	33.4	29.9	30.5
Non-Defense								
Transportation	24.9	25.6	25.8	25.6	25.4	26	26.7	27.6
Power	12.3	13.5	14.6	15.9	17.5	18.8	19.6	20.6
State and Local								
Transportation	625.1	659.2	684.5	701.9	715.4	748.3	788.1	833.7
Power	308.9	319	328.4	341.4	349.3	359.6	367.7	383.2
Government Assets SubTotal	***2268.8***	***2364.4***	***2442.4***	***2513.3***	***2556.8***	***2655.1***	***2757.1***	***2898.1***
Total Private and Government Fixed Assets, Cumulative							**TOTAL**	**8,008.9**

Table 2. Legends/Footnotes:

[7] United States, Department of Commerce, Bureau of Economic Analysis. "National Data Fixed Assets Accounts Table." *National Data Fixed Assets Accounts Table*, Bea, 2019. apps.bea.gov/iTable/iTable.cfm?ReqID=10&step=2.

3. Includes transportation structures that are "not elsewhere classified," or n.e.c.

The foregoing estimates derive from the Department of Commerce's Bureau of Economic Analysis[8]. To complement and corroborate these findings, the research team also consulted data from the Department of Transportation, Bureau of Transportation Statistics (BTS). According to the Department of Transportation's most recent BTS study on infrastructure assets[9], Transportation Infrastructure and Other Assets have a current value of about $7.7 trillion. However, this amount includes the value of highways and streets (approximately $3.5T), but does not include the value of infrastructure that is exclusive to the oil and gas industry and dedicated to delivery of hydrocarbons from above (about $3.4T). To obtain a roughly comparable estimate, one arrives at a total asset value of the upstream HC industry and the downstream vehicles and equipment, less roadways and land value, of slightly more than $7.6T. So, taken together, these two Federal sources (DOC and DOT) suggest the replacement value of the subject infrastructure is between about $7.6 trillion and $8.4 trillion[10].

Depending on the timing and phase-out plan, the creation of an energy economy that entirely eliminates the use of fossil fuels in favor of full electrification may conceivably require the forfeiture of a majority of the above sums. That is, unless major assets can be liquidated or depreciated in a gradual and orderly manner, and coordinated with the phase-in of replacement technologies. It should be noted that many conventional assets are not likely to transition into an electricity-based energy economy. Done too rapidly, therefore, the electrification of the entire vehicle fleet could result in not only the loss of trillions of dollars in investment, but could also necessitate a complete renovation of our transportation infrastructure and incur substantial additional investments of a similar order of magnitude. This restructuring would need to encompass the full spectrum of hardware, equipment and IT/OT systems associated with transportation's demand for the generation, transmission and distribution of energy, as well as addressing any traditional associated industries, ranging from gas stations to oilfield machinery.

- Notes:
  - The average lifespan of a US light duty vehicle is about 16 years
  - Major components of HD trucks (i.e., engines) turnover in less than 5 years
  - Aircraft can have lifespans in excess of 30 years
  - EV batteries have an estimated lifespan as original equipment of about 10 years, but in addition to a calendar life, there is importantly, a cycle lifespan component as well.
  - Much traditional electric grid infrastructure has average lifespan of about 28 years, but this can be widely variable, based on the device, application, location and duty cycle.

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[8] and United States, Department of Commerce, Bureau of Economic Analysis. "National Data Fixed Assets Accounts Table." *National Data Fixed Assets Accounts Table*, Bea, 2019. apps.bea.gov/iTable/iTable.cfm?ReqID=10&step=2.

[9] Department of Transportation, Bureau of Transportation Statistics https://www.bts.gov/transportation-economic-trends/tet-2018-chapter-8-infrastructure-assets

[10] Included in this estimate are the following: vehicles (air, ground, maritime), equipment (construction, ag, heavy industry), refineries, pipelines, and other assets dedicated to liquid fuels. Excluded from this estimate are common infrastructure assets (not directly linked to a given energy source), such as roads, bridges, parking areas, ports, airports, and land dedicated to transportation. Sources: [7] and [8]

Hydrocarbon and Transportation Assets as a share of All U.S. Infrastructure

How much is $8T? After having attempted to quantify the value of hydrocarbon and transportation assets, even with heavy qualifications on precision, our research team recognized that such numbers are so large that they require a basis for comparison. Unfortunately, though not surprisingly, the broader the system of interest, the greater the certainty. Obviously then, estimating the asset value of all (non-land related) U.S. infrastructure is an even more complicated endeavor that is subject to greater sources of uncertainty[11]. Nonetheless, one recent study[12] estimates this to be in the ballpark of roughly $37T. So, despite the uncertainty and limitations associated with such estimates, this cumulative U.S. infrastructure $37T benchmark provides useful context for comparing and contrasting rough orders of magnitude for U.S. infrastructure assets allocated to the respective hydrocarbon, transportation, and electric grid sectors.

The Value of the US Grid and Future Electric Vehicle Infrastructure

A full accounting of the cost of all infrastructure required to displace conventional hydrocarbon technologies with fully electrified ones in the U.S. transportation sector (at any point in future time) is beyond the scope of this study. The research team suggests that additional attention to this specific matter would be extremely valuable. Nonetheless, several additional points are worth noting.

First of all, estimates[13] to replace the entire U.S. electric power system, including generation, transmission and distribution are on the order of $4.8T. Anecdotally, estimates suggest that residential charging of a typical U.S. passenger car consumes about the same order of magnitude of delivered electric power as currently consumed by households (i.e., the energy consumption of daily vehicle use is "directionally similar" to the average daily energy consumption of a U.S. household). It should be noted this statement must be heavily qualified, as it will depend on specific attributes of both the home and the driving profile. At any rate, for the purposes of this exercise, it would not be unreasonable to assume that to reach very high electric vehicle penetration rates, a similar order of magnitude investment to the current asset value of the U.S. grid may be needed. Estimates from the same source suggest that the depreciated value of the entire U.S. electrical grid (including generation) is about $2T (ca. 2017). It is noteworthy that building capacity for increased deployment of electric vehicles would incur new capital investments (i.e., more akin to replacement value than depreciated value), and history suggests that the preponderance of early investments are made by private rather than public entities.

Not only would full electrification require large new investments (on the order of 10% of the net worth of all infrastructure), but it could result in stranded assets in the hydrocarbon sector of a similar

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[11] Please see the brief discussion, "A Note on Limitations" at the end of this whitepaper.

[12] Arcadis, 2017. https://gizmodo.com/heres-how-much-americas-infrastructure-is-worth-compar-1739382781

[13] Joshua Rhodes, UT Austin, Energy Institute, ca. 2017, as reported at the 2017 Duke Energy Conference.

order of magnitude (perhaps 20% of the net worth of all infrastructure). This estimated 30% swing represents a non-trivial share of overall U.S. infrastructure.

Finally, the build-out of Electric Vehicle infrastructure is uncertain and extremely complicated to predict. Not least because the required investment, whether for private or government entities is unknown today, and increasingly uncertain in the future. Part of the reason for this is that penetration rates and costs are mutually dependent, as we have witnessed to some degree with recent substantial reductions in battery prices and corresponding increases in new EV sales. However, some experts contend that at low fleet shares (i.e., currently <1% of the US fleet is EV), existing reserve margins and excess capacity of the grid result in minimal substantive issues satisfying marginal additional demand. In addition, large subsidies (e.g., Federal and State tax credits on electric vehicles, rebates on charging equipment, etc.) have accelerated the deployment of EVs. What is less clear is how the future grid will respond when EV shares approach double digits or ultimately a majority of the U.S. fleet, and when or whether such growth can be self-sustained in a financial sense (i.e., not reliant on Federal, state or local subsidization).

Underpinning the uncertainty on delivering adequate electric power, are the costs of charging infrastructure, and the costs of the replacement vehicles themselves. While much data is available on these issues[14,15,16,17,18,19,20], the details are beyond the scope of the present study.

Recap of high-level points specific to EV-related grid infrastructure:

- The current level of EV deployment at <1% of the US fleet can fairly readily be support by excess capacity in the current system;
- However, as deployment reaches high single digits, and in particular when it exceeds 10% locally, each major category of grid infrastructure (i.e., generation, transmission, distribution and charging) is estimated to require a relatively large range of new investment;

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[14] Engel Hauke Engel, et al. "Charging ahead: Electric-vehicle infrastructure demand." *McKinsey & Company*, August 2018, www.mckinsey.com/industries/automotive-and-assembly/our-insights/charging-ahead-electric-vehicle-infrastructure-demand.

[15] Cattaneo, Lia. *Investing in Charging Infrastructure for Plug-In Electric Vehicles.* Center for American Progress, 2018. www.americanprogress.org/issues/green/reports/2018/07/30/454084/investing-charging-infrastructure-plug-electric-vehicles/.

[16] Agenbroad, Josh, and Ben Holland. "EV Charging Station Infrastructure Costs." *Rocky Mountain Institute*, 3 May 2014, cleantechnica.com/2014/05/03/ev-charging-station-infrastructure-costs/.

[17] Lutsey, Nic, and Michael Nicholas. "Update on Electric Vehicle Costs in the United States through 2030." *International Council on Clean Transportation*, June 2019,

[18] Light-Duty Vehicles Sector Baseline ALLIANCE 50X50 COMMISSION ON U.S. TRANSPORTATION SECTOR EFFICIENCY. Alliance to Save Energy , 2018, Light-Duty Vehicles Sector Baseline ALLIANCE 50X50 COMMISSION ON U.S. TRANSPORTATION SECTOR EFFICIENCY, www.ase.org/sites/ase.org/files/ase-50x50-light-duty-vehicles-sector-final.pdf.

[19] Rissman, Jeffrey. "The Future Of Electric Vehicles In the U.S., Part 1: 65%-75% New Light-Duty Vehicle Sales By 2050." *Forbes*, 14 Sept. 2017, www.forbes.com/sites/energyinnovation/2017/09/14/the-future-of-electric-vehicles-in-the-u-s-part-1-65-75-new-light-duty-vehicle-sales-by-2050/#458ef3b5e289.

[20] Davidson, Todd, et al. "Is America's Power Grid Ready for Electric Cars?" *CityLab*, 7 Dec. 2018, www.citylab.com/transportation/2018/12/americas-power-grid-isnt-ready-electric-cars/577507/.

  - This investment is likely to be varied, depending on existing infrastructure and the regional/local penetration of EV;
  - It should be noted that any estimates should be stated as qualified ranges;
  - It remains unclear how these costs should appropriately be allocated. Likely it will be some combination of:
    - direct consumer responsibility (e.g., home EV charging units),
    - utilities (e.g., transmission and distribution upgrades),
    - Federal/state support (e.g., subsidies, tax credits), etc.
  - It is also unclear whether the costs would best be dealt with in the financial analysis as an upfront capital item, or an item that is effectively levelized and included in the per unit cost of electricity;
  - The research team recommends future attention to the implications of existing assets and future infrastructure investments as it relates to the decarbonization of transportation and the grid.

A Note on Limitations

It is clear that any macro-level estimate of the value of U.S. infrastructure is difficult to pinpoint with great precision. This present study is no exception, owing to inherent limitations associated with the estimation of extremely broad asset classes, namely the entire upstream and downstream domestic hydrocarbon/transportation sector, the entire grid, and even the entire set of non-real estate U.S. assets itself. While certain publicly available and/or Federally maintained databases have developed rigorous asset classifications by industry sector, there remains natural uncertainty in the data. Primary sources of uncertainty include differences in reporting protocols, differences in economic assumptions (e.g., the economic year for the reported data, differences in interest rate assumptions, adjustments based on various inflation indices (which can vary by sector), variations on valuation methods applied to new assets, depreciation, useful lifespan, cost of financing, tax implications, rates of foreign exchange, etc.), country of origin of original equipment, delivery cost, location of assets, soft costs associated with equipment installation and commissioning, differences in accounting practices between organizations across both public and private sectors, potential for complex bundling of asset classes (which may unintentionally result in minor instances of missed or double counted assets), and so on. The approaches employed in this study are deemed reasonable and appropriate for the established objectives, namely, the development of rough order of magnitude approximations, baselines and comparisons.

Implications and Concluding Remarks

As it relates to the present study, the research team performed a high-level analysis of the estimated value of public and private infrastructure that is linked directly to liquid hydrocarbon fuels used predominantly for transportation, and the vehicles and other assets that depend exclusively upon them. A reasonable approximation of the current value of these assets will facilitate meaningful techno-economic comparisons between the current baseline (or business as usual assumptions), and future alternative scenarios for transportation energy (e.g., synthetic hydrocarbons, biofuels, electric vehicles, fuel cells, etc.) The infrastructure estimate, then, becomes a critical, if not complex, factor in establishing the viability of a substitute to today's incumbent technologies.