FRANK PALLONE, JR., NEW JERSEY
CHAIRMAN

CATHY McMORRIS RODGERS, WASHINGTON
RANKING MEMBER

ONE HUNDRED SEVENTEENTH CONGRESS

Congress of the United States
House of Representatives

COMMITTEE ON ENERGY AND COMMERCE
2125 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6115

Majority (202) 225-2927
Minority (202) 225-3641

July 1, 2021

Dr. Amol Phadke
Staff Scientist and Deputy Department Head, International Energy Analysis Department
Lawrence Berkeley National Laboratory
Affiliate and Senior Scientist, Goldman School of Public Policy,
University of California Berkeley
1 Cyclotron Road
Berkeley, CA 94720

Dear Dr. Phadke:

Thank you for appearing before the Subcommittee on Energy on Wednesday, May 5, 2021, at the hearing entitled "The CLEAN Future Act: Driving Decarbonization of the Transportation Sector." I appreciate the time and effort you gave as a witness before the Committee on Energy and Commerce.

Pursuant to Rule 3 of the Committee on Energy and Commerce, members are permitted to submit additional questions to the witnesses for their responses, which will be included in the hearing record. Attached are questions directed to you from a member of the Committee. In preparing your answers to these questions, please address your response to the member who has submitted the questions in the space provided.

To facilitate the printing of the hearing record, please submit your responses to these questions no later than the close of business on Friday, July 16, 2021. As previously noted, this transmittal letter and your responses, as well as the responses from the other witnesses appearing at the hearing, will all be included in the hearing record. Your written responses should be transmitted by e-mail in the Word document provided to Lino Peña-Martinez, Policy Analyst, at Lino.pena-martinez@mail.house.gov. To help in maintaining the proper format for hearing records, please use the document provided to complete your responses.

Thank you for your prompt attention to this request. If you need additional information or have other questions, please contact Lino Peña-Martinez, with the Committee staff at (202) 225-2927.

Sincerely,

Frank Pallone, Jr.
Chairman

Attachment

cc: The Honorable Cathy McMorris Rodgers
Ranking Member
Committee on Energy and Commerce

The Honorable Bobby L. Rush
Chairman
Subcommittee on Energy

The Honorable Fred Upton
Ranking Member
Subcommittee on Energy

Attachment—Additional Questions for the Record

Subcommittee on Energy
Hearing on
"The CLEAN Future Act: Driving Decarbonization of the Transportation Sector."
May 5, 2021

Dr. Amol Phadke, Staff Scientist and Deputy Department Head, International Energy Analysis, Department Lawrence Berkeley National Laboratory, Affiliate and Senior Scientist, Goldman School of Public Policy, University of California Berkeley

The Honorable Kathy Castor (D-FL)

1. Dr. Phadke, the 2035 Transportation Report finds that there are "no insurmountable barriers" to significant scale-up of EV supply chains. It also highlights the potential for recycling to improve materials efficiency and create jobs. **How can investments in materials R&D and recycling infrastructure strengthen battery and EV supply chains? What is the current state of EV battery recycling infrastructure in the U.S., and what investments can we make to ensure that battery materials are recovered and reused efficiently?**

RESPONSE:

Investments in materials R&D and recycling infrastructure can play a critical role in strengthening battery and EV supply chains.

- **The US Department of Energy (DOE) has recently outlined A National Blueprint for Lithium Batteries which makes a clear case of how investments in materials RD&D and recycling infrastructure strengthen battery and EV supply chains. On materials RD&D, this blueprint states:**
  The pipeline of R&D, ranging from new electrode and electrolyte materials for next-generation lithium-ion batteries, to advances in solid-state batteries, and novel material, electrode, and cell manufacturing methods ***remains integral to maintaining U.S. leadership.*** *The R&D will be supported by strong IP protection and rapid movement of innovations from lab to market through public-private R&D partnerships such as those established in the semiconductor industry. Further three specific goals have been identified for materials RD&D to support strengthening battery supply chains. They include 1. Support the development of materials processing innovations to produce cobalt- and nickel-free active materials and enable scale up 2. Develop cobalt- and nickel-free cathode materials and electrode compositions that improve important metrics*

such as energy density, electrochemical stability, safety, and cost and outperform their current commercial, imported counterparts 3.Accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including solid-state and Li-metal, that achieve a production cost of less than $60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free.

- **Cost-effective battery recycling is a promising way to secure raw materials, reduce waste, and create high-quality jobs**. One study suggests that 15 jobs are created to recycle every 1,000 metric tons of end-of-life lithium-ion batteries (Akram, 2020). Multiple systems and processes already exist to recover rare earth metals from used batteries. Battery recycling will be especially important for the United States as it achieves high-volume EV manufacturing in the 2020s and 2030s. The United States could meet about 30%–40% of anticipated demand for lithium, nickel, manganese, cobalt, and graphite in passenger EVs with recycled battery materials by 2035 (Reichmuth 2019). In order to achieve this future, investments in materials R&D and recycling infrastructure must be made.
- **We can see the effectiveness of these investments in the case of China and their current domination of the EV market.** To date, China is the only country with a dedicated vehicle battery recycling policy (Reichmuth 2019). This outcome was a result of China's focus on building capacity at every stage of the battery and EV supply chain. China used their NEV credits towards the promotion of battery recycling infrastructure and supported the burgeoning market of battery recycling and materials R&D through a series of subsidies and incentives for newly formed battery companies.
    - This investment has made China the leader in battery recycling, and also strengthened their domination of material processing and battery production.
    - As of 2019, China recycled around 67,000 tons of lithium-ion batteries or 69 percent of all the stock available for recycling worldwide.
- Material development and recycling infrastructure are critical components of EV supply chains, and investments made in them allow a market ecosystem to develop in which the pace of EV innovation is accelerated.
- The current state of EV battery recycling infrastructure is relatively nascent. This is a result of the United States' broader lag in the development of a global lithium-ion battery production market with China standing at 75% of total capacity, per a Wood Mackenzie report.
- In June, DOE announced new policy actions to scale up domestic battery manufacturing and technology supply chains. These actions include strengthening US manufacturing requirements around battery production, the development of a national blueprint for domestic advanced battery supply chains, financing for battery manufacturers, and federal procurement of stationary battery storage. However, these plans do not outline specific investments to enhance the United States' battery recycling capacity.

- Recycling battery materials is a critical pathway for American companies to stay competitive in a tightening global supply chain and develop a larger stake in the battery materials market. China currently has over 80% of the world's lithium refining capacity, over 60% for cobalt, and more than a third of global nickel refinement according to the same Wood Mackenzie report.
- American companies and research labs have recognized this need and are already working to develop domestic recycling technology and facilities. General Motors is investing in raw material recovery through recycling and reuse of their excess scrap.
  - **GM has partnered with battery maker Ultimatum and battery recycling company Li-Cycle to use hydrometallurgy[1] to derive cobalt, lithium, nickel, and other useful materials for battery production**. Li-Cycle has stated that 95% of the repurposed scrap material can be used in the production of new batteries.
  - **Other American companies include Redwood Materials which takes Tesla batteries that do not meet quality standards and through a combination of pyrometallurgical[2] and hydrometallurgical processes, repurposes the battery into lithium carbonate, cobalt sulfate, and nickel sulfate**.The company said it can recover between 95-98% of a battery's nickel, cobalt, copper, aluminum, and graphite, and over 80% of its lithium.
- **DOE's Argonne National Laboratory is leading the ReCell center, a program dedicated to finding ways to improve lithium-ion recycling techniques.**
  - A key goal of the center is the support of direct recycling. Rather than smelting or breaking down the materials with acid, direct recycling allows components from the battery with complex nanostructures to be reused. That way, raw materials do not have to go through a costly step in being processed back into usable components. The processes for direct recycling have worked in lab trials, but a scalable economic model has yet to be developed.
- **Government support and investment in burgeoning technologies like the ones mentioned here will give the United States a competitive edge in terms of a more efficient battery recycle and reuse industry.**

---

[1] Hydrometallurgy is the less common approach to recycling but initial results showcase it as the more sustainable option. The process involves soaking the battery cells in acids to dissolve the metals into a solution. This causes a higher amount of useful materials to be drawn out, including lithium. The process is more involved than smelting, and requires the recycler to reprocess the cells, removing plastic casings and draining the charge on the battery.

[2] Pyrometallurgy involves burning batteries to remove unwanted organic materials and plastic. This process produces a fraction of the original material, leaving behind copper, or some nickel and cobalt from the cathode. It is done in a fossil-fuel powered furnace, and a lot of aluminum and lithium are lost in the process. This process is not efficient from an energy and materials standpoint but pyrometallurgical smelters are commonland are ready to take on the rising supply of end-of-life batteries.

2. Dr. Phadke, the pandemic has been a powerful and tragic reminder of the importance of equitable access to clean air for all Americans. Studies have shown that exposure to air pollutants increases the risk of severe impacts, including death, from COVID-19. What are the health and environmental benefits of transportation electrification? Who is most impacted by transportation-related pollution, and how can Congress ensure that these communities are among the first—not the last—to benefit from electrification?

RESPONSE:

What are the health and environmental benefits of transportation electrification?

- Our study finds that accelerating EV adoption would save 150,000 premature deaths and avoid $1.3 trillion in health and environmental damages between 2020 and 2050.
- Gasoline- and diesel-powered vehicles harm human health and the environment via emissions of pollutants such as fine particulate matter, nitrogen oxides, and sulfur oxides as well as greenhouse gas emissions that contribute to climate change. These emissions disproportionately impact low-income communities, communities living close to the highways, and communities of color. Ensuring a 90% clean grid by 2035, would avoid additional 85,000 premature deaths and over $1.7 trillion in health and environmental damages between 2020 and 2050.
- Vehicle electrification and grid decarbonization also contributes to the DRIVE Clean scenario's combination of accelerated EV sales, a 90% clean electricity grid, and additional electrification of buildings and industry results in 45% economy-wide GHG emissions reductions by 2030, relative to 2005 levels.

Who is most impacted by transportation-related pollution, and how can Congress ensure that these communities are among the first—not the last—to benefit from electrification?

- African American, Latino, and low-income households in California are exposed to 43%, 39%, and 10% more $PM_{2.5}$ pollution, respectively, than white households (Reichmuth 2019). Broadly speaking, communities of color face higher risk from particulate pollution, and living or working near highways or heavy traffic is particularly risky (ALA 2020). Thus the health benefits of transport electrification would notably benefit low-income communities and communities of color, where vehicle pollution is worst.
- There are several strategies that could enhance access to affordable electric vehicles and charging infrastructure to communities affected by vehicular air pollution. The strategies could include higher economic incentives / subsidies / tax rebates for low-income households, subsidizing public charging infrastructure and EV charging prices in low-income / frontline communities, prioritizing electrification of heavily trafficked highway

/ freight routes that pass through affected communities by supporting truck charging infrastructure and subsidizing electricity prices etc.

- Heavy-duty trucks contribute a disproportionate share of vehicle emissions. They constitute only 5% of U.S. on-road vehicles but are responsible for 36% of particulate emissions, suggesting that electrifying trucks can have an outsized influence on emissions and human exposure to pollutants (Kodjak 2015). As such, it is important to prioritize electrification of freight corridors that run directly through these communities.
- Similarly electrification of diesel trains and inland ships should be a priority. Near elimination of air pollution from diesel electric trains by 2025-2030 is technically feasible at net costs nearing zero by retrofitting them with battery tender cars. This new opportunity is created by recent dramatic declines in battery prices and renewable electricity rates that were seldom anticipated just a few years ago (see Popovich et al 2021, forthcoming). Converting the existing 24,000 freight locomotives to battery electric will: Eliminate NOx and PM emissions from the sector, saving 19,013 lives in disadvantaged communities (by 2050 over BAU; Generate ~250 GWh of mobile batteries that can be deployed to the grid during extreme events; Avert up to 1 billion metric tons CO2; Achieve net cost savings of $204 billion.
- For most individuals and businesses, the ability to utilize EV incentives hinges on their ability to access fair financing. **Traditional financing options are not readily available to those with lower incomes, poor or no credit, and high debt-to-income ratios.** In addition, communities of color, the elderly, and low-income households are often targeted by predatory lenders and face disproportionate financial discrimination.
- The push to achieve an electrified transportation future creates a growing need for new financing models and innovative funding programs that significantly expand consumer and business access to EVs (and other clean energy and clean transportation options). These include green banks, community developed financing institutions (CDFI), microfinance, tariff-based financing, and sustainable capital ventures.
- Where they exist, they can and should be leveraged to maximize the impact of any incentive programs. Working alongside policymakers, the financial sector, private businesses, and utilities are key to developing and implementing workable financing options that meet the needs of more consumers and businesses and in particular those communities that face structural hurdles to financial access can be supported by federal, state and local governments in creating access to EVs.
    - An example of this can be seen with California's Clean Cars 4 All Program which supports lower-income consumers in acquiring cleaner technology vehicles by retiring their older, higher-polluting vehicles and upgrading to a cleaner vehicle or an alternative mobility option of their choice. This program has been recently expanded by Governor Gavin Newsom in the latest CA budget in order to center frontline communities in California's ambitious ZEV sales targets.

- Other barriers to entry for frontline communities in accessing EVs include lack of charging infrastructure investment in disadvantaged communities which makes the purchase of an EV particularly unrealistic for these communities.
  - Prioritizing federal investment in **<u>public fast charging</u>** in these communities can also ensure more equal opportunities for purchasing.
  - Incentives for buildings, in particular apartment buildings, to provide fast charging.
  - Prioritizing electrification of freight corridors that run directly through these communities.

3. Dr. Phadke, President Biden says that when he thinks about solving the climate crisis, he thinks about jobs. That's how Democrats in Congress view it too, especially as we work toward a pollution-free transportation sector. In your testimony, you say that electrifying the transportation sector will create jobs across the economy. What types of jobs will be created by Federal investments in electrification and where could they be located? The 2035 Transportation Report also considers the falling cost of EVs. Do you expect that consumers will save money by buying EVs?

RESPONSE:

What types of jobs will be created by Federal investments in electrification and where could they be located?

- Though economic recovery seems just within reach, major sectors of the U.S. economy remain devastated by the COVID-19 pandemic. Already with the American Rescue Plan Act of 2021, substantial resources have been allocated to help individuals, families, and businesses. Enacting policies that rapidly electrify America's transportation sector present an opportunity to put more Americans back to work, and put more money back into consumers' pockets.
- **The DRIVE Clean scenario, where EV's constitute 100% of new vehicle sales by 2035, supports consistent job gains during 2020-2035, peaking at over 2 million jobs in 2035.** These employment gains are mostly induced jobs (1.4 million), spurred by $1 trillion in consumer savings that the electric vehicle transition will bring by 2035. Assuming the same unionization rates by industry today, in 2035 union jobs will increase by 276,000, while non-union jobs will increase by 1.8 million.
- The direct job impacts due to vehicle electrification are also positive overall. Altogether, gains in direct electricity and fuel sector jobs in 2035 (790,000) offset direct job losses in the auto sector (483,000). In 2035, job gains caused by the push to achieve a 90 percent clean electricity system with significant load growth are concentrated in construction (228,000), electrical equipment (105,000), and electricity delivery (197,000), and should be relatively evenly distributed among states as investment in clean electricity is ubiquitous. Direct impacts in auto manufacturing remain relatively unchanged.
- After 2035, net-job impacts of vehicle electrification remain positive but start to decrease due to stable renewable build-out rates and decreasing power sector and vehicle operation and maintenance costs, though any job figures after 2035 remain highly uncertain.

The 2035 Transportation Report also considers the falling cost of EVs. Do you expect that consumers will save money by buying EVs?

- Consumers save substantially on electric vehicle ownership due to decreased repair costs. However, reduced vehicle maintenance has a negative impact on jobs in vehicle repairs.
- Historically, EV sales have been hindered by two consumer-cost disadvantages: the total cost of ownership (TCO) and upfront prices of EVs have both been high in relation to internal combustion engine (ICE) vehicles.
- Our results show, however, that electric heavy-duty trucks already hold a TCO advantage today, and light-duty EVs will overtake ICE vehicles in TCO terms within 5 years (Figure 1).
- In addition, light-duty EVs will reach upfront price parity with their ICE counterparts in the mid to late 2020s, while electric HDTs will approach upfront price parity with diesel trucks in the mid to late 2030s.
- Significant barriers remain, but the total consumer cost savings and societal benefits of accelerated vehicle electrification are staggering. Achieving 100% electrification of new vehicle sales puts the United States on a 1.5°C pathway for economy-wide decarbonization while yielding substantial human health and environmental benefits and saving consumers $2.7 trillion in vehicle spending – approximately $1,000 in household savings each year – over the next 30 years. If light-duty vehicle electrification is delayed to 2035 in accordance with many currently proposed transportation electrification goals, we leave significant cost savings on the table.

Figure 1. TCO for EVs (bars) vs. ICE vehicles (lines), showing TCO parity achieved by 2023 for LDVs (left and center) and an existing TCO advantage for HDTs (right). Upfront costs include taxes. Maintenance costs of EVs include battery replacement cost.

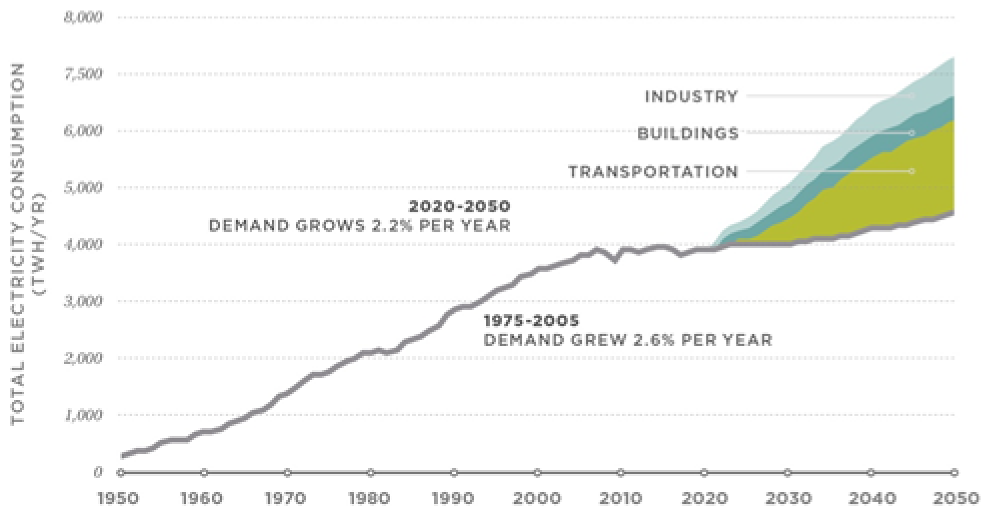
4. Dr. Phadke, I am working on legislation to help upgrade and expand our electric grid to bring affordable clean energy to more homes across America and to support electrification in transportation, buildings, and other sectors. **What kinds of grid upgrades will be needed to support EV infrastructure build-out and the goal of 100% electric vehicle sales by 2035?**

RESPONSE:

- By 2035, 100% new vehicle sales electrification, coupled with a 90% clean electricity generation target, would require a significant change in the composition of U.S. electricity supply and demand, with wind, solar, hydro, and nuclear making up 90% of supply (up from about 40% in 2020), and demand increasing by about 35% over 2020 levels. The electricity demand would increase by over 70% by 2050.
- While such demand increase is significant, it is not historically unprecedented. Between 2020 and 2050, we find that the combined demand growth due to vehicle, buildings, and industrial electrification would be approximately 2% per year, consistent with the 2.6% average historical growth in the electric sector during 1975–2005.
- To ensure a 90% clean grid and meet the additional electricity demand, about 110 GW of wind and solar energy capacity needs to be installed annually (Figure 2). This also requires about 30 GW (190 GWh) of battery storage (2- to 10-hour batteries) each year. For reference, the United States installed around 31 GW of new utility-scale renewable capacity in 2020, despite the pandemic (SEIA 2021; ACP 2020). This ambitious target will require strong policy support, but it is not unprecedented internationally. China installed 120 GW of wind and solar capacity in 2020 (Murtaugh 2021). We find that the average electricity generation cost in 2035 would actually be slightly lower than 2020 electricity costs owing to the steep renewable energy cost reductions and higher system utilization enabled by increased electrification. The benefit derives from the complementary load profiles of different types of EV charging and electric loads in the building sectors—electricity use is higher due to electrification, but it is more evenly distributed across seasons. Finally, we find that even with additional electric loads, the 90% clean grid is dependable without coal plants or new natural gas plants through 2035.
- In 2035, the additional electricity demand is dominated by EV charging (Figure 4). Public chargers are primarily used during the day and home chargers in the evening, helping to smooth the electricity demand across all hours of the day. Small load increases from building electrification occur mostly in winter due to space heating. The higher winter load results in more efficient renewable energy use, because net peak load occurs in summer, with significant renewable energy curtailment in winter and spring. The

higher winter load reduces renewable energy curtailment in those months, which also reduces the need for battery capacity.

- Distribution grids will require upgrades to support increasing electric loads from vehicle charging. We find that two types of distribution system upgrades would be required: primary distribution costs such as distribution transformers and feeder lines driven by coincident peak EV charging (coincident peak load); and secondary distribution costs such as lines connecting distribution transformers to homes, driven by the interconnection of EV chargers (connected load). We find that annual revenue requirements for distribution system upgrades range from $0.7 to $2.8 billion per year by 2035 and $2.8 to $20 billion per year by 2050. Even at the high end, this is a fraction of the $162 billion of annual distribution revenue requirement projected for 2050 by the 2021 Annual Energy Outlook. Additionally, the added EV charging load would actually reduce average $/kWh distribution rates. The 2021 AEO projects a national average distribution cost of $0.03397/kWh based on retail sales of 4,748 TWh in 2050. We find that end-use electrification would result in an average distribution rate of $0.03221/ kWh, a reduction of $0.0018/kWh or 5%. Furthermore, simple managed charging solutions such as time of use (TOU) rates could reduce distribution costs by 50% or more. Note that the key drivers of distribution upgrade costs vary widely and are location-specific, so such nationwide estimates are necessarily approximate.
- Increased electrification and pervasive renewable energy and battery storage deployments require investments mainly in new transmission spurs connecting renewable generation to existing high-capacity transmission. While massive renewable energy investments require about three times more spurline investment compared with a No New Policy (baseline) scenario, the total transmission investments add only 0.2 cents/kWh to the total system costs. Recent studies that account for low renewable energy and battery storage costs indicate similar findings (Jayadev et al. 2020). Studies that assume much higher renewable energy costs or do not consider substantial battery storage find higher levels of additional bulk transmission are required (Clack et al. 2017, NREL 2012). Further work is needed to understand transmission needs more precisely.



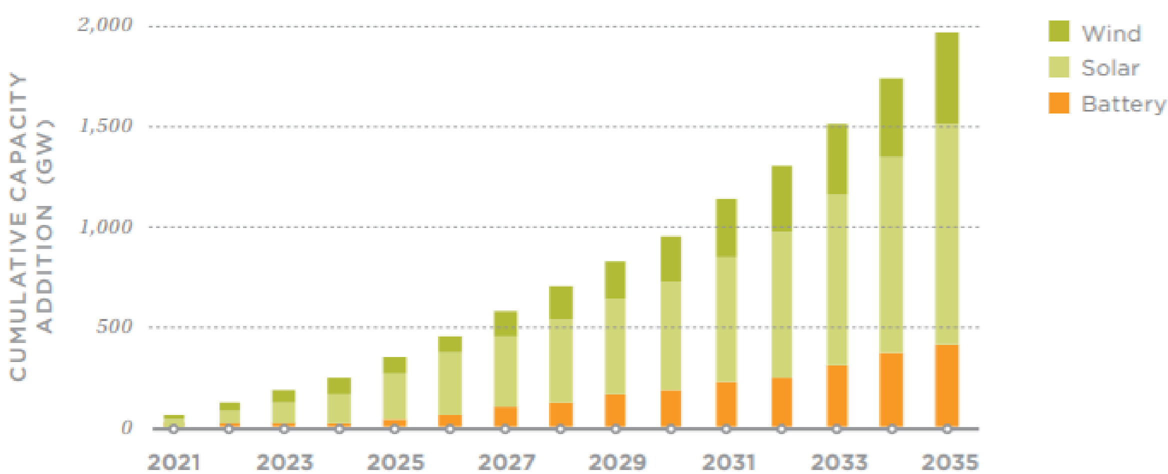


Figure 2. Average annual U.S. electricity demand growth, 2020–2050 (top) and average U.S. renewable energy capacity additions necessary to support the DRIVE Clean scenario, compared to projected renewable energy capacity additions in the United States through 2035 (bottom). The United States must add approximately 110 GW of new wind and solar each year through 2035.

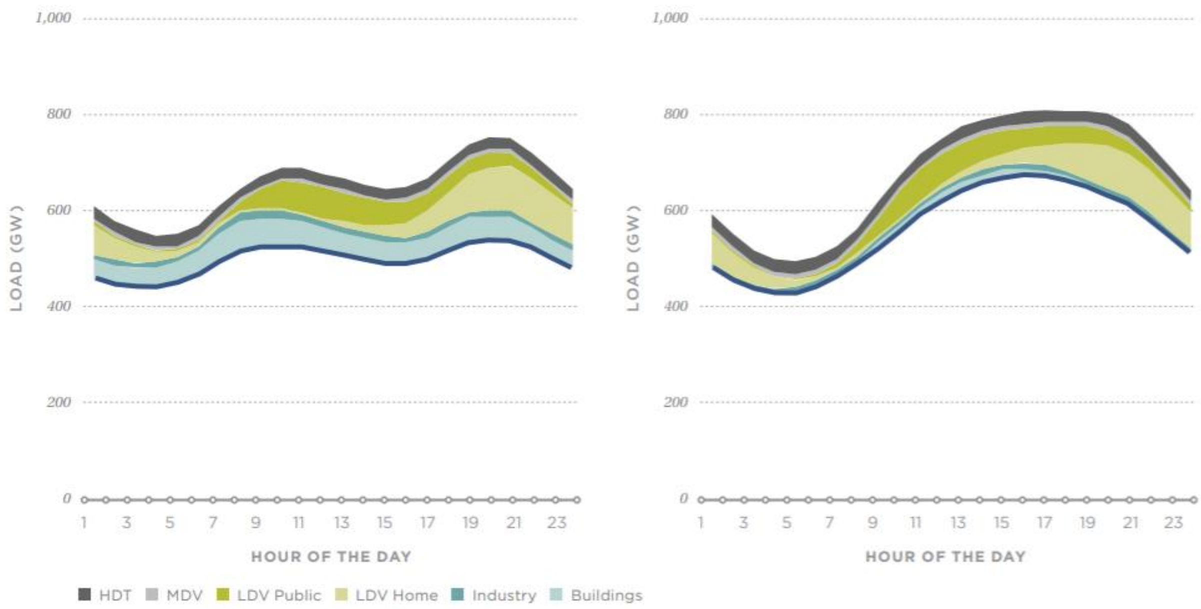


Figure 3. Average hourly load profile in the DRIVE Clean scenario during January (left) and July (right), 2035. The baseline load (with no additional electrification) is shown by the black line, while the areas in color show the additional load due to electrification of each end-use.