Preparing for Future Truck Operations

MID-AMERICA FREIGHT COALITION

Fleet Electrification and Alternative Fuels

Authors

Anupam Srivastava
University of Wisconsin–Madison

Ernest Perry
Co-Principal Investigator
University of Wisconsin–Madison

Soyoung Ahn
Co-Principal Investigator
University of Wisconsin–Madison

About the Mid-America Freight Coalition (MAFC)

The industries and farms of the Mid-America region can compete in the marketplace only if their products can move reliably, safely and at reasonable cost to market.

State Departments of Transportation play an important role in providing the infrastructure that facilitates movement of the growing amount of freight. The Mid-America Freight Coalition was created to support the ten states of the Mid America Association of State Transportation Officials (MAASTO) region in their freight planning, freight research needs and in support of multi-state collaboration across the region.

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This project provides an assessment of factors influencing the implementation of electrification of large trucks on major freight corridors in the MAASTO region. The project will provide agencies and decision makers with information to help develop freight electrification plans and policy in the MAASTO region that will support continued economic development, efficient freight movement and decarbonization of freight transportation.		
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CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. INTRODUCTION

The adoption and integration of alternative fuels within the logistics sectors, and especially the trucking sector, will require new administrative and operations policies, infrastructure, investments, and agency operations. This technological change within transportation is increasing in speed and scope and will continue to challenge the status quo in infrastructure design, operations, and maintenance, as well as in freight operations, policy, and administrative areas.

There is the potential that alternative fuels will render traditional truck operations, regulatory statutes, and planning frameworks antiquated. Effective planning will require new data, potentially different concepts of operations, new guidance and regulation, and potentially different expectations.

Project Objective

The purpose of this project is to provide a review and synthesis of the state of the practice in the development of alternative fuels, predominantly electrification. While alternate candidate fuels for commercial truck operations were researched, the project focuses on understanding the relationship between the development of electrification, commercial truck operations, and the planning, program, and policy functions of state transportation agencies. Further, the project addresses only electrification for commercial trucks on major regional freight corridors and does not consider urban settings or servicing personal vehicles.

Current electric vehicle (EV) directives focus on developing a charging network for light vehicles. The National Electric Vehicle Infrastructure (NEVI) Formula Program authorized under Paragraph (2) under the Highway Infrastructure Program provides funding to plan and establish this nationwide charging network. While logistics and the freight sector are considered as stakeholders, the unique challenges of implementing a charging network for heavy trucks presents a path to adoption much different than with passenger vehicles. Due to freight factors such as parking space limitations, driver hours of service, and charging characteristics of freight vehicles, a strategic approach to implementing charging stations is required.

Scope of Work

The intent of the project was to generate and assimilate information to understand truck operations and alternate fueling needs in relation to freight corridors and freight operations. As EV technology and the resulting operations patterns evolve, agencies can be better prepared to customize planning, programs, operations, and facilities in support of the electrification of freight movement.

The study was carried out through two main tasks described below.

Task 1

In **Task 1**, focus areas are identified and summarized to assess the state of the practice, the trajectory, and the potential futures with electrification of long haul, intercity, and regional freight movements on major regional freight corridors. The focus areas include:

- An overview of competing alternate fuels, costs, environmental tradeoffs, market feasibility, and trajectory based on existing research, testing, and practice.
- A review of the federal perspective, federal programs, and trajectory with alternate fuels.
- Identification and review of industry interests, trials, advocacy, and challenges.
- A review of state DOT activities, programs, research, legislation, and policy addressing alternate fuels.
- A review of activities, the focus, and trajectory of alternate freight fuels in the EU.

The synthesis of these focus areas provides a foundation to understand and plan for the evolving EV environment and its nexus with freight policy, planning, operations, and facilities. The project also importantly provides insight and an understanding of the unique factors associated with alternate fuel usage in heavy trucks.

Task 2

In **Task 2**, the information synthesized through a review of the alternate fuel sector, along with the characteristics of their implementation, is applied to the electrification goals for long haul trucks on major freight corridors. This allows for identification of opportunities as well as constraints to the implementation of electric freight vehicles on these corridors.

Given longer charging cycles, electrification of heavy commercial vehicles is inherently linked to truck parking availability and locations to allow for the overlap of charging and Hours of Service (HOS) regulations. The length of charge cycles and charging station availability could impact driver hours of service, and result in unexpected demand at available charging locations.

To understand the range of factors agencies must consider, meetings were conducted with MAASTO CAV and EV committees, MAFC representatives, and invited representatives from traffic operations, facilities, and maintenance groups across the MAASTO states. Points of major discussion during the process included revenue recovery strategies currently employed or considered by the MAASTO states, and weight considerations for Battery Electric Vehicles (BEVs) as they impact truck weights and permitting. Finally, a discussion is presented on the potential adoption and implementation strategies for BEVs versus Hydrogen Fuel Cell Electric Vehicles (FCEVs).

Organization of the Report

The report is organized as follows:

- Chapter 2 presents an overview of the current state of affairs in alternate fuels.
- Chapter 3 outlines key considerations for freight electrification in the region.
- Chapter 4 provides a summary discussion designed to raise awareness of electrification of large trucks on major freight corridors.

2. REVIEW OF WORK

Competing Alternative Fuels

More than a dozen alternative fuels are in production or under development for use in alternative fuel vehicles and advanced technology vehicles. Government and private-sector fleets are the primary users for most of these fuels and vehicles, but individual consumers are increasingly interested in them. Using alternative fuels, including electricity, along with advanced vehicles supports fuel conservation and reduced emission goals. The Alternative Fuels Data Center hosted by the U.S. Department of Energy provides information for various alternative fuels [1]. Figure 1 shows national maps of accessibility to various public alternative fuel recharging/refueling stations. In addition to these, there are also various private recharging/refueling stations across the country.

Alternative Fuels

Biodiesel

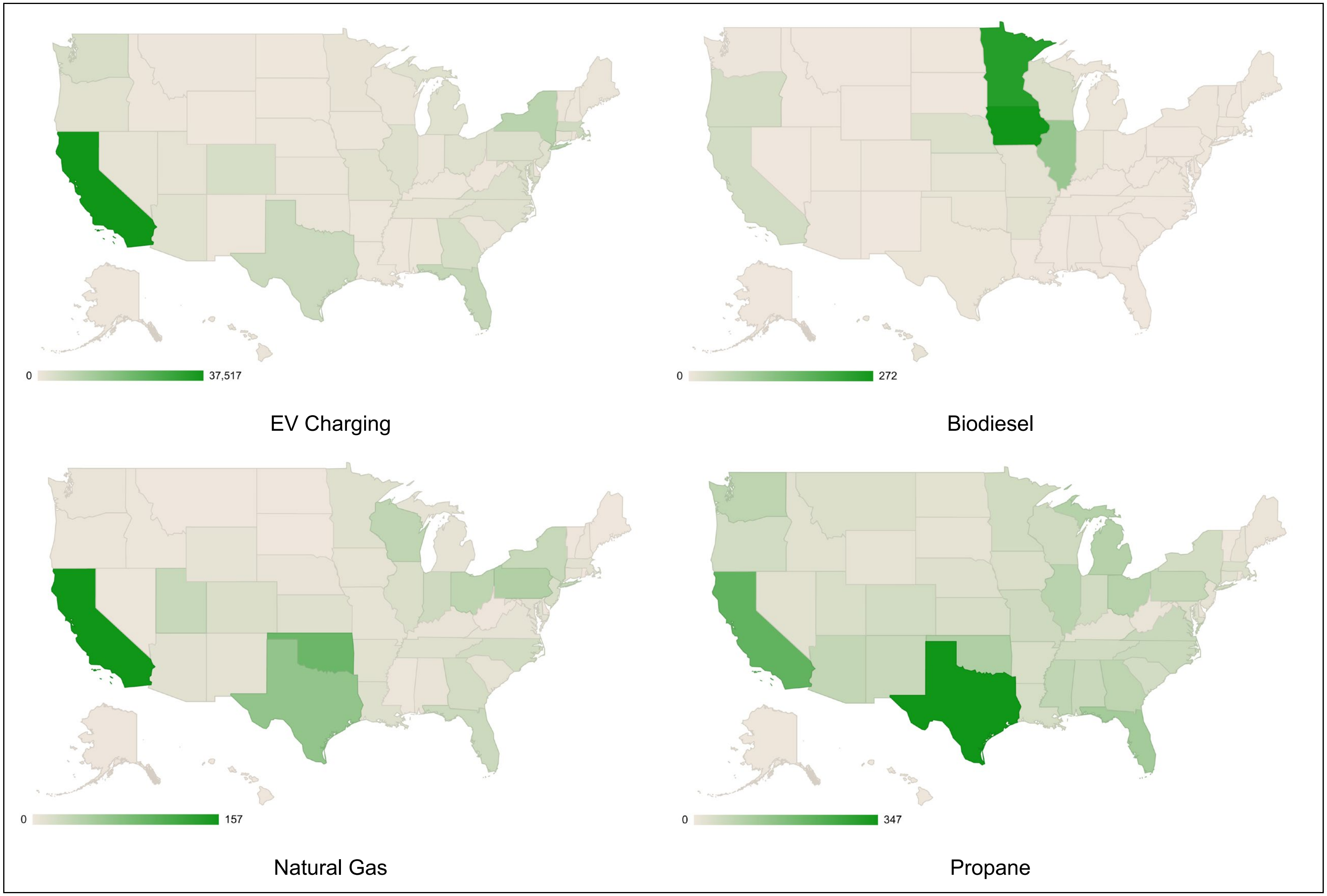
Biodiesel is a renewable fuel derived from vegetable oils, recycled cooking grease, and/or animal fats generated as waste products. Biodiesel behaves similar to regular diesel and releases less carbon dioxide. Usage of biodiesel also reduces life cycle emissions as the carbon dioxide ($CO2$) released from biodiesel combustion is partially offset by the carbon dioxide absorbed from growing soybeans or other feedstock used to produce the fuel. Studies have suggested that biodiesel reduces lifecycle carbon dioxide emissions by up to 74 percent. It is, however, more expensive and much less commonly available than standard diesel. Biodiesel meets ASTM D6751 and is approved for blending with petroleum diesel.

In the MAASTO region, biodiesel refueling stations are widely available in Iowa (272 stations), Minnesota (245 stations), and Illinois (104 stations). There are also multiple stations in Wisconsin (23), Missouri (14), Kansas (12), Indiana (8), Michigan (4). There is currently 1 biodiesel fueling station in Ohio and none in Kentucky.

Renewable Diesel

Renewable diesel is a fuel made from fats and beans, such as soybean oil and canola oil, and is processed to be chemically identical to petroleum diesel. It meets the ASTM D975 specification for petroleum in the U.S. and EN 590 in Europe. Being chemically identical to petroleum diesel, renewable diesel can be used both as a replacement fuel or blended with petroleum diesel in any ratio desired. Renewable diesel is produced and sold primarily in California due to economic benefits under the Low Carbon Fuel Standard. It has significant carbon dioxide reduction benefits, compared to diesel, when considering well-to-wheel lifecycle emissions from the production of the fuel.

Figure 1: Alternative Fuels – Public Recharging / Refueling Stations Accessibility (source: [1]).



Natural Gas

Natural gas is an odorless, gaseous mixture of hydrocarbons, predominantly made up of methane (CH4). It accounts for about 30 percent of total energy used in the U.S. About 40 percent of the fuel goes towards electric power production and the remaining is split between residential and commercial uses. Although natural gas is a proven reliable alternative fuel that has long been used to power natural gas vehicles, only about 0.2 percent is used for transportation fuel.

Two forms of natural gas are currently used in vehicles: compressed natural gas (CNG), and liquified natural gas (LNG). Both are produced domestically, commercially available, and provide low-cost alternatives.

Compressed Natural Gas (CNG)

CNG is produced by compressing natural gas to less than 1 percent of its volume at standard atmospheric pressure. CNG is typically stored onboard a vehicle in a compressed gaseous state at a pressure of up to 3,600 pounds per square inch (psi). CNG is used in light-, medium-, and heavy-duty applications. CNG is used in more than 175,000 vehicles in the U.S. Lifecycle carbon dioxide emissions of CNG can be up to 30 percent lower than diesel.

Liquified Natural Gas (LNG)

LNG is natural gas in its liquid form. LNG is produced by purifying natural gas and super-cooling it to -260°F to turn it into a liquid. During the process known as liquefaction, natural gas is cooled below its boiling point, removing most of the extraneous compounds found in the fuel. The remaining natural gas is primarily methane with small amounts of other hydrocarbons.

Because of LNG's relatively high production cost, as well as the need to store it in expensive cryogenic tanks, the fuel's use in commercial applications has been limited. LNG is more suitable for class 7 and class 8 vehicles that require longer ranges because liquid is denser than gas and, therefore, more energy can be stored by volume.

Access to natural gas refueling stations varies by state in the MAASTO region with 5 stations in Kentucky, 6 each in Michigan and Missouri, 7 in Iowa, 11 each in Kansas and Minnesota, 15 in Illinois, 23 in Indiana, and 34 each in Ohio and Wisconsin.

Liquified Petroleum Gas (LPG) or Propane

Liquified Petroleum Gas (LPG) or “propane” is a cleaner burning alternative fuel. Propane is a three-carbon alkane gas (C3H8). Propane contains about 27 percent less energy than gasoline but has a higher octane rating that can result in improved performance and better fuel economy. It is stored in tanks under pressure as a liquid and vaporizes into a gas for the combustion cycle. Propane is produced as a by-product of natural gas processing and crude oil refining.

Propane is accessible across the region with 18 public fueling stations in Kentucky, 33 in Iowa, 37 in Kansas, 47 in Minnesota, 49 in Indiana, 50 in Wisconsin, 52 in Missouri, 82 in Illinois, 87 in Ohio, and 88 in Michigan.

Ethanol

Ethanol is a renewable fuel made from various plant materials collectively known as "biomass." More than 98 percent of U.S. gasoline contains ethanol to oxygenate the fuel. Typically, gasoline contains E10 (10 percent ethanol, 90 percent gasoline), which reduces air pollution.

Ethanol is available as E85 (or flex fuel), which can be used in flexible fuel vehicles, designed to operate on any blend of gasoline and ethanol up to 83 percent. Another blend, E15, is approved for use in model year 2001 and newer light-duty vehicles.

Hydrogen / Fuel Cell Electric Vehicles (FCEVs)

Hydrogen, when used in a fuel cell to provide electricity, is a zero tailpipe emissions alternative fuel produced from diverse energy sources, emitting only water from the tailpipe. Although the market for hydrogen as a transportation fuel is in its infancy, government and industry are working toward clean, economical, and safe hydrogen production and distribution for widespread use in FCEVs. Light-duty FCEVs are now available in limited quantities to the consumer market in localized regions domestically and around the world. The market is also developing for buses, material handling equipment (such as forklifts), ground support equipment, medium- and heavy-duty trucks, marine vessels, and stationary applications.

Hydrogen is abundantly available in the environment, as water (H2O), hydrocarbons (such as methane), and other organic matter. However, efficiently extracting hydrogen as a fuel from these compounds presents a challenge and is still under development. Currently, steam reforming accounts for the majority of the hydrogen produced in the U.S., with electrolysis as a second popular process being developed. Electrolysis uses water to produce hydrogen and is more energy intensive but can be done using renewable energy, such as wind or solar, and avoiding the harmful emissions associated with other kinds of energy production.

Hydrogen is typically classified as green, blue, or gray hydrogen depending on the extraction process. Green hydrogen, also sometimes referred to as Renewable Hydrogen, is obtained from renewable sources and is considered totally clean. Blue and gray hydrogen are extracted from natural gas, thus not reducing energy dependance on fossil fuels. Blue hydrogen involves capturing and storing the carbon dioxide released, thus being cleaner than gray hydrogen where the carbon dioxide is not captured. Green hydrogen is obtained by using renewable energy to produce hydrogen from electrolysis of water. It is the cleanest and most sustainable form of hydrogen production. Development of renewable hydrogen production, storage and transport infrastructure can be a critical opportunity towards reducing emissions. Investment towards renewable hydrogen infrastructure is also heavily supported at the federal level.

Although the production of hydrogen may generate emissions affecting air quality, depending on the source, an FCEV running on hydrogen emits only water vapor and warm air as exhaust and is considered a zero-emission vehicle. Major research and development efforts are aimed at making these vehicles and their infrastructure practical for widespread use.

Hydrogen is considered an alternative fuel under the Energy Policy Act of 1992. The interest in hydrogen as an alternative transportation fuel stems from its ability to power fuel cells in zero-emission vehicles, its potential for domestic production, and the fuel cell's fast filling time and high efficiency.

Because hydrogen has a low volumetric energy density, it is stored onboard a vehicle as a compressed gas to achieve the driving range of conventional vehicles. Most current applications use high-pressure tanks capable of storing hydrogen at either 5,000 or 10,000 psi. Retail dispensers, which are mostly co-located at gasoline stations, can fill a 10,000-psi tank in about 5 minutes, and a 5,000-psi tank in about 10 to 15 minutes. Other ways of storing hydrogen, such as bonding it chemically with a metal hydride, are under development.

California is leading the nation in building hydrogen fueling stations for FCEVs. As of mid-2021, 47 retail hydrogen stations were open to the public in California, as well as one in Hawaii, and 55 more were in various stages of construction or planning in California. These stations are serving over 8,000 FCEVs. In addition, 14 retail stations are planned for the northeastern states, with some of those already serving fleet customers.

Vehicle manufacturers are only offering FCEVs to consumers who live in regions where hydrogen stations exist. Non-retail stations in California and throughout the country also continue serving FCEV fleets, including buses. Multiple distribution centers are using hydrogen to fuel material-handling vehicles in their normal operations. In addition, several announcements have been made regarding the production of heavy-duty vehicles, such as line-haul trucks, that will require fueling stations with much higher capacities than existing light-duty stations.

Although Scania, the first major heavy-duty vehicle manufacturer to have FCEV trucks in operation, recently announced they are stopping their FCEV program to focus on full electric powertrains, there are many large OEMs, including Hyundai, Volvo, Daimler, Toyota, and GM with active fuel cell development programs. Additionally, The North American Council for Freight Efficiency (NACFE) released a December 2020 Guidance Report titled “Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors,” which suggests fleets should consider hydrogen fuel cell trucks if [2]:

- Zero emission at the tailpipe is important,
- Tractor tare weight is critical to maximizing payload,
- Long distance routes over 500 miles are common,
- Winter conditions are significant to operations,
- Green or blue hydrogen is readily available,
- Operate in less mountainous regions.

Alternative Fuels for Heavy Vehicles

For long-haul heavy-duty trucks (classes 6-8), energy density/storage and driving range are the most critical characteristics when considering alternative fuels. The most practically realistic alternatives for such vehicles to be considered are BEVs, Hydrogen FCEVs, and Liquified Natural Gas. There is a constantly evolving discussion on the strengths of BEV vs FCEVs for long-haul trucks. Most analysis suggest FCEVs edge out BEVs in terms of cost of operation and emissions reduction. However, the cost of associated infrastructure has been a major impediment in adoption. BEV transition would also require infrastructure developments above and beyond those being done for lighter vehicles (as long-haul trucks would require faster charging capabilities, similar to the time needed to fuel with traditional diesel).

Federal Perspective

The National Electric Vehicle Infrastructure (NEVI) Formula Program

The Infrastructure Investments and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL), signed into law on November 15, 2021, established the "National Electric Vehicle Infrastructure (NEVI) Formula program [3]. NEVI (through Federal Highway Administration [FHWA]) will provide funding to states to strategically deploy EV charging stations and to establish an interconnected network to facilitate data collection, access, and reliability. BIL committed up to $7.5 billion towards developing the nation's EV charging network, through a $5 billion allocation for NEVI, and an additional $2.5 billion for competitive grants.

The development of charging infrastructure through this program will enable states to leverage federal money to cover up to 80 percent of costs of establishing, connecting, and operating EV charging stations on alternative fueled corridors. As of August 2022, the Biden administration announced that all 50 states, as well as Washington, D.C. and Puerto Rico, had successfully submitted their NEVI plans for review by FHWA [4] [5].

The Joint Office of Energy and Transportation [6] was created through the BIL to facilitate collaboration between the U.S. Department of Energy and the U.S. Department of Transportation. The Joint Office is designed to assign resources and expertise across the two departments towards leveraged outcomes and to oversee funding activities. This office will be responsible for creating program guidelines and providing aid to states as they implement the program and use the funds.

The Joint Office, through FHWA, proposed mandatory standards concerning the development and operation of publicly available EV charging infrastructure in U.S. markets. This proposal is the first-ever effort of the U.S. government to impose mandatory standards on EV charging infrastructure. The standards are designed to cater to goals of uniformity and customer transparency. The Joint Office issued a Notice of Proposed Rulemaking in June 2022, to establish regulations that would set minimum standards and requirements for projects funded under NEVI. This involves installation of Direct-Current Fast Chargers (DCFC), also known as Level 3 charger, which uses a 3-phase AC electric circuit that is converted to DC before being delivered to the vehicle. Some key guidelines specified include [7]:

- Each charging station developed pursuant to NEVI DCFC must contain a minimum of four charging ports and provide for the ability of simultaneous charging by multiple EVs.
- Each DCFC charging port should have a power rating of at least 150 kW and each port should be capable of changing at this minimum speed simultaneously.
- The charging stations will be required to utilize the Combined Charging System port as a universal connector to accommodate a baseline of vehicles as well as adapters to provide charging for all EV models.
- Stations must accept credit cards and provide transparent pricing.
- Charging stations funded under the proposed rule will be required to be available for public use 24 hours a day, seven days a week, and on a year-round basis.
- Charging stations should have an uptime of 97 percent or higher. This implies that the hardware and software are online and available for use 97 percent of the time or higher.

National Alternative Fuel Corridors

The Fixing America's Surface Transportation (FAST) Act of 2015 required U.S. DOT to designate National Alternative Fueling Corridors (Title 23, United States Code, Section 151) with alternative fueling and charging infrastructure along the NHS corridors. Additionally, the BIL amended Section 151 to update the requirements related to the designation of national alternative fueling corridors (AFC), which tied funding eligibility provisions under the BIL to the nomination/designation process for AFCs. The BIL created the Discretionary Grant Program for Charging and Fueling Infrastructure, which calls for the strategic deployment of publicly accessible EV charging infrastructure, hydrogen fueling infrastructure, propane fueling infrastructure, and natural gas fueling infrastructure along designated AFC.

As shown in Table 1, there are two designation types available for a given corridor:

- "Corridor-Ready": the route has enough facilities to warrant signage indicating locations of alternative fueling stations.
- "Corridor-Pending": the route does not yet have enough facilities to warrant signage. FHWA coordinates with state and local entities to bring corridor-pending routes up to corridor-ready.

Designation status is based on a maximum distance between fuel stations of the same type along the corridor (see Table 1 for a synopsis):

- EV charging: EV charging facilities at 50-mile intervals along designated EV corridors.
- Hydrogen: Hydrogen fueling facilities at 100-mile intervals along designated hydrogen corridors.
- Propane: Propane (LPG) fueling facilities at 150-mile intervals along designated propane corridors.
- Natural gas: Compressed natural gas (CNG) and liquefied natural gas (LNG) facilities at 150-mile intervals and at 200-mile intervals respectively, along designated corridors.

FHWA established four phases to organize designation of corridors. Rounds 1-6 (2016 - 2022) are completed, with the redesignation of all corridors ongoing.

- Round 1: FHWA designated 55 routes across 35 states.
- Round 2: FHWA solicited nominations from state and local officials for additional routes, expansion of originally designated routes, or additional fuel types/fuel stations along Round 1 designated routes. FHWA designated 27 routes across 8 states.
- Round 3: FHWA designated 33 additional routes across 46 states.
- Round 4: FHWA designated 24 additional routes across 3 states.
- Round 5: FHWA designated 101 additional routes across 25 states.
- Round 6: FHWA designated an additional 177 EV corridor-pending and six EV corridor-ready routes across 29 states. Other alternative fuel corridor nominations resulted in the designation of nine CNG, nine LNG, 11 propane, and 30 hydrogen corridor-pending corridors, along with the designation of three CNG and four propane corridor-ready highways.

Table 1: National Alternative Fuel Corridors – Requirements for reaching corridor ready and corridor pending status.

Fuel Type	Corridor-Ready	Corridor-Pending
Electric Vehicle (EV)	Public DC Fast Charging no greater than 50 miles between stations. Stations should include four Combined Charging System (CCS) connectors - Type 1 ports (simultaneously charging four electric vehicles). Site power capability should be no less than 600 kW (supporting at least 150 kW per port simultaneously across 4 ports). Maximum charge power per DC port should not be below 150 kW.	A strategy/plan and timeline for public DC Fast Charging stations separated by more than 50 miles. Location of station/site- no more than 1 mile from Interstate exits or highway intersections along the corridor.
Liquid Propane Gas (LPG)	Public, primary propane stations no greater than 150 miles between stations, and no more than 5 miles from Interstate exits or highway intersections along the corridor.	Public, primary propane stations separated by more than 150 miles. Location of station - no more than 5 miles from Interstate exits or highway intersections along the corridor.
Compressed Natural Gas (CNG)	Public fast fill, 3,600 psi CNG stations no greater than 150 miles between stations, and no more than 5 miles from Interstate exits or highway intersections along the corridor.	Public fast fill, 3,600 psi CNG stations separated by more than 150 miles. Location of station - no more than 5 miles from Interstate exits or highway intersections along the corridor.
Liquefied Natural Gas (LNG)	Public LNG stations no greater than 200 miles between stations, and no more than 5 miles from Interstate exits or highway intersections along the corridor	Public LNG stations separated by more than 200 miles. Location of station - no more than 5 miles from Interstate exits or highway intersections along the corridor.
Hydrogen	Public hydrogen stations no greater than 150 miles between stations, and no more than 5 miles from Interstate exits or highway intersections along the corridor.	Public hydrogen stations separated by more than 150 miles. Location of station - no more than 5 miles from Interstate exits or highway intersections along the corridor.

A list of all designated corridors in the U.S. by state are listed on FHWA's website [8], and Table 2 lists designated corridors (including corridor ready and pending designations) in the MAASTO states, color coded to show if the corridors are designated for EVs and Hydrogen fuel. Reader can also refer to AFC maps for each fuel on FHWA's website [9].

Table 2: List of designated corridors in the MAASTO states

State	Designated Corridors
Illinois	**I-39, I-55, I-57, I-64, I-70, I-74, I-80, I-90, I-94**
Indiana	**I-64, I-65, I-69, I-70, I-74, I-80, I-94, I-265, I-275, I-465, I-469, US-31, SR-37**
Iowa	**I-29, I-35, I-80, I-380**, *US-34, US-61*
Kansas	**I-35, I-70, I-135, I-335, US-81, US-400**
Kentucky	**I-24, I-64, I-65, I-69, I-71, I-75, I-165, I-264, I-265, I-275, I-471, US-27, US-60, KY-4, KY-80, KY-914, KY-922, Audubon Pkwy, Bluegrass Pkwy, Breathitt Pkwy, Cumberland Pkwy, Hal Rogers Pkwy, Mountain Pkwy, Purchase Pkwy, Western Kentucky Pkwy**
Michigan	**I-69, I-75, I-94, I-96, I-196, I-275, I-696, US-2, US-31, US-127, US-131**
Minnesota	**I-35, I-94**
Missouri	**I-29, I-35, I-44, I-49, I-55, I-70**
Ohio	**I-70, I-71, I-74, I-75, I-76, I-77, I-80, I-90, I-270, I-275, I-675, I-680, US-23, US-30, US-33, SR-13**
Wisconsin	**I-39, I-41, I-43, I-90, I-94, I-535, US-2, US-8, US-41, US-51, US-53, US-141, US-151**

Key: **Bold maroon** font represents EV Ready/Pending AFCs, **bold blue** represents AFCs designated as both EV and Hydrogen Ready/Pending, and *black italics* font represents AFCs designated for other fuels (CNG/LNG/LPG) but not for EV/Hydrogen. Note that EV/Hydrogen ready/pending AFCs might be also designated for other fuels.

Compiled from FHWA's list of AFC designations from rounds 1 through 6 [10].

Other Federal Updates

In December 2021, President Biden signed the executive order, *Catalyzing Clean Energy Industries and Jobs through Federal Sustainability*. The order was aimed at achieving a carbon free electricity sector by 2035 and net-zero emissions economy-wide by no later than 2050. This order included a commitment to achieve 100 percent zero-emission vehicle acquisitions by 2035 and 100 percent zero-emission light-duty vehicle acquisitions by 2027.

Specifically, Section 204 under the order covers the commitment to transition to zero-emission fleets stating: "Each agency's light-duty acquisition shall be zero-emission vehicles by the end of 2027".

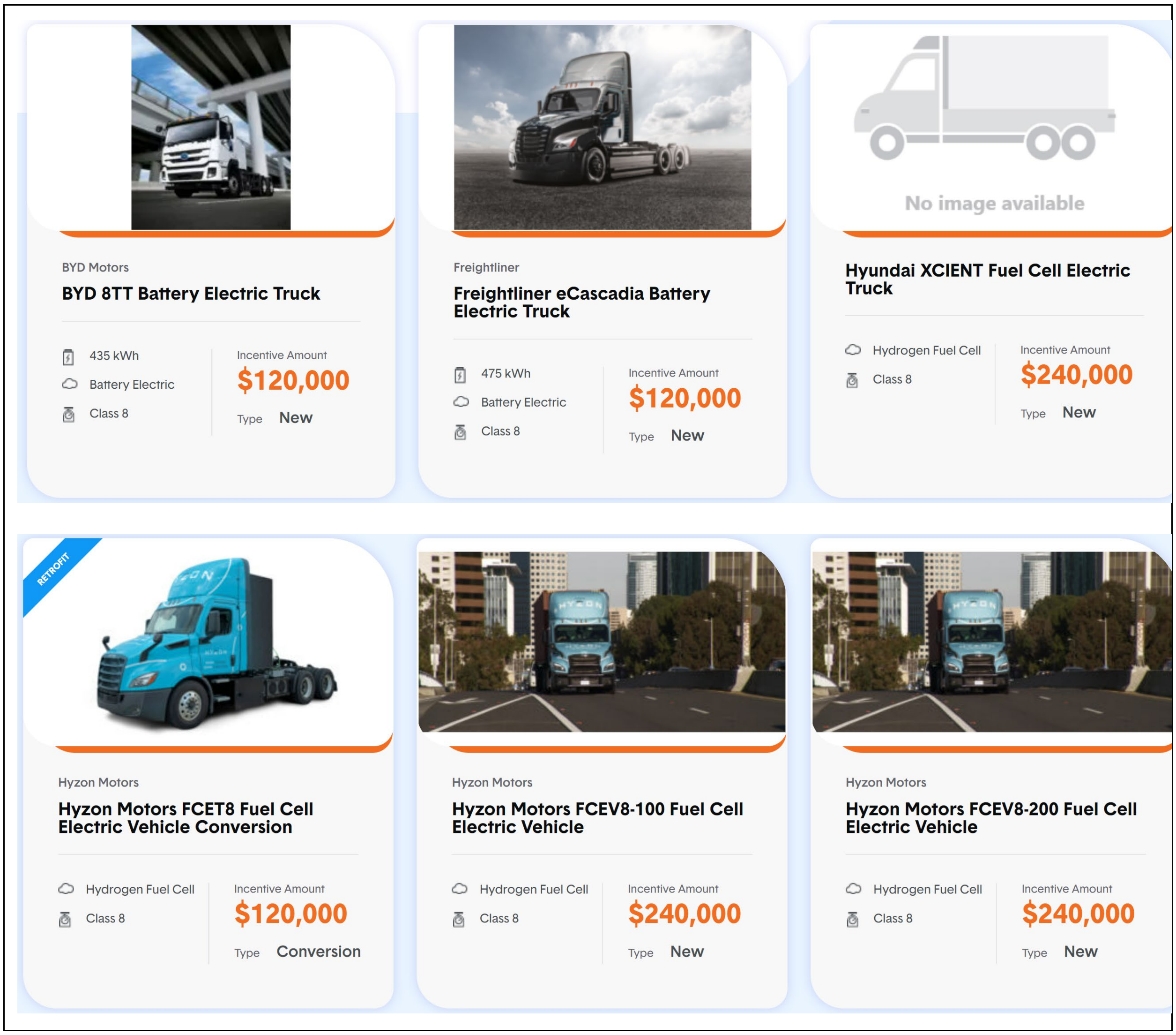
On December 20, 2022, U.S. Postal Services (USPS) announced a plan toward electrification of its fleets with an aim to achieve 100 percent EVs starting in 2026. The commitment entails acquisition of at least 66,000 BEVs as part of its 106,000-vehicle acquisition plan by 2028. USPS is expected to incorporate 60,000 Next Generation Delivery Vehicles (NGDV), 75 percent of which (45,000) would be battery electric. The total anticipated investment towards this target is expected to reach $9.6 billion, $3 billion of which is expected to come from the Inflation Reduction Act funds.

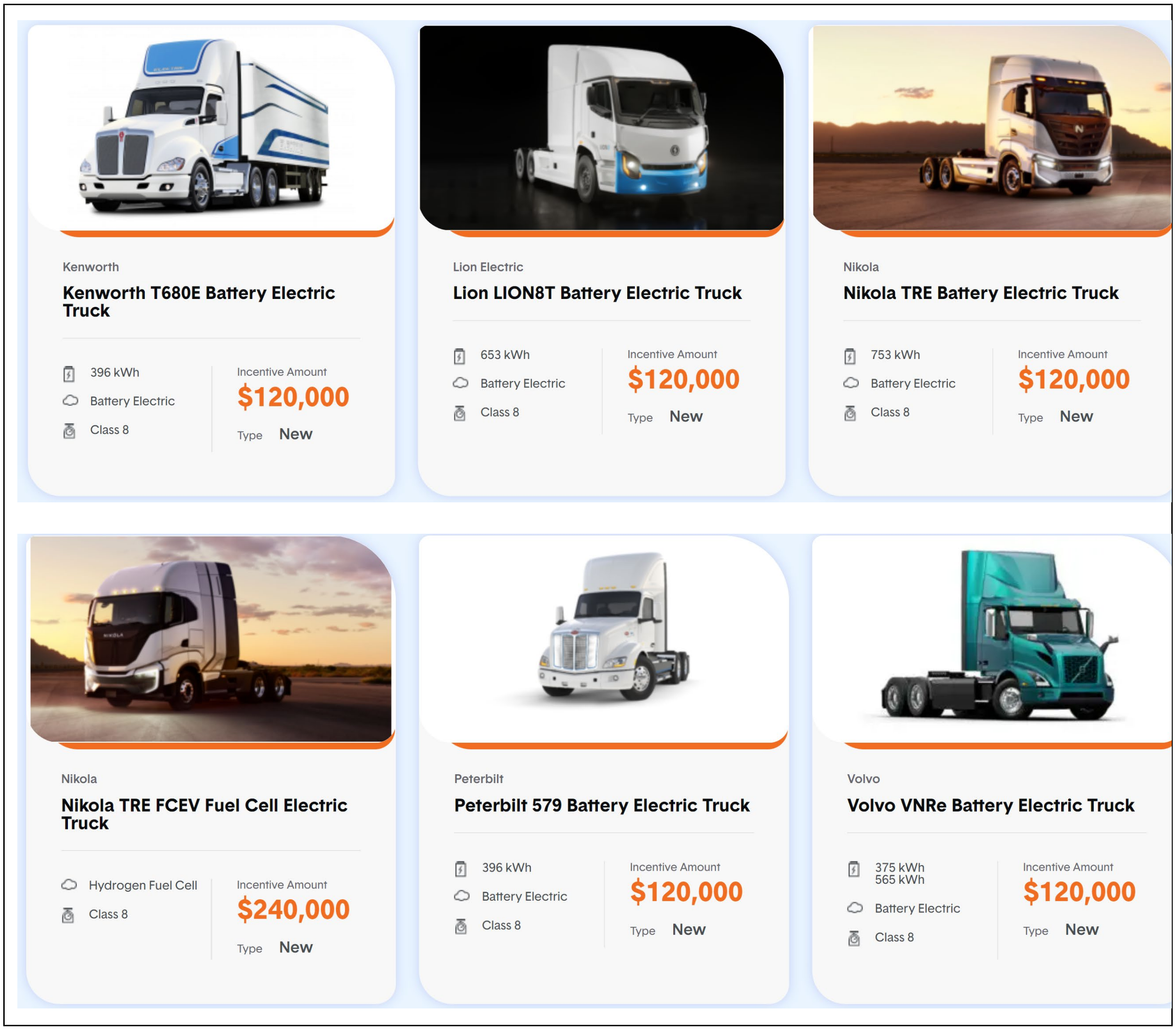
Industry Interests

Manufacturers

There are currently 13 BEV or FCEV Class 8 combination trucks available for purchase in the U.S., as listed by the California Hybrid and Zero Emission Truck and Bus Voucher Incentive Program (HVIP) [11]. These include BEV models available from BYD Motors, Freightliner, Kenworth, Lion Electric, Nikola, Peterbilt, Volvo, and Tesla. There are also five FCEV models available from Hyundai and Nikola and three models from Hyzon Motors. The BEV semis vary in the battery size offered, from 375 kWh for a Volvo VNRe offering, to 753 kWh for Nikola TRE model, and 850 kWh for Tesla Semi. In turn, these vehicles offer maximum range per full battery charge anywhere between 150 miles for the smaller battery offerings, up to 500 miles.

Figure 2: Inventory of currently available BEV and FCEV Semis (source: HVIP [11]).





Most major truck manufacturers have shown commitment to producing BEVs and are moving towards full zero emission fleet production over the next two decades. Large manufacturers are also actively working in developing FCEV models.

Battery Lifecycle

A key aspect to understanding the cost comparison of BEVs vs ICEs is the expected life cycle and maintenance costs for a BEV heavy duty truck compared to a traditional diesel truck. There have been estimates for the expected battery / power train lifecycle, but it is too early in the stage of the technology to be able to make an accurate prediction. According to an article from the North American Council for Freight Efficiency (NACFE), the expect life of a BEV Class 3 through 8 vehicle is seven to ten years before requiring a major refurbishing and that the battery lifecycle would in fact exceed this (estimated to see only a 20% reduction in capacity over ten years) [12]. In case of passenger vehicles, EVs such as Tesla Model X have been known to demonstrate a much longer lifecycle, past 400,000 miles [13] [14]. However, it is important to note that these are neither academically rigorous estimations, nor OEM statements. Another relevant aspect is the infrastructure required for battery swapping if/when needed and national readiness for production, transport, and disposal of batteries. A better understanding of the nation's readiness for battery production can be found in an ATRI report on freight electrification [15].

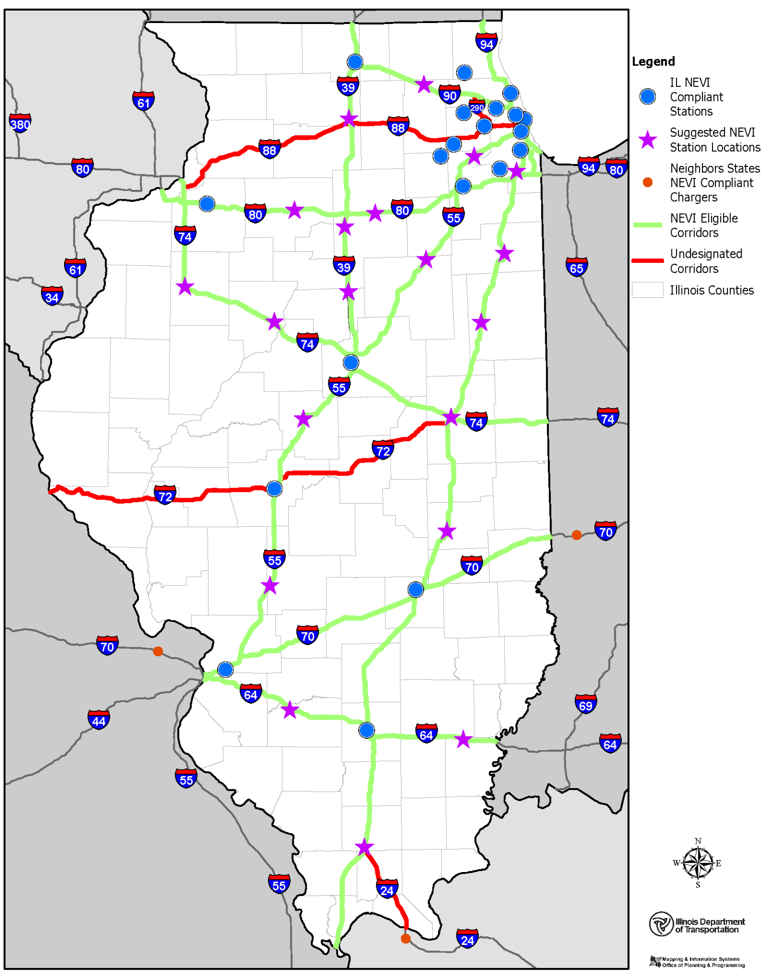
State DOT Activity, Programs, Research, Legislation, and Policy

The NEVI program established a set of key guidelines in February 2022, one of which required all states to submit their plans for utilizing NEVI allocated funds. The plans were required to be submitted by August 1, 2022. As submitted, the NEVI plans review each state's intended actions towards electrification of transportation, including freight electrification. In this section we present summaries for some of the ten MAASTO states' plans and highlight freight electrification plans where applicable.

Illinois

The "Illinois Electric Vehicle Infrastructure Deployment Plan" outlines Illinois' plans for utilizing its allotted $31 million in annual NEVI funding [16]. While Illinois' final list of sites will be generated after a partner study being performed at the University of Illinois Urbana-Champaign (UIUC) is completed, Illinois DOT (IDOT) has generated a map of potential EV charging station locations to meet minimum NEVI requirements through a simple siting exercise (Figure 3).

Figure 3: Illinois - Map of potential NEVI charging locations (source: [16]).



While the primary focus of the NEVI program is on passenger vehicle electrification, Illinois intends to take advantage of the opportunity to prepare to support future medium- and heavy-duty truck electrification. In addition to requiring all new station locations accessing NEVI funds to have the minimum 4 ports at 150 kWh, Illinois intends to require that one of those 4 ports be able to charge at 350 kWh for medium and heavy-duty utilization. Furthermore, IDOT sees benefits in making all NEVI-compliant stations pull-through sites with the ability to have at least one class 8 truck charge without blocking access to the other 3 ports.

Michigan

Michigan's NEVI Formula Program plan is titled, "Michigan State Plan for Electric Vehicle Infrastructure Deployment" [17]. Michigan is expected to receive $110 million through the NEVI program during FYs 2022-2026 to create an EV charging network across the state. Michigan provided a list of 60 candidate sites along its AFCs to be fully NEVI built, with a total of 127 NEVI chargers deployed across the sites (Figure 4).

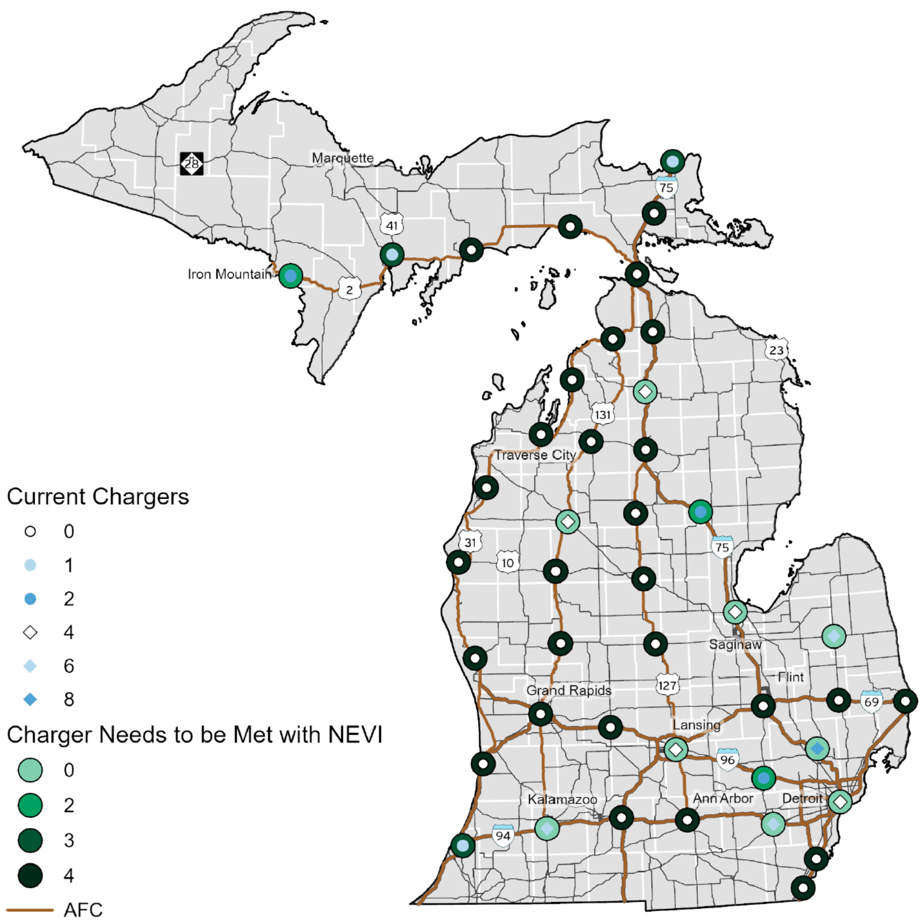
In the report, Michigan specifically identifies the need for high-capacity (350 kW or higher) and megawatt (1,000 kW) charging stations with special structural and site accommodations for commercial heavy-duty freight vehicles with pull-through designs.

Wireless Charging

Michigan DOT (MDOT) is collaborating with Israeli company Electreon to develop and work towards implementing a scalable wireless public in-road charging network for EVs. Under the five-year agreement, MDOT and Electreon will work collaboratively to develop best practices for a wireless electric road system (ERS). MDOT is providing $1.9 million towards the five-year pilot project, with Electreon funding the undisclosed remainder of the total cost.

This development follows a February 2022 deal with Electreon to turn a one-mile section of road in Detroit's central district, along 14th Street and Michigan Avenue (U.S. Route 12) into a wireless EV charging road system where EVs can recharge while stationary or while on the move.

Figure 4: Michigan - FY2022 NEVI Funding Deployment Plan (source: [17]).



Minnesota

Minnesota's NEVI Formula Program plan is titled, "Minnesota Electric Vehicle Infrastructure Plan" [18]. Minnesota is expected to receive $10.1 million annually over the next 5 years through the NEVI program to create an EV charging network across the state.

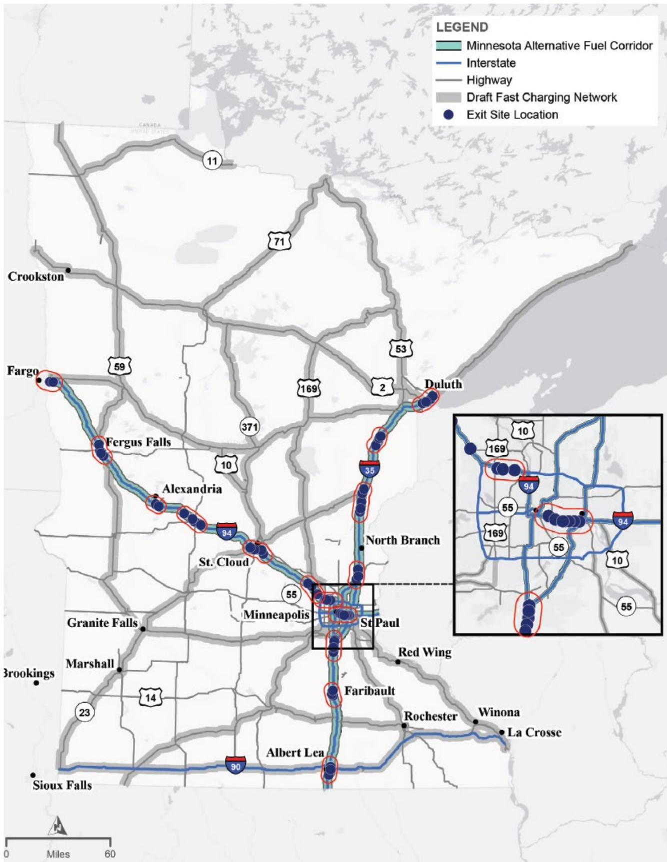
Minnesota's plan estimates an average cost of $900,000 per site, allowing a total of 14 charging stations (Figure 5) to be built with FY 2022 funding. These locations will provide nearly complete EV coverage along the I-94 and I-35 corridors.

While initial NEVI funds would target only light-duty EV charging needs, Minnesota DOT (MnDOT) identifies considerations for freight electrification infrastructure once the I-94 and I-35 EV corridors are fully built out, and I-90 EV corridor planning begins.

An ongoing study by University of Minnesota, commissioned by MnDOT, is looking at identifying and optimizing placement for EV charging infrastructure in Minnesota for medium and heavy-duty trucks [19] [20]. This study is looking at multiple criteria, such as truck traffic volumes, power grid stations, truck stations, DC chargers, gas station locations, and other factors, to determine the best candidates for freight electrification corridors. In a report generated from the study, I-35 between Albert Lea and Duluth, I-94 between Lakeland and Fargo (ND), I-90 between La Crosse

(WI) and Luverne, US-10 between Cottage Grove and Moorhead, and US-169 between Elmore and Grand Rapids were identified as best candidates for freight electrification sites in the state.

Figure 5: Minnesota - Initial NEVI Investment Locations (source: [18]).



Ohio

Ohio DOT (ODOT) and Drive Ohio (ODOT's center for smart mobility) published a freight electrification report for the state in August of 2021 [21]. The report summarized the state of the last-mile, medium-, and heavy-duty electric vehicle market, and identified actions for Ohio stakeholders to help facilitate the transition to an EV future.

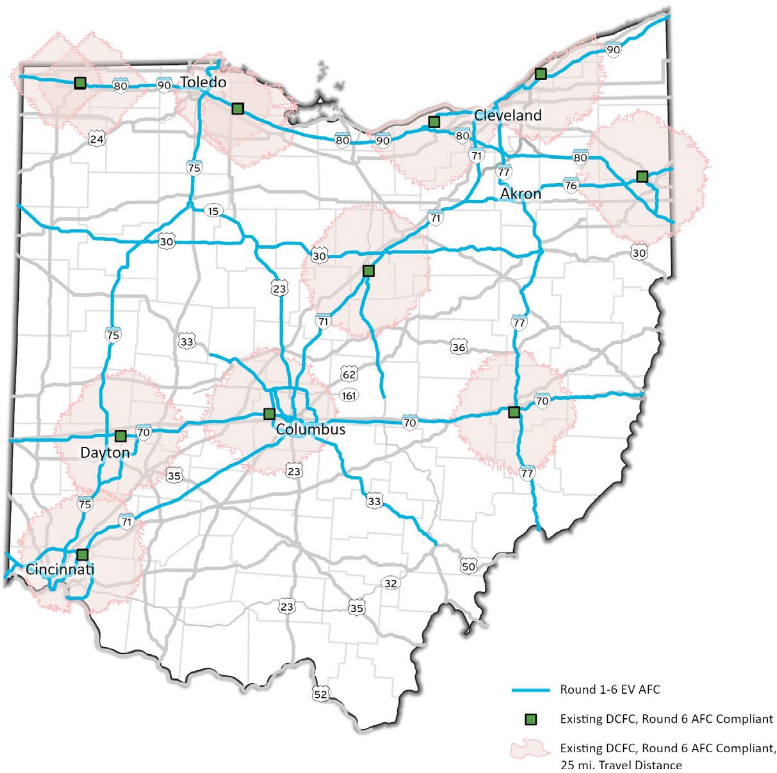
Ohio prepared and submitted its NEVI Formula Program plan titled "Ohio Electric Vehicle Infrastructure Deployment Plan". Ohio is expected to receive $20.7 million annually over the next 5 years through the NEVI program to create an EV charging network across the state.

The plan identifies gaps along the AFC in existing NEVI compliant charging locations (Figure 6), and identifies sites within the gaps for deploying new charging locations to fill charging gaps. Four 150 kW chargers are planned to be deployed at any site within each group / gap to fulfill NEVI requirements for those facilities.

A vendor outreach performed by ODOT suggests that average cost to build a new NEVI compliant site ranges from $600,000 to $1.2 million, depending on site attractiveness, cost of upgrading power service, and other site or charger-specific needs. An estimated 42 new charging locations would be needed to make all Ohio AFCs fully built along the 15 current AFCs, at an estimated cost of $42 million.

The plan further states that ODOT plans to evaluate opportunities to utilize NEVI formula funding remaining after building out the State’s AFCs, including consideration for funding Electric Vehicle Supply Equipment (EVSE) projects that support freight electrification.

Figure 6: Ohio - Existing NEVI Compliant DCFC Locations along AFCs (source: [21]).



Electrification and Alternate Freight Fuel in EU

The alternate fuel strategies and practices developed in the European Union are reviewed to provide insight to how complex governments moved forward with electrification and decarbonization.

Fit for 55

With the European Climate Law, the European Union (EU) set a binding target of achieving climate neutrality by 2050. As an intermediate step towards this goal, the EU has raised its climate ambitions to make it a legal obligation to reduce EU greenhouse gas emissions by a minimum of 55 percent by 2030.

The Fit for 55 package is a set of proposals to revise and update EU legislation and put in place initiatives with the aim of ensuring the policies are in line with the EU climate goals [22]. The Fit for 55 package was submitted to the European Council in July 2021 and it is being discussed across multiple policy areas, including environment, energy, transport, and economic and financial affairs.

The proposal notably aims to:

- Include emissions from maritime transport in the EU Emissions Trading System (ETS).
- Phase out free allocation of emission allowances to aviation and to the sectors that are to be covered by the Carbon Border Adjustment Mechanism (CBAM).
- Implement the global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) through the EU ETS.
- Increase funding available from the modernization fund and the innovation fund.
- Revise the market stability reserve to continue ensuring a stable and well-functioning EU ETS.
- Create a new self-standing emissions trading system for buildings and road transport to support member states in meeting their national targets under the effort sharing regulation in a cost-efficient way.

A general approach on the revision of the EU ETS was adopted by the European Council in June 2022. The Council reached a provisional deal with the European Parliament on the revision of the ETS in December 2022. Also in December 2022, the Council adopted the decision on the notification of CORSIA-offsetting requirements.

A component of the package very relevant to transportation emissions introduces increased EU-wide reduction targets for 2030 and sets a new target of 100 percent reduction for 2035 for cars and vans. This would make it impossible to place cars or vans with an internal combustion engine on the market in the EU after 2035.

The Trans-European Transport Network

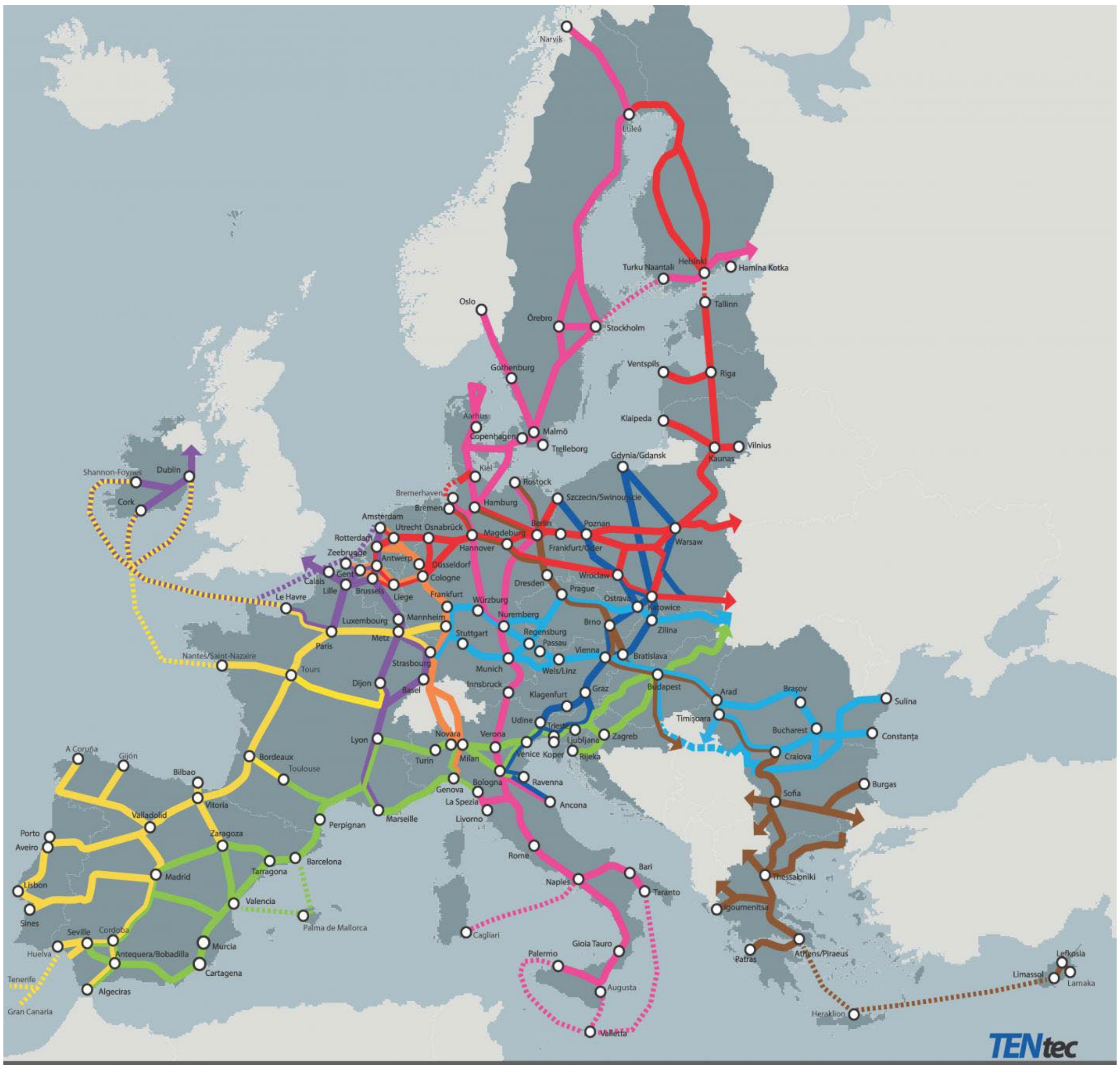
The Trans-European Transport Network (TEN-T) is a planned network of roads, railways, airports, and water infrastructure in the EU (Figure 7). TEN-T envisages coordinated improvements to primary transportation systems across the EU and is a fundamental component of the AFIR plans. Figure 7 shows a map of the nine core corridors of the TEN-T.

The nine core corridors include:

- Dark blue: The Baltic – Adriatic corridor,

- Red: The North Sea – Baltic corridor,
- Green: The Mediterranean corridor,
- Brown: The Orient / East – Med corridor,
- Pink: The Scandinavian – Mediterranean corridor,
- Orange: The Rhine – Alpine corridor,
- Yellow: The Atlantic corridor,
- Purple: The North Sea – Mediterranean corridor, and
- Light Blue: The Rhine – Danube corridor.

Figure 7: TEN-T Core Network - 9 core network corridors.



The Alternative Fuels Infrastructure Regulation (AFIR)

The European Commission has presented a proposal to revise the existing legislation to accelerate the deployment of alternate fuel infrastructure for recharging or refueling vehicles.

The Alternative Fuels Infrastructure Regulation (AFIR), released as a part of Fit for 55, is an update to the existing legislation named Alternative Fuels Infrastructure Directive (AFID) [23]. The AFID, dating back to 2014, spells out technical requirements concerning infrastructure for charging and refueling with alternate fuels. The AFIR is expected to set binding targets for the 27 current EU member states to deploy their charging and refueling networks with minimum energy capacity targets.

Some specific regulatory targets related to heavy-duty vehicles that would be implemented through the AFIR (Articles 4 and 6) include:

Electric Recharging

- Each Member State providing publicly accessible recharging pools along the TEN-T core network (most important connections linking major cities and nodes) dedicated to heavy-duty vehicles deployed in each direction of travel with a maximum distance of 60 km between them.
  - Each such recharging pool should offer a minimum power output of 1400 kW by December 2025, with at least one recharging station with an individual power output of at least 350 kW.
  - The power output for each such recharging pool should be increased to a minimum of 3500 kW by December 2030, with at least two recharging stations with individual power outputs of 350 kW or more.
- Each Member State providing publicly accessible recharging pools along the TEN-T comprehensive network (connecting all regions of the EU to the core network), dedicated to heavy-duty vehicles deployed in each direction travel with a maximum distance of 100km between them.
  - Each such recharging pool should offer a minimum power output of 1400 kW by December 2025, with at least one recharging station with an individual power output of at least 350 kW.
  - The power output for each such recharging pool should be increased to a minimum of 3500 kW by December 2030, with at least two recharging stations with individual power outputs of 350 kW or more.

Hydrogen Refueling

- Member States will ensure that publicly accessible hydrogen refueling stations be deployed with a minimum capacity of 2 tons per day and equipped with at least a 700 bars dispenser with a maximum distance of 150 km between them along the TEN-T core and comprehensive network by December 2030, and that liquid hydrogen be made available at publicly accessible stations at a maximum spread of 450 km.

Electric Truck Manufacturing in EU

Major European truck manufacturers have committed to transition to 100 percent electric and hydrogen vehicles by 2040 through a joint declaration released in December 2020 [24]. The five largest EU electric truck manufacturers have announced their plans and goals towards the transition [25]:

- **Scania** expects EVs to have a 10 percent share of total vehicle sales by 2025 in Europe and have a 50 percent share of total vehicle sales by 2030 [26].
- **MAN** plans to have 60 percent of their new delivery truck sales and 40 percent of new long-haul trucks as zero-emission by 2030 [27].
- **Volvo**, the world's second largest truck manufacturer, intends to achieve 50 percent electric sales by 2030 and 100 percent electric and hydrogen new sales by 2040 [27] [28].
- **Daimler**, the world's largest truck manufacturer, declared its intent to reach 100 percent zero emission new truck sales by 2039 [29].
- **IVECO** and **DAF** were also parties to the declaration and agreed that 2040 should be the last year that diesel trucks are sold in Europe.

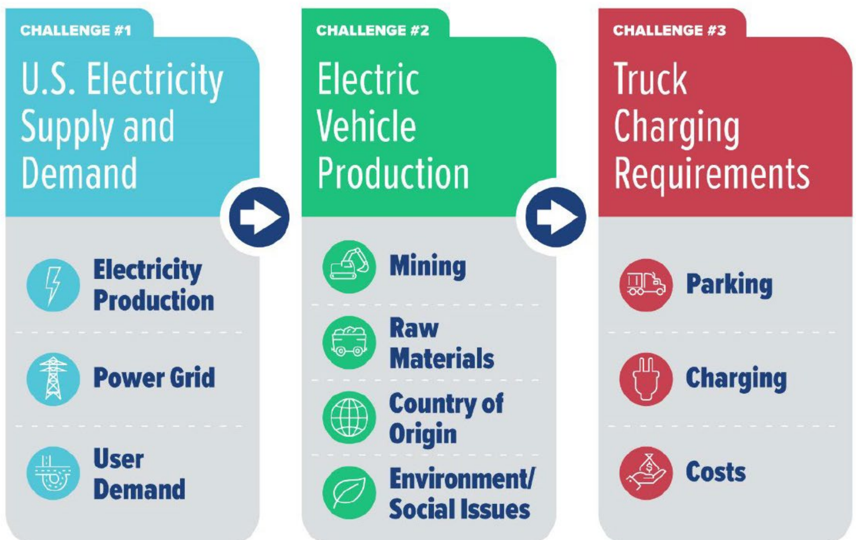
Opinion Studies on EU readiness

An opinion piece by the International Council on Clean Transportation (ICCT) argues that while the targets set through Fit for 55 and AFIR are critical, the estimates on the charging needs is undervalued [30]. The article suggests that the AFIR forecasts for the number of electric trucks in operation by 2030 is underestimated at a total of 170,000 electric trucks, compared to ICCT's forecast of 820,000 (including 300,000 long haul trucks) based on truck manufacturers' announcements and plans. The article lauds the AFIR efforts as a necessary first step towards electrification but implores that targets need to be aligned to the real magnitude of the challenge to push for electrification.

ATRI Report on BEV Charging Infrastructure in U.S.

The American Transportation Research Institute (ATRI) published a report titled "Charging Infrastructure Challenges for the U.S. Electric Vehicle Fleet" in December 2022 [15]. The study considered the challenges to vehicle electrification in the country, with a focus on trucking. The report analyzed three critical components of building and maintaining a national BEV charging infrastructure: 1. Electricity Demand and Supply; 2. Electric Vehicle Production; and 3. Truck Charging Requirements (Figure 8).

Figure 8: ATRI Study - Challenges to Electrification in U.S.



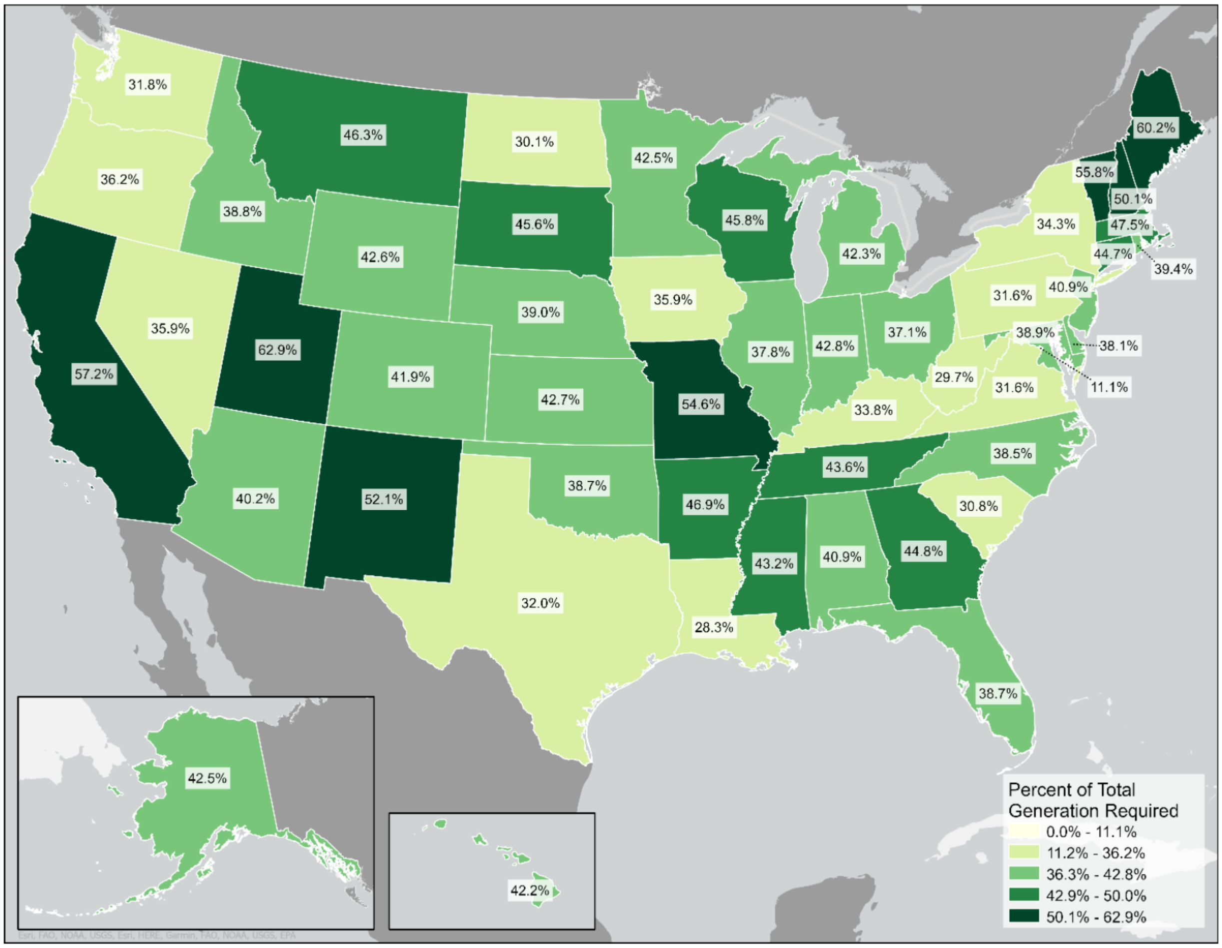
Electricity Demand and Supply

The first challenge considered by the report was demand and generation of electricity and how full electrification of the national vehicle fleet would affect this balance. According to the findings, 4,204 billion kWh of electricity was produced in 2021 in the U.S., with a consumption of 3,930 billion kWh (with roughly a 6.5 percent loss between generation and consumption).

Using Bureau of Transportation Statistics (BTS) and FHWA data on national vehicle fleet size and vehicle miles traveled, the study estimated the need for an additional 1,593.8 billion kWh of electricity to supply for a fully electrified fleet of light, medium, and heavy-duty vehicles in the U.S. Roughly one-third of this additional demand, or 553 billion kWh, would be for trucks. Figure 9 shows the percentage of existing power generation, by state, that would be needed to support a fully electrified fleet of vehicles, and Figure 10 shows the percent of current power generated that would be demanded by electrification of truck fleets only.

In addition to the daunting task of setting up additional power generation capacity to meet these additional demands, other challenges identified by the report include the impact that any outages could have on surface transportation, challenges related to variability in electricity rates, and balancing temporal nature of demand.

Figure 9: ATRI Report - Electric consumption for fully electric fleet as percentage of current generation.



Electric Vehicle Production

The second challenge towards electrification of vehicle fleets studied was the production of EVs, including expansion of mining and processing of raw materials, battery manufacturing, maintenance, and battery recycling.

The report finds that there would be a substantial demand for additional raw materials for battery manufacturing, perhaps one of the biggest challenges towards electrification. The need for cobalt, graphite, lithium, and nickel production to replace the existing vehicle fleet with BEVs would amount to tens of millions of tons of material (Table 3), as high as up to 35 years' worth at current production rate for some of these materials. The additional mining, refining, and manufacturing would in turn have significant environmental impacts.

Figure 10: ATRI Report - Electricity consumption for fully electric medium- and heavy-duty trucks as percentage of current production.

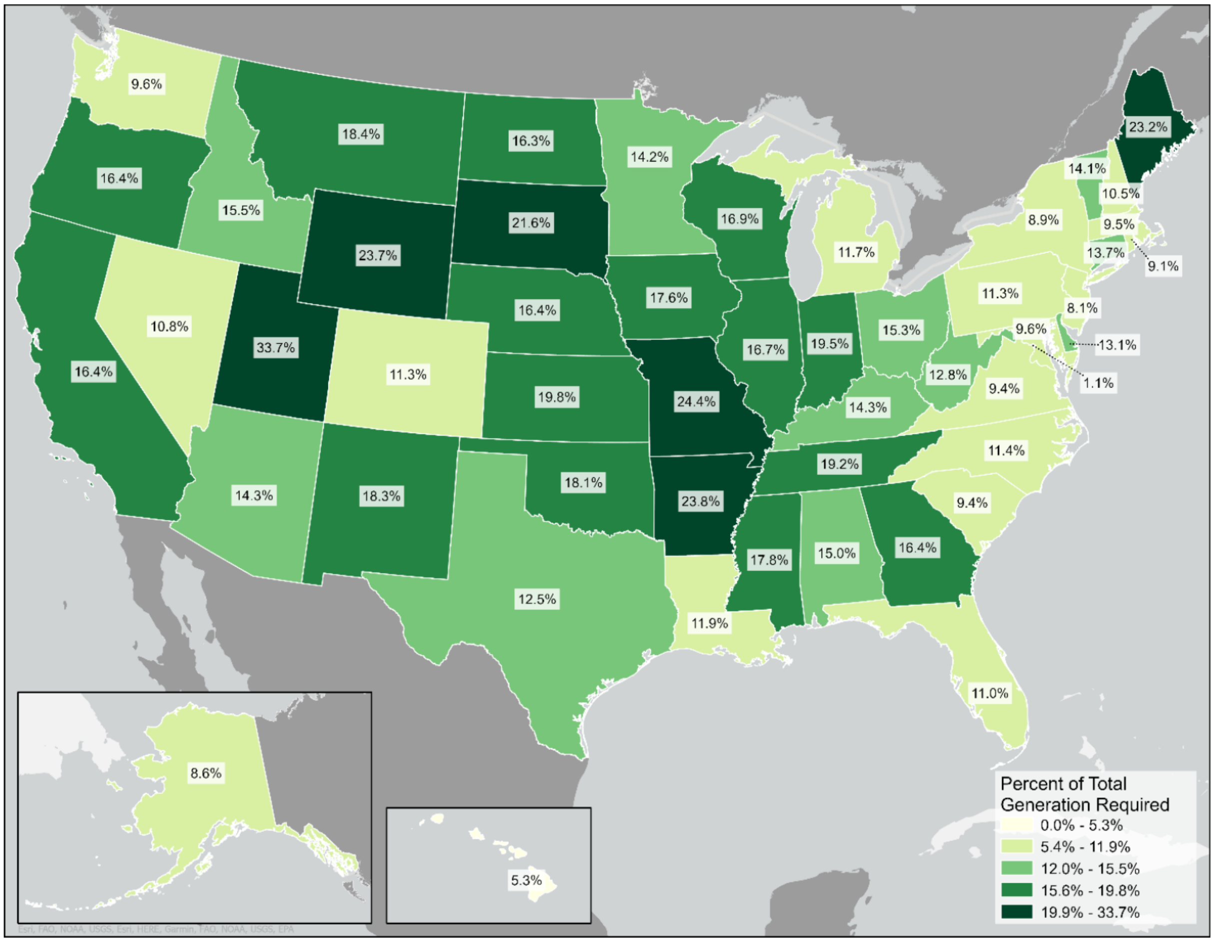


Table 3: ATRI Report - Raw material needed for full electrification of fleet.

Vehicle Type	Cobalt (tons)	Graphite (tons)	Lithium (tons)	Nickel (tons)
Light duty vehicles	4,251,227	23,306,655	3,026,688	14,815,756
Single unit trucks	478,103	2,621,124	340,389	1,666,216
Combination trucks	667,403	3,658,929	475,162	2,325,936
Total U.S. vehicle fleet	5,396,733	29,586,708	3,842,239	18,807,908
Source: ATRI Report [15]				

Truck Charging Requirements

The final challenge that the report analyzes is truck charging requirements. ATRI dubs the truck charging availability problem as the truck parking crisis 2.0, suggesting that for a fully electrified truck fleet in the country, more charging stations would be required than there are total truck parking spaces currently. This issue gets further complicated due to Hours of Service regulations.

Some key findings of the report were:

- A long-haul truck would need a 5.7 hour charging time and a 1500 kWh battery capacity to get 500 miles of travel range using 210 kW charging rate. The 210 kW charging rate was determined as the average intake rate of seven BEV trucks currently in production.
- For a fully electric truck fleet (2.9 million combination trucks), the total annual power needed for recharging would be an estimated 417.4 million kWh.
- A total of 585 million charging events would be needed per year for such a fully electric combination truck fleet, with each event lasting 3.4 hours. This is estimated based on 210 kW charging rate, an average driving range of 300 miles per day for each truck when on duty and needing a single charging event per day per truck when on duty.
- With a near 100 percent charging station utilization, corresponding to seven charging events per day of 3.4 hours per event, a total of 228,979 chargers would be needed across the country.

It is important to note that the estimates provided in ATRI's study for freight electrification are computed for an immediate transition to a fully electric fleet and with current technologies. Major OEMs expect to transition to zero-emission production of new vehicles by the year 2040. Internal Combustion Engine (ICE) trucks on average have an expected lifecycle of 15 years. From production point of view, this would suggest that the transition to zero-emission for long haul trucks would happen over a long period extending into the 2050s or 2060s. The infrastructure needs to be ready to support the transition as it happens. This should start with setting up baseline recharging infrastructure that can be improved upon as faster charging technologies become available and bringing hydrogen generation and delivery infrastructure across the country.

3. PLANNING FOR ELECTRIFICATION IN THE REGION

Based on the literature review, interviews and the working session, several key areas that impact the trajectory of freight electrification, freight operations, and agency planning were identified and are discussed below.

Hours of Service Regulations

Hours of Service (HOS) regulations are an important aspect to be considered when planning charging infrastructure for heavy-duty long-haul vehicles. "Hours of Service" refers to the maximum amount of time drivers are permitted to be on duty including driving time, and specifies the number and length of rest periods to help ensure that drivers stay awake and alert. In general, all carriers and drivers operating commercial motor vehicles (CMVs) must comply with Hours of Service regulations found in 49 CFR 395 [31].

Summary of Hours-of-Service Regulations:

11 Hour Driving Limit

A property-carrying commercial vehicle driver may drive a maximum of 11 hours after 10 consecutive hours off duty.

14 Hour Limit

A property-carrying commercial vehicle driver may not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.

30 Minute Driving Break

Drivers must take a 30-minute break when they have driven for a period of 8 cumulative hours without at least a 30-minute interruption. The break may be satisfied by any non-driving period of 30 consecutive minutes (i.e., on-duty not driving, off-duty, sleeper berth, or any combination of these taken consecutively).

60/70-Hour Limit

May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.

Sleeper Berth Provision

Drivers may split their required 10-hour off-duty period, as long as one off-duty period (whether in or out of the sleeper berth) is at least two hours long and the other involves at least seven consecutive hours spent in the sleeper berth. All sleeper berth pairings MUST add up to at least 10 hours. When used together, neither time period counts against the maximum 14-hour driving window.

Hours of Service regulations are a key consideration in conversations about recharging needs for BEVs and the impact of longer charging times when compared to ICE vehicles. It would be critical to develop strategies that would allow for efficient overlapping of hours-of-service rest times (10 hours of mandatory off duty rest) with recharging of BEV batteries if charging cycles cannot be reduced to a similar time commitment for traditional fueling.

Recharging Locations and Parking

Creating sufficient recharging locations is referred to as the "Truck Parking Crisis 2.0" in the ATRI report.

Studies estimate that a national average of nearly one hour of driving time per day is lost due to drivers parking early to avoid the risk of not finding parking space or violating Hours of Service regulation limits [32]. If charging requires more time than traditional fueling, increased parking needs and impacts to Hours of Service can be expected.

Rest Areas

There are approximately 40,000 public rest area truck parking spaces across the country. These could serve as the basis for a national truck charging infrastructure. However, a 1965 federal regulation restricts commercial activity at public rest areas. This includes fueling and selling food and beverages. While some exceptions exist, such as allowing vending machines where the revenue goes to the Blind Commission (Randolph Sheppard Act, 20 U.S.C. 107), and certain grandfather clauses along previously-operated tollways and turnpikes, the regulation presents a major obstacle towards allowing rest areas to be used as BEV recharging stations. The underlying justification for such a regulation is to disallow state departments of transportation to compete against the private sector. These regulations can be found under Title 23 of the United States Code, Section 111 (23 U.S.C. 111), which has been effective since Jan 2012 [33].

There has been interest in revising these regulations to permit BEV charging at rest areas, such as through HR2 of the Moving Forward Act [34] [35]. However, this has been met with strong opposition by various groups that see such efforts as a doorway to larger commercialization of rest areas and may also discourage existing refueling stations from investing in charging infrastructure. Moreover, rest areas were designed for quick turnovers and not for long-term parking. Considering such an undertaking would require a complete repurposing of rest area operation and logistics which may prove to be impractical for many locations.

In addition to the 40,000 public rest area truck parking spaces, there are an estimated 273,000 private truck parking spaces at private rest areas across the country [36]. The industry seems to be planning to target private charging stations as a viable option rather than waiting for public rest areas to become available as charging alternatives, given the legal hurdles previously discussed.

Revenue Recovery Considerations

Tax Implications

State motor fuel taxes are a significant portion of most states' revenues. Transition from ICE to alternate fuel vehicles would result in substantial tax revenue implications. For example, Ohio estimated a 13 percent drop in the state's commercial vehicle tax revenue, amounting to $103 million per year, due to electrification of Class 2b-8 vehicles.

Revenue Recovery Mechanisms

Related to the previous discussion, states would need to find revenue recovery mechanisms to offset the loss in revenue from gas taxes. There are multiple alternatives that could be considered.

Motor Vehicle Registration Fee: Additional motor vehicle registration fee offers a simple, reliable means of collection. Such a fee would be calculated using average miles traveled and fuel economy of vehicles across the class to set a single fee for each vehicle class. Such a fee suffers obviously from being flat and not scaled by driver usage. Further, registration fees would not capture road usage by vehicles traveling from other states.

Motor Fuel Tax: A fuel tax could be charged for the amount of recharging availed (tax per kWh). Such a tax would be consistent with standard fuel taxes applicable for ICE vehicles and with other alternative fuels as well. However, this would require a new method of revenue grade metering for vehicle charging and would further require new International Fuel Tax Association (IFTA) standards for heavy-duty vehicles.

Vehicle Miles Traveled (VMT) Fee: A VMT based fee offers the most accurate tax based on usage. Any VMT-based fee would need to be set by vehicle class. However, VMT monitoring remains a debated topic as it requires tracking movement of vehicles in order to compute the fee to be applied.

MAASTO States

The ten MAASTO states were surveyed to learn whether any state has active legislation on revenue recovery for EVs, specifically for heavy-duty trucks, or is expecting to have such legislation soon. The survey was sent to state electrification, freight, and CAV representatives and the results are presented in Table 4 below. Seven of the nine states that responded mentioned that they either have an EV surcharge on vehicle registration fee, a licensing fee already in place, or are expecting to have one implemented within a year. In addition, while Missouri does not currently have any such legislation, its DOT is in the process of evaluating a need for an EV registration surcharge in addition to other revenue recovery alternatives. Iowa has an EV registration fee, but it does not apply to heavy-duty semi-trucks. There are currently no plans to implement or study an EV registration fee option for heavy-duty trucks, but instead has already passed legislation to implement a fuel tax equivalent for both recharging BEVs (to be implemented within the year) and fueling hydrogen FCEVs (already in effect). Kentucky is the only state in the region that has plans to implement both an EV registration fee, as well as a fuel tax for charging BEVs that is expected to take effect in January 2024. The EV registration fees differ for each state, ranging from $100 to $248. The two states implementing a BEV charging fuel tax are expected to charge 2.6 cents per kWh in the case of Iowa, and either 3 or 6 cents per kWh depending on ownership of fueling station in the case of Kentucky.

The survey also found that some states are interested in studying and exploring revenue recovery alternatives outside of registration and fuel taxes. These come in the form of a usage-based (or VMT based) fee, a new blanket delivery charge, or reallocating part of sales tax revenue from EV sales towards roadway maintenance and operations. In conversations with study participants, most states see a usage-based fee as the preferred long-term solution to the revenue loss from gas fuel tax but believe that such system can only effectively work if it is implemented at a national standardized level. A delivery tax applied as a surcharge to the sales tax is also an interesting alternative, where the tax is transferred to the consumer instead of the shippers. For fleet operators, this could help offset some of the financial burden associated with using BEV trucks due to the higher tare weight and battery costs.

Table 4: Survey responses - Revenue recovery legislation.

State	Revenue Recovery Option			Notes
	Reg. Fee	Fuel Tax	VMT Fee	
Indiana				Starting to explore other strategies
Iowa		Jul 2023		Iowa's registration fee does not apply to EV semi-trucks.
Kansas			Studying	Considering other strategies
Kentucky	Jan 2024	Jan 2024		
Michigan			Interested	
Minnesota			Studied and trialed	Proposals for additional sales tax / delivery tax ($0.27)
Missouri				Studying alternatives
Ohio				Studying alternatives
Wisconsin				Proposal to redirect sales tax from EV and auto part sales.

Dark shade represents legislation already active in state. Lighter shade represents legislation passed and with expected date of implementation in cell.

Charging Load

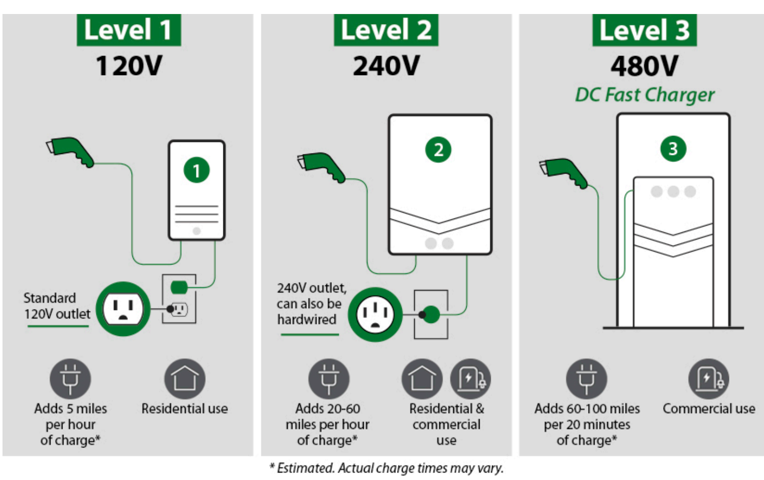
The recharging needs of an electrified trucking fleet will clearly not be met without major improvements in the charging infrastructure beyond what is covered through existing programs and undertakings such as NEVI. As presented earlier, ATRI's report suggests that with existing charging capabilities, an estimated minimum of 229,000 truck charging ports would be needed across the country to support a fully electric truck fleet, with each truck spending an average of 3.4 hours per day off duty for recharging. Table 5 shows estimated charging times from the ATRI report corresponding to four candidate battery setups.

Table 5: Charge times at 210 kW.

Battery Capacity	Mileage range at 80% charge	80% Charging Time (mins) @ 210 kW
750 kWh	252 miles	171.4 mins or 2.9 hrs.
1000 kWh	336 miles	228.6 mins or 3.8 hrs.
1250 kWh	420 miles	285.7 mins or 4.7 hrs.
1500 kWh	504 miles	342.9 mins or 5.7 hrs.
source: ATRI Study		

Exploring alternative solutions to charging, especially for trucks, is critical to planning electrification of transportation fleets. Charging times can be significantly reduced by using 370 kW rating DCFC chargers compared to Level 1 or Level 2 chargers operating with lower output and at lower voltages (Figure 11). Charging stations with even higher power output would be needed to ensure electrification of long-haul heavy-duty trucks remains a realistic goal. Alternate charging infrastructure and opportunities would need to be identified to supplement standard charging stations.

Figure 11: Level 1, Level 2, and Level 3 (DCFC) charging systems for BEV recharging.

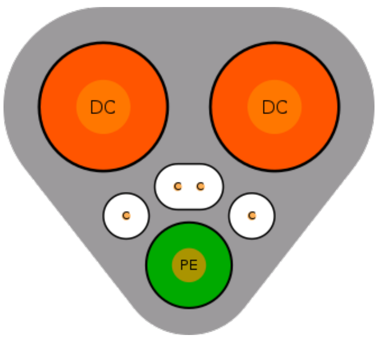


Megawatt Charging

Megawatt Charging or Multi-Megawatt Charging are charging systems that allow for BEV truck charging at an output of 1 megawatt (MW) or higher power rating. Multiple agencies are actively developing megawatt charging systems in Europe and in the Americas.

A Megawatt Charging System (MCS) is currently being developed (Figure 12), and the connector is expected to be rated at a maximum power rate of 3.75 MW, delivered as 3,000 amps at 1,250 volts direct current. Charging Interface Initiative (CharIn), a task force formed by international industry members in 2018, is responsible for developing the MCS.

Figure 12: Megawatt Charging System (MCS) adapter design standard.



While the MCS is still under development, there have been multiple advances in developing high power charging. Some key demonstrations of high power charging in the last year have been:

- Scania demonstrated truck charging for BEV trucks at more than 1 MW at the International Electric Vehicle Symposium and Exhibition (EVS35) held in Oslo, Norway in June 2022.
- Swiss firm ABB also demonstrated a new multi-megawatt charger that they expect to be ready for pilot in 2023 and ready for commercial deployment by 2024. The ABB multi-megawatt charger boasts a charging capacity of up to 3 MW.
- Tesla has also launched Megachargers at two locations to support their recently released Tesla Semi. These can be charged at 1 MW using 1k volt power train [37].
- Swiss based Designwerk Technologies has also announced a new charging system for heavy trucks that can provide up to 1 MW of power.

It is important to note that while the power rating of the charging infrastructure is important, it is likely that over the next few years, actual charging rates for long haul trucks would be restricted by acceptance rates of the vehicles. Manufacturers are actively working on being able to increase the acceptance rates on their production line vehicles to match charger capacity.

Table 6 shows charging times utilizing charging rates for the same four battery setups explored earlier. Comparing the two, charging time for a 500-mile range will drop from 5.7 hours under current charging capacities to roughly 20 minutes using a 3.7 MW charger. Applying ATRI's calculations for 1.6 million charging events per year required to support a fully electric truck fleet, the 3.7 MW charging time would shrink to being comparable to a diesel fill: only 12 mins of charging per event rather than 3.4 hours. If a charging port was being utilized at roughly 70 percent efficiency (a vehicle is actively charging for 70 percent of the time), a single port can then cater to 84 charging events per day. Under such rapid charging capacity, instead of needing 229,000 chargers at a 210 kW charge rate, only 19,082 3.7 MW chargers would be needed.

Table 6: Charging times with Mega-Watt chargers.

Battery Capacity	Mileage range at 80% charge	80% Charging Time (mins)	
		@ 1 MW	@ 3.7 MW
750 kWh	252 miles	36.0	9.7
1000 kWh	336 miles	48.0	13.0
1250 kWh	420 miles	60.0	16.2
1500 kWh	504 miles	72.0	19.5

As an example, Illinois estimates an average daily multi-unit truck count of 14,300 on I-39, one of its busiest freight corridors. A BEV long-haul truck needs roughly 2.4 kWh of charge per mile of traveling. If charging stations were available on average every 10 miles along a corridor serving an average daily count of 15,000 trucks, such a charging station would require output of roughly 15,000*10*2.4 = 360,000 kWh of charging rate daily to support a fully electric fleet of trucks. This corresponds to 15 MW charging capacity per station. Thus, even at 3.7 MW charging capacity, a charging station would need to support five such outlets with trucks perfectly synchronizing their charging times such that the outlets are being utilized at over 80 percent efficiency.

Embedded Roadway Charging

Embedded roadway charging is a technology that is being developed and tested for charging on-the-go BEVs. This is usually accomplished through a magnetic resonance induction system embedded into a stretch of the roadway. Vehicles can accumulate charge while driving along such roadways using a receiver mounted on the undercarriage. Such technology can provide up to 25 kW of charge according to current research. While this is a much slower charge rate than standard DCFC charging stations, the embedded roadway charging does not require any operational down-time as the vehicle charges while being driven. The biggest hurdles to large scale deployment of such technology are the associated costs for installation of the embedded charging and for bringing electricity to roadways. However, this could be viable as a complementary charging strategy to reduce the dwell-time needed at recharging stations. Additionally, a related strategy of mounting solar panels to the roof of vehicles in order to accrue some charge for the batteries has also been considered but has been discounted as the charge rate that can be derived from such a strategy is minimal compared to what is required.

Opportunity Charging

Opportunity charging refers to charging BEVs at facilities where the vehicle is stopped for non-rest related activities. This could be at shipper, carrier, or warehouse facilities. These instances would provide brief durations of time where a small amount of charge could be added to the battery, thus complementing the major recharging stops and reducing the dwell-time or number of stops required.

Battery Swapping

Another possible strategy to address the longer recharging times for BEVs when compared to refueling ICE vehicles is battery swapping. Under this strategy, long haul trucks would pull into battery swapping service stations, where depleted batteries would be swapped out with newly charged batteries. Depending on the capacity and type, a typical BEV heavy-duty truck battery could weigh between seven tons (for current battery sizes averaging 750 kWh with a 300-350 mile range) and 15 tons (based on assumption of 1,622 kWh lithium-ion battery required to match ICE long-haul ranges) [38]. The weights are derived from Argonne Lab's Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation model, also known as the GREET model [39]. BEV heavy-duty truck batteries are also a sizeable portion of the cost of BEV trucks. However, battery swapping would lead to higher load on the manufacturing of batteries and associated environmental impacts from the entire life cycle of batteries. These elements would pose challenges to the feasibility and practicality of such a strategy, but it would potentially cut down the down time for drivers / trucks in the recharging process and could be considered as a complementary strategy to recharging.

Weight Considerations

One of the primary concerns for shippers related to conversion of fleets to BEV fleets is increase in vehicle tare weight due to the substantially higher weight of batteries when compared to diesel fuel tanks. Under current standards, combination heavy-duty trucks are restricted to 80,000 pounds gross vehicle weight limit in most states, with higher weights requiring special Over Sized / Over Weight (OSOW) permits. The gross vehicle weight limit applies to the sum of vehicle and cargo weights. Due to the additional tare weight seen in BEVs when compared to traditional ICE equivalents, imposing the same weight limit would translate to the BEVs hauling lighter loads to avoid exceeding the gross weight limit. This is turn translates to lost revenue for the trucking companies employing BEVs. Table 7 shows a summary of expected average weight components for a heavy-duty ICE, BEV and FCEVs sourced from a recent ATRI report [38]. Note that the BEV weight is estimated based on a 1,622 kWh lithium-ion battery as stated in previous section.

Table 7: Vehicle Weight Comparisons, GREET Model, ATRI [38].

Weight (lbs.)	ICE	BEV	FCEV
Maximum Gross Weight	80,000	80,000	80,000
Tractor Weight	18,216	32,016	21,337
Trailer Weight	11,264	11,264	11,264
Vehicle Tare Weight	29,480	43,280	32,601
Available Revenue Weight	50,520	36,720	47,399
Lost Revenue Weight from ICE Baseline		13,800	3,121

The table shows that based on current vehicle specifications, the tare weight of an ICE combination truck averages to around 29,500 pounds, compared to a slightly higher 32,600 pounds for Hydrogen FCEVs, and a substantially higher 43,280 pounds for BEVs. Subtracting the tare weights from the 80,000 maximum gross weight limit indicates the total weight available for goods being carried by the combination truck. An average ICE truck can carry roughly 50,500 pounds of revenue weight, compared to 47,400 for an FCEV, and 36,720 for a BEV. Using these estimates, switching from an ICE truck to an FCEV truck would correspond to roughly a 6.2 percent loss in revenue weight carried and switching from an ICE truck to a BEV would result in a substantial 27 percent loss in revenue weight.

As part of the study, the representatives for the 10 state DOTs were invited to a freight electrification working session. The literature review and freight operations findings were discussed, and the participants explored how the states expect to address the higher BEV tare weights. With vehicle weight limits established by federal and state laws, states currently have limited options to consider the allowance of additional weight without corresponding legislative action. However, options discussed ranged from expecting shippers to bear the burden completely and not providing any weight relaxations to BEVs, exercising a special OSOW BEV permit with subsidized rates up to a certain limit, to allowing weight concessions to BEVs to completely offset the additional tare weight for trucks. Given the goal of decarbonization, an economic penalty for adopters of electric technologies presents an additional challenge.

While most states responded that there is currently no legislation or ongoing discussions towards a legislation that would allow for gross vehicle weight concessions to BEVs, some states did mention current provisions in place for natural gas-powered vehicles that relax gross vehicle limits to 82,000 pounds. The natural gas provision provides a basis for considering a similar relaxation for BEVs. However, there would be two major concerns: 1) based on the GREET model, in order to completely offset the tare weight difference, the gross weight limit would need to be increased up to 94,000 pounds from 80,000 pounds; and 2) as multiple DOT representatives highlighted in the survey, an increase in gross vehicle weight limit would require significant changes to the bridge and pavement design standards, which are based on the current limit of 80,000 pounds. It should be noted here that Michigan anticipates that the BEV tare weight issue might not affect it the same way it affects other states due to their current vehicle weight allowance structure.

Creating federal legislation to relax the gross vehicle weight limit for BEVs nationally is one possible avenue to consider. This would be similar to the provision for natural gas-powered vehicles. However, it is unlikely that such relaxation could completely offset the additional vehicle weight for BEVs.

Another alternative is to let the trucking industry bear the burden. This would likely translate to reduced BEV adoption for long haul trucking, especially for high value goods where the loss in revenue weight translates to higher loss in actual revenue. With FCEV tare weights being much closer to ICE tare weights, FCEVs would probably be favored over BEVs by the trucking industry to fill the long-haul gap.

Hydrogen, Electric, or Both

A key consideration when planning electrification of trucks is the market share and trajectory of BEVs versus Hydrogen FCEVs. Each comes with its own benefits and shortcomings and requires uniquely different and new infrastructure setups. While BEVs seem to have the dominant market, especially in passenger vehicles, FCEVs present fewer limitations and more efficiencies for long haul trucking on major freight corridors.

BEVs have the first mover advantage in the industry as light duty BEVs and medium duty BEVs have already been in production for several years. Through the NEVI program, and even prior, substantial efforts have been made to create a nationwide BEV recharging network, even though a comparable process has not developed for heavy-duty trucks. Further, electric grids already exist across the nation and can deliver electricity far and wide. However, BEVs have certain obvious shortcomings, outside of the electricity supply side issues, including the previously discussed issue of extra tare weight, longer recharging times, and cost of battery production.

FCEVs, on the other hand, require a completely new refueling infrastructure to be set up, something which so far has only been achieved at a rudimentary level of accessibility in California and Hawaii. There are ongoing efforts to set up refueling stations across the East Coast but setting up a refueling infrastructure that can support nationwide operation of FCEVs will be challenging. However, FCEVs are more comparable to ICE vehicles as they have roughly the same tare weight, can offer long range movement, can be refueled very quickly, and offer zero tailpipe emissions, making them a favorable choice for long-haul usage from these aspects. FCEVs are expected to be much more cost effective for shippers due to the ability to carry large loads for a longer range and lower down-time due to refueling.

The general opinion within the private sector and DOT officials seems to be moving towards a combination of BEVs and FCEVs with FCEVs being considered the more viable option for long-haul freight movement and BEVs for shorter distances / lighter loads. This could mean a shared long-haul BEV and FCEV fleet. The U.S. Department of Energy and U.S. Department of Transportation recently announced $7 million in investment towards seven new zero emission projects that appear to promote development for both FCEV and BEV infrastructure [40].

4. CONCLUDING REMARKS

According to the U.S. Environment Protection Agency (EPA) Facts on Transportation Green House Gases [41], the transportation sector accounts for 27 percent of all greenhouse gas (GHG) emissions, and within transportation, medium- and heavy-duty trucks account for 26 percent of the sector's GHGs. Light-duty vehicles, such as passenger cars account for 57 percent of the sector's GHGs. Given the focus on decarbonization, the electrification of freight transportation will provide significant relief towards these environmental and sustainability goals.

However, this will be a significant transition for all sectors of the trucking industry, and while the exact trajectory of BEVs and FCEVs is uncertain, they will both play a large role in the transition. From an operations and policy perspective, the three most critical aspects to consider are: 1) charging dwell times and associated need for space; 2) revenue recovery mechanisms that are consistent and easy to interpret across state borders; and 3) weight considerations to encourage BEV adoption in trucking companies.

While MAASTO states are positioned to recover any reduced income from the transition, a national approach to develop a mileage-based fuel tax and usage-based fees that are consistent across state borders should be pursued. This is considered a high priority given the potential for development of unique revenue approaches across the states which would complicate development of a national, harmonized, and efficient system to match current diesel fuel taxation.

MAASTO states will also assess the impacts of battery weight on freight loads and efficiency to ensure equity during the permitting process. This could influence trucking companies' willingness to adopt BEV fleets. Economic incentives and little or no threat of economic loss with the transition will aid the adoption of BEVs and can support equity across industry sectors.

On the industry side, rapid battery chargers and vehicles able to accept rapid charging are needed immediately. This implies a current and immediate need to align HOS requirements with charging periods to ensure break times are used for charging. As a reminder, states cannot currently provide charging facilities for vehicles at rest areas due to federal and state legal restrictions. As the transition continues, states should continue to work with the trucking and electrification sectors to ensure sufficient charging availability, and a safe, more environmentally benign, and efficient freight sector.

The transition also raises new policy, program, and system level questions. As the transition to a zero-emission transportation fleet continues, infrastructure and vehicle resiliency becomes an important component to explore. Emergencies and disasters can impact BEV charging and FCEV refueling infrastructure differently than the existing gas/diesel refueling infrastructure. Obstacles in supply chains for materials included in critical battery manufacturing can also adversely affect the freight BEV system. Further, disruptions in vehicle manufacturing due to labor or materials could prove costly to the industry and consumers. These resiliency issues and others should be addressed in the immediate future to support electrification. A proposed research topic titled "*Resiliency and Freight Vehicle Electrification: Threats to Adoption and Utility*" is being considered.

And while the environmental benefits of electrification are focused on emissions and fuels, these positive outcomes also include noise reduction, reduced idling, new industries, and business clusters to support the charging infrastructure. Such a project could support the environmental rationale for transition to alternative fuels and support BIL equity initiates. A proposed research titled "*Justice40 for Freight*" is also being considered that could cover environmental justice impacts of freight electrification.

Electrification of freight movement on the MAASTO's region's major multistate freight corridors brings unique challenges and opportunities. Overall, the MAASTO region is well-positioned for the transition primarily because of the high level of collaboration across the states to initiate and implement innovation. Electrification of freight vehicles and corridors will benefit from collaboration across these states to ensure a harmonized, efficient, and equitable transition from ICE.

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Mid-America Freight Coalition
Ernest Perry, PhD, Program Manager
University of Wisconsin–Madison
College of Engineering
Department of Civil and Environmental Engineering
1415 Engineering Drive, 2205 EH
Madison, WI 53706
ebperry@wisc.edu
(608) 890-2310

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UNIVERSITY OF WISCONSIN–MADISON