MINNESOTA GO

Planning Minnesota's
Transportation Future

VEHICLE ELECTRIFICATION & ALTERNATIVE FUELS TREND ANALYSIS

CONTENTS

SUMMARY

The way vehicles are powered is diversifying, and cars and trucks are now using options such as electricity, biofuels, natural gas and more. While gasoline and diesel remain the dominant fuels internationally and domestically, government subsidies and advances in technology have made alternative fuels more readily available to the public. Electricity, in particular, has implications for reducing carbon dioxide emissions as the production of electricity can come from clean energy sources like wind and solar.

New technologies and fuel sources are critical to managing greenhouse gas emissions and making the transportation industry more sustainable in the coming years. While fully electric vehicles remain too expensive for many people to access, the cost of these innovations is decreasing every year. Charging stations for electric vehicles are becoming more widely available in Minnesota as demand is increasing, making electric vehicle ownership more viable. Other fuel sources, such as renewable natural gas and biofuels, also offer alternatives to traditional gas and diesel fuels. These alternatives are crucial to ensuring that Minnesota's transportation system is sustainable and accessible to all.

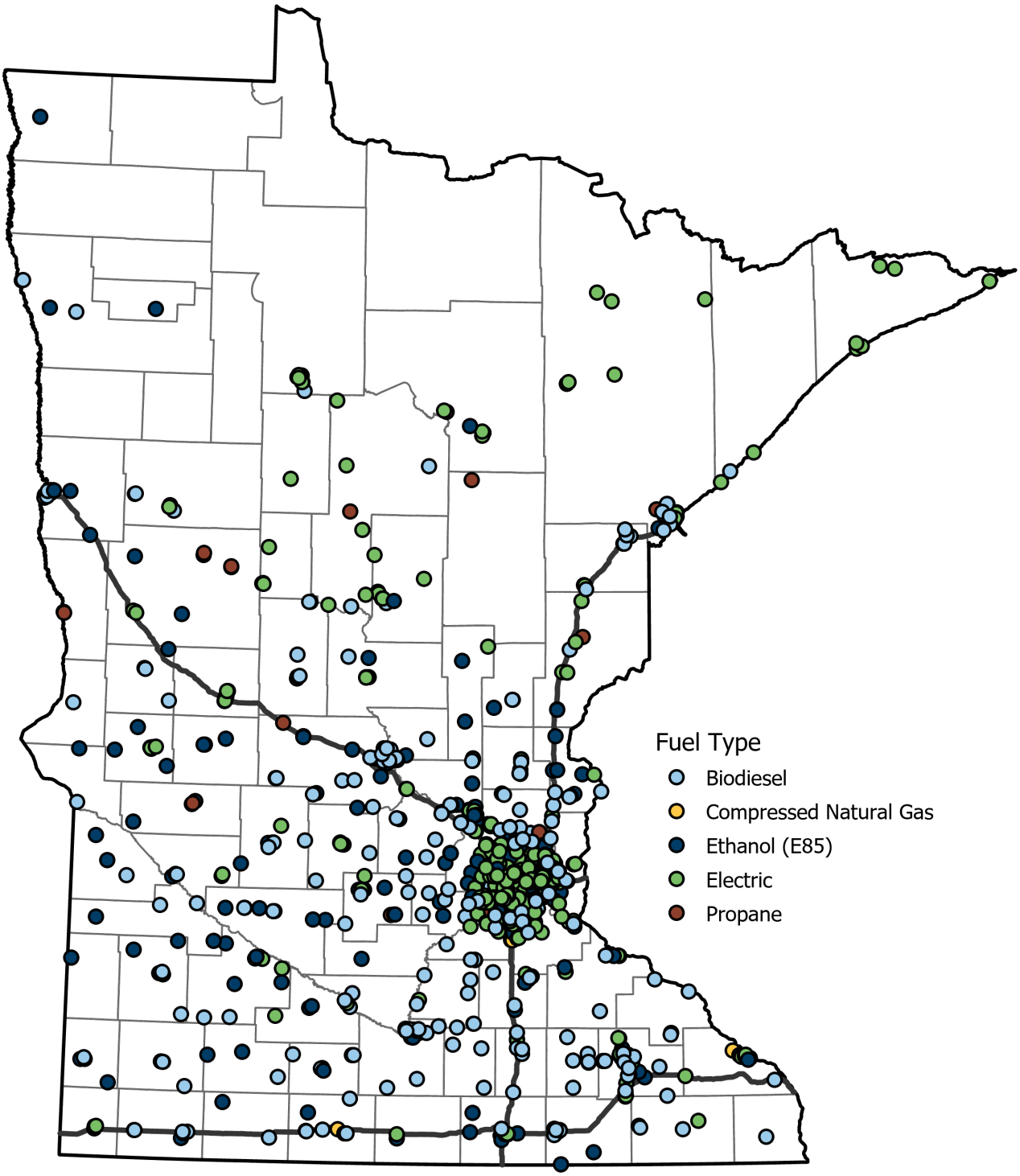
INTRODUCTION

This paper will introduce fuel technologies on the market today as well as those in research stages, and possible implications for the transportation network.

- Electric vehicles
- Biofuels
- Natural gas
- Other alternative fuels

Figure 1 shows the location of the alternative fueling stations that are open to the public in Minnesota as of May 2022.

FIGURE 1: PUBLIC ALTERNATIVE FUELING STATIONS IN MINNESOTA BY FUEL TYPE[1]



VEHICLE ELECTRIFICATION

While electric vehicles have been around in some form as long as those powered by gasoline, it wasn't until the oil shortages of the 1970s that the auto industry began considering them as a viable option. However, due to low gas prices through the 1980s and the limitations of electric vehicle technology and infrastructure at the time, they were abandoned until once again resurfacing with General Motor's EV1 following the Energy Policy Act of 1992.[2]

For the majority of the 2000s, Toyota led the electric vehicle market with its hybrid Prius model. In recent years, both plug-in hybrid and fully electric models have given drivers additional alternatives to the conventional gas-only vehicle. Though these vehicles can be more costly to purchase than a vehicle with a traditional internal combustion engine, this cost is decreasing with new technology and many find the cost of maintaining an electric vehicle to be less. More drivers are considering this a financially viable alternative through savings from more limited maintenance and repair and not needing to purchase gasoline.

ELECTRIC VEHICLES

Fuel source is an apparent difference between electric vehicles (EVs) and internal-combustion engines. EV powertrains, called e-axels, play a determining role in a vehicle's range and performance. There are a few types of powertrains.

POWERTRAIN TYPES[3]

Hybrid Electric Vehicles (HEVs) like the Toyota Prius run on both electricity and gasoline. During different stages of driving, the electric motor or the standard combustion engine may take over. The batteries powering the electric motor are charged by the car, using both the energy generated by the gas engine and the power generated when braking to recharge the battery. An HEV does not need to be plugged in, which provides the driver with a range limited only by the availability of gasoline. The gasoline-powered engine is the main power source, with the electric motor acting to increase fuel economy.[4]

Plug-In Hybrid Electric Vehicles (PHEVs) like the Chevrolet Volt switch between combustion engine power and electric motor depending on driving stage. They may also charge with regenerative braking technology, but receive their primary charge from plugging into the electricity grid. The battery-powered electric motor is the main power source, with the gasoline engine acting to extend its range.[5]

Fully Electric Vehicles (EVs) like the Nissan Leaf or all Tesla models use power drawn directly from the electricity grid and store it on board in batteries. There is no gasoline engine on board. The range of these vehicles is limited

[1] United States Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/data_download (accessed May 5, 2022).
[2] United States Department of Energy, "The History of the Electric Car," https://www.energy.gov/articles/history-electric-car (accessed March 16, 2020).
[3] Power train "is the intervening mechanism by which power is transmitted from an engine to a propeller or axle that it drives." Merriam–Webster, "Power train" https://www.merriam-webster.com/dictionary/power%20train (accessed August 21, 2020).
[4] United States Environmental Protection Agency, "Explaining Electric & Plug-In Hybrid Electric Vehicles," https://www.epa.gov/greenvehicles/explaining-electric-plug-hybrid-electric-vehicles (accessed August 21, 2020).
[5] Ibid.

to the amount of battery energy stored in them, and the availability of charging stations. As battery technology advances, the range of vehicles has increased. Many models can now travel up to 300 miles on a single charge.

TYPES OF VEHICLES

At the start of 2021, there were 19 EV and 30 PHEV models available for purchase in the United States.[6] These are passenger and smaller vehicle types. Heavy-duty vehicles like semi-trucks often travel long distances between stops, making current battery technology impractical. To accommodate the power and mileage requirements, batteries need to be much larger (and thus heavier), which reduces the amount of cargo a truck can carry. There are currently five models of EV medium-duty delivery vans on the market.[7] Amazon announced in February 2020 that they were ordering 100,000 custom, electric vans to help them reach their carbon neutral goal by 2040 and began a pilot program for the vehicles in the fall of 2020.[8] While electric vehicles can handle shorter deliveries, biofuels and fuels such as liquid natural gas are currently more viable replacements for diesel on longer trips.

Hybrid electric buses have been in operation in transit agency fleets around the country since the mid-2000s. In 2019 there were only 650 fully-electric buses in the United States.[9] In comparison, China was operating 421,000 buses in 2018.[10] In 2019, New York's Metropolitan Transportation Agency had 5,700 conventional municipal buses, and only ten were fully electric. They have since added 15 more electric buses.[11] Metro Transit, in Minneapolis-Saint Paul, added eight fully electric buses and 114 hybrid-electric buses in 2021.[12] In 2018, the Duluth Transit Authority purchased seven electric transit buses through a Federal Transportation Administration Low and No Emission grant.[13] They serve select routes within the City of Duluth, and are tested on their performance in extreme weather and on steep terrain. The buses are equipped with long-range batteries, allowing them to serve daily- and peak-commuter routes and recharge in the garage overnight and during off-peak periods.

ENVIRONMENT

The effect of electric vehicles on the environment varies. Every model of vehicle performs differently, every driver faces different conditions, and behaves differently. The vehicles use different power sources and rely on a unique mixture of electricity. While fully electric vehicles produce no tailpipe emissions, there are indirect emissions related to the production of the electricity. Electricity generated from sources using fossil fuels will have more environmental impacts than energy generated by renewable sources like wind and solar. The level of these emissions depends on the method of power generation associated with a particular charging station or wall plug-

[6] "BEV Models Currently Available in the US," https://evadoption.com/ev-models/bev-models-currently-available-in-the-us/ (accessed March 3, 2021); "Available PHEVs (in the US)," 2021, https://evadoption.com/ev-models/available-phevs/ (accessed March 3, 2021).
[7] Step-vans as classified by the U.S. Department of Energy. United States Department of Energy, "Alternative Fuel and Advanced Vehicle Search," under *Alternative Fuels Data Center*, https://afdc.energy.gov/vehicles/search/ (accessed April 30, 2022).
[8] Lora Kolodny, "Amazon Is Testing Rivian Electric Delivery Vans in Los Angeles," February 3, 2021, https://www.cnbc.com/2021/02/03/amazon-is-testing-rivian-electric-delivery-vans-in-los-angeles.html (Accessed March 3, 2021).
[9] Bloomberg New Energy Finance, "Electric Vehicle Outlook 2020," https://about.bnef.com/electric-vehicle-outlook/ (accessed August 21, 2020).
[10] Brian Eckhouse, "The U.S. Has a Fleet of 300 Electric Buses. China Has 421,000," *Bloomberg*, May 15, 2019. https://www.bloomberg.com/news/articles/2019-05-15/in-shift-to-electric-bus-it-s-china-ahead-of-u-s-421-000-to-300 (accessed August 21, 2020).
[11] Ibid.
[12] Metro Transit, "Metro Transit Facts," https://www.metrotransit.org/metro-transit-facts (accessed April 30, 2022).
[13] News Tribune Business, "DTA to unveil electric buses," *Duluth News Tribune*, October 23, 2018. https://www.duluthnewstribune.com/business/4518334-dta-unveil-electric-buses (accessed August 21, 2020).

in. Because of these factors, it is very difficult to say with certainty how each vehicle will impact the environment. This section will highlight select environmental effects of electric vehicles.

TAILPIPE IMPACTS

Tailpipe emissions are the environmental impact that come directly from operation the vehicle. Burned fuel releases exhaust that contains various pollutants that affect air quality and adds to greenhouse gases in the atmosphere. In Minnesota, light- and medium-duty vehicles produce more than half of all transportation emissions.[14] The internal combustion engine found in standard gasoline cars, as well as hybrid vehicles (both HEVs and PHEVs), run on fuel derived from oil—although ethanol and biodiesel release many of the same pollutants as conventional gasoline.[15] HEVs and PHEVs both use a conventional internal combustion engine and electric motor during operation. Tailpipe emissions depends largely on the intensity and duration each engine is working while driving. More generally, the average tailpipe emissions of an HEV or PHEV will be less than that of a gasoline-only vehicle. EVs have zero tailpipe emissions but can rely on energy generated at power plants that still produce emissions elsewhere.[16]

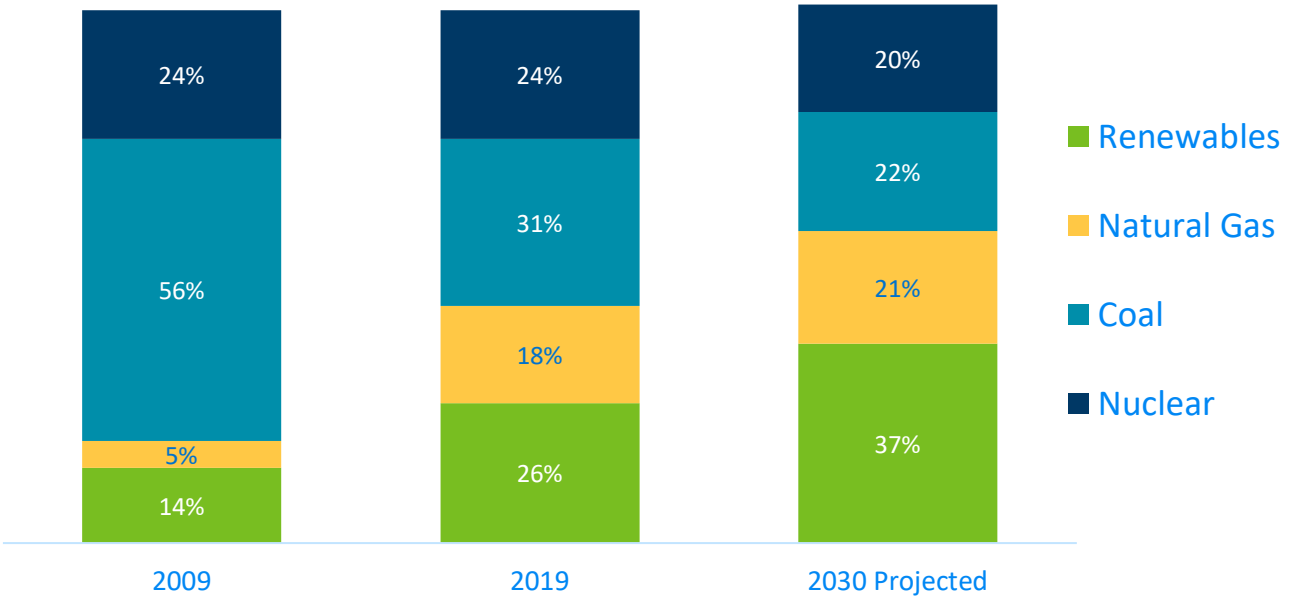
ELECTRICITY GENERATION IMPACTS

Although EVs do not produce emissions from their tailpipe, there are still environmental impacts when electricity is generated. The environmental impact will vary depending on how this electricity is generated—the "grid mix" (fossil fuels, renewable sources, or some combination of both).

EVs charged at both public and personal charging stations, each supplied with different grid mixes. As a result, it is often difficult to determine if the electricity used for a particular car is "emission-free" or associated with pollutant generation. Many public charging stations will advertise themselves as zero-emission (marked with a Zero Emission Charging decal in the Twin Cities)—indicating the electricity is supplied from renewable sources like wind or solar. Furthermore, owners who charge their vehicles at home in their driveway or garage may purchase renewable energy certificates (RECs) from energy companies. These RECs are required to be linked to renewable energy and are "retired" after use. Only when additional renewable energy is generated can new RECs be issued to a customer. Figure 2 shows the change in electricity generated in Minnesota between 2009 and 2019. Renewable and natural gas experienced the largest growth, and coal declined from 56% of Minnesota electricity to 31%.

[14] Minnesota Pollution Control Agency, "About Clean Cars Minnesota," https://www.pca.state.mn.us/air/about-clean-cars-minnesota (accessed April 30, 2022).
[15] United States Department of Energy, "Ethanol Vehicle Emissions," under *Alternative Fuels Data Center*, https://afdc.energy.gov/vehicles/flexible_fuel_emissions.html (accessed August 21, 2020).
[16] Minnesota Department of Transportation, Minnesota Pollution Control Agency, & Great Plains Institute, *Accelerating Electric Vehicle Adoption*.

FIGURE 2: ELECTRICITY GENERATED IN MINNESOTA[17]



EFFICIENCY OF ENERGY USE

In addition to supplementing engines for added fuel efficiency, electric motors use energy more efficiently than their gasoline counterparts. Only 12 to 30% of gasoline's energy actually generates movement. The majority is lost to heat and mechanical friction. In comparison, electric motors convert 77% of the energy to movement, as they have fewer moving parts and do not rely on high-temperature combustion for movement.[18]

In cold weather climates like Minnesota, electric vehicles do not perform as well as they do in moderate temperatures. Lithium-ion batteries are temperature sensitive. Also, electric vehicles cannot scavenge excess heat that comes from an internal combustion engine to warm the cabin. The vehicle must generate heat using the battery. Researchers at the Idaho National Laboratory found that an EV Nissan Leaf driven in Chicago during the winter lost on average 26% of its range.[19] Researchers are progressing towards solid-state batteries that hold up better in the cold than liquid ones.[20]

LIFE CYCLE EFFECTS

Life cycle effects refer to those that can be associated with all life stages of the vehicle. The environmental impacts of a vehicle (or any product) are not limited only to its operation. The raw materials used to build the

[17] Minnesota Department of Commerce, "Minnesota Energy Data Dashboard," under *Energy Data & Reports*, https://mn.gov/commerce/policy-data-reports/energy-data-reports/energy-data.jsp (accessed August 21, 2020); Minnesota Pollution Control Agency, "Technical Support Document" in *Rulemaking: Clean Cars Minnesota*, https://www.pca.state.mn.us/air/clean-cars-mn-rulemaking (accessed April 26, 2021).
[18] United States Department of Energy, "All-Electric Vehicles," under *www.fueleconomy.gov*, https://www.fueleconomy.gov/feg/evtech.shtml#end-notes (accessed August 21, 2020).
[19] United States Department of Energy, "Maximizing Electric Cars' Range in Extreme Temperatures," under *Office of Energy Efficiency & Renewable Energy*, https://www.energy.gov/eere/electricvehicles/maximizing-electric-cars-range-extreme-temperatures (accessed August 21, 2020).
[20] James Lynch, "Range-doubling lithium metal batteries 'build themselves' in lithium ion manufacturing machinery," *The Michigan Engineer News Center*, November 12, 2020, https://news.engin.umich.edu/2020/11/range-doubling-lithium-metal-batteries-build-themselves-in-lithium-ion-manufacturing-machinery/ (accessed April 26, 2021).

vehicle must first be extracted. The extraction of rare metals found in electric vehicle batteries is energy-intensive, requiring mining and significant chemical use.[21] The raw materials are then refined, manufactured, assembled, and transported to the dealership where the consumer purchases the finished product. At the end of the car's life, the vehicle is destroyed. All of these stages require energy. Still, gasoline powered cars produce more emissions than electric vehicles do throughout their lives, and powering electric vehicles from renewable energy sources can make their emissions even smaller.[22]

LOCAL CONTEXT

As of April 2022, Minnesota has 1,259 electric vehicle plug-in ports at hundreds of charging stations around the state.[23] These vary in charging speed by station type and vehicle battery. There are three types of charging stations: level 1, level 2, and DC Fast charging. Level 1 is a standard 120-volt household outlet that can charge between three and five miles of range per hour. Level 2 carries 240 volts and can charge between 10 and 20 miles of range per hour. DC Fast Charging carries 480 volts and can charge 80% of a vehicle in 20 to 60 minutes.[24]

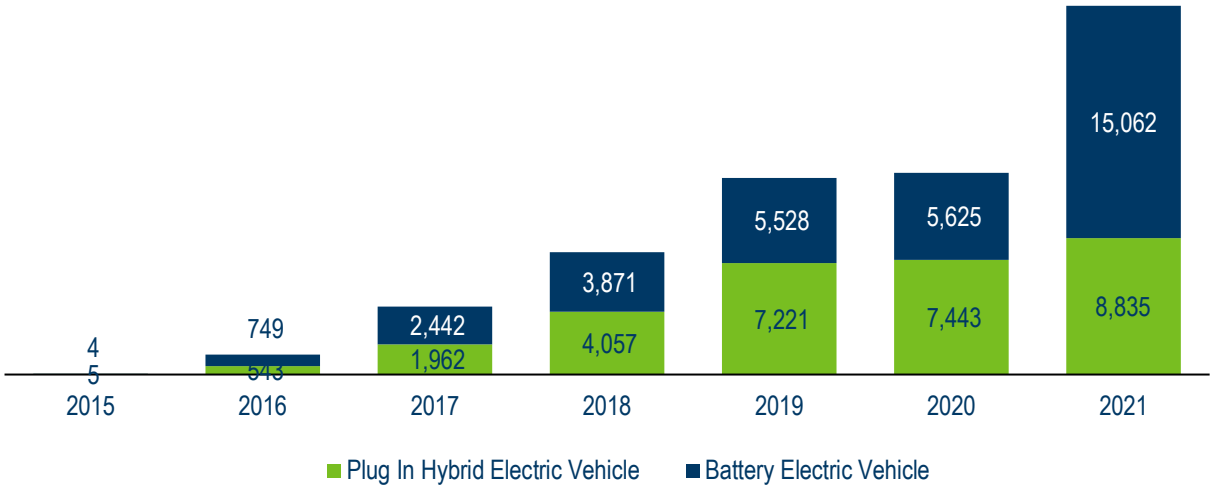
The number of registered electric vehicles in Minnesota is also steadily growing. In 2018, there were 4,057 plug-in hybrid vehicles registered in Minnesota. By December 2021, there were 8,835 PHEVs registered in the state. The growth of batter electric vehicles has been even faster. In 2018, there were 3,871 BEVs registered in the state. In December 2021, 15,062 BEVs were registered in Minnesota. See Figure 3 for more details.[25]

[21] United Nations Conference on Trade and Development, "Demand for raw materials for electric car batteries set to rise further," June 25, 2020, https://unctad.org/news/demand-raw-materials-electric-car-batteries-set-rise-further (accessed April 26, 2021).
[22] United States Department of Energy, "Reducing Pollution with Electric Vehicles," https://www.energy.gov/eere/electricvehicles/reducing-pollution-electric-vehicles (accessed April 30, 2022).
[23] Minnesota Department of Transportation, "Electric Vehicle Dashboard," http://www.dot.state.mn.us/sustainability/electric-vehicle-dashboard.html (accessed April 8, 2021).

[24] Plug In America, "What is DC fast charging for electric vehicles?," https://pluginamerica.org/dc-fast-charging-for-electric-vehicles/ (accessed April 8, 2021).

[25] Note: registered vehicle totals in 2020 are incomplete. This is accurate as of Spring 2020.

FIGURE 3: NUMBER OF REGISTERED ELECTRIC VEHICLES IN MINNESOTA



While roughly 70% of charging stations are Level 2 (roughly 70 miles of range in two to four hours of charging), there is a growing number of DC Fast charging stations in and around the Twin Cities that offer a complete charge in less than an hour.[26] Several groups are working to install rapid charging stations in Greater Minnesota, which would allow more travel throughout the state. A challenge is that fast chargers are expensive, costing $60,000 to $80,000 each.[27] Drive Electric Minnesota, a partnership of businesses, utilities, non-profits, and state and local governments, promotes and supports electric vehicles' advancement. This includes buying EVs and building charging infrastructure.[28]

In addition to the supporting infrastructure necessary for EVs, incentive programs give prospective EV buyers reason to switch to EV or hybrid plug-in models. Since the 2009 passage of the American Recovery and Reinvestment Act, new PHEVs and EV purchases qualified for a tax credit ranging from $2,500 to $7,500.[29] On January 1, 2020, the federal government ended the tax credit program.

Locally, several Minnesota utilities offer electric vehicle charging at off-peak hours for a reduced rate.[30] The state also provides grants for installing DC fast-charging stations.[31] Great River Energy, through the REVOLT Program, offers renewable energy credits for EV wind power for the life of the vehicle at no additional charge to customers. Xcel Energy is conducting a residential plug-in charging pilot—providing discounts on Level 2 equipment, installation and charging costs. The Minnesota Department of Transportation (MnDOT) is piloting an Electric

[26] United States Department of Energy, "Natural Gas Fueling Station Locations," under *Alternative Fuels Data Center*, https://afdc.energy.gov/fuels/natural_gas_locations.html#/find/nearest?fuel=CNG (accessed August 21, 2020).
[27] Elizabeth Dunbar, "Climate Curious: When are Electric Vehicle Fast Chargers Coming to Greater Minnesota?" *Minnesota Public Radio News*, December 6, 2019. https://www.mprnews.org/story/2019/12/06/climate-curious-when-are-ev-fast-chargers-coming-to-greater-minnesota (accessed August 21, 2020).
[28] Drive Electric Minnesota, "Charging," https://www.driveelectricmn.org/charging/ (accessed August 21, 2020).
[29] United States Internal Revenue Service, "Energy Incentives for Individuals in the American Recovery and Reinvestment Act," under *News*, https://www.irs.gov/newsroom/energy-incentives-for-individuals-in-the-american-recovery-and-reinvestment-act (accessed August 21, 2020).
[30] United States Department of Energy, "Electricity Laws and Incentives in Minnesota," under *Alternative Fuels Data Center*, https://afdc.energy.gov/fuels/laws/ELEC?state=MN (accessed August 21, 2020).
[31] Ibid.

Vehicle Incentive for managed lanes. Managed lanes are currently known as E-ZPass and previously called MnPASS in the Twin Cities. From November 2019 to October 2022, individuals who purchase a new or used battery electric or plug-in hybrid will receive an E-ZPass credit. EVs receive $250 worth of credit, and plug-in hybrids receive $125 worth of credit.[32]

In 2016, the German car producer Volkswagen violated the Clean Air Act federal emission standards. To make amends, the company agreed to a $2.9 billion settlement—including $47 million to Minnesota. Starting in 2018, VW began paying installments to Minnesota.[33] With that money, the Minnesota Pollution Control Agency (MPCA) is funding vehicle replacements—replacing diesel vehicles with vehicles that run on cleaner fuels. MPCA is also funding the growth of EV charging stations across the state.[34]

Minnesota is also home to two electric bus manufacturing plants for the New Flyer of America Company. New Flyer is the largest transit bus manufacturer in North America. They specialize in buses that run on battery-electric and compressed natural gas. They distribute electric buses all over the United States.

CURRENT AND FUTURE TRENDS

In 2021, Minnesota adopted a set of clean car standards, including a zero-emission vehicle (ZEV) standard.[35] The zero-emission vehicle (ZEV) standard requires auto manufacturers to deliver more vehicles with zero tailpipe emissions for sale in Minnesota, increasing each year. The new rules begin with model year 2025. The ZEV standard is designed to increase the number of BEV vehicles available for purchase in the state.

The Infrastructure Investment and Jobs Act (also referred to as the Bipartisan Infrastructure Law) created a new National Electric Vehicle Infrastructure Formula program to build out fast charging along designated corridors throughout the country. Minnesota expects to receive about $68 million through the program over five years. MnDOT is currently developing its first annual plan to invest the funds.[36]

As electricity generation in Minnesota continues to shift away from coal dominated to include a large contribution from wind and solar, EVs and plug-in hybrids will continue to be a cleaner alternative to conventional gasoline vehicles. According to the U.S. Energy Information Administration, Minnesota has reduced the amount of utility-scale energy coming from coal-fired electric power plants from 53% in 2011 to 31% of total state electricity generation in 2019.[37] Xcel Energy also plans to be coal-free by 2030 and nuclear-free by 2040.[38] [39]

[32] Minnesota Department of Transportation, "MnPASS Electric Vehicle Incentive—Three Year Pilot Program," under *MnPASS*, http://www.dot.state.mn.us/mnpass/mnpassnews.html#incentive (accessed August 21, 2020).
[33] Minnesota Pollution Control Agency, "Volkswagen Settlement FAQ," https://www.pca.state.mn.us/air/volkswagen-settlement-faq (accessed August 21, 2020).
[34] Ibid.
[35] https://www.pca.state.mn.us/air/about-clean-cars-minnesota
[36] https://talk.dot.state.mn.us/ev-infrastructure-plan
[37] United States Energy Information Administration, "Minnesota State Profile and Energy Estimates," https://www.eia.gov/state/?sid=MN (accessed August 21, 2020).
[38] Martin Moylan, Elizabeth Dunbar and Kirsti Marohn, "Xcel's new plan: Coal-free by 2030, nuclear until 2040," *Minnesota Public Radio News*, May 20, 2019. https://www.mprnews.org/story/2019/05/20/xcel-energy-coal-nuclear-power-wind-solar-minnesota (accessed August 21, 2020).
[39] Mike Hughlett, "Xcel Looks at New Nuclear Options as it Moves to Carbon-Free Power Goals," *Star Tribune*, August 22, 20220. https://www.startribune.com/xcel-looks-at-new-nuclear-options-as-it-moves-to-carbon-free-power-goals/572185972/ (accessed August 24, 2020).

BIOFUELS

Biofuels are made from organic material (also known as biomass). Biofuel is found in almost all gasoline sold today—not just those marked explicitly at the pump. Ninety-seven percent of U.S. gasoline contains biofuels—usually 90% gasoline, 10% ethanol made from corn and other plant materials. The most common biodiesels are B5 and B20 blended with petroleum.[40] Ethanol and biodiesel have positive energy balances. According to the United States Department of Agriculture, for every unit of fossil fuel used in the production of ethanol, 2.1 units of ethanol energy are generated.[41] Soybean biodiesel yields 4.6 units of energy for every unit of fossil fuel.[42] States and the federal government are exploring ways to increase domestic ethanol and biofuel blends to reduce dependency on foreign oil and carbon dioxide emissions.[43]

TYPES OF BIOFUELS

Ethanol: The most common biofuel found at gas stations is ethanol. It is derived from a variety of plant species such as sugar beet, sugarcane, corn and wheat.[44] Most ethanol available in Minnesota comes from corn. After fermentation and chemical reactions, the unused products are blended with gasoline at varying levels. E10, E15, and E85— or 10, 15 and 85% ethanol, respectively—are all currently available in Minnesota.[45]

- E10: Most gasoline is blended with 10% ethanol (E10) and is not explicitly noted at the pump. The U.S. Environmental Protection Agency classifies E10 as "substantially similar" to gasoline and is legal for use in all gasoline-powered vehicles.
- E15: Containing only slightly more ethanol than E10, E15 is approved only for vehicles made in 2001 or later.
- E85: Depending on location and season, pumps that list E85 contain between 50 and 83% ethanol and may only be used in flexible fuel vehicles. Although drivers using E85 will see lower gas mileage, this ethanol blend is often considerably cheaper than other conventional gasoline due to federal and state subsidies.

Biodiesel: Most often used as a blend with conventional petroleum diesel, biodiesel is produced with vegetable oils, animal fats or recycled restaurant grease. Similar to ethanol, blends can range from as low as two to 100%. The most common biodiesel blends in the U.S. are B5 (up to 5% biodiesel) and B20 (20% biodiesel).[46] Vehicles

[40] United States Department of Energy, "Biodiesel Blends," under *Alternative Fuels Data Center*, https://afdc.energy.gov/fuels/biodiesel_blends.html (accessed August 21, 2020).
[41] Minnesota Department of Agriculture, "Ethanol Basics and FAQS," under *Ethanol*, https://www.mda.state.mn.us/environment-sustainability/ethanol-basics-and-faqs (accessed August 21, 2020).
[42] United States Department of Energy, "Biodiesel Benefits and Considerations," under *Alternative Fuels Data Center*, https://afdc.energy.gov/fuels/biodiesel_benefits.html (accessed August 21, 2020).
[43] United States Department of Energy, "Biofuel Basics," Office of Energy Efficiency & Renewable Energy, https://www.energy.gov/eere/bioenergy/biofuels-basics (accessed February 21, 2020).
[44] Levinson, D. et al., "The Transportation Futures Project: Planning for Technology Change," Minnesota Department of Transportation Research Services & Library, 2016.
[45] United States Department of Energy, "Ethanol Blends," Office of Energy Efficiency & Renewable Energy, https://afdc.energy.gov/fuels/ethanol_blends.html (accessed February 21, 2020).
[46] United States Department of Energy, "Biodiesel Blends"

that are not technically alternative fuel vehicles can run on B20. Many transit fleets run on some level of biodiesel blend.

LOCAL CONTEXT

Minnesota is the United States' fourth largest ethanol producer.[47] Since 1980, Minnesota has incentivized and regulated biofuel production and consumption. The state sought to create a new market for its agricultural products, reduce fossil fuel dependence, and help meet the U.S. EPA standards for air quality in the Twin Cities.[48] Minnesota currently has 426 E85 fueling stations—more than any other state.[49]

Retailers offering lower blends of biodiesel (B5 and B10) can be found across Minnesota.[50] Annually, Minnesota produces 85.5 million gallons of biodiesel—from three locations. In 2021, Minnesota produced approximately 1.27 billion gallons of ethanol—which far outpaced annual consumption of 315 million gallons.[51] In 2017, the Departments of Agriculture, Commerce and the MPCA determined the state could increase biodiesel content based on Minnesota's infrastructure and federal standards. On May 1, 2018, Minnesota mandated that all diesel fuel sold from April 15 to September 30 must contain at least 20% biodiesel.[52]

In September 2019, Governor Tim Walz signed an executive order initiating the Governor's Council on Biofuels. The council's role is to lead the charge in studying and recommending policies to accelerate petroleum replacement with biofuels, investment in carbon efficiency, and achievement of greenhouse gas reduction targets.[53]

CURRENT AND FUTURE TRENDS

In the last year, the ethanol industry has struggled. Ethanol has been overproduced, and demand is down because of international trade restrictions and federal rules on ethanol use in small refineries.[54] The COVID-19 pandemic has also strained the industry. Measures to curtail the spread of the virus have depressed travel and gasoline demand. Chippewa Valley Ethanol in Benson, Minnesota, saw a 25 to 30% reduction in demand for ethanol in March 2020 alone.[55] They anticipate demand will continue to decline. To make up for lost business, some ethanol

[47] Mike Hughlett, "Minnesota Ethanol Producer Ramping up Production of Industrial Alcohol Used in Sanitizers," *Star Tribune*, March 24, 2020. https://www.startribune.com/minnesota-ethanol-producer-ramping-up-production-of-industrial-alcohol-used-in-sanitizers/569072402/ (accessed August 21, 2020).
[48] Levinson, D. et al., "The Transportation Futures Project: Planning for Technology Change," Minnesota Department of Transportation Research Services & Library, 2016.
[49] United States Department of Energy, "Alternative Fueling Station Counts by State," Office of Energy Efficiency & Renewable Energy, https://afdc.energy.gov/stations/states (accessed February 21, 2020).
[50] Biodiesel: America's Advanced Biofuel, "Finding Biodiesel Retail Locations," https://www.biodiesel.org/using-biodiesel/finding-biodiesel/retail-locations/retail-map#map (accessed February 26, 2020).
[51] Minnesota Bio-Fuels Association, "Ethanol Statistics," https://www.mnbiofuels.org/resources/facts-about-ethanol/ethanol-statistics (accessed May 1, 2022).
[52] Minnesota Department of Agriculture, "Minnesota Biodiesel," https://www.mda.state.mn.us/environment-sustainability/minnesota-biodiesel (accessed February 26, 2020).
[53] State of Minnesota Executive Department, Governor Tim Walz, *Establishing the Governor's Council on Biofuels* (Executive Order 19-35), September 16, 2019. https://mn.gov/governor/assets/2019_09_16_EO_19-35_tcm1055-403064.pdf (accessed August 21, 2020).
[54] Hughlett, "Minnesota Ethanol Producer Ramping up," *Star Tribune.*
[55] Ibid.

refineries in Minnesota have pivoted to increasing their output of industrial alcohol, which is used in hand sanitizer.

Researchers are looking for a way to convert inedible fibrous material to fuel, called cellulosic fuel. In addition to using inedible parts of the plant for fuel, cellulosic ethanol is potentially less environmentally harmful than both gasoline and corn ethanol.[56] Cellulosic ethanol has been technically possible for a long time, but no one has found an economically feasible method that can compete with corn-based ethanol.[57]

To develop the alternative fuels market, the Energy Independence and Security Act of 2007 (EISA) required 36 billion gallons of renewable fuel to be blended into domestic transportation fuels annually by 2022. However, most of the renewable fuel benchmarks along the way have been missed. Congress had hoped for 22.25 billion gallons by 2016 but ended up with 18.11.[58] In 2019, the goal was 28 billion gallons, but the result was 19.92.

Flex fuel vehicles, a trend in the first half of the 2010s, appear to be phasing out. Flex fuel vehicles can run on various fuels. From regular gasoline to gasoline-ethanol blends of up to 85% ethanol.[59] Flex fuel vehicles, on average, save drivers money on fuel and emit fewer greenhouse gases than regular gasoline powered vehicles. In 2015, there were 80 flex fuel vehicle models.[60] In 2020, that number has dropped to 16. Six of those are only available to fleet purchasers. In the 2010s, the EPA provided an array of grants, loans, matching funds, bonds and tax credits that supported biofuel producers. Many of these incentives ended between 2017 and 2020.[61]

NATURAL GAS

Natural gas used for vehicle fuel, which is similar to heating and cooking gas, accounts for only 0.2% of all domestic natural gas usage. For transportation use, the gas must be compressed (Compressed Natural Gas or CNG) or liquefied (Liquefied Natural Gas or LNG).[62] There are currently three million miles of pipelines that link natural gas production areas and storage facilities in the United States.[63] Moreover, there is a combined 1,677 public and private CNG and LNG filling stations.[64]

The low number of natural gas fueling stations limits the widespread adoption of light-duty natural gas vehicles. Personal vehicles like these require the wide geographic distribution of standard gas stations seen today. However, medium- and heavy-duty vehicles in a fleet that return to the same location every day are more likely to

[56] Center for Climate and Energy Solutions, "Renewable Energy," http://www.c2es.org/content/renewable-energy (accessed February 26, 2020).
[57] University of Illinois Extension, "The Future of Ethanol: Cellulosic," https://web.extension.illinois.edu/ethanol/cellulosic.cfm (accessed August 21, 2020).
[58] Congressional Research Service, *The Renewable Fuel Standard (RFS): an Overview*, 42, updated April 14, 2020. https://fas.org/sgp/crs/misc/R43325.pdf (accessed August 21, 2020).
[59] United States Department of Energy, "Flex-Fuel Vehicles," under www.fueleconomy.gov, https://www.fueleconomy.gov/feg/flextech.shtml (accessed August 21, 2020).
[60] Ken Colombini, "RFA Review of 2020 Vehicle Models Reveals Good News for E15, Bad News for Flex Fuels," *Renewable Fuels Association*, November 26, 2019. https://ethanolrfa.org/2019/11/rfa-review-of-2020-vehicle-models-reveals-good-news-for-e15-bad-news-for-flex-fuels/ (accessed August 21, 2020).
[61] United States Department of Energy, "Ethanol Laws and Incentives in Federal," under *Alternative Fuels Data Center*, https://afdc.energy.gov/fuels/laws/ETH?state=US (accessed August 21, 2020).
[62] United States Department of Energy, "Consumption of Natural Gas in the United States," Office of Energy Efficiency & Renewable Energy, https://afdc.energy.gov/data/10460 (accessed February 24, 2020).
[63] United States Energy Information Administration, "Natural Gas Explained: Natural Gas Pipelines," https://www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php (accessed February 27, 2020).
[64] United States Department of Energy, "Natural Gas Fueling Station Locations."

benefit from natural gas. These vehicles, which often run on diesel and operate in a limited range, may see reduced operational costs and greenhouse gas emissions by switching to natural gas.[65] Medium- and heavy-duty vehicles have fewer options for electrification than smaller, light-duty vehicles, which leaves natural gas as a potential option for achieving environmental and operational benefits. Over the life cycle of natural gas, it produces approximately 30% less greenhouse gas than diesel. To encourage natural gas use in heavy-duty vehicles, refueling infrastructure must be in place to enable full deployment. For example, Los Angeles deployed CNG refueling stations throughout the metropolitan area in 2015, which allowed LA Metro to adopt a bus fleet powered entirely by natural gas. [66]

While traditional natural gas is considered a fossil fuel and non-renewable, there is renewable natural gas. It is made from decomposing organic materials. It can be produced from landfills, livestock operations and wastewater treatment plants.[67]

LOCAL CONTEXT

As of 2022, there are 23 CNG filling stations scattered across Minnesota, of which 13 are public.[68] Nine are Kwik Trip Gas Stations. Similar to other alternative fuels, Minnesota taxes CNG at a reduced rate relative to gasoline. In 2014, Saint Cloud Metro Bus added 23 CNG powered buses to their fleet, making them the first transit system in the state to convert to CNG. CNG fueled buses currently represent over 50% of Metro Bus' fleet.[69]

CURRENT AND FUTURE TRENDS

There have not been significant trends in natural gas powered transportation in the last few years, due in part to the use of natural gas fuel focused on medium and heavy freight. As mentioned earlier, UPS is currently shifting delivery vehicles away from high carbon fuels to renewable liquefied natural gas.[70]

OTHER ALTERNATIVE FUELS

HYDROGEN

Hydrogen powered vehicles are still in their infancy. In vehicle applications, the reaction of air and hydrogen in a fuel cell produces electricity. It can then be used to power the drivetrain of a vehicle, much like the power stored in a battery. Very few models of hydrogen powered cars are currently available or in use. In 2020, only three hydrogen fuel cell cars were commercially available, including the Toyota Mirai, Honda Clarity Fuel Cell, and

[65] United States Department of Energy, "Natural Gas Vehicle Emissions," Office of Energy Efficiency & Renewable Energy, https://afdc.energy.gov/vehicles/natural_gas_emissions.html (accessed February 28, 2020).
[66] Levinson, D. et al., "The Transportation Futures Project: Planning for Technology Change," Minnesota Department of Transportation Research Services & Library, 2016.
[67] Ibid.
[68] United States Department of Energy, "Natural Gas Fueling Station Locations" https://afdc.energy.gov/fuels/natural_gas_locations.html#/find/nearest?fuel=CNG, (access May 1, 2022).
[69] St. Cloud Metropolitan Transit Commission, "Overview," Metro Bus, https://www.ridemetrobus.com/home/overview/ (accessed March 13, 2020).
[70] Holder, "Bikes, EVs and LNG Trucks'" *BusinessGreen*.

Hyundai NEXO.[71] These cars are exclusively available in California. As of December 2020, California had 42 retail hydrogen refueling stations.[72] Hydrogen vehicles produce only heat and pure water as emissions, making them an attractive alternative to vehicles producing carbon dioxide. The refueling time is also comparable to gasoline powered vehicles.[73] However, to support a broader market, fueling and storage infrastructure must expand.[74]

PROPANE

Propane fuel is a byproduct of oil refining and natural gas processing. It is used primarily for cooking and heating. Propane is often an energy source used in rural areas. It accounts for 2% of all energy use in the U.S., less than 3% for transportation.[75] Similar to natural gas, the use of propane is primarily by fleet managers. Forty Minnesota school districts are using propane school buses, including, but not limited to, Eastern Carver County, Mendota Heights ISD, Minneapolis Public Schools, Proctor Public Schools, and the St. Francis district.

DIMETHYL ETHER

Dimethyl ether is a synthetically produced alternative to diesel fuel. DME fuel has "half the energy density of diesel fuel, requires a fuel tank twice as large as that needed for diesel."[76] However, DME produces lower emission levels than diesel. DME lacks carbon-to-carbon bonds, so there are virtually no particulate emissions from burning DME. In September 2015, Oberon Fuels of San Diego partnered with Ford and others in a three-year study to research, design, and test the first DME-powered passenger vehicle.[77] This follows several years of DME field testing for use in heavy-duty trucks by Swedish carmaker Volvo, where it has received certification in the U.S. for production of DME from food wastes.[78] In 2019, Oberon received a $2.9 million grant from the State of California to produce renewable DME. The goal of the award is to demonstrate that DME can reduce greenhouse gases, pollutants and replace diesel fuel.[79]

RENEWABLE DIESEL

Renewable diesel has been available to fleet trucks and industrial fields since 2015. It is derived from animal fats, plant waste, and other organic sources, and is technically referred to as R99. Compared to biodiesel, it reduces

[71] Morgan Korn, "Are hydrogen fuel cell vehicles the future of autos?" *ABC News*, December 12, 2020, https://abcnews.go.com/Business/hydrogen-fuel-cell-vehicles-future-autos/story?id=74583475 (accessed April 8, 2021).
[72] Ibid.
[73] Adam Kaslikowski, "Hydrogen was the Fuel of Tomorrow, so What Happened?" *Digital Trends*, October 23, 2019. https://www.digitaltrends.com/cars/hydrogen-cars/ (accessed March 13, 2020).
[74] Office of Energy Efficiency & Renewable Energy, "Hydrogen Storage Challenges," under *Hydrogen and Fuel Cell Technologies Office,* https://www.energy.gov/eere/fuelcells/hydrogen-storage-challenges (accessed August 21, 2020).
[75] United States Department of Energy, "Propane Fuel Basics," Office of Energy Efficiency & Renewable Energy https://afdc.energy.gov/fuels/propane_basics.html (accessed March 13, 2020).
[76] United States Department of Energy, "Dimethyl Ether," Office of Energy Efficiency & Renewable Energy, https://afdc.energy.gov/fuels/emerging_dme.html (accessed March 13, 2020).
[77] Oberon Fuels, "Oberon Fuels Partners with Ford & FVV on 3-Year, €3.5 Million Project to Build and Test World's First Production Passenger Car Powered by DME," September 15, 2015, http://oberonfuels.com/2015/09/15/oberon-fuels-partners-ford-fvv-3-year-e3-5-million-project-build-test-worlds-production-passenger-car-powered-dme/ (accessed March 13, 2020).
[78] Cheryl McMullen, "Key Takeaways from Volvo Group's New Sustainability Report," *Waste 360*, March 7, 2016. https://www.waste360.com/waste-reduction/key-takeaways-volvo-group-s-new-sustainability-report (accessed March 13, 2020).
[79] Oberon Fuels, "Oberon Fuels Partners with SHV Energy to Accelerate Use of Renewable DME (rDME) to Decarbonize Transportation," February 11, 2020, http://oberonfuels.com/2020/02/11/oberon-fuels-partners-with-shv-energy-to-accelerate-use-of-renewable-dme-rdme-to-decarbonize-transportation/ (accessed March 16, 2020).

greenhouse gas emissions by 80%. Price and legislation curtail renewable diesel growth. California and Oregon are the largest consumers of renewable diesel because they have legislation that creates a market for clean fuel. The Eugene Water and Electric Board in Oregon has also used renewable diesel since 2015. During that time, the price per gallon of renewable diesel fluctuated and became more expensive than regular diesel. To cope, they blended 50% renewable with regular diesel. EWEB went back to R99 after the Oregon Legislature fully implemented the Clean Fuels Program in 2016—which annually increases clean fuel standards for fuels coming into the state.[80] Over time, R99 will increasingly become more competitive with other fuels. Similar rules in California prompted the City of Oakland, California, to use renewable diesel—starting in 2015. In spring 2019, Oakland announced that it would begin sourcing cooking oils from local restaurants and cafeterias to fuel its fleet.[81]

RELATED TRENDS

- Air quality
- Climate change

Minnesota's vision for transportation is known as Minnesota GO. The aim is that the multimodal transportation system maximizes the health of people, the environment and our economy. A transportation vision for generations, Minnesota GO guides a comprehensive planning effort for all people using the transportation system and for all modes of travel. Learn more at MinnesotaGO.org.

REVISION HISTORY

Date	Summary of revisions
May 2016	Original paper.
May 2022	Updated to reflect new data and change in trends.

[80] Oregon Department of Environmental Quality, "Clean Fuels Program Regulations," under *Air Quality Programs,* https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels-Regulations.aspx (accessed August 21, 2020).
[81] City of Oakland, "City of Oakland Drives Environmental Progress with New Renewable Diesel Model," under *News*, https://www.oaklandca.gov/news/2019/city-of-oakland-drives-environmental-progress-with-new-renewable-diesel-model (accessed August 21, 2020).