Low-Carbon Mobility

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Learning Goals
This chapter looks to get readers thinking about the future of how to get around and:
- describe how low-carbon vehicles work, their benefits, and areas of potential improvement;
- complete higher order calculations of carbon intensity;
- describe liquid and gaseous fuels from renewable energy sources; and
- appreciate the scale and magnitude of energy transformations for transportation and think about other ways to get us and our things around.

Overview
A tremendous amount of energy is used for getting us and our stuff around. Humans have always been a mobile species, always on the go. But the advent of cheap energy coupled with our new transportation technologies let humans move farther, faster, and more often. As we described earlier, cheap modes of transportation have resulted in deleterious environmental impacts from energy extraction, pollution, and infrastructures built to move people and stuff around. Transportation and its energies also have structured social relations in unequal ways. In the US, cheap energy helped facilitate suburban sprawl, leading to urban pollution when all these suburban cars were used each day in the city. On the flip side, some designs of transportation systems deepen racial inequalities such as with the infamous case of Robert Moses intentionally designing highways, specifically to prevent buses from New York City from traveling to the suburban and rural parts adjacent to the city, including many beaches to escape the heat of the city. This made it difficult for Blacks, other people of color, or other less well-off communities in the city to reach the beaches on Long Island to cool off during summertime.

This chapter focuses on the use of energy and transportation system, reviewing sources of energy used for transportation, and describes different ways of organizing infrastructure for future transportation systems. Electric vehicles (EVs), of course, play a key role. Of all the greenhouse gas (GHG) emissions produced from energy sources in the US, nearly one-third come from transportation with over 90% of GHGs from petroleum burned in gasoline and diesel-powered engines. Over 1.2 billion combustion engine vehicles on the road, in 2020, will need to be retired and replaced with more efficient and lower-carbon transit solutions. As of 2018, there are over 3 million electric vehicles (EVs) on the road, which is a good start but means there are still 1.2 billion cars to phase through. India and China will be major players in the low-carbon transportation revolution, with announcements already to prohibit the sale of cars using internal combustion engines (ICEs) by 2040. Professor Dan Sperling (2018) of the University of California, Davis Transportation Institute, says the future of mobility will be shaped by revolutions in automation, electrification, and decarbonization. The changes from the 2019–2020 coronavirus pandemic may reorient spaces to make more room for people.
8.1 Transportation in 2020 Is Powered Mostly by Petroleum

Why is transportation powered by petroleum? One important attribute of petroleum is that it is easy to store and transport. The fuels from petroleum—diesel, gasoline (known as petrol outside of the US and Canada), kerosene, jet fuel, and liquefied petroleum gas—have very high energy densities. Even with today’s best batteries, a gasoline tank the same size of a given battery will contain several times more energy.

There are social reasons that societies and regions become committed to certain fuel arrangements as well. Some countries use more petroleum than others, and the US is the leading consumer of gasoline and diesel fuel. Vaclav Smil (2011) argues that the US excessively consumes oil products compared to Europe because of (1) its inefficient fuel fleet, (2) virtual absence of more efficient diesel cars, and (3) complete absence of high-velocity trains.

There are many different proposed ways suggested to get people around with lower GHG emissions. The attractive areas in this space to investors and entrepreneurs include EVs, batteries, devices that utilize the Internet of Things (IoT), and autonomous vehicles (AVs). But the mainstay everyday practices of people—biking, walking, and telecommuting—may have a bigger impact. Infrastructure critically plays a role because if parts of Earth humans inhabit become more walkable and bikeable, many of the technological solutions could take care of the rest of the major remaining impacts. Look around, you are seeing new arrangements today to manage the pandemic. These are very low-tech solutions.

The paths to decreasing impacts from transportation focus on three areas. First, driving less, with more biking, walking, and telecommuting (or avoided travel). This requires significant changes to lifestyles and patterns of travel, which often reflect decisions about infrastructure or zoning. Second, it will be critical to replace combustion engines with electric vehicles to make transportation more efficient. Finally, the sources of energy that power vehicles must be decarbonized. This means producing electricity or fuels with low-carbon sources of power. These three tasks will reduce the bulk of the GHG emissions associated with mobility.

These considerations are very technologically centered, when in reality the complex social entanglements that make up extractive activities help us understand...
how these social forms are reproduced. To ensure a just transition requires building effective institutions that can help issues that can offer relief from the violence and human rights violations associated with the oil complex. Some corporate social responsibility efforts may be helping in this space, but the political dynamics are complex, and many activities are non-transparent.

8.2 Electric Vehicles

The shift toward EVs away from combustion vehicles will have significant public health benefits since more than 90% of criteria air pollutants are from combustion. Falling costs for energy storage are increasing the odds that most automobiles sold by 2050 will be EVs and not some other low-carbon-fueled sources like biofuels or hydrogen. In 2016, the sale of EV passed one million. A half year later, another million, and only a few months later, three million. This growth is poised to continue as places with large populations like China and India are banning combustion engines and sending signals to increase the demand for EVs.

EVs have lower operating costs than internal combustion engine (ICE) vehicles because they use electricity more efficiently. EVs have the added benefit of lower maintenance costs as they require fewer trips to the mechanic. More than likely, the emissions will get cleaner over time as more electric power comes from renewable, noncombustion sources. ICE engines get less efficient over their lifetime, owing to wear and tear, and become more polluting over time.

The full life-cycle economic cost of a vehicle is its cost plus the cost of fueling it over some determined time.

The recent boom in EVs is driven by significant cost reductions and performance improvements in lithium-ion (Li-ion) batteries. Technical advances have led to several doublings of energy capacity of batteries and stark cost declines. Li-ion batteries are also widely used in various electronics, so EVs benefit from all the attention from different industries. The capacity to hold charge over many cycles and their position as number three on the period table (very light!) make them ideal metals to base batteries on. It is important to note that these batteries do not contain very much lithium as a percentage of the total battery. A list of common battery chemistries classified as Li-ion are lithium manganese oxide used by Tesla, Nissan, and General Motors; lithium nickel cobalt oxide used by Toyota; and lithium iron phosphate used by BYD.

Electrifying transportation will not be without its challenges. Finding sites to charge in urban areas can present challenges in the densest parts of cities. They may not have driveways, and wires crossing streets pose tripping hazards and would likely raise some aesthetic resistance. Although many would argue this is where there should be no cars at all! Even homes with driveways may not have an electrical outlet with 20 feet or so of the parking space for the vehicle. The odds of having an electrical outlet that can utilize higher amps and volts are even lower. This is why building codes are so important.
Battery density challenges mean that the range of EVs can be limited compared to gasoline. Range anxiety is an important issue that faces EV adoption. How far apart should be the charging stations? Can EV charging infrastructure be developed in rural areas? Rural drivers often have more long-distance travel patterns since most vehicle trips are short, and batteries can be topped off with every return home or where charging infrastructure may be present. The good news is that everyone has an electric outlet at home, and future homes will be built better and may include faster charging equipment.

The time it takes to charge an EV battery depends on the size of the battery but also the “level” of charging. The level 1 charger used in a common household electrical outlet adds four or five miles of driving per hour of charge. Level 2 units can add 10–15 miles of driving per hour or more. New level 3 stations add 80–100 miles of charge. The goal is to approximate stoppage times for shopping or a short meal, so make for more suitable refueling options. Level 4 chargers are supposed to rival stopping at a gasoline station.

Battery swapping is another way that EV companies are thinking about solving this challenge of slow charge times. In this model, a driver would pull up to a refueling station, and the battery would be owned by a service that would swap the battery out with a charged one.

Other options including green hydrogen vehicles and biofuels may play a role as well, especially for heavy-duty transportation. These are discussed in more detail later in this chapter. Using tools already introduced and trade-offs between different energy sources and their impact on the environment can be evaluated to optimize future transportation systems. For a comprehensive assessment of these trade-offs, researchers have developed a framework called well-to-wheel analysis to compare different vehicle and fuel combinations.

**Example 8.1 Estimate the Equivalent Power Flow of Pumping Gasoline**

Imagine pulling up to the pump at a gasoline station and pumping ten gallons of gasoline into your tank in three minutes. What would be the equivalent power exchange if instead of gasoline we were using electricity? First, convert the energy of ten gallons of gasoline into MWh using dimensional analysis. Next, convert three minutes to hours. Since there are 60 minutes in an hour, 3 minutes = 3/60th or 1/20th of an hour. A total of 3 minutes is 0.05 hours. Finally, divide MWh by hours to get MW or power flow.

\[
0.35 \text{ MWh divided by } 0.05 \text{ h} = 7 \text{ MW}
\]

This means the act of pumping gasoline into an automobile is the equivalent of pulling 7 MW of power. Compare this to the typical charging power of a level 1 charger, which is a little over 7000 W or 0.007 MW.
### 8.3 Well-to-Wheel Analysis

Life-cycle assessment (LCA) is common to compare emissions from vehicles and fuels in the transportation sector. Well-to-wheel (WTW) analysis is a specific LCA framework to understanding the environmental impacts of fuel and vehicle combinations. The general idea is to capture all the inputs and emissions along the stages of production for both the fuel and vehicle combination. The findings from this type of research show that the fuel in an automobile, in general, yields the highest life-cycle impacts. WTW analysis framework can lend itself to comparing emissions from different fuel and vehicle combinations. To compare different fuels, researchers and regulatory agencies have conducted well-to-tank (WTT) analysis.

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#### Assignment 8.1 Well-to-Wheel Analysis

**Part 1:** Compare the WTW emissions of the following 16 future low-carbon vehicle-fuel mixes to conventional vehicles on conventional gasoline today.

**Part 2:** Plot your results in Excel or Google Drive as a bar graph with each vehicle and fuel mix labeled on the x-axis and the WTW annual GHG emissions from each of these vehicles in the y-axis if they are driven 12,000 miles per year.

**Hybrid-Fuel Mixes**—these vehicles only use liquid fuels. Each vehicle should be listed in row in the spreadsheet.

1. Conventional ICE vehicle using the gasoline/ethanol blend available in 2020: 10% ethanol (E10) produced in the Midwest US; 90% gasoline.
2. Hybrid ICE vehicle using the gasoline/ethanol blend available in 2020: 10% ethanol (E10) produced in the Midwest US; 90% gasoline.
3. Hybrid Flex Fuel vehicle using 85% ethanol (E85) produced in the Midwest US; 15% gasoline.
4. Conventional ICE vehicle using the gasoline/ethanol blend of 90% gasoline and 10% cellulosic ethanol from poplar trees.
5. Hybrid ICE vehicle using the gasoline/ethanol blend of 90% gasoline and 10% cellulosic ethanol from poplar trees.
6. Hybrid Flex Fuel vehicle using 85% ethanol (E85) obtained from cellulosic ethanol extracted from poplar trees; 15% gasoline.

*Use the following column headings in Excel:*

- Energy fuel-fuel density;
- Energy % density carbon intensity;
- Energy density fuel;
- Vehicle annual miles; Fuel economy;
- EtOH mix %; MTCO$_2$e; Miles; gCO$_2$e/Mile (miles/gal); MJ/mile; MJ/gal; gCO$_2$/MJ; Volume MJ/gal; gCO$_2$/MJ gasoline; gCO$_2$/MJ EtOH; EtOH MJ/gal;

*Energy density of gasoline = 132 MJ/gallon; Energy density of ethanol = 89 MJ/gallon; Carbon intensity cellulosic trees = 20.40 gCO2e/MJ; Conventional ICE fuel economy = 35 miles/gallon; Hybrid ICE fuel economy = 54 miles/gallon; Drive cycle/annual miles = 12,000 miles/year.*
**EV-Fuel Mixes**—these vehicles only take electricity. Add each as a row under a new set up headings for vehicles that take these fuels.

EV electricity on-peak EV electricity off-peak; EV PV charging; H₂ fuel cell vehicle (FCV) wind electrolysis; H₂ FCV electricity off-peak electrolysis; H₂ FCV natural gas/methane steam reforming (renewable feedstock); H₂ FCV natural gas/methane (natural gas feedstock).

*Use the following row headings in Excel:*

- Fuel vehicle;
- Annual MTCO₂e;
- Annual miles;
- gCO₂e/mile;
- Fuel economy (miles/kWh);
- Electricity CI gCO₂e/kWh;
- CI EtOH;
- EtOH gasoline %;
- CI fuel.

Some data to fill out the fuel/energy data: Carbon intensity (CI) of Pacific Gas & Electric (PG&E) electricity on peak = 428 gCO₂e/kWh; CI of PG&E electricity off peak = 187 gCO₂e/kWh; CI of PV charging = 15 gCO₂e/kWh; CI H₂ FCV wind electrolysis = 10 gCO₂e/kWh; CI H₂ FCV CA electricity off-peak electrolysis = 187 gCO₂e/kWh; CI H₂ FCV nat gas (renewable feedstock) = 273 gCO₂e/kWh; CI H₂ FCV nat gas (nat gas feedstock) = 511 gCO₂e/kWh; EV fuel economy city = 4.0 miles/kWh; H₂ FCV fuel economy city = 4.0 miles/kWh.

**PHEV-Fuel Mixes**

Evaluate the following plug-in electric vehicles (PHEVs):

- PHEV gasoline 2020;
- Electricity on peak;
- PHEV gasoline 2020;
- Electricity off-peak PHEV;
- Cellulosic gasoline 2020; electricity on peak PHEV;
- Cellulosic gasoline 2020; electricity off peak

*Use the following row headings in Excel: Then (1) paste red cells in columns F–H from the header in the EV section and (2) paste blue cells in columns J–T from the hybrid section. You will assume that gas supplies 25% of the overall energy; 75% of the time the PHEV is running in EV mode. You will calculate the annual MYCO₂e from the EV mode operation (75% of the 12,000 miles) and the MTCO₂e from gasoline mode, then add them to compare with the other results.*

- Annual miles;
- MTCO₂e Annual from EV;
- Fuel vehicle MTCO₂e mode;
- Annual MTCO₂e from gasoline mode;
- Annual miles;
- % on EV mode.

**Part 3:** Now plot your results. Add a second sheet to your Excel file. Copy and “paste special” (set to “values”) the results from the calculator into one master list on that second sheet. You should have two columns. One listing all 16 fuel vehicles, and one listing the annual MTCO₂e. Go to CHARTS. Click BAR and select CLUSTERED BAR. Give your graph a more appropriate title and you’re done.

**Part 4:** Everyone in class will join a collectively shared Google Sheets or equivalent. This sheet will be the master form for all of our sustainable energy
strategy calculations. In this sheet, begin to populate the total list of vehicles in the 2050 fleet. One idea might be to have a separate line for each class of transportation. This would allow you to require cars get more fuel efficient over time. Treat the annual miles traveled as the total vehicle miles traveled by each vehicle type. If you prefer, you can begin to make these vehicle types very specific. To make it for all of place you are aiming to assess California, we’ll have to add in freight and rail transportation and add in new categories of transportation types, light trucks, heavy-duty trucks, public transportation, and so on. Let’s build this with several hundred cars if possible. Here are some other odds and ends for now.

- Insert a column that reports the amount of fuel in gallons, mass of $\text{H}_2$, and kWhs used. This will be helpful later because for some fuels, you will have to be able to see how much can be produced in the state.
- Add another column with the heading “Water Use” because for each of these fuels, we will need to supply water. This increased water use will be added to the California water unless it displaces some agricultural production.
- Add a column for rare earth elements or other rare inputs. These can be sourced from the places you specify, under the preferred production standards. Also add fertilizer, land, and any other limiting factors.
- Add a column titled “MT electric batteries” (MT = metric tons) as each car type will have different battery amounts. Battery manufacturing will be a new major industry in California. Imagine that this California sustainable energy strategy is going to invite investors like Elon Musk to build giga-factories but also Panasonic, Toyota, and GM. Reno, Nevada, is close to numerous placer mine claims in the state of Nevada. In the future, it might become possible to source lithium for Tesla’s giga-factory from these sites of extraction. Either way each team will have to estimate how many batteries go to all sectors and estimate the life-cycle energy required to manufacture them all.

8.4 Hydrogen Fuel Cells

Hydrogen is the most widely occurring element in the universe, constituting about 75%. Astrophysicists tell us that all hydrogen has been around since the universe was a few thousand years old. On Earth, there is plenty of hydrogen bound to other chemicals, but hydrogen gas is pretty rare. A key attribute that makes hydrogen a good fuel option is it is very energy dense, with a lot of energy packed in a small volume (or mass). Hydrogen has a higher energy density than gasoline. But hydrogen is also very volatile and poses safety challenges because of the potential for it to explode during storage or transport. Nevertheless, the production of green hydrogen from renewable energy could make hydrogen fuel cell technologies a part
of the automotive fleet of a decarbonized world. There are several energy transition analysts who have proposed and touted the benefits of a “hydrogen economy” (Rifkin 2003). More recent conversations are talking about hydrogen as seasonal storage or in industry.

**Definition**

Green hydrogen commonly refers to hydrogen produced by electrolysis powered by renewable energy.

Hydrogen is an energy carrier, not a primary energy source. As a fuel, hydrogen can be used in several ways, including mixed with natural gas for combustion (e.g., for heating) or passed through a fuel cell for electric power generation. Hydrogen fuel cells take hydrogen and release energy, and they produce oxygen and water. They are functionally the opposite of electrolysis, where water is split into hydrogen and oxygen. Electrolysis uses electricity, and so its impacts are a result of electricity mix. The process of electrolysis will have an efficiency rate between 50% and 80%. New proposed designs for electrolysis processes utilize solid oxide electrolysis cells are aiming to achieve efficiencies of 90–95%.

**Definition**

Hydrogen fuel cell—a device that converts hydrogen and oxygen into water and produces electricity.

Hydrogen is energy intensive to harness from water, requiring more energy than is gained from the fuel. Most hydrogen today is from steam reforming of natural gas. It can also be produced by way of gasification of coal and from ethanol. Hydrogen can be taken from methane derived from decayed plant matter produced by photosynthesis. Methane from biogas at wastewater treatment facilities is primary biomass-derived material, although there may be some fossil fuel products in these waste streams, for example, plastics, used motor oil, industrial lubricants for machines, and so on.

Borrowing ideas from nature might offer ideas. University of Michigan researchers developed a device that uses artificial photosynthesis. The device is made of very similar components to photovoltaics and LEDs, such as silicon and gallium nitride. The gallium nitride transforms light (in the form of photons) into freely flowing electrons and holes (positively charged electron-vacancies). As photons hit the device, the electric field separates excited electrons from holes to produce hydrogen and oxygen. Natural photosynthesis has an efficiency of 0.6%, but this method they claim achieves 3% and in theory could be much higher. Since the device just uses sunlight and water, much like natural photosynthesis, it could be a pathway for large-scale production of clean hydrogen fuel.

A major disadvantage of hydrogen fuel cells for vehicles is inefficiency. After production, distribution, and storage, hydrogen energy is still only about a third
of an electric vehicle’s efficiency. However, despite the fact that a hydrogen fuel cell vehicle can charge significantly faster than a battery of an electric vehicle, 5 minutes opposed to up to 18 hours, there is a lack of infrastructure, such as hydrogen charging stations, that support the vehicle—electric car charging stations are much more accessible. With a lack of infrastructure, it will be difficult for consumers to be motivated to buy the cars Nature. Even if the cars are out in the market, it is very difficult to “establish a [loyal] customer base, increase production, [achieve economies of scale], and bring down costs” (Tollefson 2010). But this has definitely been a positive development for EVs, which is that people who buy them would buy them again, and most would never buy a gasoline car again. So long as the EV revolution is led by safe, reliable, and hopefully soon affordable cars, they seem destined to have increasing market share from here to 2050.

The distribution of a future automobility of battery-powered electric cars, hydrogen fuel cell-powered cars, and hybrids will be based on the resource size, availability, and economic potential of each option, and it may be regionally specific to the available fuels and infrastructure. It is not just the total amount of energy (resource size) that needs to be available, but also the time when that energy would be available, including factors such as the time of day, seasonal availability observations), miles and duration of driving, and new ideas about how roads should be used, which might not see a future for passenger cars at all except for those who could better accessibility.

### 8.5 Ethanol

Sugar- and starch-based platforms for liquid biofuels make up the most significant portion of the biofuel supply. The leading crops for ethanol production include corn and sugarcane, largely from the US and Brazil, respectively. Almost one-third of the US corn supply went to ethanol production in 2016 (USDA 2017).

| Definition | Energy Content of Selected Liquid Fuels (in kilo-British thermal units (kBtu)) |
|------------|---------------------------------------------------------------------------------|
|            | Gasoline                                                                        | 125 k Btu/gallon |
|            | Ethanol                                                                      | 84 k Btu/gallon  |
|            | Compressed natural gas                                                        | 106 k Btu/gallon |
|            | Propane                                                                       | 91 k Btu/gallon  |

To utilize ethanol, we can use flex-fuel engines, an internal combustion engine able to take higher percentages of ethanol, but also liquid fuels with high proportions of gasoline. The nomenclature that relates these high percentages of gasoline versus ethanol are E10 (10% ethanol), E100 (all ethanol), E90 (90% ethanol), and so on.
Many studies of GHG emissions from ethanol suggested that the energy balance did not yield positive returns. In other words, it had an energy return on investment (EROI) less than 1. The best corn ethanol EROIs are in the range of 2 and 3. The worst-performing ethanol plants for decarbonization are those that use coal for the heat process and have large amounts of coal on the power grid.

If energy crops remain major sources of liquid fuels, they will compete with high-quality land for agriculture, creating trade-offs between food and fiber and fuel production, or other land uses. During the rapid scaling-up of corn ethanol after the ethanol mandate, there were so-called “tortilla riots” in Mexico, not because of a shortage of corn, but from rapidly rising prices (McMichael 2009). This particular situation may have been a historically uncommon situation as there were several factors driving the price of food. The backdrop was the financial crisis of 2007–2008 when many investors were moving cash out of financial products like mortgage-backed securities into commodities; people having hedge funds and futures speculators were looking for safer bets, even if the returns were more modest. Also, major processed food companies began to hoard any available food on the market to ensure they remained profitable. It was a perfect storm when the increased demand for ethanol is accounted for.

### Example 8.2 Energy in Ethanol

The Energy Policy Act of 2005 is a US law that requires the production of 36 billion gallons of ethanol (EtOH) by 2020. (1) How much energy does 36 billion gallons of ethanol contain (in megajoules (MJ))? (2) If US drivers use the same amount of energy to get around, how many gallons of gasoline would this displace each year?

(1) \[ 36,000,000,000 \text{ gallon EtOH} \times \frac{80.2 \text{ MJ}}{\text{gallon EtOH}} = 2,890,000,000,000 \text{ MJ} \]

(2) \[ 2,890,000,000,000 \text{ MJ} \times \frac{\text{gallon gasoline}}{121.3 \text{ MJ}} = 23,800,000,000 \text{ gallons gasoline} \]

### Example 8.3 Energy Density and Well-to-Wheel Greenhouse Gas per Mile

1. What is the energy density of E10 fuel?

   Assume: Energy density of gasoline = 120,000 Btu/gallon
   Energy density of ethanol = 80,000 Btu/gallon
   Calculate energy density of the combination of ethanol (10%) and gasoline (90%) called E10 = 116,000 Btu/Gal

2. (a) How much well-to-wheel (WTW) life-cycle energy per mile is used to move a compact hybrid car, and (b) what are the annual GHG emissions associated with this vehicle if driven 12,000 miles annually? Assume the vehicle is running on an E10 blend. You will have to calculate the carbon intensity of E10 fuel.
Food versus fuel debates could instead ask, is it possible to produce food and fuel? One past example is the German alcohol economy during World War II. Farmers would deliver potatoes to energy producers, who would distill these foodstuff to alcohol, then the farmer would get one-third of the biomass pulp for pigs. This is sort of what happens even in the ethanol economy today in the US, where distillers’ grains are sold to the livestock industry, and there are some studies that suggest this food is better for animal health. The food versus fuel tension points to a need to develop more next-generation biofuel sources such as algae and cellulosic ethanol that do not compete with food or prime farmland. There are a handful of candidates for cellulosic ethanol. Sugarcane is a relatively less land-use-intense biofuel system, using niche wetland-type areas but deserves critical scrutiny too; the corn-ethanol system is not a good use of agricultural resources considering global problems with uneven access to high-quality chemical fertilizers.

Water quantity and quality issues are other considerably large impacts from producing biofuels. Water footprint studies of biofuels find very large water needs for growing many energy crops with the evapotranspiration associated with photosynthesis. Freshwater use is clearly more important in regions that rely on fossil rainwater harvesting from irrigation, such as agricultural operations growing corn for ethanol on the Ogallala aquifer in the Midwest US rather than rain-fed corn or energy crop production.

Nitrogen pollution is another factor, as farmers typically overuse cheap fertilizer to ensure that yields are maximized. Also, as ethanol emerged as a marketable product, many farmers brought nitrogen fertilizer back to the soil instead of bringing nitrogen by rotating corn with soybean, the latter mimicking the way nature moves nitrogen from the atmosphere into the rhizosphere. Likewise, where pesticides are used, there are concerns about residues in the soil and waterways, and data showing that these chemicals do not readily break down.

In the case of corn ethanol in the Midwest US, the major ecological and water quality concern is where land is taken out of conservation easements and brought
into corn production. Conservation easements allow farmers earn revenue by leaving native grasses or prairie in place as a buffer to absorb nitrogen and soil runoff, and as forage and habitat for insects and wildlife. When agricultural prices are high, these lands might be taken out of easement. Or, if crops are designed for marginal land, these too could put easement habitat at risk.

Candidates for second-generation ethanol crops include miscanthus (*Miscanthus sinensis*), giant reed grass (*Arundo donax*), elephant grass (*Pennisetum purpureum*), poplar trees (*Populus* sp.), and switchgrass (*Panicum virgatum*). Some of these crops require more research and development in plant breeding, which will likely play a major role in making these feedstocks economically viable. Some of these objectives include increasing biomass, decreasing fertilizer requirements, optimizing yields, introducing enzymes into the plant, modifying/removed lignin, and converting cell wall to sugars.

One final consideration in evaluating the environmental impacts of biofuels has to do with plant breeding. It turns out many of the same traits sought-after in biofuel crops are similar to those found in invasive species: drought tolerance, tolerance to salinity in water and soils, ability to grow in low-fertility soil where prime farmland is not required, high water-use efficiency to lower the water footprint, increased harvestable biomass to increase the productivity per acre, increased seed production where seeds provide the fuel (biodiesel, next section), fewer pests and less susceptibility to diseases so fewer pesticides are required, and high density for greater land-use efficiency.

Third generation biofuels include micro- and macro-algae. Algae biodiesel or biocrude can be produced from numerous feedstocks, including diatoms, green algae, blue-green algae, and golden algae. These biofuels, which can be ethanol, biodiesel, and even biobutanol, can also be grown in the ocean or wastewater. Many of these algae species contain up to 50% body weight of lipids—fatty cells that can be used for biodiesel. These feedstocks can use CO₂ emissions as an input from other production processes to enhance the feedstock production. Algae purportedly has a high-power density at 2,000–20,000 gallons per acre per year, though it has not been possible to produce commercially to date due to affordability and scale.

Producing ethanol from waste biomass streams could make sense where there is an abundance of biomass availability, where it might already be collected and concentrated, and where the waste flows are regular and in large volumes. Some communities have biomass available through yard clipping programs or wood for wildfire fuel reduction or invasive plant removal efforts could provide supplies of energy. Cattails grown at wastewater treatment plants could be harvested and fermented with very high conversion rates.

Today, ethanol remains a contested potential energy source. Some of this disdain is because it remains a product of combustion, which still leads to some kinds of air pollution. Other concerns are raised because some corn ethanol sources might not yield back the energy or GHGs invested to make them. For now, ethanol production is interlinked with many regulatory standards but also a growing number of certification and labeling schemes and will be part of the energy mix for the foreseeable future (Bailis and Baka 2011).
One final consideration is that ethanol is added to gasoline in order to replace methyl-tertiary butyl ether (MTBE), a fossil fuel additive mixed in to lower the air pollution caused by combustion. Adding even corn ethanol to gasoline instead of MTBE should lower GHGs emissions in a gallon of gasoline. From 2002 to 2004, the EPA conducted a multiple-year LCA of impacts from swapping MTBE and ethanol and found that the air pollution and water pollution impacts from ethanol were much lower than MTBE.

8.6 Biodiesel and Renewable Diesel

Biodiesel and renewable diesel are actually different liquid fuels. Both are produced through a thermochemical conversion process, so they are in what is called the thermochemical platform for bioenergy. Transesterification is the process to turn triglycerides from fats and oils in the presence of methanol into methyl esters (biodiesel) and glycerin. Biodiesel is made of fatty acid methyl esters (FAME), which can be used in most engines in small quantities, but it requires some engine modifications for blends with high FAME content. The key difference between FAME biodiesel and renewable diesel is the presence of oxygen. Hydro-treating is the process of making renewable diesel, which has the same chemical formula as diesel does. This process does require high temperatures, so it can be more energy intensive to produce. B100 means 100% biodiesel, whereas B10 is 10% biodiesel. Much like the nomenclature for ethanol, the number stands in for the percentage. Renewable diesel, because it has the same formula, does not similarly have a nomenclature.

Global renewable and biodiesel feedstocks and production are largely restricted to a handful of countries and regions, including across the European Union, the US, Brazil, and Malaysia. Common feedstocks include canola, soybean, palm, hempseed, vegetable, and corn oil. Soybeans are one of the most common biodiesel sources, but they yield relatively small amounts of crop per land. Directing all the US soy crop (and the US is a major producer) would satisfy only about 5% of US biodiesel demand if it were to replace diesel. US annual consumption of diesel is about 60 billion gallons per year (Energy Information Agency 2017). The entire continent of Africa used 2.5 billion gallons in 2016.

Palm oil from Indonesia and Malaysia (which is also destined to the food industry) is impacting habitat for the critically endangered orangutan, a resident of the forests that are converted to palm plantations. In the mid-2000s, growth in palm oil production was spurred by EU policy, and much of this habitat came under pressure for development. Greenpeace and other groups began campaigns, and soon a Roundtable on Sustainable Biofuels team emerged specifically to work on sustainability certification schemes for palm for biodiesel. One challenge is that more palm oil goes to the food industry, so growers have alternative markets to sell to.

A number of second-generation biodiesel crops are being explored, including jatropha, algae, and other exotic oilseeds. These crops promise to have lower input requirements, as they are not the fertilizer-hungry crops typically used for biofuels. Likewise, these crops should be more productive per unit area. In the case of algae, these can be grown offshore or indoors. Several key policies have driven much of
the development of markets for biodiesel over the past decade, including a blenders credit for biodiesel or vegetable oil, a small producer tax credit. But beware of policy design, google “splash and dash” biodiesel loophole for an example pitfall.

Straight vegetable oil (SVO) is a fuel made from “off-the-shelf” cooking oils that can be directly dropped into fuel tanks. While functionally it is good to use up waste, and most likely the fuel has very low carbon, there are resource limitations to the availability of some of the oil produced, and the costs to produce these oils are relatively high. Waste vegetable oil (WVO) is made from used tallow or food greases. This resource also is limited in its availability, but it could be used in niche energy applications and markets, for example, on farm or in fleets of vehicles near food processing centers or restaurants. If all of the greases and animal fats in the US were converted to biodiesel, it would replace about 1.5 million gallons of diesel fuel, which is not much at all (National Renders Association 2000).

Assignment 8.2  Environmental and Ecological Justice in Supply Chains for Biofuels, Electric Vehicles, and Hydrogen Fuel Cells

Biofuels, electric vehicles (EVs), and hydrogen fuel cell vehicles will provide cleaner, lower carbon options for transportation California. Yet, there are serious critiques regarding the sustainability and environmental justice issues in the supply chain for several of these prime mover and fuel combinations. John Sheehan (2009) writes, we need to “avoid the never ending cycle of solving problems with new technology solutions from which new problems arise that need new technological solutions.” For this assignment, each student should pick one of these supply chains to investigate: (1) cobalt for EVs, (2) lithium for EVs, (3) manganese for EVs, (4) hydrogen for fuel cells, (5) platinum for fuel cells, (6) sugarcane for ethanol, (7) corn for ethanol, (8) soybean oil for biodiesel, and (9) palm oil for biodiesel.

In this assignment, each student role-plays what they would do if they are hired as a sustainability advisor to a policy-maker tasked with developing criteria to evaluate the sustainability and social justice dimensions of transportation options. The criteria you propose for sustainability and social justice will be used to benchmark and select which kinds of policies can be pursued to maximize ecological and social benefits of sustainable energy strategies. How can we pursue the prime mover and fuel options mentioned earlier without reproducing the social and environmental impacts they currently cause?

Write a 1,000-word summary with five peer-reviewed research articles or high-quality white papers and reports that (1) provides an overview of what kinds of transportation technologies could be in use in 2050 and describes end uses where they could replace fossil fuel energy; (2) highlights the major socio-ecological impacts of the assigned batteries/fuel cells/energy sources and major efforts to improve, mitigate, or minimize these impacts; and (3) proposes a set of criteria, regulations, and/or best practices to ensure most sustainable and socially just biofuels are produced for the chosen region's California’s sustainable energy strategy.
8.7 Low-Carbon Drop-in Fuels

An obscure decarbonization proposal comes from a group of scientists promoting the methanol economy, which is a liquid fuel known as “wood alcohol” that can be produced by oxidizing methane or reducing carbon dioxide. Depending on the source of the methane and CO₂, this could reduce GHGs from these fuels compared to conventional gasoline or natural gas. Dimethyl ether (DME) can also be derived from methanol and can be used in gas turbines, and as a substitute in blends with diesel, gasoline, and liquefied petroleum gas (LPG). So DME offers the possibility of a drop-in fuel with minor modifications. Carbon waste streams, preferably carbon sourced via photosynthesis, can be converted to cleaner burning methanol, which contains no sulfur. To make these fuels possible, special catalysts are needed to facilitate reactions that release the hydrogen from methanol. There is also experimental research ongoing with methanol fuel cells. Much like the case of hydrogen, most of the methanol supply today is derived from fossil carbon, although numerous efforts are underway to produce bio-feedstocks for various alcohols, such as biobutanol.

A Nobel Prize–winning chemist Dr. Shah argues that the methanol economy would be a relatively easy transition from an infrastructure perspective because it is relatively inexpensive to convert existing gasoline and diesel service stations to methanol ones. The carbon for the methanol would ultimately be coming from the atmosphere. Methanol as a liquid fuel also overcomes the power transfer problem at charging stations for electric vehicles, where there are two orders of magnitude difference in power transfer when moving liquid gasoline to the tank compared to the ability to move electricity to an EV battery. Currently, there are no meaningful pursuits of a methanol economy with the exception of the more obscure research, likely because the feedstock for methanol will be natural gas for the foreseeable future.

8.8 Vehicle-to-Grid Storage

Electric vehicle batteries that are capable of two-way electricity flow into and out of the power grid can be used in vehicle-to-grid storage (V2G) applications. V2G integration can contribute energy storage capacity and provide services to
the electricity grid. By providing energy, V2G can help provide key resources at important times, as V2G systems can be used for reducing peak loads and backing up power. This added storage can integrate intermittent renewable electricity generation into the grid by using a buffer of renewable energy in the batteries when it is available. The V2G system can also improve the quality of energy, preventing critical voltage drops or frequency response services.

Any value created by V2G could be used to incentivize PEV ownership and practice. Some of the opportunities could further reduce emissions in the transportation sector. Some modeling efforts suggest that widespread V2G deployment could benefit PEV buyers, electricity ratepayers, and society more generally. California is testing V2G projects to see how it will help it reach its climate goals by 2050. That allows them to go from simply consuming energy to potentially becoming a fully functioning component of the smart grid. The two-way functionality of electric vehicle batteries makes it an ideal source for energy and storage. This will give electric vehicles power when needed and give grids power when needed. This can be a way to reduce power at peak times when the grid needs to acquire or shed load. By 2050, there could be a 39% increase in non-transportation load and vehicle miles traveled due to population growth compared to current 2015 levels. An 80% BEV penetration increased the electricity load by 32%. The net effect is an electricity load 183.5% of the current CA load (Forrest et al. 2016). In the long run, more electricity will be used by 2050. Integrating the vehicle-to-grid technologies can store electricity and allow it to be used when needed and vice versa. In 2018, BMW partnered with Pacific Gas and Electric (PG&E) to pilot smart chargers that will charge batteries during the day, when solar energy is abundant and sometimes is curtailed. By subjecting smaller amounts of renewable energy to round-trip efficiency losses, and thereby increasing the efficiency of renewable utilization, vehicle-to-grid energy storage can help achieve higher renewable utilization and quality levels and reduce GHG emissions compared to “stationary energy storage systems” (Tarroja et al. 2016).

8.9 Autonomous Vehicles

How far will autonomous driving push our civilization with regard to economic and environmental considerations? Companies such as Google, GM, Tesla, Apple, Uber, and Volvo had made significant financial commitments to this technology, and they believe it to be a critical component to the future of mobility. Combining these two technologies—EVs and AVs—together into a single, interdependent package with infrastructural and legislative changes will drastically increase driving efficiencies, reduce driving accidents, and, with the help of electric vehicles, reduce GHGs. One study suggested that taxis from a fleet of AVs would have significant GHG reductions (Greenblatt and Saxena 2015). But studies of AVs in practice have many different outcomes, depending on the operating conditions and its urban, rural, highway speeds, or stop-and-go (Mersky and Samaras 2016).

At a high level, the idea is to utilize autonomous driving technologies with electric vehicles to create ride-sharing “pods,” if you will, that will allow people commut-
ing together to ride together. High-speed travel could change drastically increasing the minimum driving speed or moving chains of large trucks or buses. Urban travel could be based on vehicles moving at slow-paced minimum speed. Both could drastically reduce the number of vehicles on the road and also the GHG emissions, while at the same time requiring great resources and fewer parking lots.

There are still some technological breakthroughs that are necessary before autonomous vehicles (AVs) can become widely available or put into use including very important ethical questions. AI has been improving rapidly and has propelled the ability of AVs to analyze and react to a dynamic driving environment to the point where minimal human interaction is necessary. However, the capabilities are currently not advanced enough to become a viable solution in today’s basket of mobility solution except in very low-risk situations.

Scenarios have been simulated to study the impact AVs will have on driving habits and GHG emissions. In some imaginations, the ideal scenario in terms of energy efficiency envisions the entire personal automobile fleet will become automated, only consist of ride-sharing, and will largely incorporate vehicles that have low emissions such as hydrogen fuel cell and electric vehicles. This will result in energy savings stemming from traffic flow smoothing, vehicle-to-infrastructure and infrastructure-to-vehicle communication, collision avoidance, and vehicle powertrain resizing. It is estimated that the US light-duty vehicle fuel consumption will decrease significantly, given the vehicles on the road are more fuel efficient. While this seems to be a likely outcome indicated by the successes in the adoption of electric vehicles and ride-sharing platforms, it is much too early to conclusively determine that AVs will result in major reductions of GHGs or improved energy efficiency.

The most concerning challenge facing the adoption of IoT or AV technology energy efficiency is the threat of cyberattacks. By connecting more devices to the Internet, especially ones that govern critical infrastructure like the power grid, we expose ourselves to attacks from political assailants and people up to no good. Bad actors would have a chance to exploit the various energy systems within an individual home, business, vehicle, or power grid at large. The issue of cyber security is both a political and technical problem, which has to be addressed with laws and technical safeguards (Singer and Friedman, 2014, 165). On the technical side, the US Senate has stressed that “security should be built into devices at the outset and throughout a device’s lifecycle,” but not as an afterthought. Although it is impossible to protect from all threats at the outset, good design practices can significantly reduce the likelihood of crippling attacks (Singer and Friedman, 2014, 55).

AVs will be connected by smart hubs spaced at some interval to ensure proper and adequate coverage to assure that each vehicle is communicating and is still on the network. These smart hubs act as the central device and hand off to the next hub is seamless from one to the next. As reliability and effectiveness of public transit via autonomous ride sharing increases, there will be more opportunities to smart transit design that can incorporate AVs. As the public engages with more autonomous driving, there could be much lower need for parking lots and structures.
As AVs have the potential to change vehicle design and use patterns, there is much potential for emissions reductions. But some suggest that AVs could increase overall emissions due to a rebound effect. The EIA reports that light-duty vehicle miles travelled could increase with AVs, leading to overall increases in emissions (Energy Information Agency 2017). A useful guide for policymakers has been developed by some of the leading experts on these topics (Anderson et al. 2014).

8.10 Public Transportation

The US constructed its first rapid transit system, a subway line, in 1895 in Boston which was 1.5 miles long and used trolley streetcars. Then, on October 27, 1904, New York City opened its own rapid transit system of what became one of the largest systems in the world. Los Angeles had an extensive public transit network that was disassembled.

There are even public health benefits documented with the use of public transportation. Transit users are more active, safer, and less stressed. The US Center of Disease Control (CDC) recommends about 22 minutes of physical activity and the average individual who uses transportation does 19 minutes from walking to stops and final destinations. Moreover, transits promote individuals in communities to interact and have access to social or recreational activities or participate in events that were not accessible initially. In addition, approximately 40,000 deaths happen annually from car accidents per year; however, traveling on a transit is safer and areas with high public transit use have security. The coronavirus pandemic is posing challenges for public transportation, and it has led to steep declines in revenues from travelers.

The kinds of technologies communities are pursuing to decarbonize transportation include electric buses. In the US, many diesel buses have already been replaced by natural gas, but much more opportunities exist for electric buses. Some cities like San Francisco have used electric buses for many decades. But these are the kinds of buses that require overhead wires. These impose a very visual blight on communities. Electric buses with a battery onboard or capable of wireless induction charging offer an opportunity to replace combustion engine buses with emissions-free electricity.

According to the American Public Transportation Association, every dollar invested into public transportation generated approximately US$4 in economic returns. These returns can be invested in communities to create jobs, increase business sales, and increase residential property values for homes near to the transportation systems, and for every US$1 billion in investments, 50,000 jobs are created. Public transport agencies employ tens of millions of people worldwide. The organization also reports that a person can save over US$10,000 per year on transportation costs by using transit. This is because a person only pays for when they are on the ride and do not have to worry about expenses such as maintenance, repairs, parking, or ongoing improvement.

Things are looking up for electrifying public transportation. Today, there are increasing orders for electric buses from cities and regional transportation agen-
cies. It is expected that by 2020, one-third of all new buses will be electric. Major rails are on the move from diesel to electric in some places. The Caltrain route from San Francisco to Gilroy, California, is expected to be electrified in the near future.

8.11 Urban Planning for Walking and Biking

Perhaps the most efficient way to improve the sustainability of mobility in urban areas is to make them more bikeable and walkable. This will take substantial time as urban planning efforts can be slow and incremental, particularly in large cities. These again are areas where there is significant evidence to demonstrate public health benefits from walking and biking because of the associated cardiovascular exercise. It would be difficult to find a city that has done this with great success, but, increasingly, there are projects that have become exemplar, especially in response to coronavirus public health measures. These designs usually keep pedestrians, cyclists, and vehicles separated in some way. Ultimately, making streets safer will result in more people walking and biking in their communities.

Bikeshare and scooter programs are taking off in some parts of the US as global positioning system (GPS) and mobile currencies allow new modes of payment and tracking. These trips may be displacing traffic rides and taxis. It may allow someone to travel by foot one way and take a ride home in some circumstances. As new business model opportunities have emerged for these bikes and scooters, their rapid deployment in some places has drawn a bit of public ire because of clutter. Most onlookers seem to tend toward endorsing this new mode of transportation as a final mile solution.

Non-automobile transit-oriented communities are another opportunity for urban planners to design communities that maximized access to public transportation. If people have safe, efficient, and effective means of public transport or biking and walking opportunities to work from home, more people would use those options. One way to do this is via local zoning where projects like these can be incentivized through tax benefits or expedited permitting. California has a state law that requires dense development around public transit corridors (Fig. 8.1).

8.12 Decarbonizing Aviation, Long-Range Travel, and Flying Less

Aviation is a significant part of the GHG problem, especially considering the total number of people who fly and how much they fly. It is first important to note that even in a wealthy country like the US, the media a person flies zero times per year. In other words, flying is not something most people even in the US do. It is more a mode of transportation for the top one-third population who fly every year (Fig. 8.2).

The degrowth argument suggests that one solution is flying less. This means reflecting more on choices about where to go. California is leading the way
in low-carbon aviation fuels. Driven by the state low-carbon fuel standard (LCFS), there are several new renewable jet fuels that are being sold in the state. One project is using waste tallow and converting it to jet fuel. Many organizations offer carbon offsets as a means to compensate for the emissions of aviation and flights. But offsets, as we learned in earlier chapters, face a number of different challenges about credibility, and in some cases, they have resulted in perverse outcomes as many critics of the Reducing Emissions from Deforestation and Forest Degradation (REDD) program have pointed out (Brown 2010) (Fig. 8.3).

New aircraft are more efficient with each generation. The Airbus 350 and Boeing 787 “Dreamliner” are both the most fuel-efficient aircraft ever built. The 787 is the first aircraft made of a carbon fiber body, which reduces the weight of the aircraft (Fig. 8.4).

High-speed rail is widely noted as a strategy to lessen the GHGs from long-distance transportation. There are success stories of different kinds, including in Japan, Germany, Italy, and France where there are high-speed rail systems that have been running for over 50 years now. In the US, California is building a high-speed rail system that will connect Los Angeles and San Francisco-San Jose (Fig. 8.5).

Electric buses are already taking over metropolitan areas around the world. China, California, Europe, South Korea, and many other countries are adopting EV buses because they have significantly lower operating costs, including fueling and maintenance.

Fig. 8.1 The PV here is not enough to charge these EVs, but the shade is nice and every drop helps
Fig. 8.2  Micromobility solutions like e-scooters may help solve the final mile problem.

Fig. 8.3  E85 fueling station in Las Vegas.
Fig. 8.4  Solar power aircraft like these may find niche markets, but large passenger jets need higher-density fuels

Fig. 8.5  Taxpayer investments like Tesla have helped create jobs and clean energy devices

References

Anderson, J. M., Nidhi, K., Stanley, K. D., Sorensen, P., Samaras, C., & Oluwatola, O. A. (2014). Autonomous vehicle technology: A guide for policymakers. Rand Corporation, New York.

Bailis, R., & Baka, J. (2011). Constructing sustainable biofuels: Governance of the emerging biofuel economy. Annals of the Association of American Geographers, 101, 827–838. https://doi.org/10.1080/00045608.2011.568867.

Brown, M. L. (2010). Limiting corrupt incentives in a global REDD regime. Ecology LQ, 37, 237.

Energy Information Administration. (2017). Gas and diesel fuel update. https://www.eia.gov/petroleum/gasdiesel/.

Forrest, K. E., Tarroja, B., Zhang, L., Shaffer, B., & Samuelsen, S. (2016). Charging a renewable future: The impact of electric vehicle charging intelligence on energy storage requirements to meet renewable portfolio standards. Journal of Power Sources, 336, 63–74.
Greenblatt, J. B., & Saxena, S. (2015). Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles. *Nature Climate Change, 5*(9), 860.

McMichael, P. (2009). The world food crisis in historical perspective. *Monthly Review, 61*(3), 32.

Mersky, A. C., & Samaras, C. (2016). Fuel economy testing of autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 65*, 31–48. https://doi.org/10.1016/j.trc.2016.01.001.

National Rendes Association. (2000). U.S. production of fats and oils.

Rifkin, J. (2003). *The hydrogen economy: The creation of the worldwide energy web and the redistribution of power on earth*. Penguin, New York.

Sheehan, J. J. (2009). Biofuels and the conundrum of sustainability. *Current opinion in biotechnology, 20*(3), 318–324.

Singer, P. W., & Friedman, A. (2014). Cybersecurity: What everyone needs to know. Oxford University Press, Oxford.

Smil, V. (2011). America’s oil imports: A self-inflicted burden. *Annals of the Association of American Geographers, 101*(4), 712–716.

Sperling, D. (2018). *Three Revolutions*. Island Press, Washington, DC.

Tarroja, B., Zhang, L., Wifvat, V., Shaffer, B., & Samuelsen, S. (2016). Assessing the stationary energy storage equivalency of vehicle-to-grid charging battery electric vehicles. *Energy, 106*, 673–690.

Tollefson, J. (2010). Fuel and waste no bar to US nuclear growth: Report finds that plentiful fuel supplies and temporary storage will buy decades of time to develop a longer-term strategy. *Nature, 467*(7314), 376–378.

USDA. (2017). Biofuels. https://www.fas.usda.gov/commodities/biofuels.