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An Environmental Assessment of Transportation Alternatives

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An Environmental Assessment of Transportation Alternatives

Executive Summary

The business of getting from here to there generates large environmental impacts. Transportation accounts for about 28%, 31%, and 24% of U.S., EU, and world energy consumption, respectively. Relative CO_2 emissions linked to transportation are similar. How much impact transportation has on the environment depends on several factors, including the mode of transport, the fuel used, the passenger and cargo load, and the distance traveled.

In this report, we examine the relative environmental impacts of various modes of travel, recognizing that in any given situation, transport choices may be quite limited. Nonetheless, choices made can significantly influence environmental impact. Consequently, individual decisions, and/or public policy shifts which broaden or influence the choice of transport options, have the potential to immensely reduce the impacts of travel.

The Environmental Impacts of Transportation

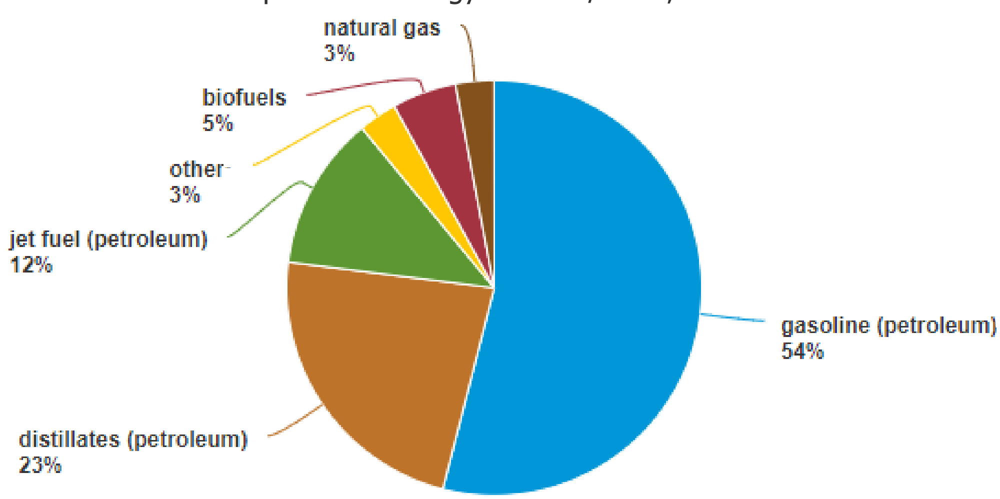
Direct Impacts

Fuels, Emissions, and Travel Mode

The direct environmental impacts of transportation are primarily linked to emissions generated as vehicles operate, which are influenced by energy sources, fuels, and efficiencies. According to the most current data, petroleum products account for about 92% of total U.S. transportation sector energy use (EIA, 2019). Biofuels, such as ethanol and biodiesel, contribute about 5%, natural gas about 3%, and electricity less than 1% (Fig. 1).

Figure 1

U.S. Transportation Energy Sources/Fuels, 2018 [1/] [2/] [3/] [4/]



[1/] Percentages based on energy content

[2/] Petroleum gasoline (blue) includes motor gasoline and aviation fuel (excludes ethanol)

[3/] Other includes residual fuel oil, lubricants, hydrogen gas liquids (mostly propane) and electricity.

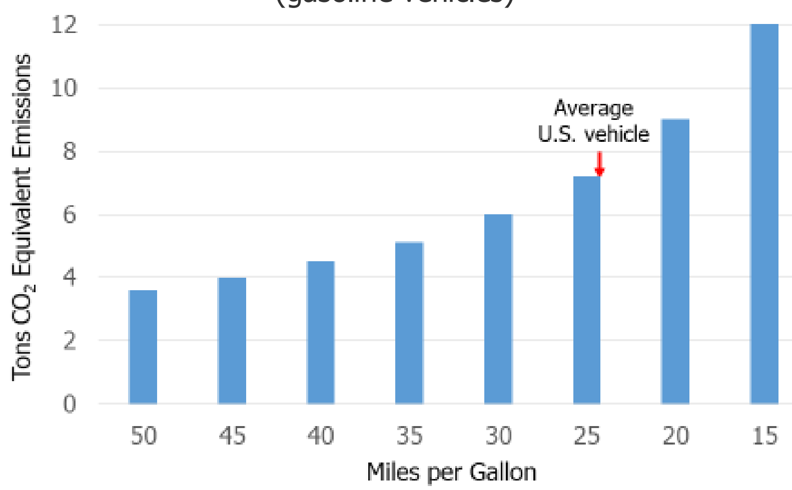
[4/] Distillates are primarily diesel fuel and motor oils.

Source: Energy Information Administration (EIA) (2019c)

When gasoline is combusted, the substances produced include carbon dioxide and monoxide, nitrogen oxides, volatile organic compounds, and particulate matter. All of these contribute to air pollution. Carbon dioxide is a greenhouse gas (GHG) and a primary contributor to climate change. In 2018, the transportation sector accounted for 78% of U.S. CO_2 emissions from petroleum and more than one-third of all U.S. energy-related CO_2 emissions.[1]

A gallon of gasoline weighs 6 pounds (2.7kg). Combustion of that gallon of gasoline produces about 19.6 pounds (8.9 kg) of carbon dioxide (CO_2) if it does not contain ethanol, and 17.68 pounds (8.0 kg) of fossil CO_2 if it contains 10% ethanol.[2] For an average U.S. vehicle (see red arrow, Figure 2)[3] these numbers translate to about 6 tons (5.4 metric tons) of CO_2 emissions annually in addition to significant emissions of the other fuel combustion-related compounds. Vehicles with higher than average fuel efficiency (small, hybrid, and electric vehicles) generate significantly lower emissions than those at the low end of the efficiency scale (large sport utility vehicles (SUVs) and light duty trucks) (Figure 2). GHG emissions from combustion of a gallon of diesel fuel are about 15% greater than from gasoline; on the other hand, the energy content of diesel is about 10-15% greater than a gallon or liter of gasoline, with the result that emissions per distance traveled are often lower for diesel than gasoline powered vehicles.

Figure 2
Annual Greenhouse Gas Emissions 1/ by Vehicle MPG
(gasoline vehicles)



1/ Includes tailpipe and fuel extraction and processing emissions.

Source: USDOE/USEPA (2019)

GHG emissions (in CO_2 equivalents) from jet fuel are 21.1 pounds per gallon. Combustion products include carbon dioxide and monoxide, nitrogen oxides, carbon particles, and volatile organic compounds. Airplanes also sometimes create contrails as heated air from jet engines mixes with much cooler air at low vapor pressure. Fine particulates (soot) that are released as part of combustion products contribute to contrail formation.

[1] EIA (2019a)
[2] EIA (2019b)
[3] USDOE/USEPA (2019), USEPA (2019)

For individual passenger vehicles, fuel type and combustion efficiency are leading contributors to the direct impacts of travel. Impacts are also influenced by passenger load, speed of travel, and frequency of stops.

When all transportation alternatives are considered, the mode of travel stands out as a major determinant of environmental impact. In general, traveling by bus or rail results in the lowest impact per passenger mile traveled, while air travel results in the highest.

Effects of New Technologies, Policies, and Increasing Travel

In recent decades, a combination of technological improvements and cost-saving measures has reduced average energy consumption per passenger mile for auto, rail, and air transport. Improved energy performance has also resulted in lower per passenger mile emissions of carbon dioxide, methane, sulfur dioxide, nitrogen oxides and other compounds.

The greatest performance gain has been in air travel, where energy consumption per passenger mile is only one-fourth of what it was in 1970.[4] This achievement is the result of technological improvements in aircraft body and engine design and increasing passenger loads. Passenger loads are up in part due to the fact that greater numbers of people than ever before are traveling by air. Packed airplanes can also be attributed to changes in airline policies and shifts in flight schedules over the years, sometimes to the displeasure of customers, to ensure that a greater percentage of seats are filled.

Assuming one passenger per vehicle, energy consumption per average U.S. auto (and per passenger mile) is less than half of what it was in 1970.[5] Technology development has been the primary factor in reduction of energy consumption in the auto industry. In response to mandated fuel efficiency standards, vehicles have steadily become lighter and more fuel efficient. Increasing availability of hybrid, plug-in hybrid, and all electric vehicles will further increase energy efficiency in the future while also dramatically reducing carbon emissions.[6] However, development of hybrid and electric vehicles have to this point had only a modest impact on energy efficiency and carbon emissions of the auto fleet as a whole due to limited consumer adoption of these technologies. But consumer acceptance continues to grow.

Train travel is also more efficient on a per passenger mile basis than in the 1970s, although efficiency gains have been more modest than for air and auto travel. In 2017, energy consumption per passenger mile on intercity trains was about two-thirds of what it was in 1970.[7] Gains in energy efficiency of bus transportation have also been modest, with energy consumption per passenger mile only about 10-12 percent lower than 4-5 decades ago.

Relative Efficiencies of Various Modes of Travel

Long-Distance Travel

Two recent analyses illustrate relative efficiencies of long-distance travel in the U.S. The International Council on Transportation (ICT) and National Geographic both found bus

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4 U.S. Department of Transportation, Bureau of Transportation Statistics (2018), p. 7-2.

5 1970 estimated mpg from Sivak and Tsimhoni (2009)

6 See Environmental Assessment of Conventional vs. Hybrid vs. Battery electric Vehicles (2019) (http://www.dovetailinc.org/report_pdfs/2019/DovetailRespVehicles0315.pdf)

7 U.S. Department of Transportation, Bureau of Transportation Statistics, Energy Intensity of Passenger Modes (2019)

transportation to be the most energy efficient mode of travel, and travel by air the least efficient (Figures 3 and 4). In fact, virtually every study of energy efficiencies of various modes of travel has found bus transportation to have at least twice the energy efficiency as other modes of travel.

Findings regarding train and auto travel are mixed, with travel via an "average" car determined by ICT to be more energy efficient than travel via train, whereas National Geographic found travel by train to be more efficient than travel via sport utility vehicle (SUV) – a type of vehicle that has lower fuel efficiency than the average passenger car.

Figure 3
Fuel Economy of Various US Transport Modes of 300 to 500 Mile Trips*
(Source: Kwan, International Council on Clean Transportation, 2013)

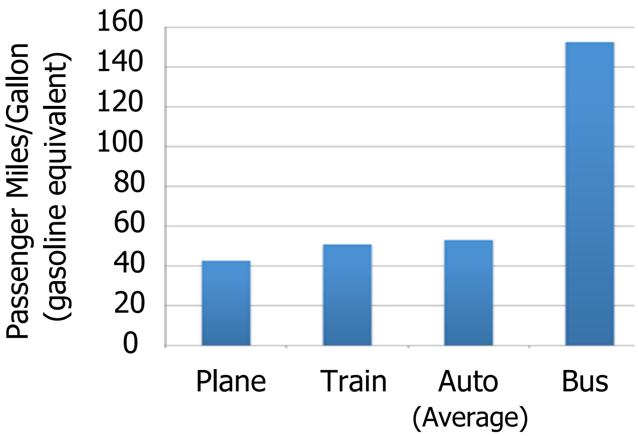
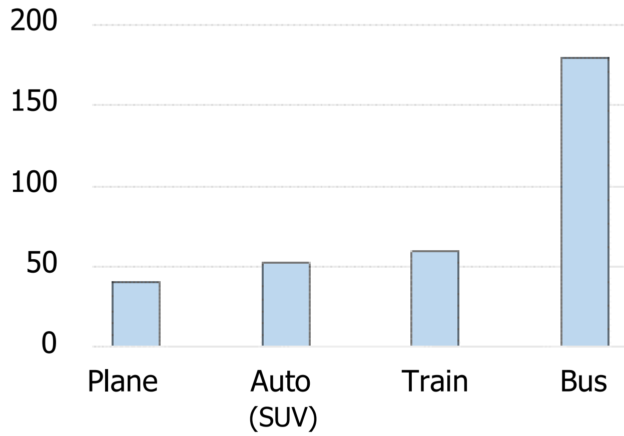


Figure 4
Fuel Economy of Various Transport Modes, New York to Toronto (352 miles)
(Source: Valińo, National Geographic, 2018)



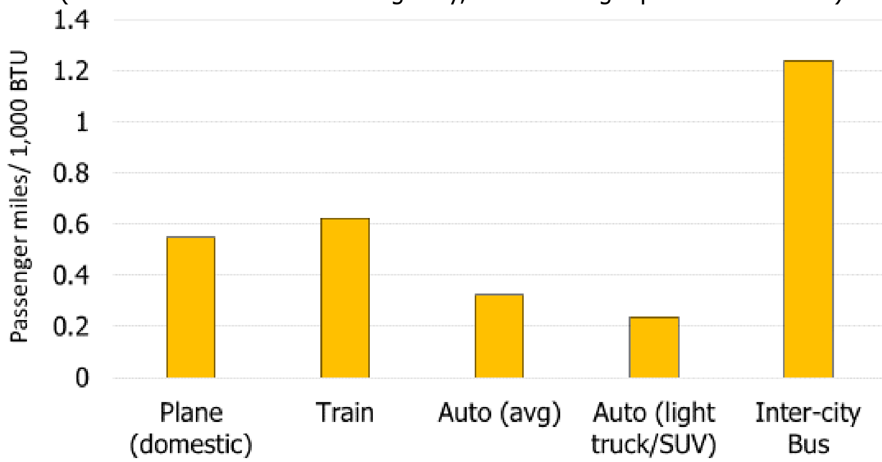
* All values are based on average passenger loads. An average of 2.2 passengers was used for car travel

For forms of transit other than auto, assumed passenger loads are informed by periodically updated public data sources which report percent occupancy. For these forms of transit, changes in occupant loads of one to several individuals has little effect on energy consumption per passenger mile. For auto travel, however, a difference in passenger load by as little as one passenger can have a major effect on results. For example, results shown in Figures 3 and 4 assume 2.2 passengers on average for car travel. When there is only one passenger, energy consumption per passenger mile is obviously much higher (more than double) than when there are 2 or more passengers. The effect on energy per passenger mile for a single occupant vehicle can be seen in data from the Bureau of Transportation Statistics (Figure 5). In this case, a single occupant motor vehicle ranks as the most energy consumptive form of travel – even more so than air travel.

Several studies have confirmed that flying can be more energy efficient per passenger mile than driving, but only when flying is compared to single occupant large passenger vehicles and where the flight distance is long enough to compensate for high energy consumption during takeoff (~300-400 miles or more).[8] In general, flying is the highest impact mode of travel.

8 Sivak (2014, 2015), Liu et al. (2016)

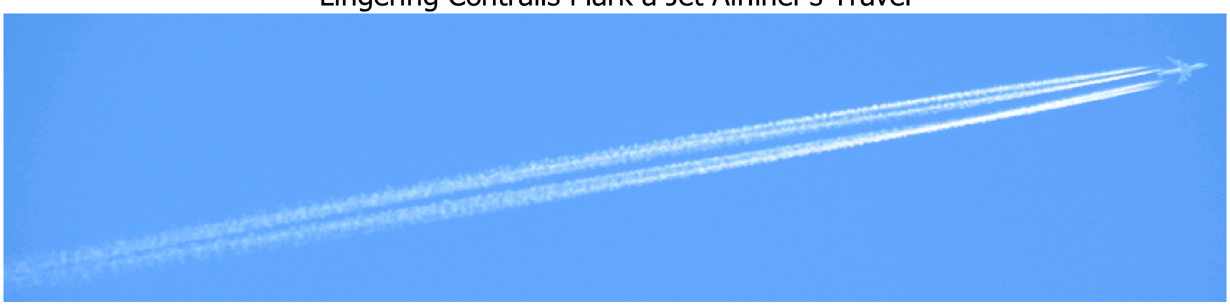
Figure 5
Fuel Economy of Various U.S. Transport Modes in 2017
(All Ground-Based Travel via Highway, One Passenger per Auto Assumed)



Source: U.S. Department of Transportation, Transportation Statistics (2019)

A complicating factor in the flying vs. driving debate is the development of contrails often left in the wake of jet airliners (Figure 6)[9], and their apparent climate effects. One recent study[10] found that the climate impacts of contrails approach those of CO_2 emissions from fuel combustion. Because of this, air travel is generally viewed as a higher impact form of travel than auto travel, regardless of findings (such as in the Michigan study) in which contrail development is not considered.[11]

Figure 6
Lingering Contrails Mark a Jet Airliner's Travel



Source: Weather.gov

Recognizing the high climate impact potential of flying, Sweden implemented a per-passenger flight tax in 2018 with a goal of reducing the number of flights originating in that country.[12] In 2019 the French government announced a similar tax, with proceeds to be used to support environmental initiatives.[13] While relatively modest, the announcement caused a drop in airline stocks across Europe, perhaps due in part to a fear of the beginning of a trend. As of this writing, several countries have signaled interest in environmentally inspired flight taxes – most notably

9 Rädel and Shine (2008), Borken-Kleefield et al. (2010), Burkhardt and Kärcher (2011), Borken-Kleefeld et al. (2013)
10 Bock and Burkhardt (2019)
11 Borken-Kleefeld et al. (2013)
12 Centre for Aviation (2019), Anonymous (2019)
13 Pennetier and De Clercq (2019), Chappel (2019)

Germany and the Netherlands. Meanwhile, the UN is working on what it calls the *Carbon Offsetting and Reduction Scheme* under which airlines would be forced to buy emissions reductions or carbon offsets to keep their impact in check, a measure that would effectively transfer the cost of offset credits to all ticket holders. Piloting (no pun intended) is planned for 2021 with full roll out in 2024.[14] Another proposal calls for implementation of an *Air Miles Levy* which would escalate with the accumulated air miles travelled by an individual within a three year accounting period.[15] The idea is to place the greatest burden for funding of air travel related climate mitigation on those who fly the most, while also creating strong price signals to encourage shifts from long-haul to short-haul destinations. The proposal suggests that funds raised be used to fund research into low-carbon aviation technology.

One reason for the focus on reduced flying as a way of reducing individual carbon emissions is the large potential climate impact of shifts in flight habits vs. changes in other human activity. One calculation of the relative impacts of various climate mitigation options available to individuals[16] showed that taking one less trans-continental flight annually would have more impact on annual CO_2 emissions reduction than the *combined* benefits of adopting a vegetarian diet, driving a hybrid car, and recycling.

Commercial airlines and airplane manufacturers are aggressively seeking ways to reduce environmental impacts of flights. Efforts to build more energy efficient planes are continuing. The U.S. National Aeronautical and Space Administration (NASA), which has long led experimentation in future aircraft design, reported that prototype designs now under study could reduce fuel consumption and pollution by 70%.[17] In the nearer term, another strategy which is currently being pursued by a number of airlines is to shift away from reliance on petroleum-based fuel and toward use of biofuels. Renewable biofuels have the potential to markedly reduce carbon emissions, while also potentially reducing contrail formation. NASA scientists have found that a high blend of biofuels can reduce soot formation, and thus contrail development, by 50-70%.[18]

Short Distance (Urban) Travel

For most people, daily transportation choices are:

- Drive individually
- Carpool
- Drive to park-and-ride for connection to bus, light rail, or train[19]
- Walk to nearby transit stop for connection to bus, light rail, or train
- Bike
- Walk

Underlying the above list of transit choices are individual decisions which have the effect of either limiting or expanding transit options. Someone who is concerned about the cost of environmental impact of his or her transit, and whose only practical option is a long drive with few opportunities to carpool, could opt to move closer to a public transit station or their place of work. Or, they

[14] Frost (2019)
[15] Carmichael (2019)
[16] Wynes and Nicholas (2017)
[17] Hawken (2017)
[18] Silberg (2017)
[19] For some, the list includes daily air shuttle commuting, with transit to and from airports another part of the daily equation.

might actively seek carpooling opportunities, purchase a highly fuel-efficient vehicle, and/or investigate possibilities of telecommuting.

Choices regarding local, daily travel basically come down to driving vs. use of public transit systems. Urban areas develop public transit systems for several reasons, among them to reduce traffic congestion and need for parking spaces, to provide an alternative for those who don't or can't drive, and to reduce energy consumption and pollution. But is it environmentally better to use public transit when it is available?

Figure 7
Renault Twizy Urban 80

Source: Groupe Renault

An answer to this question is provided by a study[20] in Graz, Austria – a city of about 330,000 – where public transit has long been embraced by residents. Energy consumption of all forms of travel were investigated, from walking and cycling, to light urban electric vehicles (Figure 7), to standard and electric automobiles, to use of transit buses and trams.

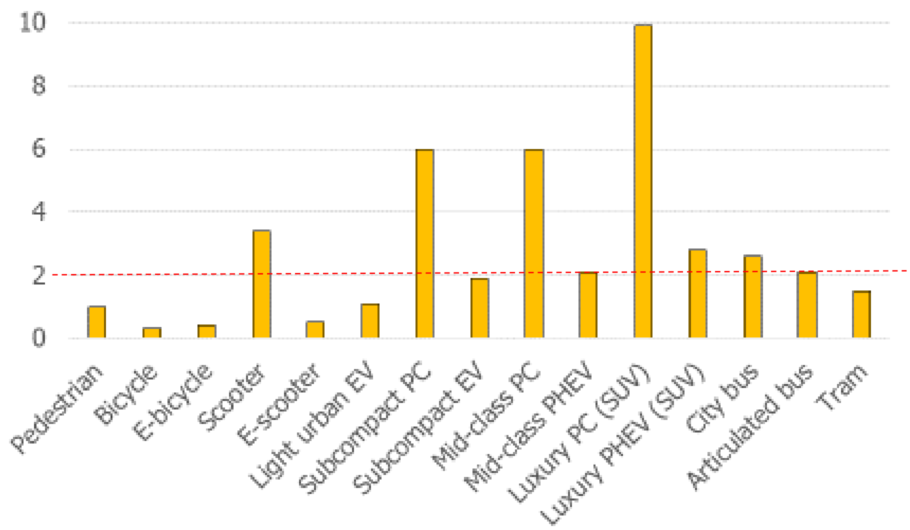
Average ridership numbers were used in assessing various travel modes. Examined were direct energy consumption and CO_2 emissions in transit, impact of various travel modes on traffic congestion and average speed of travel, parking space demand, and vehicle mass as a measure of resource demands for vehicle production. Measured energy consumption was converted to an equivalent standard measure, liters of petrol per 100 km of travel, on both a per-vehicle and per-passenger basis (Figure 8). Although these units of measure may be unfamiliar, the relative relationships are the same whether expressed this way or in gallons and miles.

The Graz study found that buses and trams (light rail) consume far less energy and produce substantially less GHG emissions per passenger distance traveled in comparison to conventional automobiles (PCs and SUVs). However, buses and trams are comparable to small-size plug-in hybrid (PHEV) and fully electric autos (EVs) in energy performance per passenger distance traveled. All sizes of standard auto (subcompact PC, mid-class PC, and luxury PC) ranked as the three worst options with respect to environmental performance. When the Graz study team considered all factors, including traffic congestion, parking demand, and the impact of vehicle mass on resource demand (steel, aluminum, copper, titanium, plastic, rubber, etc. used in vehicle manufacture and maintenance), the impacts of driving all individual passenger cars – standard as well as electric vehicles – were found to substantially exceed those of public transit.

When public transit is available, both light rail and bus are almost always the lowest environmental impact transit modes during peak periods of travel when bus and rail ridership tend to be highest and traffic congestion greatest. During off-peak periods, on the other hand, it could be argued that auto transport yields the lowest environmental impact since low bus ridership during these periods may translate to very high energy consumption per passenger mile traveled. However, in that a bus travels its route regardless of ridership at any point in time, fulfilling objectives beyond energy efficiency and environmental concerns, bypassing the bus in favor of auto travel adds to overall impact.

[20] Brunner et al. (2018)

Figure 8
Energy Consumption per Passenger Distance Traveled
for Various Modes of Transportation*
(Equivalent Fuel Consumption - liters per 100 passenger km)



* E-bicycle and E-scooter = electric bicycles and scooters
EV = electric vehicle
PC = passenger car
PHEV = plug-in hybrid electric vehicle
SUV = sport utility vehicle
Articulated bus = extended bus with back portion joined by flexible connection
Tram – electric trolley

Source: Brunner et al. (2018)

A similar U.S. study yielded almost identical results.[21] In addition to common modes of urban travel, this study also included demand response travel (i.e. taxi, Uber, Lyft). Demand response was found to result in substantially greater energy consumption and carbon emissions than all other modes of travel, not surprising since the responding vehicle must move to a pickup point before moving with passengers to destination, then travel to another pickup point before beginning the next movement of passengers.

Indirect Impacts

The environmental impacts of transportation extend beyond direct emissions generated as vehicles operate. Auto travel, for example, is enabled by an infrastructure network, which requires substantial inputs of energy and materials in construction and maintenance (including periodic expansion). Energy and fossil-fuel based inputs are also required in producing tires, repair parts, and the vehicles themselves. Other modes of travel are likewise supported by infrastructure in the form of passenger terminals, runways or tracks, and repair and support operations.

One study evaluated full life cycle impacts of various transportation modes, including construction and maintenance of infrastructure, production and maintenance of transport vehicles, fuel

[21] American Bus Association (2014)

production, and vehicle operation.[22] Life-cycle energy inputs and associated emissions were found to be far greater than those resulting from vehicle operation alone. For example, life-cycle energy consumption of automobiles per passenger mile traveled was found to be 39-56% greater than that for vehicle operation alone, and greenhouse gas emissions 47-65% greater. Energy consumption and GHG emissions over full life cycles were also found to be significantly greater than for vehicle operation alone for other modes of travel (Table 1).

Table 1
Increase in Full Life Cycle Energy Consumption and GHG Emissions per Passenger Mile for Various Modes of Transport When Construction and Maintenance of Infrastructure and Production and Maintenance of Vehicles are Included in Analyses

	Increase in Energy Consumption (percent)	Increase in GHG Emissions (percent)
Automobile	39-56	47-65
Bus	38	43
Rail	93-160	39-150
Air	19-24	24-31

Source: Chester (2008)

Indirect impacts associated with existing infrastructure, while not relevant to everyday selection of transportation mode (i.e. whether to fly or drive to next week's business meeting), are important when considering future development and policy decisions that impact transportation choices and availability.

An interesting California-focused study examined direct as well as indirect impacts of long-distance travel (≥ 300 miles) in looking at future transportation options for the state. The study considered infrastructure development and maintenance, vehicle production and maintenance, energy production, and vehicle operation.[23] Included among the modes of travel considered in the study were current technology vehicles, emerging fuel-efficient vehicles, new train designs, high-speed rail, and aircraft long distance travel under various scenarios whereby the region would meet future renewable electricity goals.

The study found that high speed rail would generate the lowest GHG per passenger kilometer traveled when compared with travel via passenger sedan or airplane. This was found to be the case even in comparisons of half-full trains and fully loaded airplanes. Only when emissions from lightly occupied (less than one-quarter filled) trains were compared to those from fully loaded aircraft were GHG emissions per passenger kilometer lower from air travel.

Comparisons of emissions from travel by auto vs high speed rail found auto travel to generate by far the greatest level of emissions. The most fuel-efficient autos (i.e. 55 mpg) were found to have comparable emissions to trains per passenger kilometer traveled only when carrying 3 or more passengers and when trains are less than one-quarter filled. With two passengers per vehicle, all autos considered generated greater emissions than high speed trains and mid-size aircraft. Study results indicate that adding high speed rail to transportation options would have a significant

[22] Chester (2008)
[23] Chester and Horvath (2012)

carbon emissions benefit, potentially reducing auto travel by 3.6 billion miles annually – equivalent to pulling 300,000 cars off the roads every day.

Minimizing Transportation Impacts

Individual Choices

For an individual, choosing between transportation options is seldom based primarily upon consideration of environmental impact. Convenience, including time of transit and cost, are the overriding factors in selecting between available options. Nonetheless, there are several things that people can do within the bounds of convenience to reduce the impacts of their travel. Options include:

- Purchase a highly fuel-efficient vehicle
- Carpool
- Plan travel to minimize the number of trips
- Use public transit systems, if available, and support transit system expansion
- Minimize use of on-demand transport
- Move closer to work
- Investigate possibilities of telecommuting
- Fly less and concentrate travel more on short haul rather than long-haul destinations
- Purchase carbon offset credits when flying (or purchase annually to help to reduce travel impacts)

Business Opportunities

Businesses are in a particularly opportune position to influence the impacts of travel since policies can influence practices of many people. Among things that can be done in this regard are:

- Provide employee incentives for carpooling and use of public transit
- Upgrade company vehicles to hybrid and all electric
- Invest in teleconferencing equipment and shift portions of distant employee and customer communication to teleconference
- Purchase carbon offsets when circumstances require employee travel
- Examine opportunities for allowing employees to work from home
- Support community initiatives for expansion of public transit options and expansion

Governmental Responsibilities

Local and regional governments with responsibility for long-range planning confront a wide range of issues – traffic congestion, air pollution, air quality, growing local and regional population, and in some cases, environmental issues of importance beyond the local area. With the luxury of an extended time horizon and the power to effect change, those in public decision-making roles owe it to society to stay abreast of developing problems and trends and emerging technologies, with an eye to proactively effecting positive change.

With respect to transportation:

- Planning of future development should be based on life cycle-based thinking.
- Consideration of indirect as well as direct impacts of future transportation options and systems should be factored into planning.
- Actions should broaden transport options and/or have the potential to markedly reduce the impacts of travel.

- Urban planning should place priority on development and/or expansion of convenient, safe public transit options.
- Planning should involve coordination with decision-makers in other jurisdictions.

Summary

Various modes of travel have significantly different environmental impacts. Differences include greenhouse gas and other emissions, and resource demand. Research shows that use of transit systems rather than individual vehicles, use of highly energy-efficient vehicles, and reduction of air travel are actions with the greatest potential to reduce the volume of carbon emissions attributable to any one person.

From a public perspective, substantial reduction in future transportation impacts is possible with careful planning. It is important that planning involve life cycle-based thinking and consideration of both indirect and direct impacts of transportation options, with a goal of broadening convenient, efficient transport choices while reducing negative climate and other environmental impacts.

Sources of Information

American Bus Association. 2014. Updated Comparison of Energy Use and CO_2 Emissions from Different Transportation Modes. Study submitted by M.J. Bradley and Associates, April. (https://www.buses.org/assets/images/uploads/general/Report%20-%20Energy%20Use%20and%20Emissions.pdf).

Anonymous. 2019. Sweden's New 'Eco-Friendly' Aviation Tax is Already Beginning to Affect Air Connectivity. Blue Swan Daily. (https://blueswandaily.com/swedens-new-eco-friendly-aviation-tax-is-already-beginning-to-effect-air-connectivity/).

Bock, L. and Burkhardt, U. 2019. Contrail Cirrus Radiative Forcing for Future Air Traffic, Atmos. Chem. Phys. 19, 8163–8174. (https://www.atmos-chem-phys.net/19/8163/2019/#&gid=1&pid=1).

Borken-Kleefeld, J. 2010. Going by Car, Plane, Coach or Train? Climate Impact from Passenger Travel Recalculated. International Institute for Applied Systems Analysis (IIASA). (https://www.pa.op.dlr.de/attica/stakeholder-meeting/PDF/Borken-Kleefeld_Comparison_100720.pdf).

Borken-Kleefeld, J., Berntsen, T., and Fuglestvedt, J. 2010. Specific Climate Impact of Passenger and Freight Transport. Environ. Sci. Technol. 44(15): 5700-5706. (https://pubs.acs.org/doi/abs/10.1021/es9039693).

Borken-Kleefeld, J., Fuglestvedt, J. and Berntsen, T. 2013. Mode, Load, and Specific Climate Impact from Passenger Trips. Environ. Sci. Technol. 20134714, 7608-7614, June 13. (https://pubs.acs.org/doi/pdf/10.1021/es4003718).

Brunner, H., Hirz, M., Hirschberg, W. and Fallast, K. 2018. Evaluation of Various Means of Transport for Urban Areas. Energy, Sustainability and Society, Vol. 8, No. 9. (https://energsustainsoc.biomedcentral.com/articles/10.1186/s13705-018-0149-0).

Burkhardt, U. and Kärcher, B. Global Radiative Forcing from Contrail Cirrus. 2011. Nature Climate Change 1, 54–58.

Carmichael, R. 2019. Behaviour Change, Public Engagement and Net Zero: A Report for the Committee on Climate Change. Imperial College, London, Centre for Energy Policy and Technology (ICEPT) and Centre for Environmental Policy (CEP). October. (https://www.theccc.org.uk/wp-content/uploads/2019/10/Behaviour-change-public-engagement-and-Net-Zero-Imperial-College-London.pdf).

Centre for Aviation. 2019. Aviation Emissions: Sweden's 'Flight Shame'; Possible Jet Fuel Tax. (https://centreforaviation.com/analysis/reports/aviation-emissions-swedens-flight-shame-possible-jet-fuel-tax-479859).

Chappell, B. 2019. France Plans to Put an 'Ecotax' on Nearly All Air Travel. National Public Radio, July 9. (https://www.npr.org/2019/07/09/739981243/france-plans-to-put-an-ecotax-on-most-air-travel-out-of-the-country).

Chester, M. 2008. Life-cycle Environmental Inventory of Passenger Transportation in the United States. PhD Dissertation, Institute of Transportation Studies, University of California, Berkeley. Paper UCB-ITS-DS – 2008-1. (https://escholarship.org/uc/item/7n29n303).

Chester, M. and Horvath, A. 2012. High-speed Rail with Emerging Automobiles and Aircraft Can Reduce Environmental Impacts in California's Future. Environmental Research Letters 7(3), July 26. (https://iopscience.iop.org/article/10.1088/1748-9326/7/3/034012).

Energy Information Administration (EIA). 2019a. EIA Projects U.S. Energy-Related CO_2 Emissions Will Remain Near Current Level through 2050. (https://www.eia.gov/todayinenergy/detail.php?id=38773).

Energy Information Administration (EIA). 2019b. Gasoline and the Environment. (https://www.eia.gov/energyexplained/gasoline/gasoline-and-the-environment.php).

Energy Information Administration (EIA). 2019c. Use of Energy Explained: Energy Use for Transportation. (https://www.eia.gov/energyexplained/use-of-energy/transportation.php).

Frost, N. 2019. If You Care About Your Impact on the Planet, You Should Stop Flying. Quartz, July 3. (https://qz.com/1657067/should-you-stop-flying/).

Hawken, P. (ed.) 2017. Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming.

Kwan, I. 2013. Planes, Trains and Automobiles: Counting Carbon. International Council on Clean Transportation. (https://theicct.org/blogs/staff/planes-trains-and-automobiles-counting-carbon).

Liu, H., Xu, Y., A., Stockwell, N., Rodgers, M. and Guensler, R. 2016. A Comparative Life-Cycle Energy and Emissions Analysis for Intercity Passenger Transportation in the U.S. by Aviation, Intercity Bus, and Automobile. Transport and Environment 48: 267-283. (https://www.sciencedirect.com/science/article/pii/S1361920915301760).

Page, S. 2015. No, Flying is Not Greener than Driving. Think Progress, Apr. 29. (https://thinkprogress.org/no-flying-is-not-greener-than-driving-7de8d53959ab/).

Pennetier, M. and De Clercq, G. 2019. France to Tax Flights from its Airports, Airline Shares Fall, Reuters, July 9. (https://www.reuters.com/article/us-france-airlines-tax/france-to-tax-flights-from-its-airports-airline-shares-fall-idUSKCN1U412B).

Rädel, G. and Shine, K. 2008. Radiative Forcing by Persistent Contrails and its Dependence on Cruise Altitude. Journal of Geophysical Research, vol. 113, issue D7. (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2007JD009117).

Silberg, B. 2017. NASA Test: Jet Biofuel May Reduce Climate-Warming Clouds. NASA Jet Propulsion Laboratory, June 21. (https://climate.nasa.gov/news/2601/nasa-test-jet-biofuel-may-reduce-climate-warming-clouds/).

Siddiqui, F. 2018. Falling Transit Ridership Poses an 'Emergency' for Cities, Experts Fear. Washington Post, March 24. (https://www.washingtonpost.com/local/trafficandcommuting/falling-transit-ridership-poses-an-emergency-for-cities-experts-fear/2018/03/20/ffb67c28-2865-11e8-874b-d517e912f125_story.html) .

Sivak, M. 2015. The Energy Intensities of Flying vs Driving. University of Michigan Transportation Research Institute, Report 2015-14.(https://deepblue.lib.umich.edu/bitstream/handle/2027.42/111894/103194.pdf).

Sivak, M. 2014. Making Driving Less Energy Intensive than Flying. University of Michigan Transportation Research Institute, Report 2015-14. (http://www.umtri.umich.edu/our-results/publications/making-driving-less-energy-intensive-flying)

Sivak, M. and Tsimhoni, O. 2009. Fuel Efficiency of Vehicles on U.S. Roads: 1923-2006. Energy Policy 37(8): 3168-3170.(https://www.sciencedirect.com/science/article/pii/S0301421509002274).

Smith, J. 2019. Nationwide Transit Ridership is Plummeting: Can San Diego's High Speed Rail Proposal Buck this Trend? Los Angeles Times, Oct. 21. (https://www.latimes.com/california/story/2019-10-21/nationwide-transit-ridership-plummeting-san-diego-buck-trend).

U.S. Department of Energy (USDOE)/U.S. Environmental Protection Agency (USEPA). 2019. Model Year 2019 Fuel Economy Guide, p. 1. (https://www.fueleconomy.gov/feg/pdfs/guides/FEG2019.pdf)

U.S. Department of Transportation, Bureau of Transportation Statistics. 2018. Transportation Statistics Annual Report- 2018. (https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/transportation-statistics-annual-reports/Preliminary-TSAR-Full-2018-a.pdf).

U.S. Department of Transportation, Bureau of Transportation Statistics. 2019. Energy Intensity of Passenger Modes. (https://www.bts.gov/content/energy-intensity-passenger-modes).

U.S. Environmental Protection Agency. 2019. Estimated Real-World Fuel Economy, CO_2 Emissions, and Vehicle Attributes. (https://www.epa.gov/automotive-trends/explore-automotive-trends-data).

Valińo, Á. 2018. This Graphic Maps the Greenest Modes of Transportation. National Geographic. (https://www.nationalgeographic.com/travel/features/carbon-footprint-transportation-efficiency-graphic/).

Wynes, S. and Nicholas, K. 2017. The Climate Mitigation Gap: Education and Government Recommendations Miss the Most Effective Individual Actions. Environmental Research Letters Vol. 12, No. 7. (https://iopscience.iop.org/article/10.1088/1748-9326/aa7541).