Encyclopedia of
TRANSPORTATION
Social Science and Policy

Volume 2

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SAGE reference

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Library of Congress Cataloging-in-Publication Data

Encyclopedia of transportation : social science and policy / Mark Garrett, editor, University of California, Los Angeles.
volumes cm
Includes bibliographical references and index.
ISBN 978-1-4522-6779-1 (hardcover : alk. paper) 1. Transportation--Encyclopedias. 2. Transportation and state--Encyclopedias. I. Garrett, Mark Evan, 1955-
HE141.E534 2014
388.03--dc23

2014004321

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1

applied to alternative or green fuel. First, financial barriers, or increased costs for manufacturers and consumers, reduce the likelihood of green fuel acceptance and use. Governments and private donors may subsidize research or infrastructure development. In the United States and the United Kingdom, national governments provide tax incentives and grants to individuals and some commercial fleets who purchase vehicles powered by green fuels. Even with incentives, consumers may have difficulty calculating the long-term benefits of green-fueled vehicles versus the short-term immediate costs of the vehicle if the vehicle demands a premium price, as electric vehicles do.

Technological barriers include machines and processes to manufacture green fuels, as well as concerns about the availability of raw material or structural barriers related to the infrastructure, including the retail availability of green fuels, which can dissuade companies from investing in green fuel vehicle research and development and consumers from purchasing what vehicles are on the market. Institutional barriers include the predominance of fossil fuels in the transportation industry, which breeds commitment to the status quo and fear of change among stakeholders.

The preceding three barriers impact the fourth, public acceptability, which requires that consumers favorably evaluate the fuels in terms of availability, impact, safety, and cost. With new technologies, regulatory or legal barriers can inhibit development, such as competing standards for plugs and receptacles in electric vehicles and charging stations or fear of legal challenges.

A fifth barrier, policy failures or unintended impacts, can diminish support of green fuels, as when media reported spikes in corn prices making the material cost prohibitive in some regions due to demand for corn to manufacture ethanol. Physical barriers represent the final impediment to green fuel adoption, such as limits to raw material. Equally applicable to all types of green and alternative fuels, these barriers must be tackled by governments, interested nonprofit organizations, and manufacturers if the world's drivers are to successfully transition from a fossil-fuel based transportation system.

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See Also: Alternative Fuels; Biodiesel; Biofuels; Electric Vehicle Recharging Stations; Environmental Protection Agency; Ethanol; Hybrid Automobiles/Hybrid Electric Vehicles; Hydrogen Fuel; Hydrogen Fuel Cells.

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Green Transportation

Green transportation is a concept that relates ecological and aesthetic concerns to transportation. Green transportation is associated with efforts to minimize carbon footprints and is often linked to a transportation infrastructure supporting a green milieu or more resilient cities. This concept also relates to energy systems as well as questions of urban planning and urban form (including architecture). Examples of green transportation modes include walking,

cycling, alternative-fueled vehicles, and mass transportation. Transportation is responsible for about 13 percent of global greenhouse gas (GHG) emissions and 26 percent of global CO_2 emissions. Cities consume 75 percent of the world's energy and emit 80 percent of the world's greenhouse gases. Therefore, redesign of transportation systems and cities is essential for achieving ecological objectives. Peak oil and climate change are seen as key drivers for greener cities and transportation modes. A transportation system can also affect air quality, noise, water quality, soil quality, biodiversity, and land utilization, such as transit infrastructure.

There are different ways to define green transportation. First, one can analyze the emergence of a discourse that helped define what "green" or "ecological" outcomes are. Second, one can examine the history and impacts of various technologies and explore whether they have a greater or lesser carbon footprint, are more energy efficient, or can adapt themselves to a renewable or sustainable system. Third, one can look at the land use impacts of different transportation technologies and associated infrastructure in terms of their ability to limit congestion, promote concentration, or affect aesthetic outcomes. In sum, to understand what constitutes green transportation, one must apply multiple criteria.

There are advantages and disadvantages to various green transportation modes, depending on the criterion one applies. Something may be called "green" but may only be ecological in relative rather than absolute terms. The ensemble of how different green transportation modes fit together with an ecological infrastructure could be said to constitute a "green transportation" system, with such an infrastructure working better in some cities than others.

What Is Green?

An early source of environmentalism was the idea of conservation, which placed an emphasis on preserving nature and with human beings having special responsibility for such preservation. Robert J. Brulle notes that "conservation had a resurgence under the label of Sustainable Development" in the mid-1980s. Sustainability, however, involves "many different definitions, none of which has achieved ascendancy." One key question is the extent to which governments and corporations embrace the concept and the consequences of their doing so. In the context of green transportation, the debate centers on the ecological impacts of some modes of transportation or fuels supporting such transportation, with criticism directed particularly at ethanol-based cars or the use of alternative-fueled cars rather than mass transportation.

Barry Commoner explained a basic green principle concerning the relationship between two realms: "the natural ecosphere, the thin global skin of air, water, and soil and the planets and animals that live in it," and the human-made "technosphere." The technosphere "has become sufficiently large and intense to alter the natural processes that govern the ecosphere." The result of a clash between these two spheres has resulted in flooded cities, droughts, contamination of water and food, poisoning of bodies, and a diminished capability to provide for human needs.

Thinkers like Commoner, Seymour Melman, and Paul and Percival Goodman saw a way out of this contradiction, partly through alternative energy, alternatives to the internal combustion engine, and alternative ways to design cities. Through direct or indirect means, these kinds of interventions could lower carbon emissions. Technology and alternative plans can play an important role in solutions, with Peter Newman and colleagues arguing that "the ability to experiment and innovate" is "the tissue of hope and the core of resilience." The buildup of atmospheric greenhouse gases from land use changes and continued combustion of fossil fuels over the past century threatens to promote catastrophic changes if certain remedial thresholds are not met. Thus the ultimate criterion for what is "green" could be the combined policies and practices that put us on a transportation path that avoids the worst ecological outcomes. As of 2012, one internationally accepted estimate was that the planet should not increase more than 2 degrees C, with leading U.S. climatologist James Hansen arguing that even this threshold is far too high and that the latitude society has to emit more greenhouse gases is decreasing significantly by the day.

The Energy Dimension

In some cities, green interventions have been linked. For example, Bilbao, Spain, was the first city to use only renewable energy sources to power its subway system. Jon Rynn explains that with electrified vehicles on transit systems, "motors are located right

next to the wheels," whereas in "an internal combustion system, the motor has to transmit [to] the drive shaft, that is, a rigid piece of steel that is turned by the power of the engine, and that in turn turns the wheels." Electricity creates a more efficient system because it allows you "to take the power source off the vehicle," in contrast to cars and trucks, which must carry the power sources in the vehicle." Most important is the ability of electricity to act as a conduit between various kinds of green vehicles on the one hand (high-speed rail, heavy rail, light rail, electric buses) and cleaner or renewable energy sources on the other (wind, solar, hydroelectric power). Despite the potential advantages of electric power, there can be thermal losses when converting fuels to electricity. Even if electricity is generated by wind or solar power, there can be losses associated with moving that power to points of use. The U.S. Energy Information Administration found that "national, annual electricity transmission and distribution losses average about 7 percent of the electricity that is transmitted in the United States."

The ability of an energy system to be green requires that it follow the principles of sustainable development. Herman E. Daly lists two key principles regarding renewable resources: "First that harvest rates should equal regeneration rates (sustained yield). Second, that waste emission rates should equal the natural assimilative capacities of the ecosystems into which the wastes are emitted." The basic idea is that the best energy systems can be replenished with minimal waste and that the use of an energy source should not surpass the capacities of the ecosystem. For example, wind energy is renewable (replenishable). The wind turbine by weight is mostly composed of recyclable metal, with much of the rest coming directly or indirectly from fiberglass, sand, and plastic. Plastics can be recycled and can come from sustainably harvested biomass. The linkage of electric-powered cars and trains to such clean energy sources therefore has ecological advantages.

Automobiles and Alternative Fuels

Automobiles are the second-largest contributor to greenhouse emissions in the transport sector. Stephen Potter shows that 76 percent of CO_2 emissions from an average car come from fuel usage, 15 percent from emissions and losses in the system used to supply fuel, and 9 percent from manufacturing the vehicle. The internal combustion engine dominates auto propulsion systems. There are different ways to advance green transportation alternatives, including increasing fuel efficiency, the use of alternative fuels, car sharing, and attempts to reduce automobile usage. Driverless cars might contribute to reducing fatalities and congestion (by coordinating spacing), providing some limited ecological benefits. In August 2012, the Barack Obama administration issued rules that would require automakers to almost double the average fuel economy of new cars and trucks by 2025. Fuel efficiencies can be lost to increased driving made possible by the fact that such efficiencies are equivalent to decreases in fuel costs. In contrast, fuel taxes would more unambiguously reduce fuel use. The Central London Congestion Charging initiative considerably reduced traffic into the inner city. A comparison of the precongestion charging (2000–02) and postcongestion charging periods (2003–07) shows increased business activity in the central charging zone and decreased performance in outer Inner London and Outer London.

Alternative fuels include (1) electricity, which as noted can be a vehicle power source, but Jean-Paul Rodrigue notes that "The low energy capacity of batteries makes the electric car less competitive than internal combustion engines using gasoline," although the technology is improving. Such improvements would lower infrastructure costs or logistical barriers for light rail systems and could promote electric fleet vehicle use. (2) Biogas fuels (such as ethanol, methanol, and biodiesel) come from wood waste or fermentation of food crops. Production of such fuels may compete with other uses of land. Yet, Jatropha uses marginal land in contrast to sugarcane. (3) Hydrogen uses fuel cells to generate electricity to propel a motor vehicle, though much energy can be wasted by its storage, production and transfer. Hybrid electric vehicles link an internal combustion engine and a supplemental electric motor with a battery power source.

The private automobile continues to gain market share at the expense of public transit systems in North America, in much of Europe, and in most developing countries. Moreover, Maja Essebo and Guy Baeten discuss the following:

> Tataism—shorthand for the generalisation of motorised transport and production in new

> Asian growth centres . . . may dwarf the first car era and may truly globalise a socio-spatial form centred on the private motorised car.

Tataism is named after the "Tata Nano," the world's least expensive car. Despite increases in fuel efficiency or even the use of alternative fuels, Tataism considerably reduces many advantages coming from such green transportation approaches. Automobiles and trucks use far more land per person than alternative transportation modes.

Walking and Bicycles

Walking and bicycling's share in the total number of trips is significant almost everywhere. Their many advantages include favorable environmental performance, the provision of door-to-door transport, their high spatial penetration, the absence of waiting times compared to public transport, their status as inexpensive transport modes, their importance to multimodal transport chains, and their contributions to human health. Potential disadvantages of these modes include their low speed (which is relative to the level of congestion of other modes or even the layout of transit routes), relatively high accident rates, low level of comfort (susceptibility to weather conditions), and physical effort required (depending on factors such as gradients, temperature and wind, although such efforts can have health advantages).

While walking is the most important form of transportation, its fuel comes from agriculture, which is seldom "clean" and often energy intensive. A green alternative would include locally grown crops using less energy to cultivate them. Rynn notes that before the advent of trains, "cities were basically only as big as could be walked in a reasonable amount of time." While "trains allowed the first suburbs to form," suburbs still needed to have "houses within walking distance of the rail station." Increases in income levels, urban sprawl, and low-density construction have usually acted as barriers to nonmotorized transport modes. Nevertheless, there has been a renaissance in bicycle use in a number of European countries like Denmark, Sweden, Germany, and the Netherlands. In the United States, the bike mode share rose more than 500 percent in Portland, Oregon, between 1990 and 2009, and doubled in New York City during the same time span. The U.S. Rails-to-Trails Conservancy found that the total savings resulting from "shifting more short trips to bicycling or walking" could range from 2.4 to 5 billion gallons of fuel, or "between 21 and 45 million tons of CO_2 a year."

Public Transit

The collective forms of passenger-carrying transportation services go by various names, including "transit," "public transport," and "public transit." Public transit includes paratransit (including vans, jitneys, shuttles, microbuses, and minibuses), bus transit (or "coaches" in the UK), trams and light rail transit, heavy rail and metros, and commuter and suburban railways. Studies cited by Potter show that a medium-sized car releases 78 grams of CO_2 per seat-kilometer, in contrast to 26 grams for a double-deck bus, 33 for a single-deck bus, 38 for light rail, 39 for an urban electric train, 40 for a minibus, 46 for a metro/underground, and 60 for an urban diesel

A bicycle parking facility at a train station in Uppsala, Sweden, in 2007. The bicycle mode share (percentage of commuters biking to work) is increasing in some U.S. cities such as Portland, Oregon, which saw an increase of over 500 percent from 1990 to 2009.

train. Studies cited by Lee Chapman found that a gasoline (petrol) car with two occupants emitted more than twice as much CO_2 emissions (grams per kilometer per occupant) as a conventional train and four times as much as a coach. Trains can do better, depending on their fuel source.

Despite its ecological advantages, the use of public transit significantly differs, depending on the country and region. Ralph Buehler and John Pucher found that the number of annual public trips per capita in Europe and North America (2005–10) was 237 in Switzerland, 139 in both Sweden and Germany, 116 in Great Britain, 87 in France, 69 in Denmark, 65 in Italy, and 51 in the Netherlands, but only 24 in the United States (with bike transit significant in both Denmark and the Netherlands). From 2009 to 2010, the share of American workers commuting by public transit was only about 5 percent, which was one-third as high as the German share. Within Germany itself, however, the share of all trips by public transit (2003–07) was 10 percent in both Muenster and Aachen, 21 percent in Frankfurt/Main, and 27 percent in Berlin.

Other Modes: Road Freight, Aviation

Road freight is the largest contributor to greenhouse gas emissions in the transport sector. Studies by the World Business Council for Sustainability have shown that freight movement uses about 43 percent of all transportation energy, and that slow-moving vehicles cause significant highway congestion. Benefits from "dematerialization" (product miniaturization, use of lighter materials, increased product durability, service sector growth) have not reversed the increase in total material consumption tied to global growth. Fuel efficiency in freight has increased and trucks can adapt to bulkier fuels like heavy fuel cells and hydrogen, but globalization has increased freight demand and transport distances. Green policies include making manufacturers more responsible for the ecological impacts of the entire life cycle of their products, the development of regional production clusters to reduce transportation costs, and use of taxation to encourage more efficient trucks or shifts to more sustainable shipping patterns. Studies have found that, generally speaking, "intermodal transport" is far more ecological than road or unimodal transport.

Aviation has produced vast quantities of global climate-changing pollutants. Chapman explains that "aviation is now an essential part of the world economic system," with the increased use of aircraft leading not only to landing delays that reduce fuel efficiency but also to "increased gas emissions and ultimate, an institutional failure leading to an unsustainable programme of airport expansion." Among the reasons for such increases are "cheaper and more abundant flights." Tourism, often tied to air travel, is a key factor tied to growth and air pollution. Green alternatives include solar-powered planes (which are now in their infancy), and substitution for aircraft by high-speed rail (HSR). HSR has cut into air modal shares in France, Japan, Spain, and the Republic of Korea.

Infrastructure, Planning, and Urban Form

Government deregulation has increased fares for mass transit, just as rising personal incomes and car ownership, decentralization of cities and regions, and periodic declines in motoring and parking have reduced mass transit usage. A kind of vicious cycle has linked spatial decentralization and use of motorized transit: more spread-out development encourages car and truck use, and vice versa. The relatively speedy and flexible door-to-door transportation system of automobiles has usually put mass transit systems at a disadvantage when trip origins and destinations are spread all over the map. In the United States, federal policies to encourage automobile and highway use, together with the existence of cheap oil, have compounded the problem of decentralization.

There are, however, barriers to this decentralized spatial pattern and associated motor usage. First, traffic congestion has slowed speed, efficiency, and fuel economy. The existing transportation infrastructure in many countries is unable to cope with further increases in the number of motor vehicles, creating congestion problems in many towns and cities around the world. Congestion reduces the time available for alternative activities, potentially making cities with severe problems less competitive.

Second, historical and physical factors can retard an urban sprawl pattern. Land scarcity may make it too costly to spread development out, with island cities and states like New York City and Singapore unable to adapt without a dense pattern. Cities like New York, built before the car era, were unable to provide many parking lots or widen their streets to accommodate the automobile.

Third, some locales have supported denser, more sustainable patterns because of the desire to preserve open space, support ecological goals, and historical preservation interests or other aesthetic values. Mark Luccarelli explains that in the United States, the diffused metropolis produced "a sprawling, visually blighted, and functionally differentiated amalgam of existing towns and cities, residential subdivisions, industrial and office 'parks,' shopping centers, and malls." Growth not only comes at the expense of the surrounding countryside but also has deprived the urban core of its integrity and its amenities.

Finally, cities that offer cultural amenities, density, mass transit access, and certain aesthetic values have certain market advantages, particularly as cities compete with one another for members of a professional-managerial class, many of whom increasingly want to live in less automobile-dependent cities. Cities with amenities like bicycle paths, light rail, accessibility by walking, and the reduced need for a car will often be more competitive in attracting such professionals. Alan Ehrenhalt concludes that deindustrialization and reduced crime have produced cleaner, safer cities in the United States, leading to a process where more affluent persons stay or move into the inner cities, and the poorer can be pushed out to the suburbs. He says professionals are attracted to the city, some wanting the following:

> Jane Jacobs's 1950s version of Hudson Street in New York's Greenwich Village, with locally owned and slightly messy bookstores, coffeehouses, and bars, and a concentration of art galleries and studios.

Some emerging trends suggest hope for urban forms that lend themselves to greener transportation modes. Ecological thinkers like Lester Brown cite "a declining interest in cars among young people," which some link to socialization processes linked to communication technologies like smartphones and computers, a preference for urban living, or the financial squeeze facing college graduates. Parking fees have also begun to rise in many cities. A 2012 survey of 44 central business districts in the United States found only 13 percent had abundant parking availability and just six expected the construction of new parking in the next two years. Many older persons are not able or willing to drive, so here too is an important mass transit market.

Congestion problems, the need for efficiency, and reduction of energy use/ecological impacts have led to the advocacy of greater urban density as a necessary element of any green transportation system. Greater density facilitates the use of mass transit options; walking and cycling are the greenest (most ecological) modes of transportation. Mayors in the United States, concerned about air pollution and congestion, have waged a fight to reduce automobile usage. A review by Brown found that "almost every U.S. city is either introducing new light rail lines, new subway lines, or express bus lines, or they are expanding and improving existing public transit systems in order to reduce dependence on cars."

David Banister cites empirical research, concluding on key parameters of a sustainable city:

> The key parameters of the sustainable city are that it should be over 25,000 population (preferably over 50,000), with medium densities (over 40 persons per hectare), with mixed-use developments, and with preference given to development in public transport–accessible corridors and near to highly public transport–accessible interchanges.

Density supports the needs of information sharing, and various service sectors require face-to-face exchanges or the creation of a certain milieu or localized community culture.

Policy Questions

Despite these trends, Chapman argues that aviation and motor cars are "increasingly the favored modes for passenger transport, but are also significantly the most damaging" for the environment. Such "favored modes need to be made less polluting through technological change or alternative modes need to be made more attractive via behavioral change driven by policy." In the United States, trend data shows a strong preference for traditional cars, with fuel prices not drastically reducing car use. The small car share of the market is no longer driven heavily by real fuel prices. As cars get smaller and more efficient (even where fuel prices are higher due to taxes), it would take much higher taxes to obviate the economic advantages of better fuel economy.

The constraints on technological solutions come from the "Jevons paradox," in which the greater efficiency of an energy system can lead to its greater use. One view is that without stiff fuel taxes in North America and China, the expansion of mass transit will not be able to reverse the tide of global warming because oil prices are currently stable-to-falling. Conversely, the taxation of fuel and vehicle miles traveled would push citizens toward denser living and reduce the number of vehicles per household. Citizens with reduced living standards and unable to afford a car could contribute to a growing mass transit lobby.

Among the policies that have encouraged green transport cities or a shift to public transport are expanding and improving public transport service; integrated and attractive transit fares; regional and intermodal coordination; pricing and restrictions on car ownership, use, and parking; and land use policies that encourage dense and mixed-use settlements. New budget priorities at the national level are of central importance; one way to get them might be through corporatist coalitions linking the government, transit manufacturers, labor unions, and social movements.

A comprehensive understanding of green transportation necessitates that one examine potential trade-offs. There are pragmatic or policy-oriented views about the short-term benefits of a given technology and infrastructure. There are also more "utopian" visions for what an ideal community looks like, such that green transportation facilitates the achievement of multiple goals (be they related to ecology, economy, energy use, mobility, or aesthetics). For example, the technology used in an electric-powered train is more or less green, but if the energy source for the train is coal or petroleum, the technology itself ends up not being very green.

Conversely, one could have a very green-powered light rail system that promotes exurban, low-density growth, and sprawl. Such a system might be green in terms of its own environmental impacts but encourage a spatial decentralization that is not more energy efficient. On the other hand, a light rail system that decreases car use might still be considered relatively green. Some suburbanization can be considered green if it breaks down the divide between "town" and "country" (urban life and rural life) and can create a green aesthetic that is valuable on its own account, for example, "garden cities" that are small scale, pedestrian friendly, and still on the outskirts of the inner city.

Given these various trade-offs, a consideration of the utopian green transportation community that meets multiple goals is useful. So too is the study of different cities and technologies and how these fit together. Various models for green cities supporting green transportation have been compiled by the World Wildlife Fund and Timothy Beatley in *Green Urbanism*.

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See Also: Alternative Fuels; Environmental Impacts; Environmental Justice; Green Fuels; Light Rail Transit; Sustainable Transportation; Transit–Oriented Development.

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Greenhouse Gases

Greenhouse gases (GHGs) are chemical compounds in the Earth's atmosphere that trap heat by absorbing infrared radiation from the sun. Gases include water vapor, carbon dioxide, methane, and nitrous oxide and can be produced by natural systems as well as human activity. Carbon dioxide is of particular concern because it is the most abundant GHG and its level has been steadily increasing since the Industrial Revolution began around 150 years ago. The level of carbon dioxide increases when the amount of the gas produced exceeds the Earth's ability to absorb (or sequester) carbon through natural processes such as plant photosynthesis.

The Keeling curve, named after scientist Charles D. Keeling who pioneered the study of atmospheric carbon dioxide, shows how the level has increased since 1958. For earlier periods, scientists have obtained information about the amount of carbon dioxide in the atmosphere by examining ice cores. The data show that before the Industrial Revolution, the level of carbon dioxide was around 280 parts per million (ppm) and increased steadily between 1850 and 1950 to around 320 ppm. Since then, the rate of increase has been much more rapid, and the level is now in excess of 400 ppm.

Relationship to Global Climate Change

Rising concentrations of GHGs cause concern because they increase the average temperature of the earth, which sets off a chain reaction that affects climate patterns in complicated and difficult-to-predict ways. Because carbon dioxide is the most important GHG, the amount of energy used by an entity has been termed its "carbon footprint."

Transportation is an important part of any discussion about GHGs and carbon footprints because it accounts for such a large share of carbon dioxide emissions (28 percent in the United States, 24 percent in Europe, and 13 percent globally), and it has been the fastest growing component over the last several years (increasing 20 percent between 1990 and 2001 for a group of 31 European countries).

The complex ways in which people affect climate has been the subject of growing and often vigorous debate for several decades. Some have been skeptical that people's actions can affect climate at the global scale and have instead attributed changes in climate patterns to natural variations rather than a more fundamental shift caused by human activity. Two specific aspects of the scientific process that have been challenging for policy makers and the general public to reconcile are the fact that all scientific studies have some statistical uncertainty associated with them and that different studies or climate models suggest various outcomes.

In contrast to those who have been skeptical about human-induced climate change, other entities have responded to the threats associated with rising GHG emission in a more proactive manner. The United Nations Framework Convention on Climate Change (UNFCCC) is an environmental treaty with the stated goal of preventing dangerous human-induced interference of the climate system. In 1997, most countries in the world signed the