Lecture 9: Energy and Transport Systems

Efficient transport is vital to the performance of modern economies. However, oil reserves appear to be dwindling, raising questions about the sustainability of many forms of transport.

9.1 Transport and the Economy

Transport is important. Imagine what life would be like without the internal combustion or jet engine. Getting to work might be a problem, especially if your home is some distance from your place of work. Likewise, visiting family and friends would be much more difficult. This, however, would only be the tip of the iceberg. How would the countless food producers get their products onto the shelves of your local supermarket? Transport is a subject of great importance to governments around the world – for without efficient transport systems, it is difficult for economies to grow, because labour and goods cannot be moved around easily. Efficient transport is therefore of vital importance to all societies as it impacts both on their economic development and the welfare of populations as a whole. Efficient transport systems provide wide-ranging economic and social benefits whereas deficient systems impose economic costs in the form of missed or reduced opportunities.

Improved transport systems can benefit economies in two ways.

- Firstly, they enable people to gain access to places where they can engage in wealth-generating activities and can consume goods and services, including education and health care facilities. This ultimately leads to a healthier, better-educated society and enables larger markets to develop, thus saving time and reducing costs.
- Secondly, transport enables companies to access raw materials and parts with greater ease, thus reducing production costs. It also enables them to deliver their products to customers more easily. In so doing it acts as an intermediate input to production. In addition, transport plays an important social role enabling people to network and socialize, ultimately promoting the growth of leisure services and facilities.

Transport promotes mobility, and it is this that is considered by many economists to be a reliable indicator of economic development. Mobility satisfies one of the most basic characteristics of economic activity, the need to transport people, freight and information from one location to another. Economies that exhibit greater mobility therefore tend to have better opportunities to develop than those in which mobility is restricted.

Reduced mobility impedes economic development, while greater mobility acts as a catalyst promoting growth.

9.2 The History of Transport

For much of human history, travelling overland has been a difficult and dangerous business. Mountains, forests, ravines and other geographical features made land transport a slow and arduous experience. By comparison it was much easier to travel by boat along rivers and across seas. Consequently, early human settlements sprang up along rivers and coastlines. In time this led to the development of large seaports, which enabled nations to trade with each other. These seaports allowed sailors to navigate the globe in large vessels and enabled the maritime nations of Europe to grow wealthy on international trade through their colonial empires. Water transport also played an important role in the early stages of the industrial revolution. In the eighteenth and early nineteenth centuries the development of canal systems in Western Europe enabled companies to transport heavy goods over long distances with relative ease. In so doing they allowed manufacturing centres to flourish, for the first time, in inland locations.

In the mid-nineteenth century the railways emerged. These were much more flexible than the canals which preceded them and were the first truly integrated inland transportation system – enabling, for first time, the mass transport of both people and goods. With the expansion of the railways, the industrial centres of North America and Europe flourished and grew large. The twentieth century saw the development of road transport and automobile manufacturing. While this facilitated individual transportation for the masses, it was not until after the Second World War that automobile ownership became widespread. With this rise in car ownership also came improvements in highway infrastructure, with the result that travelling times were greatly reduced.

The later part of the twentieth century saw the development of global air transport. This enabled the masses, for the first time, to travel abroad and in so doing facilitated growth in international trade. The effect of this was to break down international boundaries and make the world a smaller place, an effect reinforced by the explosion in telecommunications that occurred in the later part of the twentieth century.

It can be seen that the history of transport mirrors that of the world's economic development. In a few hundred years the world has changed from what was essentially a collection of parochial societies, into an interconnected network dominated by global corporations. International trade is at the heart of this global economy, with countries like China becoming manufacturing powerhouses for the whole planet. Without an efficient international transport system it would be difficult for this global economy to function. Indeed, the economies of the world are now so dependent on international trade that it should come as no surprise that there is strong vested interest in ensuring that international transport continues to thrive.

9.3 Passenger Transport

At a national level the amount of energy consumed on transport depends very much on the distances travelled by passengers and goods, and the type of transport preferred by the population. Although transport systems adhere in many ways to the same laws of supply and demand as those of other industries, they are complicated by network effects and differences in the various modes of transport. In particular, comfort and convenience are influential.

9.4 Energy Consumption and Transport

Most vehicles that travel overland and many ships utilize internal combustion engines. Such engines use oil as fuel and tend to be very inefficient. For example, the thermal efficiency of a ***typical petrol engine*** is only about 26%, before mechanical inefficiencies are taken into account. This means that most standard engines have an overall efficiency of only about 20%. In other words, 80% of the fuel energy is lost to atmosphere as heat. By comparison, ***diesel engines*** which have a higher compression ratio than petrol engines have efficiencies around 45%, making them a much more energy-efficient option. Given that internal combustion engines are inefficient, automobile manufacturers have made strenuous efforts in recent years to improve the efficiency of petrol engines. However, despite significant improvements in engine efficiency, the average fuel efficiency of petrol-engine cars has remained relatively static [3] , simply because more people now own large luxury cars.

While manufacturers of cars and trains tend to focus on mechanical efficiency, it can be seen from the above discussion that overall efficiency is strongly influenced by the way in which vehicles are used, something that is wholly dictated by the user. This fact alone makes it very difficult to make energy comparisons between vehicle types, because many user-related variables affect energy performance. While mechanical efficiency is of some relevance, what really matters is the energy consumed per passenger kilometer – something that depends wholly on the extent to which cars, buses and trains are filled with passengers.

If a large intercity train carries only a handful of passengers, then the fuel consumption per passenger-kilometer will be much greater than if it was full. Consequently, it is often difficult to make direct energy efficiency comparisons between different forms of transport, and assumptions about passenger loading and engine size must be made, which may, or may not, be realistic.

9.4.1 Carbon Dioxide Emissions

Table 4.3 presents the real-life CO2 emissions for various types of motor vehicle. From these data it can be seen that petrol-engine cars produce considerably more CO2 than diesel cars, with petrol – electric hybrids producing less than both – about the same as a large motorbike.

Table 4.4 shows similar data for aviation transport. These data are presented in terms of CO^2 emissions per passenger-kilometer for domestic, short-haul and long-haul flights, respectively. From these data it can be seen that longer flights tend to produce fewer CO^2 emissions. The reason for this is that large amounts of fuel are consumed during take-off and landing, which makes up a greater component of a domestic flight compared with a long-haul international flight.

Comparison between the data presented in Tables 4.3 and 4.4 reveals the rather surprising fnding that air travel is not as environmentally unfriendly as some might think. The data suggest that taking a short-haul international flight (provided that the aircraft is relatively full) is almost as 'environmentally friendly' as travelling to the same destination on a large motorbike. Indeed, the data suggest that a single person travelling in a hybrid petrol – electric car would produce about the same amount of CO2 as a person travelling on a short-haul international flight. Of course if four persons were to travel in the car, then that would be a much more environmentally friendly option.

If nothing else, the above discussion highlights the difficulties associated with promoting environmentally friendly transport. Small changes in the assumptions made during the calculation process can radically alter the conclusions reached, and it is all too easy to make assumptions which neatly f t current political thinking so that the 'correct' answer is reached. However, history is littered with 'politically correct' answers, which turned out to be failures. It is therefore important to make decisions that are based on sound knowledge and accurate assumptions.

TABLE 9.1 Comparison of the 'real-life' carbon dioxide produced per kilometer travelled for various vehicle types (Source, UK government, 2007).

Vehicle type	Engine size (litres)	Miles per gallon	Grams of CO_2 produced per km
Petrol car	<1.4	35.5	183.1
	1.4–2.0	30.1	216.2
	>2.0	21.9	296.4
Diesel car	<1.7	49.3	150.7
	1.7–2.0	39.5	188.1
	>2.0	28.2	263.5
Hybrid petrol–electric car	Medium	51.5	126.2
Motorbike	<0.125	89.2	72.9
	0.125–0.5	69.2	93.9
	>0.5	50.6	128.6

TABLE 4.4 Comparison of the 'real-life' carbon dioxide produced per passenger-kilometer travelled for various aviation flights (Source, UK government, 2007).

Flight type	Example flight	Load factor (%)	Grams of CO_2 produced per passenger km
Domestic	London to Edinburgh	65	158.0
Short-haul international	London to central Europe	65	130.4
Long-haul international	London to New York	79.7	105.6

9.5. Oil

As the world's economy grows, so its transport sector continues to expand and with it the demand for oil. Oil is, however, a finite resource, which is being consumed at an increasing rate and which will eventually run out. Consequently, the future is somewhat uncertain and it is difficult to make accurate predictions about how the crude-oil markets will behave.

It has been predicted that demand for petroleum will rise from its 2004 level of 83 million barrels oil equivalent per day to 118 million barrels by 2030, with most of this increase being consumed by the transport sector.

Given that oil reserves are finite and that demand for oil is increasing, it might seem reasonable to assume that oil will run out in the near future. Although petroleum is likely to be with us for many years to come, it is unlikely to be the cheap fuel that we have known in the past. However, the very fact that oil is likely to become more expensive should change the behaviour of consumers and result in the development of transport vehicles and systems that are likely to be more fuel efficient.

9.6 Biofuels

With increased concern about global warming there has been a trend in recent years towards the production of so-called biofuels (petroleum and diesel substitutes) from crops such as maize (corn), soybean and sugar cane. Some have hailed these new biofuels as 'green' carbon-neutral fuels, because the crops absorb CO2 from the atmosphere as they grow. However, the green credentials of such fuels are somewhat dubious. The problem is that when the crop is fermented it is necessary to distil off the neat ethanol and this process requires considerable heat energy. it has been estimated that it requires 0.77 units of fossil-fuel energy to produce one unit of biofuel energy from maize. By comparison the production of biodiesel from soybeans appears to be a much more environmentally friendly process, with only 0.4 units of fossil-fuel energy required to produce one unit of biodiesel energy. They say that there is no such thing as a free lunch, and this certainly appears to be the case with biofuels.

9.7. Electric Vehicles (EV)

These use one or more electric or traction motors for propulsion. They can be powered through a collector system by electricity from off-vehicle sources or they can be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity. Electric vehicles include road and rail vehicles, surface and underwater vessels, electric aircraft and spacecraft.

EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. Modern internal combustion engines have been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types.

In the 21st century, EVs saw a resurgence due to technological developments, and an increased focus on renewable energy.

Modern internal combustion engines have been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types. However, the environmental impact of the petroleum-based transportation infrastructure, along with the fear of peak oil, has led to renewed interest in an electric transportation infrastructure. EVs differ from fossil fuel-powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, hydropower, and wind power or any combination of those. The carbon footprint and other emissions of electric vehicles varies depending on the fuel and technology used for electricity generation. The electricity may then be stored on board the vehicle using a battery, flywheel, or supercapacitors. Vehicles making use of engines working on the principle of combustion can usually only derive their energy from a single or a few sources, usually non-renewable fossil fuels. A key advantage of hybrid or plug-in electric vehicles is regenerative braking, which recovers kinetic energy, typically lost during friction braking as heat, as electricity restored to the on-board battery.

9.7.1 Electricity sources

There are many ways to generate electricity, of varying costs, efficiency and ecological desirability.

Connection to generator plants

- Direct connection to generation plants as is common among electric trains, trolley buses, and trolley trucks.
- Online Electric Vehicle collects power from electric power strips buried under the road surface through electromagnetic induction.

Onboard generators and hybrid EVs

- Generated on-board using a diesel engine: diesel-electric locomotive.
- Generated on-board using a fuel cell: fuel cell vehicle.
- Generated on-board using nuclear energy: nuclear submarines and aircraft carriers.
- Renewable sources such as solar power: solar vehicle.

Onboard storage

These systems are powered from an external generator plant (nearly always when stationary), and then disconnected before motion occurs, and the electricity is stored in the vehicle until needed.

- **Full Electric Vehicles (FEV).** Power storage methods include:
    - Chemical energy stored on the vehicle in on-board batteries: Battery electric vehicle (BEV) typically with a lithium-ion battery.
    - Kinetic energy storage: flywheels.
    - Static energy stored on the vehicle in on-board electric double-layer capacitors.

9.7.2 Lithium-ion battery

Most electric vehicles use lithium-ion batteries (Li-Ions or LIBs). Lithium ion batteries have higher energy density, longer life span and higher power density than most other practical batteries.

Complicating factors include safety, durability, thermal breakdown and cost. Li-ion batteries should be used within safe temperature and voltage ranges in order to operate safely and efficiently. Increasing the battery's lifespan decreases effective costs. One technique is to operate a subset of the battery cells at a time and switching these subsets.

Side Note: ***The 2019 Nobel Prize in Chemistry was awarded to John B Goodenough, M Stanley Whittingham and Akira Yoshino "for the development of lithium-ion batteries".***

9.7.3 Electric motor

The power of a vehicle's electric motor, as in other vehicles, is measured in kilowatts (kW). Electric motors can deliver their maximum torque over a wide RPM range. This means that the performance of a vehicle with a 100 kW electric motor exceeds that of a vehicle with a 100 kW internal combustion engine, which can only deliver its maximum torque within a limited range of engine speed. Energy is lost during the process of converting the electrical energy to mechanical energy. Approximately 90% of the energy from the battery is converted to mechanical energy, the losses being in the motor and drivetrain.

Usually, direct current (DC) electricity is fed into a DC/AC inverter where it is converted to alternating current (AC) electricity and this AC electricity is connected to a 3-phase AC motor.

For electric trains, forklift trucks, and some electric cars, DC motors are often used. In some cases, universal motors are used, and then AC or DC may be employed. In recent production vehicles, various motor types have been implemented, for instance: Induction motors within Tesla Motor vehicles and permanent magnet machines in the Nissan Leaf and Chevrolet Bolt.

9.7.4 Vehicle types

Ground vehicles

- **Plug-in electric vehicle**

A plug-in electric vehicle (PEV) is any motor vehicle that can be recharged from any external source of electricity, such as wall sockets, and the electricity stored in the Rechargeable battery packs drives or contributes to drive the wheels.

- **Hybrid EVs**

A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion.

- **On- and off-road EVs**

EVs are on the road in many functions, including electric cars, electric trolleybuses, electric buses, battery electric buses, electric trucks, electric bicycles, electric motorcycles and scooters, personal transporters, neighborhood electric vehicles, golf carts, milk floats, and forklifts. Off-road vehicles include electrified all-terrain vehicles and tractors.

- **Railborne EVs**

The fixed nature of a rail line makes it relatively easy to power EVs through permanent overhead lines or electrified third rails, eliminating the need for heavy onboard batteries. Electric locomotives, electric trams/streetcars/trolleys, electric light rail systems, and electric rapid transit are all in common use today, especially in Europe and Asia.

- **Space rover vehicles**

Manned and unmanned vehicles have been used to explore the Moon and other planets in the solar system. On the last three missions of the Apollo program in 1971 and 1972, astronauts drove silver-oxide battery-powered Lunar Roving Vehicles distances up to 35.7 kilometers (22.2 mi) on the lunar surface. Unmanned, solar-powered rovers have explored the Moon and Mars.

9.7.5 Energy and motors

Most large electric transport systems are powered by stationary sources of electricity that are directly connected to the vehicles through wires. Electric traction allows the use of regenerative braking, in which the motors are used as brakes and become generators that transform the motion of, usually, a train into electrical power that is then fed back into the lines. This system is particularly advantageous in mountainous operations, as descending vehicles can produce a large portion of the power required for those ascending. This regenerative system is only viable if the system is large enough to utilize the power generated by descending vehicles.

9.7.6 Energy sources

- Although EVs have few direct emissions, all rely on energy created through electricity generation, and will usually emit pollution and generate waste, unless it is generated by renewable source power plants. Since EVs use whatever electricity is delivered by their electrical utility/grid operator, EVs can be made more or less efficient, polluting and expensive to run, by modifying the electrical generating stations. This would be done by an electrical utility under a government energy policy, in a timescale negotiated between utilities and government.
- EVs will take advantage of whatever environmental gains happen when a renewable energy generation station comes online, a fossil-fuel power station is decommissioned or upgraded. Conversely, if government policy or economic conditions shifts generators back to use more polluting fossil fuels and internal combustion engine vehicles (ICEVs), or more inefficient sources, the reverse can happen. Even in such a situation, electrical vehicles are still more efficient than a comparable amount of fossil fuel vehicles.

9.7.7 Advantages and disadvantages of EVs

a) Environmental.

- EVs release no tail pipe air pollutants at the place where they are operated. They also typically generate less noise pollution than an internal combustion engine vehicle, whether at rest or in motion. The energy that electric and hybrid cars consume is usually generated by means that have environmental impacts. Nevertheless, adaptation of EVs would have a significant net environmental benefit, except in a few countries that continue to rely on older coal fired power plants for the bulk of their electricity generation throughout the life of the car.

- Electric motors don't require oxygen, unlike internal combustion engines; this is useful for submarines and for space rovers.

b) Mechanical

- Electric motors are mechanically very simple and often achieve 90% energy conversion efficiency over the full range of speeds and power output and can be precisely controlled. They can also be combined with regenerative braking systems that have the ability to convert movement energy back into stored electricity. This can be used to reduce the wear on brake systems (and consequent brake pad dust) and reduce the total energy requirement of a trip. Regenerative braking is especially effective for start-and-stop city use.
- They can be finely controlled and provide high torque from rest, unlike internal combustion engines, and do not need multiple gears to match power curves. This removes the need for gearboxes and torque converters.
- EVs provide quiet and smooth operation and consequently have less noise and vibration than internal combustion engines

c) Energy resilience

- Electricity can be produced from a variety of sources, therefore it gives the greatest degree of energy resilience.

d) Energy efficiency

- EV 'tank-to-wheels' efficiency is about a factor of 3 higher than internal combustion engine vehicles. Energy is not consumed while the vehicle is stationary, unlike internal combustion engines which consume fuel while idling. However, looking at the well-to-wheel efficiency of EVs, their total emissions, while still lower, are closer to an efficient gasoline or diesel in most countries where electricity generation relies on fossil fuels.

e) Cost of recharge

The cost of operating an EV varies wildly depending on location. In some parts of the world, an EV costs less to drive than a comparable gas-powered vehicle, as long as the higher initial purchase price is not factored in.

f) Stabilization of the grid

Since EVs can be plugged into the electric grid when not in use, there is a potential for battery-powered vehicles to even cut the demand for electricity by feeding electricity into the grid from their batteries during peak use periods (such as midafternoon air conditioning use) while doing most of their charging at night, when there is unused generating capacity. This vehicle-to-grid (V2G) connection has the potential to reduce the need for new power plants, as long as vehicle owners do not mind reducing the life of their batteries, by being drained by the power company during peak demand.

g) Range

Electric vehicles may have shorter range compared to Internal Combustion Engines, however, the price per mile of electric vehicles is falling. Most owners opt to charge their vehicles primarily at their houses while not in use due to their typically slower charging times, and added convenience.

9.7.8 Future

- **Improved batteries**

First, advances in lithium ion batteries, in large part driven by the consumer electronics industry, allow full-sized, highway-capable EVs to be propelled as far on a single charge as conventional cars go on a single tank of gasoline. Lithium batteries have been made safe, can be recharged in minutes instead of hours.

- **Battery management and intermediate storage**

Another improvement is to decouple the electric motor from the battery through electronic control, employing supercapacitors to buffer large but short power demands and regenerative braking energy.

- **Electric trucks**

Small electric trucks have been used for decades for specific and/or limited uses. Larger electric trucks have been made in the 2010s.

- **Hydrogen trains**

Particularly in Europe, fuel-cell electric trains are gaining in popularity to replace Diesel-electric units.

More Information can be obtained at https://en.wikipedia.org/wiki/Electric_vehicle

9.8. Hyperloop

It is a proposed mode of passenger and/or freight transportation. A Hyperloop is a sealed tube or system of tubes through which a pod may travel free of air resistance or friction conveying people or objects at high speed while being very efficient, thereby drastically reducing travel times over medium-range distances.

Elon Musk's version of the concept, first publicly mentioned in 2012, incorporates reduced-pressure tubes in which pressurized capsules ride on air bearings driven by linear induction motors and axial compressors. The Hyperloop concept has been explicitly "open-sourced" by Musk and SpaceX, and others have been encouraged to take the ideas and further develop them.

9.8.1 Theory and operation

Developments in high-speed rail have historically been impeded by the difficulties in managing friction and air resistance both of which become substantial when vehicles approach high speeds. The vactrain* concept theoretically eliminates these obstacles by employing magnetically levitating trains in evacuated (airless) or partly evacuated tubes, allowing for speeds of thousands of miles per hour. However, the high cost of maglev and the difficulty of maintaining a vacuum over large distances has prevented this type of system from ever being built. The Hyperloop resembles a vactrain system but operates at approximately one millibar (100 Pa) of pressure.

The Hyperloop concept operates by sending specially designed "capsules" or "pods" through a steel tube maintained at a partial vacuum.

Vactrain* *A vactrain (or vacuum tube train) is a proposed design for very-high-speed rail transportation. It is a maglev (magnetic levitation) line using partly evacuated tubes or tunnels. Reduced air resistance could permit vactrains to travel at very high (Hypersonic) speeds with relatively little power—up to 6,400–8,000 km/h (4,000–5,000 mph). This is 5–6 times the speed of sound in Earth's atmosphere at sea level. Vactrains might use gravity to assist their acceleration, as in a gravity train.*

More Information can be obtained at https://en.wikipedia.org/wiki/Hyperloop