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Strategies for Sustainable Energy

Lecture 3. Consumption Part I

ENG2110-01
College of Engineering
Yonsei University
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Review Homework #1

Class Discussion

1. What fraction of the energy usage in the ROK comes from fossil fuels? (Find the most recent data available and report the year to which it applies.)

2. Where do the fossil fuels used by the ROK come from? (What fraction is domestic? What fraction comes from the Middle East?)

3. Are there any examples of climate change that have been observed in the ROK?

3. Consumption: Cars

Estimating Energy Consumption by Cars

$$\text{energy used per day} = \frac{\text{distance travelled per day}}{\text{distance per unit of fuel}} \times \text{energy per unit of fuel.}$$

distance traveled per day = 50 km (30 miles)
distance per unit of fuel = 33 miles/gallon = 12 km/liter
energy per volume of fuel = 10 kWh/liter

energy used per day = 40 kWh/day

This energy doesn't include the cost of

- making the fuel
- making the car

The fuel efficiency used in this book is
kWh per hundred person-km
For a single occupied car
83.3 kWh per 100 person-km

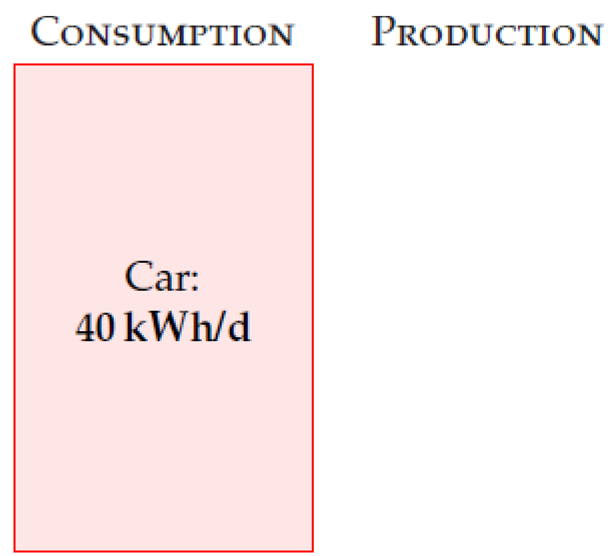

Figure 3.3. Chapter 3's conclusion: a typical car-driver uses about 40 kWh per day.

3. Consumption: Cars

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UK

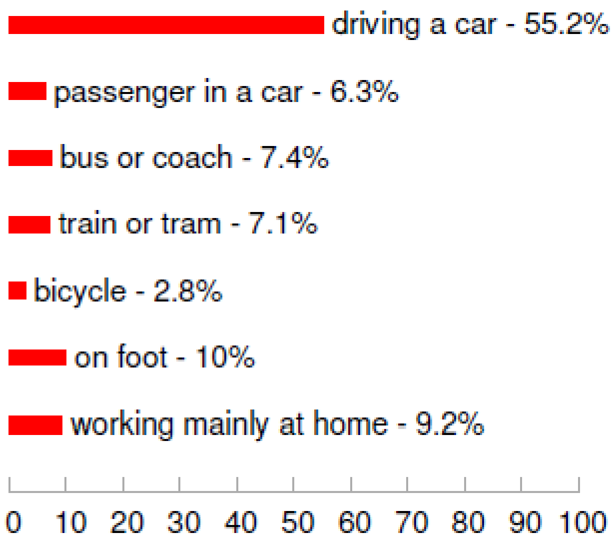

Figure 3.4. How British people travel to work, according to the 2001 census.

Explanation

- Lifestyle choice
- Access to public transportation
- Economic necessity

United States

87.7 percent of American workers use an automobile to get to work.
Most people, 77 percent, drive alone.

In contrast to that, 4.7 percent of the commuters use public transportation, such as a commuter train, to travel to work.

http://www.associatedcontent.com/article/302451/u_s_government_statistics_most_americans.html

3. Consumption: Cars

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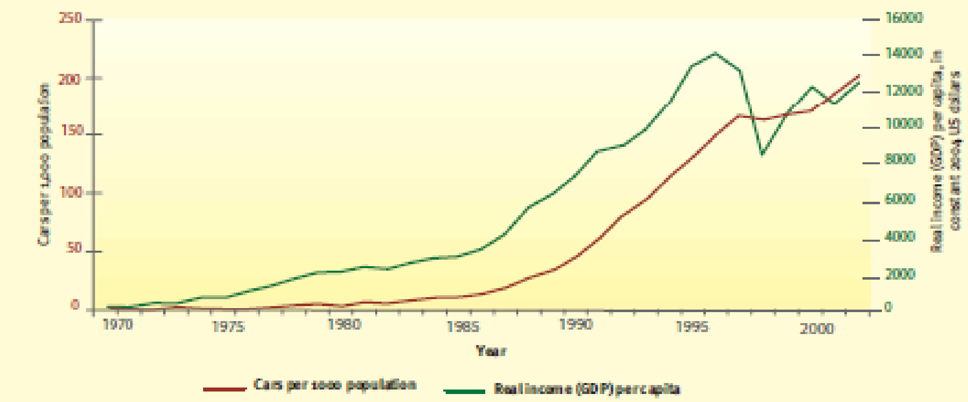
Seoul

- Car ownership is increasing
- Fraction of trips taken by car is constant
- Fraction of trips taken by car is much smaller than in UK or US

  Why?

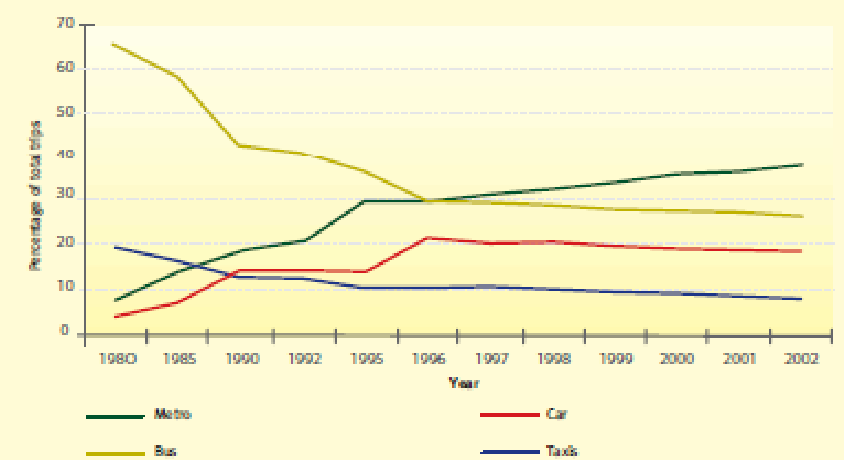
- Seoul has one of the best public transportation systems in the world

FIGURE 1: INCREASES IN CAR OWNERSHIP PARALLELING GROWTH IN REAL PER-CAPITA INCOME IN SOUTH KOREA, 1970-2002 (IN CONSTANT, INFLATION-ADJUSTED 2004 US DOLLARS)



Sources: Korea Transport Database and Korea National Statistical Office

FIGURE 2: TRENDS IN MODAL SHARES OF TOTAL TRIPS IN SEOUL, 1980-2002 (PERCENT OF TRIPS BY EACH TYPE OF TRANSPORT)



Sources: Seoul Metropolitan Government and Seoul Development Institute

http://policy.rutgers.edu/faculty/pucher/PTI_English.pdf

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Most Used Public Transportation Systems

The most-used **metro systems in terms of passenger rides** per year:

1. Tokyo Subway (Tokyo Metro and Toei Subway only) 3.160 billion (2009) [1][2][Note 1]
2. Moscow Metro 2.392 billion (2009) [3]
3. Seoul Subway (Seoul Metro and SMRT) 2.048 billion (2009) [Note 2]
4. Shanghai Metro 2 billion (2010) [4]
5. Beijing Subway 1.595 billion (2010) [5][Note 3]
6. New York City Subway 1.579 billion (2009) [6][Note 4]
7. Paris Métro 1.479 billion (2009) [7] [Note 5]
8. Mexico City Metro 1.414 billion (2009) [8]
9. Hong Kong MTR 1.41 billion (2010) [9][Note 6]
10. Guangzhou Metro (including FMetro) 1.18 billion (2010)[10]
11. London Underground 1.065 billion (2009) [11][Note 7]
12. São Paulo Metro 974 million (2009) [12]
13. Osaka Municipal Subway 877.8 million (2007) [13][Note 8]
14. Saint Petersburg Metro 829.8 million (2007) [14]
15. Singapore Mass Rapid Transit 744.8 million (2010) [15][16][Note 9]
16. Cairo Metro 700 million (2002) [17]
17. Madrid Metro 642 million (2009) [18]
18. Santiago Metro 608 million (2009) [19]
19. Prague Metro 585 million (2009) [20]
20. Caracas Metro 510.2 million (2008) [21]
21. Vienna U-Bahn 510.2 million (2009) [22]
22. Berlin U-Bahn 508.9 million (2009) [23]
23. Taipei Metro 505.4 million (2010) [24]
24. Kiev Metro 502.8 million (2009) [25]

http://en.wikipedia.org/wiki/Metro_systems_by_annual_passenger_rides

3. Consumption: Cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

1. In *short-distance travel* with lots of starting and stopping, the energy mainly goes into speeding up the vehicle and its contents. Key strategies for consuming less in this sort of transportation are therefore to *weigh less*, and to *go further between stops*. Regenerative braking, which captures energy when slowing down, may help too. In addition, it helps to *move slower*, and to *move less*.

2. In *long-distance travel* at steady speed, by train or automobile, most of the energy goes into making air swirl around, because you only have to accelerate the vehicle once. The key strategies for consuming less in this sort of transportation are therefore to *move slower*, and to *move less*, and to *use long, thin vehicles*.

3. In all forms of travel, there's an energy-conversion chain, which takes energy in some sort of fuel and uses some of it to push the vehicle forwards. Inevitably this energy chain has inefficiencies. In a standard fossil-fuel car, for example, only 25% is used for pushing, and roughly 75% of the energy is lost in making the engine and radiator hot. So a final strategy for consuming less energy is to make the energy-conversion chain more efficient.

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Six principles of vehicle design and vehicle use for more efficient surface transport

- reduce frontal area per person
- reduce the vehicle's weight per person
- when traveling, go at a steady speed and avoid using the brakes
- travel more slowly
- travel less
- make the energy chain more efficient

Figure 20.2. Team Crocodile's eco-car uses 1.3 kWh per 100 km. Photo kindly provided by Team Crocodile. www.teamcrocodile.com

A widely quoted statistic says something along the lines of "only *1 percent* of the energy used by a car goes into moving the driver" – the implication being that, surely, by being a bit smarter, we could make cars *100* times more efficient? The answer is yes, almost, but only by applying the principles of vehicle design and vehicle use, listed above, to *extreme* degrees.

2184 miles per gallon
920 km per liter

3. Consumption: Cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Figure 20.3. “Babies on board.” This mode of transportation has an energy cost of 1 kWh per 100 person-km.

Figure 20.4. This 8-carriage train, at its maximum speed of 100 mph (161 km/h), consumes 1.6 kWh per 100 passenger-km, if full.

Energy consumption (kWh per 100 p-km)	
Car	68
Bus	19
Rail	6
Air	51
Sea	57

Table 20.8. Overall transport efficiencies of transport modes in Japan (1999).

Compare to the fuel efficiency for a single occupied car of 83.3 kWh per 100 person-km

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

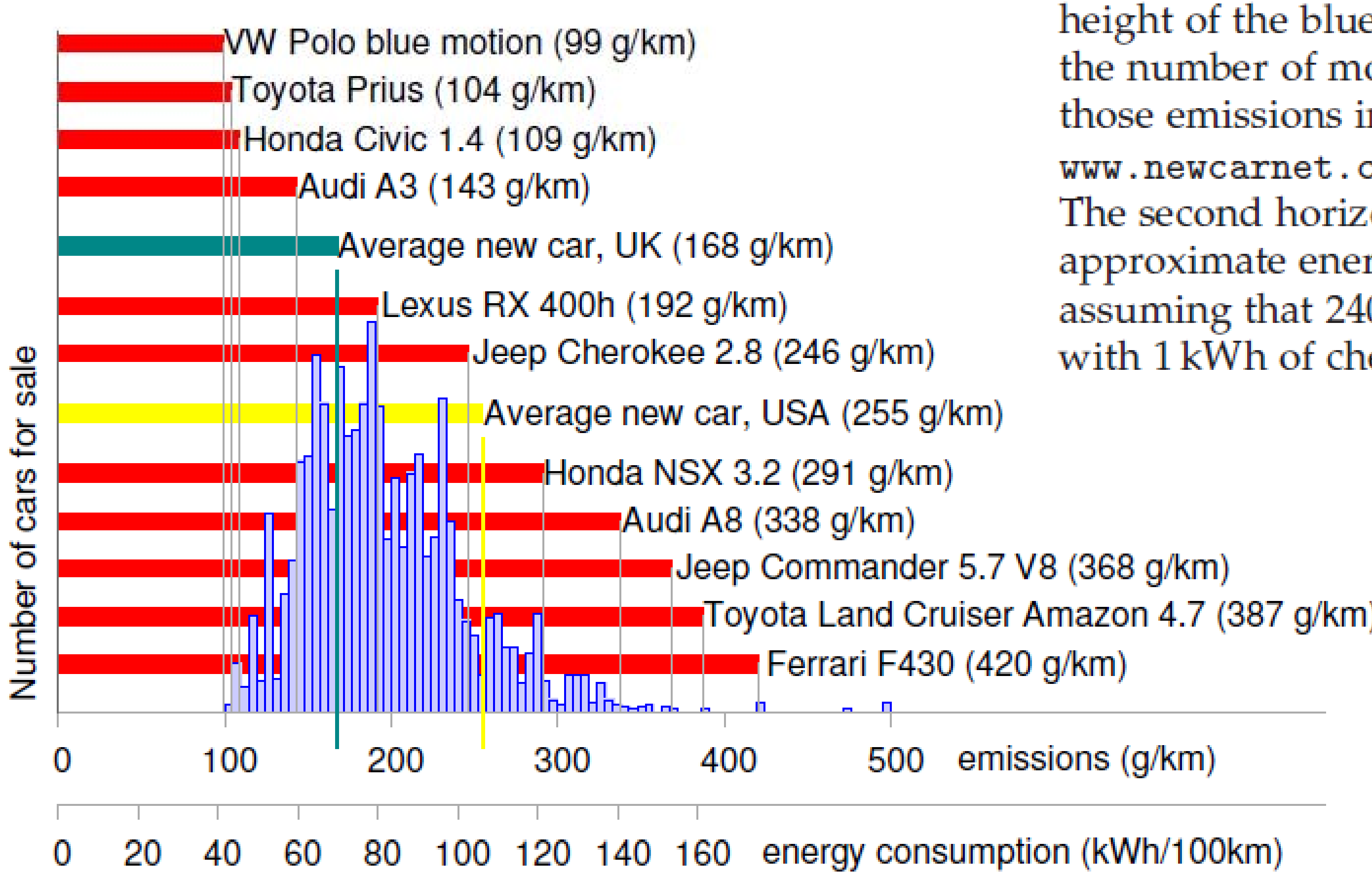

Figure 20.9. Carbon pollution, in grams CO_2 per km, of a selection of cars for sale in the UK. The horizontal axis shows the emission rate, and the height of the blue histogram indicates the number of models on sale with those emissions in 2006. Source: `www.newcarnet.co.uk`.
The second horizontal scale indicates approximate energy consumptions, assuming that 240 g CO_2 is associated with 1 kWh of chemical energy.

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

The energy consumption of individual cars *can* be reduced. The wide range of energy efficiencies of cars for sale proves this. In a single showroom in 2006 you could buy a Honda Civic 1.4 that uses roughly 44 kWh per 100 km, or a Honda NSX 3.2 that uses 116 kWh per 100 km (figure 20.9). The fact that people merrily *buy* from this wide range is also proof that we need extra incentives and legislation to encourage the blithe consumer to *choose* more energy-efficient cars. There are various ways to help con-

Legislation is necessary!

If we can't give up cars, Five technologies for improving cars

- regenerative braking
- hybrid cars
- electric cars
- hydrogen cars
- compressed-air cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Regenerative braking

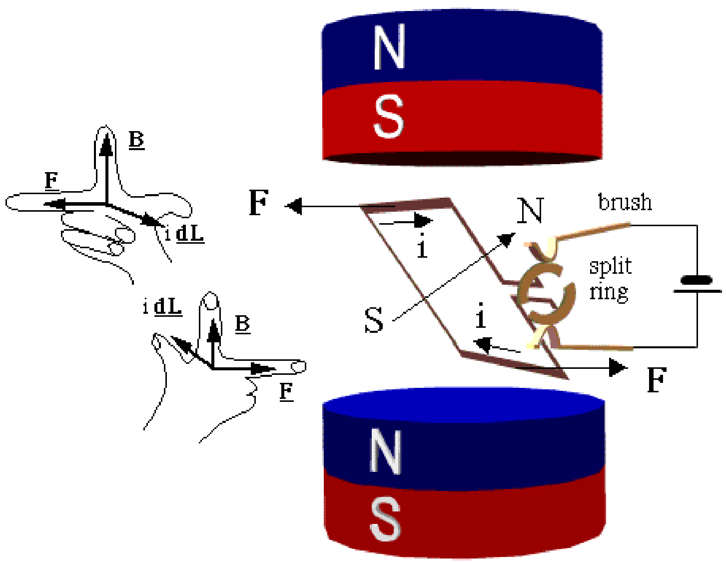
There are four ways to capture energy as a vehicle slows down.

1. An electric generator coupled to the wheels can charge up an electric battery or supercapacitor.
2. Hydraulic motors driven by the wheels can make compressed air, stored in a small canister.
3. Energy can be stored in a flywheel.
4. Braking energy can be stored as gravitational energy by driving the vehicle up a ramp whenever you want to slow down. This gravitational energy storage option is rather inflexible, since there must be a ramp in the right place. It's an option that's most useful for trains, and it is illustrated by the London Underground's Victoria line, which has hump-back stations. Each station is at the top of a hill in the track. Arriving trains are automatically slowed down by the hill, and departing trains are accelerated as they go down the far side of the hill. The hump-back-station design provides an energy saving of 5% and makes the trains run 9% faster.

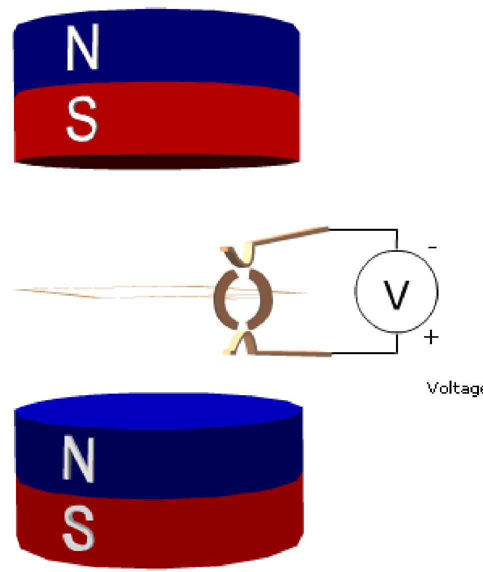
3. Consumption: Cars

Regenerative braking via electric generators

● Vehicles driven by electric motors use the motor as a generator when using regenerative braking: it is operated as a generator during braking and its output is supplied to an electrical load; the transfer of energy to the load provides the braking effect.
● Many modern hybrid and electric vehicles use this technique to extend the range of the battery pack. Examples include the Toyota Prius, Honda Insight, the Vectrix electric maxi-scooter, and the Chevrolet Volt.
● Traditional friction-based braking is used in conjunction with mechanical regenerative braking for safety and efficiency.



Electric motors convert an electric current into mechanical rotation.



Electric generators convert mechanical rotation into an electric current.

http://en.wikipedia.org/wiki/Regenerative_brake

http://www.animations.physics.unsw.edu.au/jw/electricmotors.html

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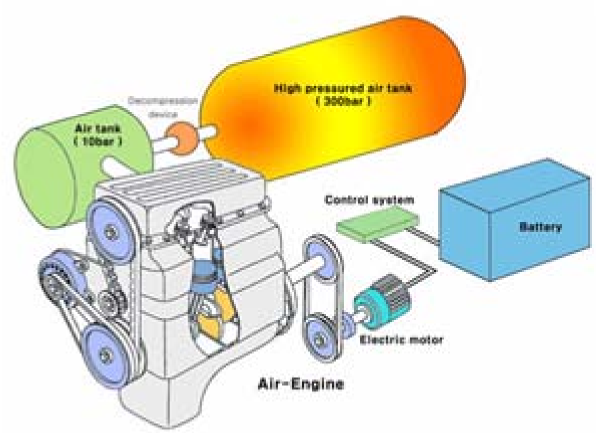
Regenerative braking via compressed air

● **Compressed Air Energy Storage** (**CAES**) is a way to store energy generated at one time for use at another time. Compression is the process of increasing the pressure of a gas. This process requires energy. Decompression or expansion is the process of decreasing the pressure of a gas. This process releases energy.

● Some of the energy released is available as mechanical work and can be captured via a pneumatic motor. Some of the energy is heat. Compression typically heats a gas. Expansion cools a gas.

● There are no commercial cars using compressed air energy storage systems currently.

● There are safety issues involving the catastrophic failure of a high pressure gas tank.



http://jalopnik.com/#!5282712/pneumatic-hybrids-urban-powertrain-of-the-future

http://en.wikipedia.org/wiki/Compressed_air_energy_storage

3. Consumption: Cars

Regenerative braking via flywheels

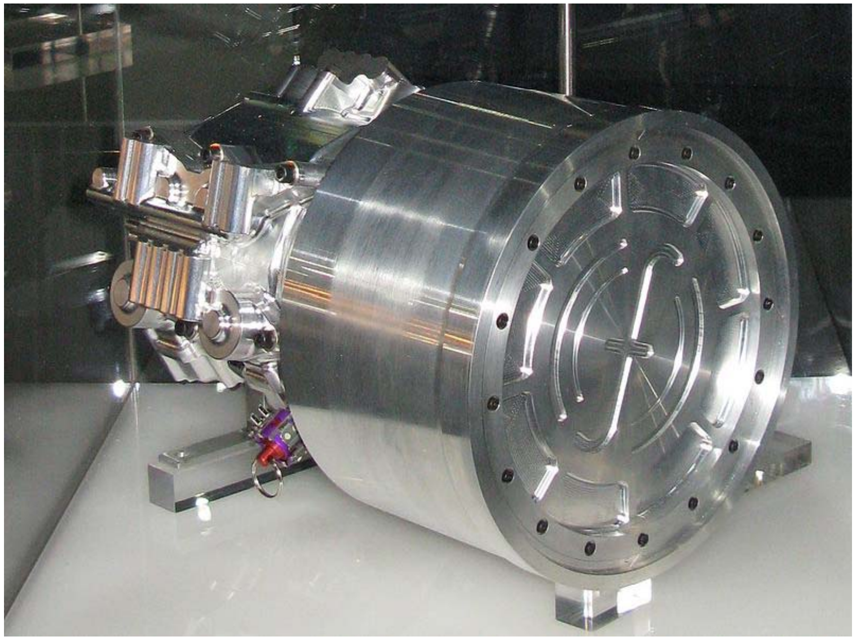
● **Flywheel energy storage** (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel.

● Most FES systems use electricity to accelerate and decelerate the flywheel, but devices that directly use mechanical energy are being developed.[1]

● Advanced FES systems have rotors made of high strength carbon filaments, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure.[2] Such flywheels can come up to speed in a matter of minutes — much quicker than some other forms of energy storage.[2]

● New applications are currently being explored.

● To help in understanding, think of toy cars that you first "rev" up by rolling on the ground (get the flywheel spinning) then set on the ground and watch as they speed away (flywheel discharging energy)



http://en.wikipedia.org/wiki/Flywheel_energy_storage

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Hybrid cars

Hybrid cars provide

- a modest improvement in fuel efficiency (20-30%)
- carbon emissions on par with non-hybrid cars
- not a sufficient advance to impact the sustainable energy challenge

Figure 20.19. Toyota Prius – according to Jeremy Clarkson, "a very expensive, very complex, not terribly green, slow, cheaply made, and pointless way of moving around."

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Electric vehicles

Electric cars provide

- significant improvement in energy efficiency
- have range limitations (good for city driving)

The environmental benefit depends upon where the electricity comes from

If you drive an electric car that is charged with electricity from a conventional coal-fired power plant, then is there any environmental advantage?

In principle, we need green electricity to make electric vehicles green.

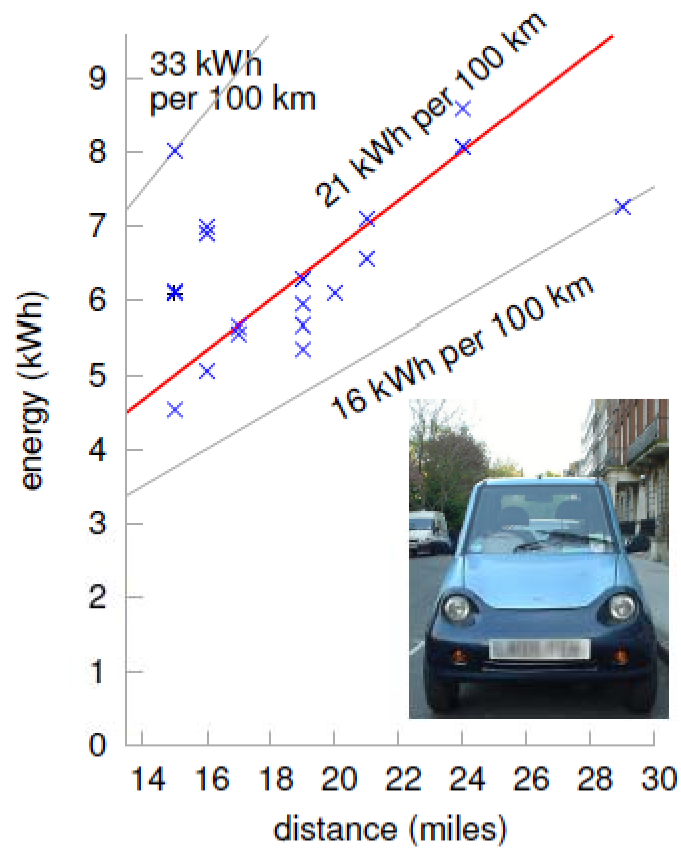

Figure 20.21. Electricity required to recharge a G-Wiz versus distance driven. Measurements were made at the socket.

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars: Electric Cars

Pollution

Electric cars produce no pollution at the tailpipe which will contribute to cleaner air in cities, but their use increases demand for electricity generation. The amount of carbon dioxide emitted depends on the emission intensity of the power source used to charge the vehicle, the efficiency of the said vehicle and the energy wasted in the charging process.

An EV recharged from the existing US grid electricity emits about 115 grams of CO2 per kilometer driven (6.5 oz(CO2)/mi), whereas a conventional US-market gasoline powered car emits 250 g(CO2)/km (14 oz(CO2)/mi) (most from its tailpipe, some from the production and distribution of gasoline).[72]

In a worst-case scenario where incremental electricity demand would be met exclusively with coal, a 2009 study conducted by the World Wide Fund for Nature and IZES found that a mid-size EV would emit roughly 200 g(CO2)/km (11 oz(CO2)/mi), compared with an average of 170 g(CO2)/km (9.7 oz(CO2)/mi) for a gasoline-powered compact car.[74] This study concluded that introducing 1 million EV cars to Germany would, in the best-case scenario, only reduce CO2 emissions by 0.1%, if nothing is done to upgrade the electricity infrastructure or manage demand.[74]

In France, which has a clean energy grid, CO2 emissions from electric car use would be about 12g per kilometer.[75]

A study made in the UK in 2008 concluded that electric vehicles had the potential to cut down carbon dioxide and greenhouse gas emissions by at least 40%.[76]

http://en.wikipedia.org/wiki/Electric_car

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars: Electric Cars

● Electric cars are generally more expensive than gasoline cars. The primary reason is the high cost of car batteries.
● "Fuel" cost comparison: 11.2 kW·h of electricity costing between US$0.56 and US$3.18 depending on the time of day chosen for recharging compared to gasoline at a cost of US$4 per 1 US gallon would cost US$6.40.
● Range: Cars with internal combustion engines can be considered to have indefinite range, as they can be refuelled very quickly almost anywhere. Electric cars often have less maximum range on one charge than cars powered by fossil fuels, and they can take considerable time to recharge. This is a reason that many automakers marketed EVs as "daily drivers" suitable for city trips and other short hauls. “Range anxiety” is the fear of the limited driving range of an electric vehicle.
● Recharging Time: If the battery can be “swapped out”, then recharging is fast. If the battery must be recharged, new infrastructure is required. DC Fast Charging stations with high-speed charging capability from three-phase industrial outlets allow consumers to recharge the 100 mile battery of their electric vehicle to 80 percent in about 30 minutes.

http://en.wikipedia.org/wiki/Electric_car

3. Consumption: Cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Hydrogen cars

Hydrogen cars

● potentially can have higher energy efficiency due to the better efficiency of fuel cells over internal combustion engines
● have not demonstrated significant improvement in energy efficiency in practice
● do not have range limitations like electric vehicles
● have storage problems (how to store hydrogen on board)
● have start-up problems (could be combined with electric vehicles to have a hybrid electric battery-fuel cell vehicle with long range and good start-up performance

The environmental benefit depends upon where the hydrogen comes from.

Figure 20.26. BMW Hydrogen 7. Energy consumption: 254 kWh per 100 km. Photo from BMW.

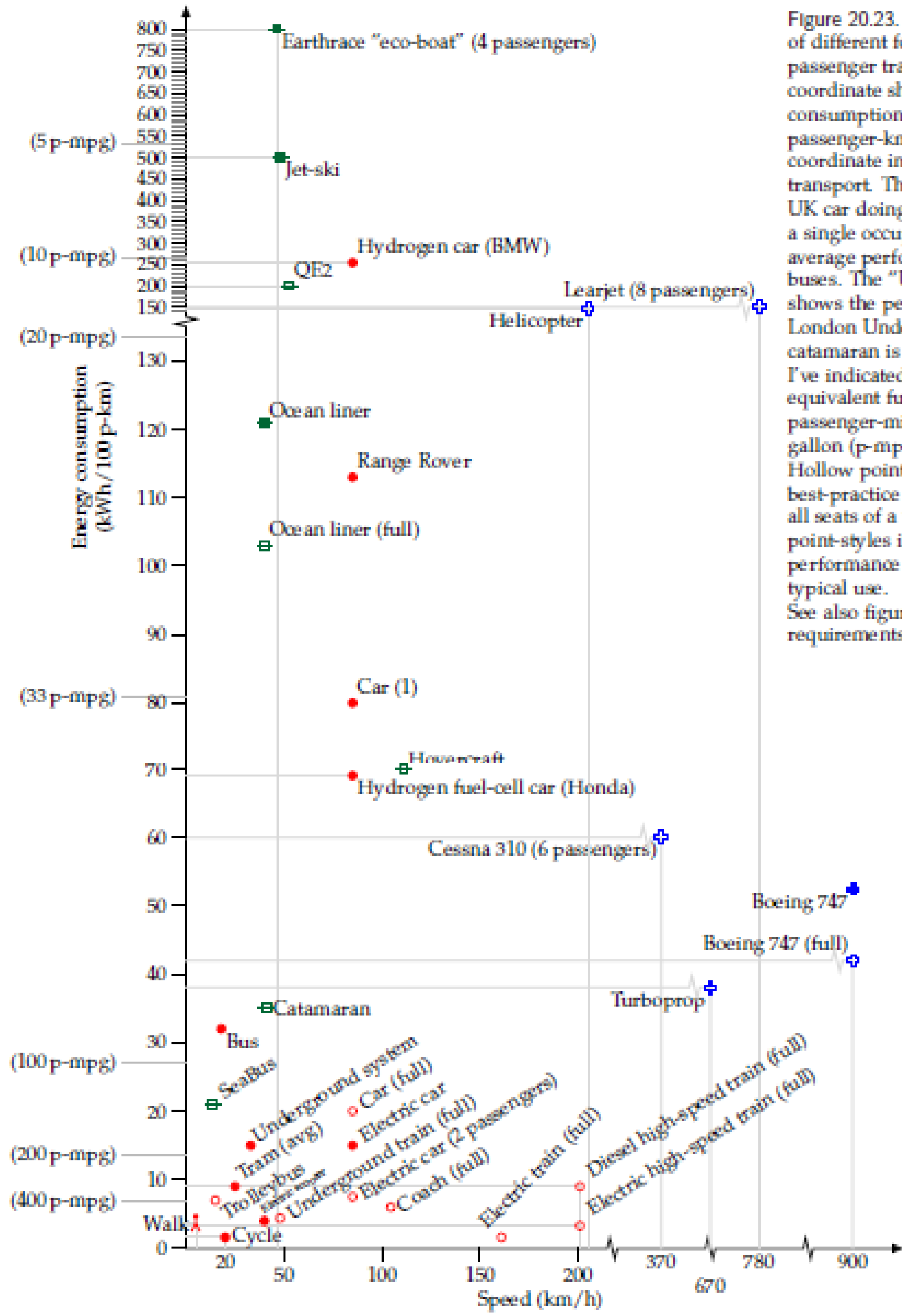

Figure 20.23. Energy requirements of different forms of passenger transport. The vertical coordinate shows the energy consumption in kWh per 100 passenger-km. The horizontal coordinate indicates the speed of the transport. The "Car (1)" is an average UK car doing 33 miles per gallon with a single occupant. The "Bus" is the average performance of all London buses. The "Underground system" shows the performance of the whole London Underground system. The catamaran is a diesel-powered vessel. I've indicated on the left-hand side equivalent fuel efficiencies in passenger-miles per imperial gallon (p-mpg).
Hollow point-styles show best-practice performance, assuming all seats of a vehicle are in use. Filled point-styles indicate actual performance of a vehicle in typical use.
See also figure 15.8 (energy requirements of freight transport).

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

You've shown that electric cars are more energy-efficient than fossil cars. But are they better if our objective is to reduce CO_2 emissions, and the electricity is still generated by fossil power-stations?

This is quite an easy calculation to do. Assume the electric vehicle's energy cost is 20 kWh(e) per 100 km. (I think 15 kWh(e) per 100 km is perfectly possible, but let's play sceptical in this calculation.) If grid electricity has a carbon footprint of 500 g per kWh(e) then the effective emissions of this vehicle are **100 g CO_2 per km**, which is as good as the best fossil cars (figure 20.9). So I conclude that switching to electric cars is *already* a good idea, even before we green our electricity supply.

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Electric cars, like fossil cars, have costs of both manufacture and use. Electric cars may cost less to use, but if the batteries don't last very long, shouldn't you pay more attention to the manufacturing cost?

Yes, that's a good point. My transport diagram shows only the use cost. If electric cars require new batteries every few years, my numbers may be underestimates. The batteries in a Prius are expected to last just 10 years, and a new set would cost £3500. Will anyone want to own a 10-year old Prius and pay that cost? It could be predicted that most Priuses will be junked at age 10 years. This is certainly a concern for all electric vehicles that have batteries. I guess I'm optimistic that, as we switch to electric vehicles, battery technology is going to improve.

3. Consumption: Cars

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Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

I live in a hot place. How could I drive an electric car? I demand power-hungry air-conditioning!

There's an elegant fix for this demand: fit 4 m^2 of photovoltaic panels in the upward-facing surfaces of the electric car. If the air-conditioning is needed, the sun must surely be shining. 20%-efficient panels will generate up to 800 W, which is enough to power a car's air-conditioning. The panels might even make a useful contribution to charging the car when it's parked, too. Solar-powered vehicle cooling was included in a Mazda in 1993; the solar cells were embedded in the glass sunroof.

I live in a cold place. How could I drive an electric car? I demand power-hungry heating!

The motor of an electric vehicle, when it's running, will on average use something like 10 kW, with an efficiency of 90–95%. Some of the lost power, the other 5–10%, will be dissipated as heat in the motor. Perhaps electric cars that are going to be used in cold places can be carefully designed so that this motor-generated heat, which might amount to 250 or 500 W, can be piped from the motor into the car. That much power would provide some significant windscreen demisting or body-warming.

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

Is there enough lithium to make all the batteries for a huge fleet of electric cars?

World lithium reserves are estimated to be 9.5 million tons in ore deposits (p175). A lithium-ion battery is 3% lithium. If we assume each vehicle has a 200 kg battery, then we need 6 kg of lithium per vehicle. So the estimated reserves in ore deposits are enough to make the batteries for 1.6 billion vehicles. That's more than the number of cars in the world today (roughly 1 billion) – but not much more, so the amount of lithium may be a concern, especially when we take into account the competing ambitions of the nuclear fusion posse (Chapter 24) to guzzle lithium in their reactors. There's many thousands times more lithium in sea water, so perhaps the oceans will provide a useful backup. However, lithium specialist R. Keith Evans says "concerns regarding lithium availability for hybrid or electric vehicle batteries or other foreseeable applications are unfounded." And anyway, other lithium-free battery technologies such as zinc-air rechargeables are being developed [www.revolttechnology.com]. I think the electric car is a goer!

4. Consumption: Airplanes

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Estimating Energy Consumption by Airplanes (Chapter 5)

Imagine that you make one intercontinental trip per year by plane. How much energy does that cost?

A Boeing 747-400 with 240 000 litres of fuel carries 416 passengers about 8 800 miles (14 200 km). And fuel's calorific value is 10 kWh per litre. (We learned that in Chapter 3.) So the energy cost of one full-distance round-trip on such a plane, if divided equally among the passengers, is

$$\frac{2 \times 240\,000\,\text{litre}}{416\,\text{passengers}} \times 10\,\text{kWh/litre} \simeq 12\,000\,\text{kWh per passenger.}$$

If you make one such trip per year, then your average energy consumption per day is

$$\frac{12\,000\,\text{kWh}}{365\,\text{days}} \simeq 33\,\text{kWh/day}.$$

4. Consumption: Airplanes

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Estimating Energy Consumption by Airplanes (Chapter 5)

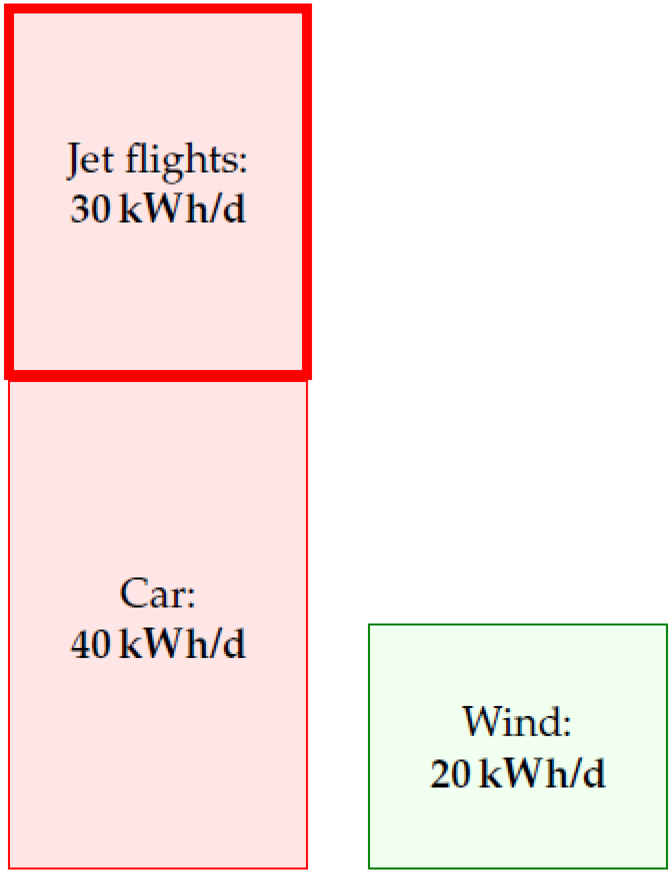

Figure 5.1. Taking one intercontinental trip per year uses about 30 kWh per day.

Flying

- requires a lot of energy
- is especially damaging to the environment because it ejects GHG directly into the upper atmosphere

"If you have $1000 (1,000,000 KRW) and you want to do the maximum damage to the environment, take an intercontinental flight. If you have $5 (5000 KRW) and you want to do the maximum damage to the environment, buy a package of fresh fruit out of season that has been flown overseas."

paraphrase from Roland Clift

4. Consumption: Airplanes

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Estimating Energy Consumption by Airplanes (Chapter 20)

The future of flying?

The superjumbo A380 is said by Airbus to be "a highly fuel-efficient aircraft." In fact, it burns just 12% less fuel per passenger than a 747.

Boeing has announced similar breakthroughs: their new 747–8 Intercontinental, trumpeted for its planet-saving properties, is (according to Boeing's advertisements) only 15% more fuel-efficient than a 747–400.

This slender rate of progress (contrasted with cars, where changes in technology deliver two-fold or even ten-fold improvements in efficiency) is explained in Technical Chapter C. Planes are up against a fundamental limit imposed by the laws of physics. Any plane, whatever its size, *has to* expend an energy of about 0.4 kWh per ton-km on keeping up and keeping moving. Planes have already been fantastically optimized, and there is no prospect of significant improvements in plane efficiency.