Strategies for Sustainable Energy

Lecture 2. Energy Consumption

CBE 652
Sustainable Technology through Advanced Interdisciplinary Research (STAIR)

University of Tennessee, Knoxville
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3. Consumption: Cars

Estimating Energy Consumption by Cars

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

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

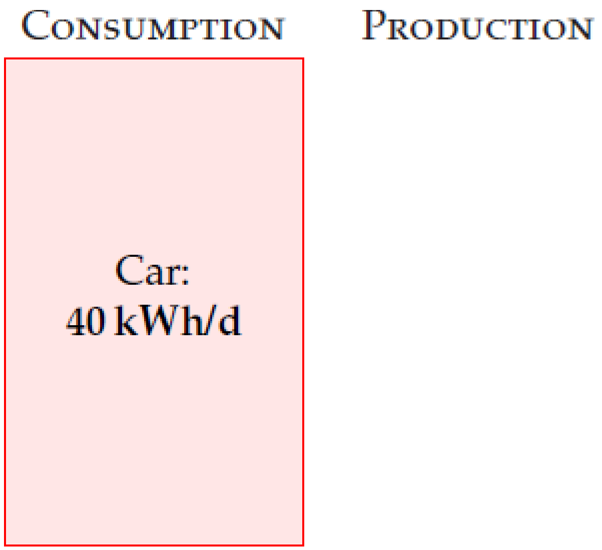


Figure 3.3. Chapter 3’s conclusion: a typical car-driver uses about 40 kWh per day.

3. Consumption: Cars

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

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.

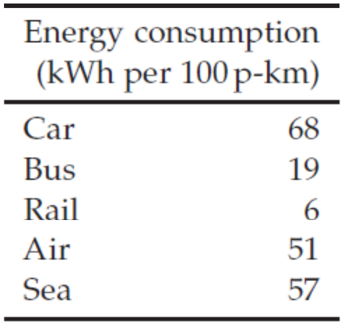
2184 miles per gallon
920 km per liter

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

3. Consumption: Cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

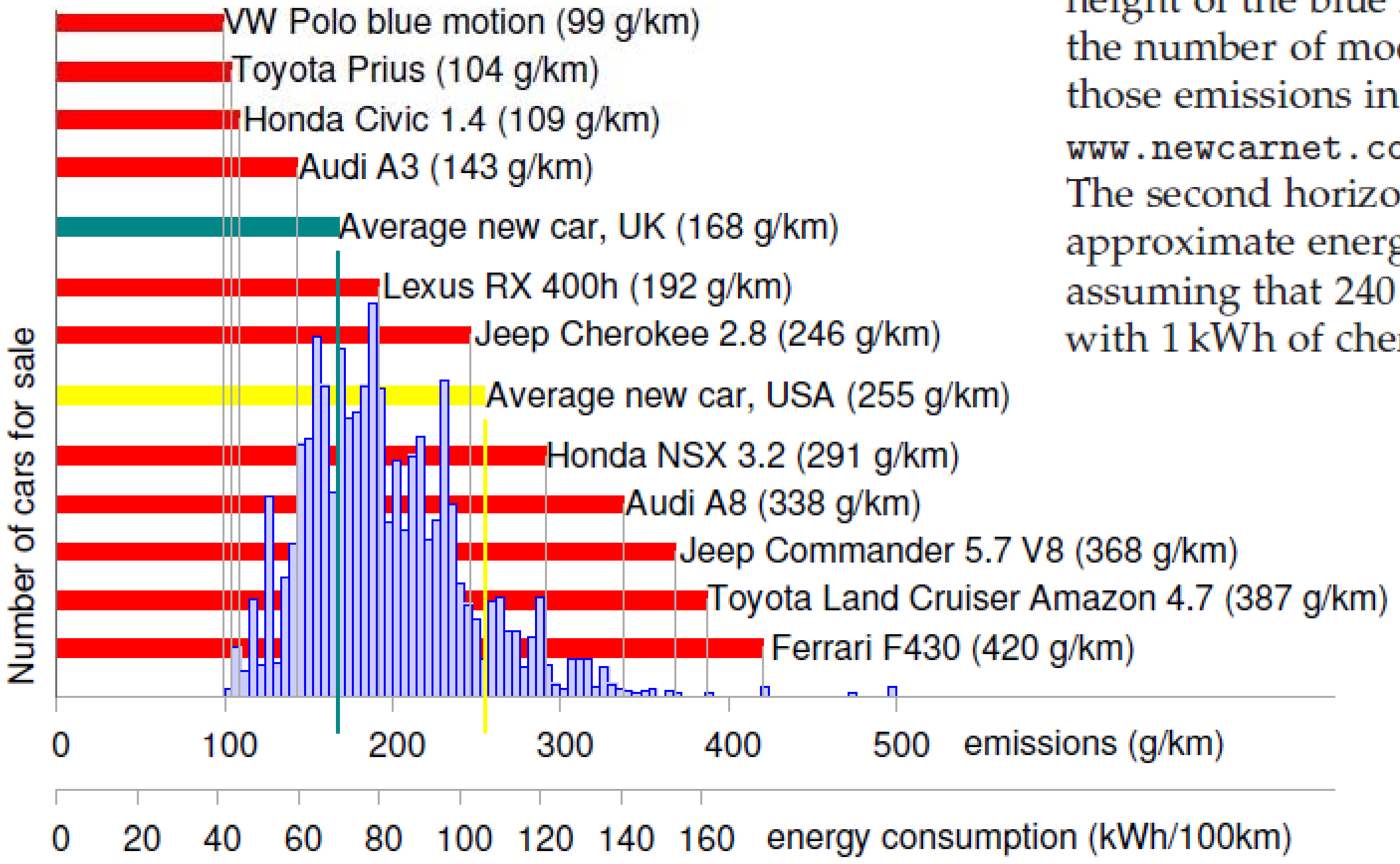
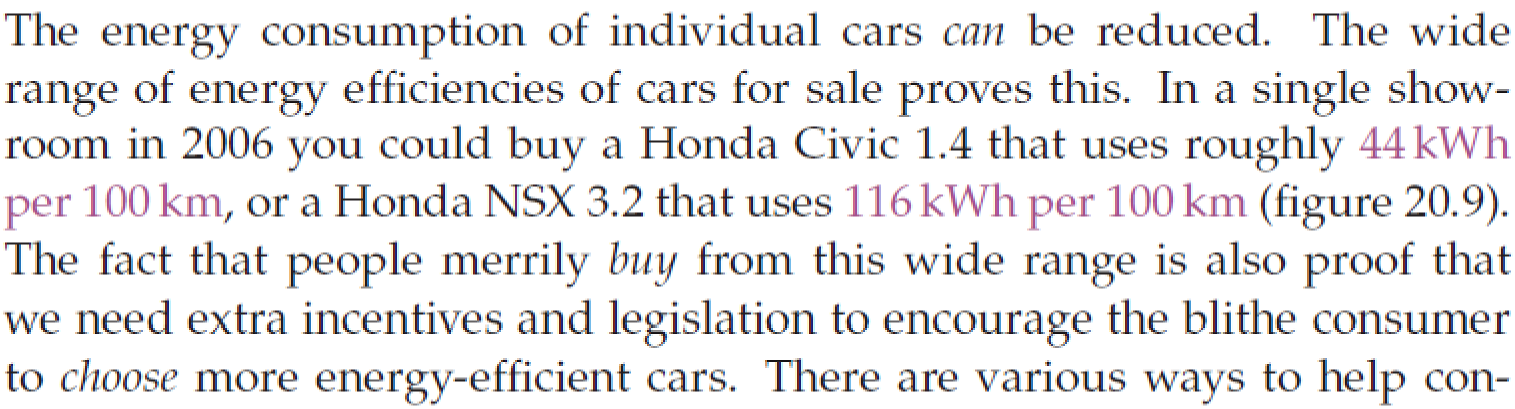


Figure 20.9. Carbon pollution, in grams CO_2 per km, of a selection of cars for sale in the UK. The horizontal axis shows the emission rate, and the height of the blue histogram indicates the number of models on sale with those emissions in 2006. Source: `www.newcarnet.co.uk`.
The second horizontal scale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

3. Consumption: Cars

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-

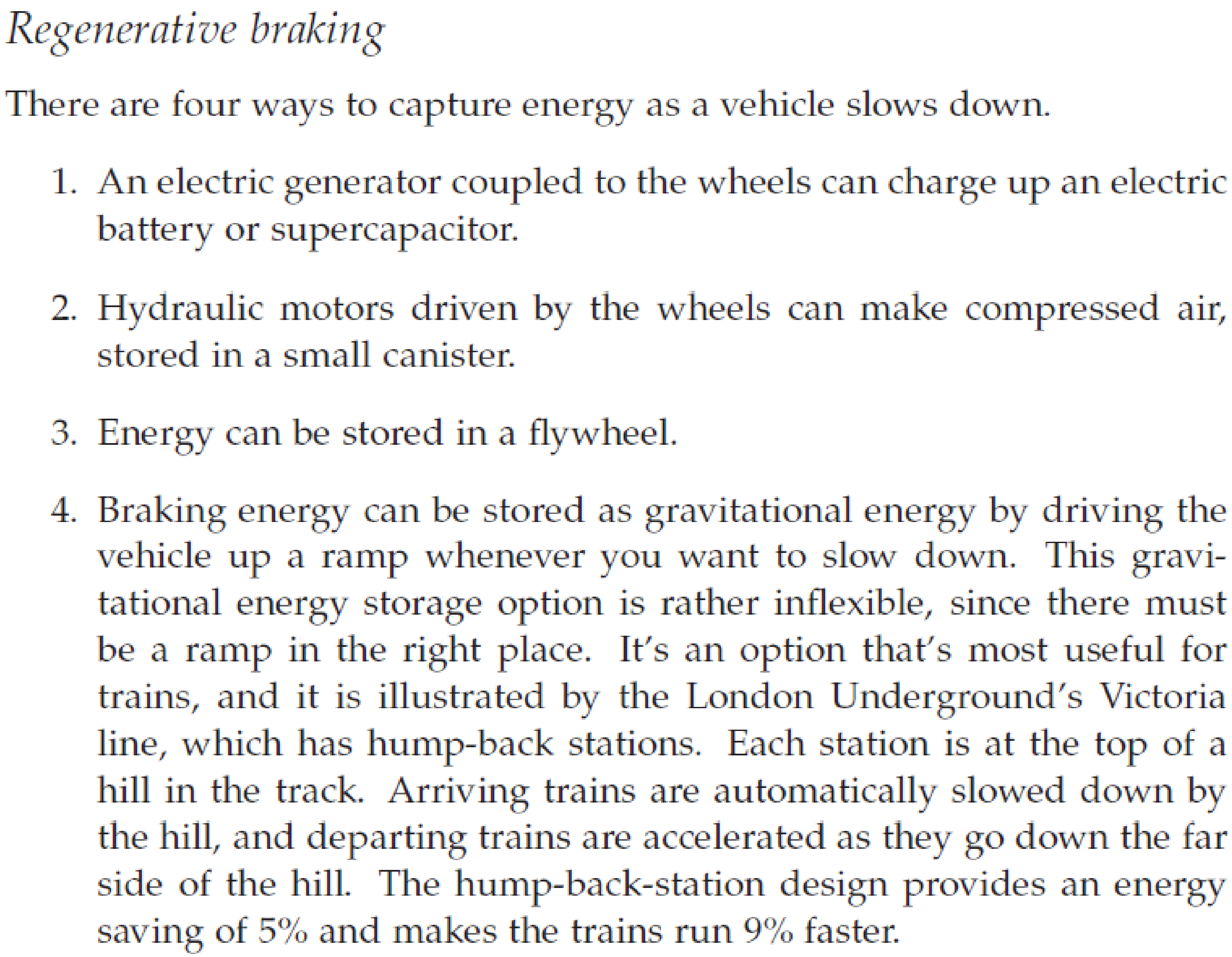
Legislation is necessary!

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

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

3. Consumption: 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

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."

3. Consumption: Cars

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?

Some studies say no. Some say yes, but only by a slight margin.

We need green electricity to make electric vehicles green.

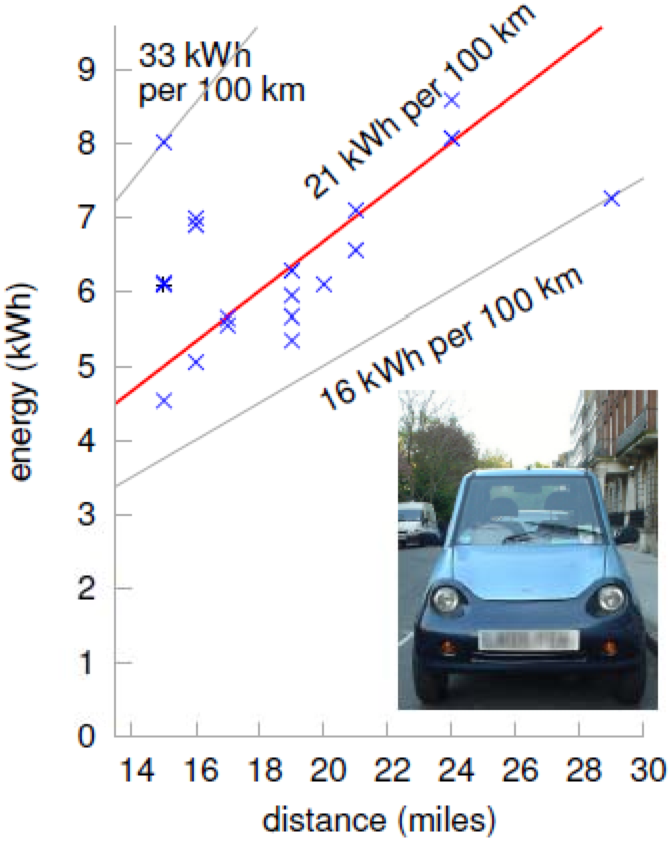


Figure 20.21. Electricity required to recharge a G-Wiz versus distance driven. Measurements were made at the socket.

3. Consumption: Cars

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.

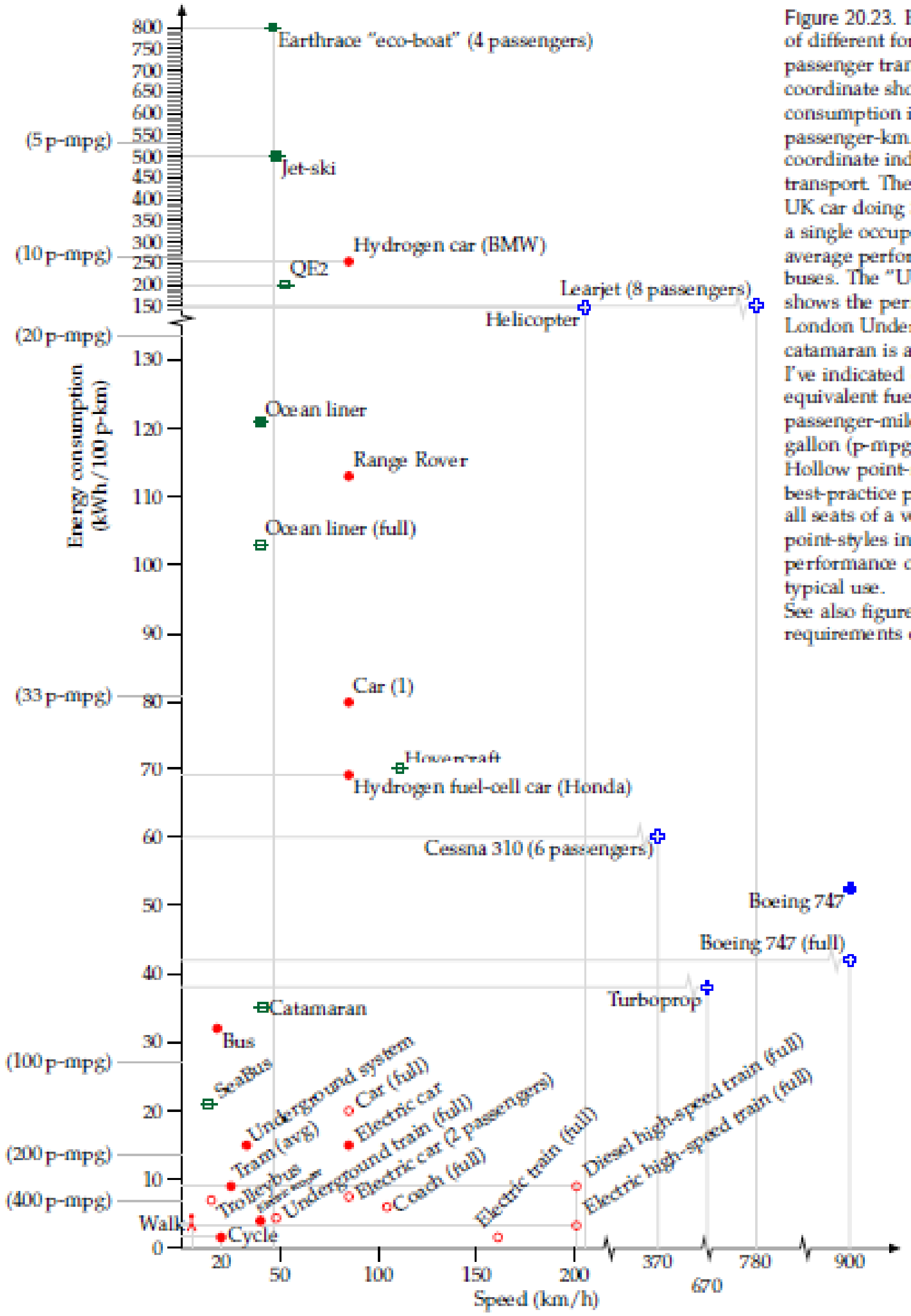
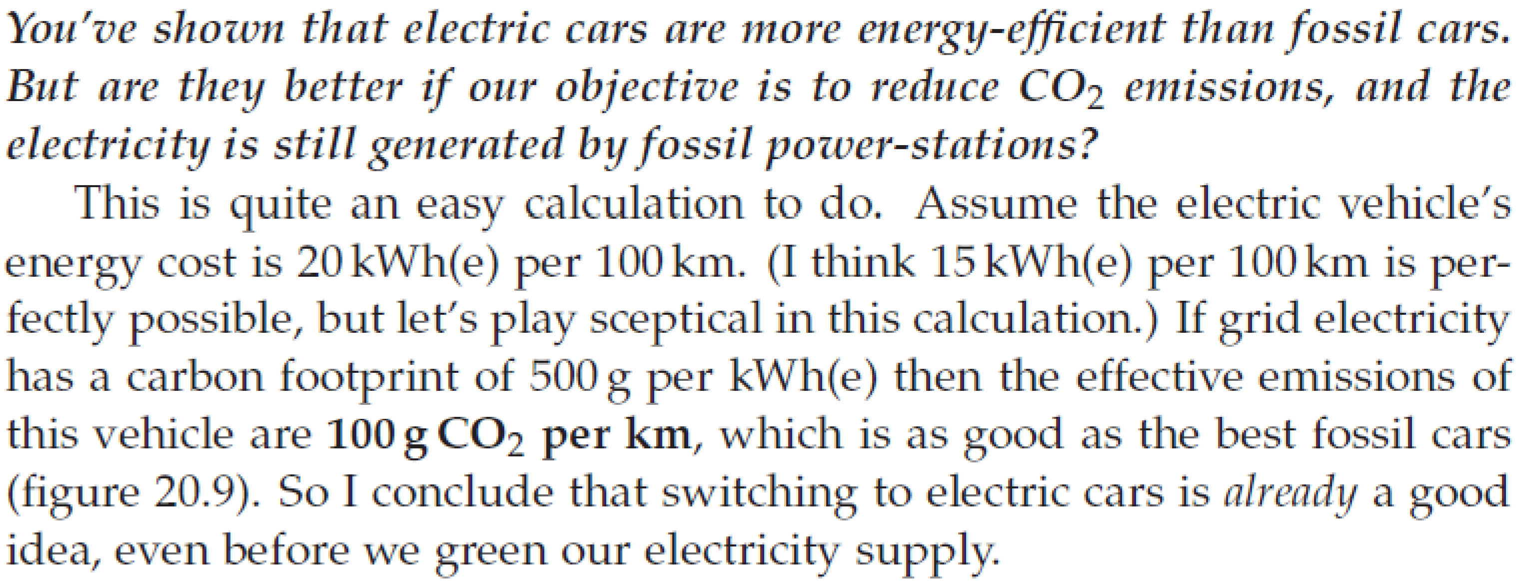


Figure 20.23. Energy requirements of different forms of passenger transport. The vertical coordinate shows the energy consumption in kWh per 100 passenger-km. The horizontal coordinate indicates the speed of the transport. The "Car (1)" is an average UK car doing 33 miles per gallon with a single occupant. 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

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

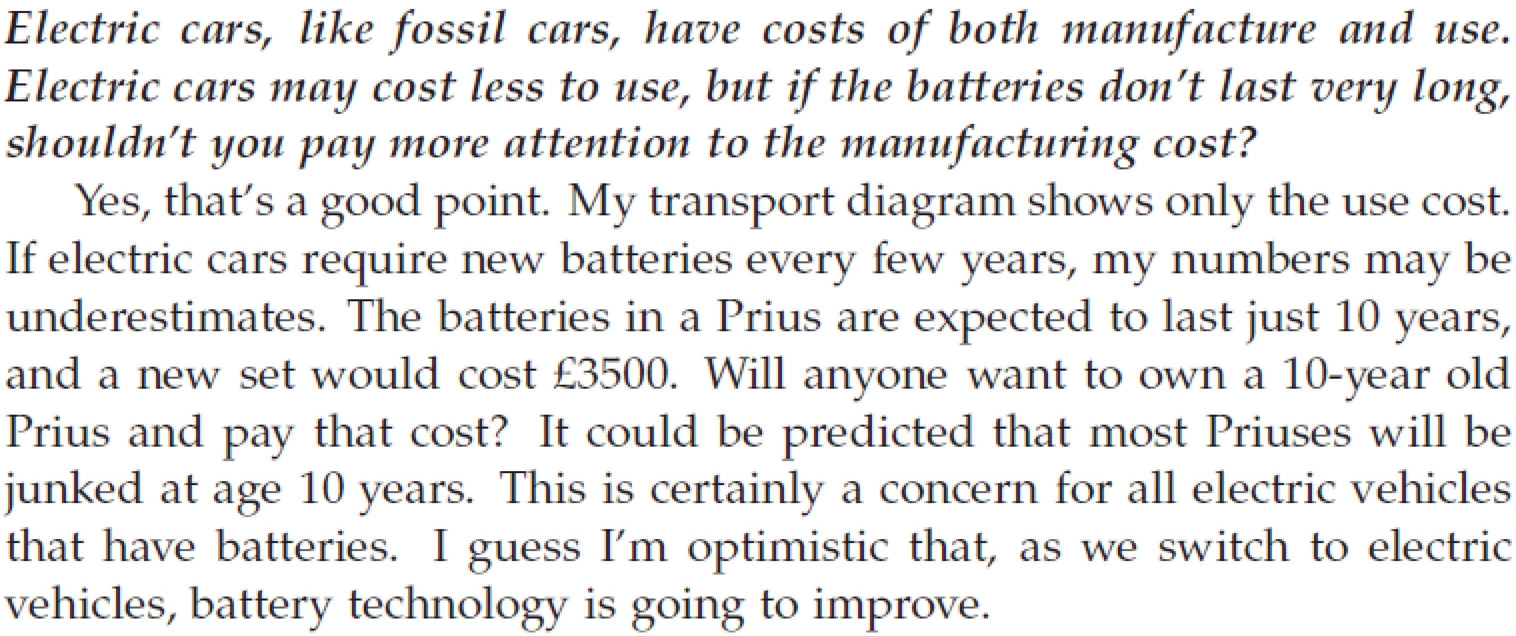


You've shown that electric cars are more energy-efficient than fossil cars. But are they better if our objective is to reduce CO_2 emissions, and the electricity is still generated by fossil power-stations?

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

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

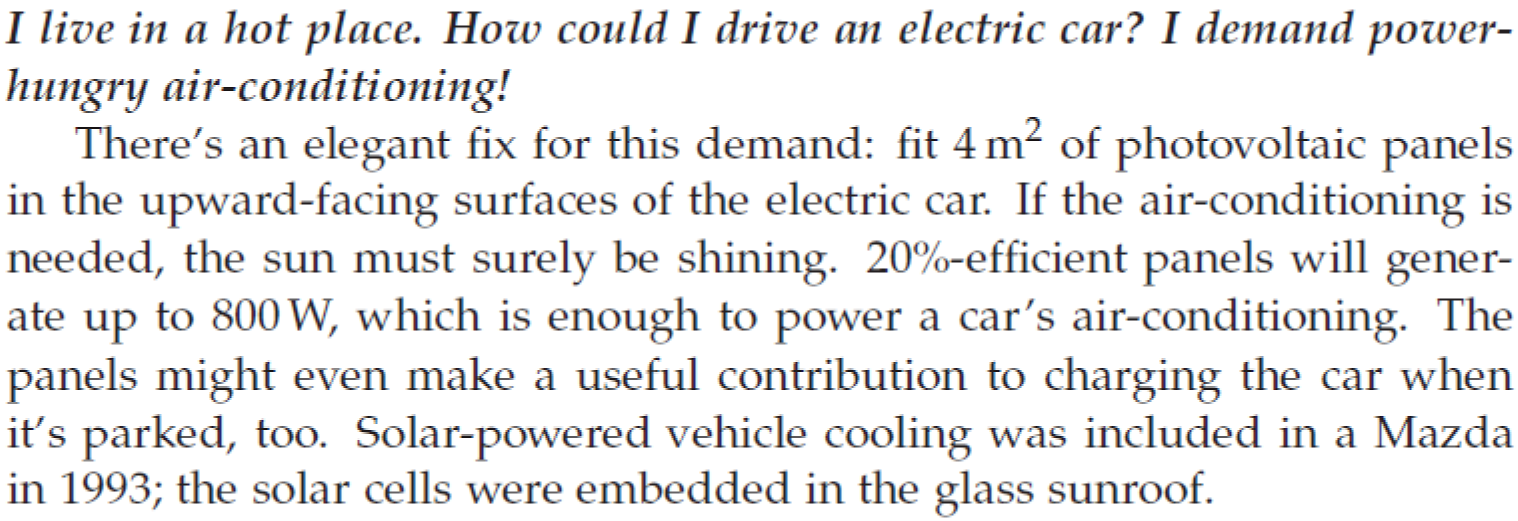


Electric cars, like fossil cars, have costs of both manufacture and use. Electric cars may cost less to use, but if the batteries don't last very long, shouldn't you pay more attention to the manufacturing cost?

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.

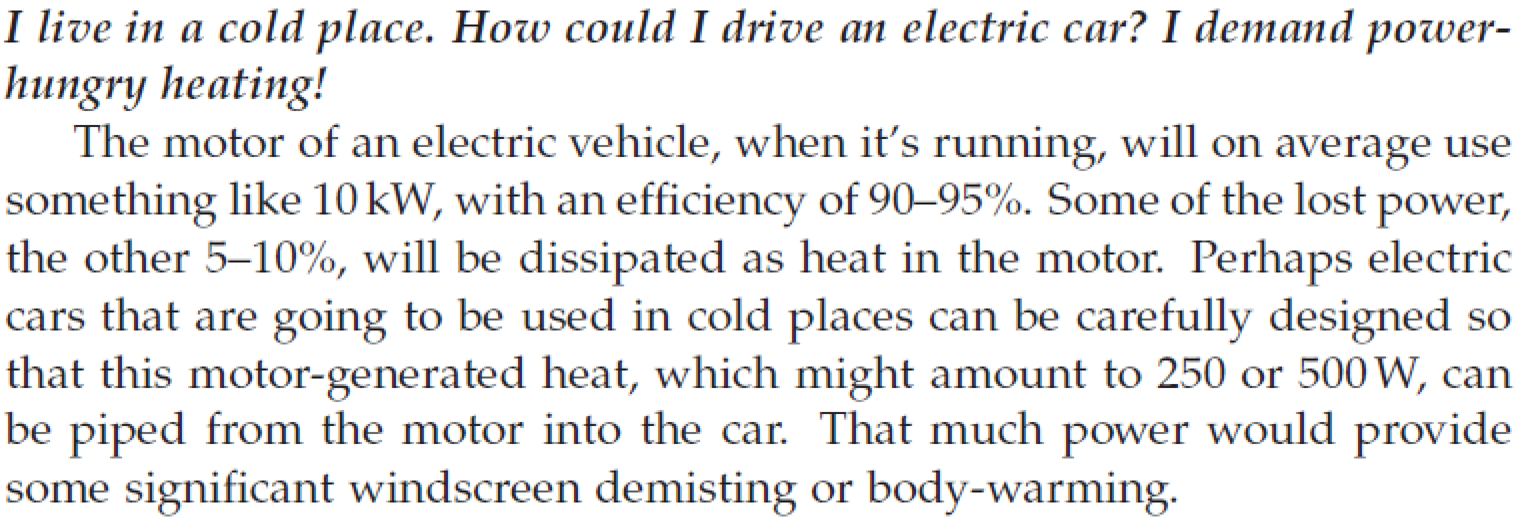
3. Consumption: Cars

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.

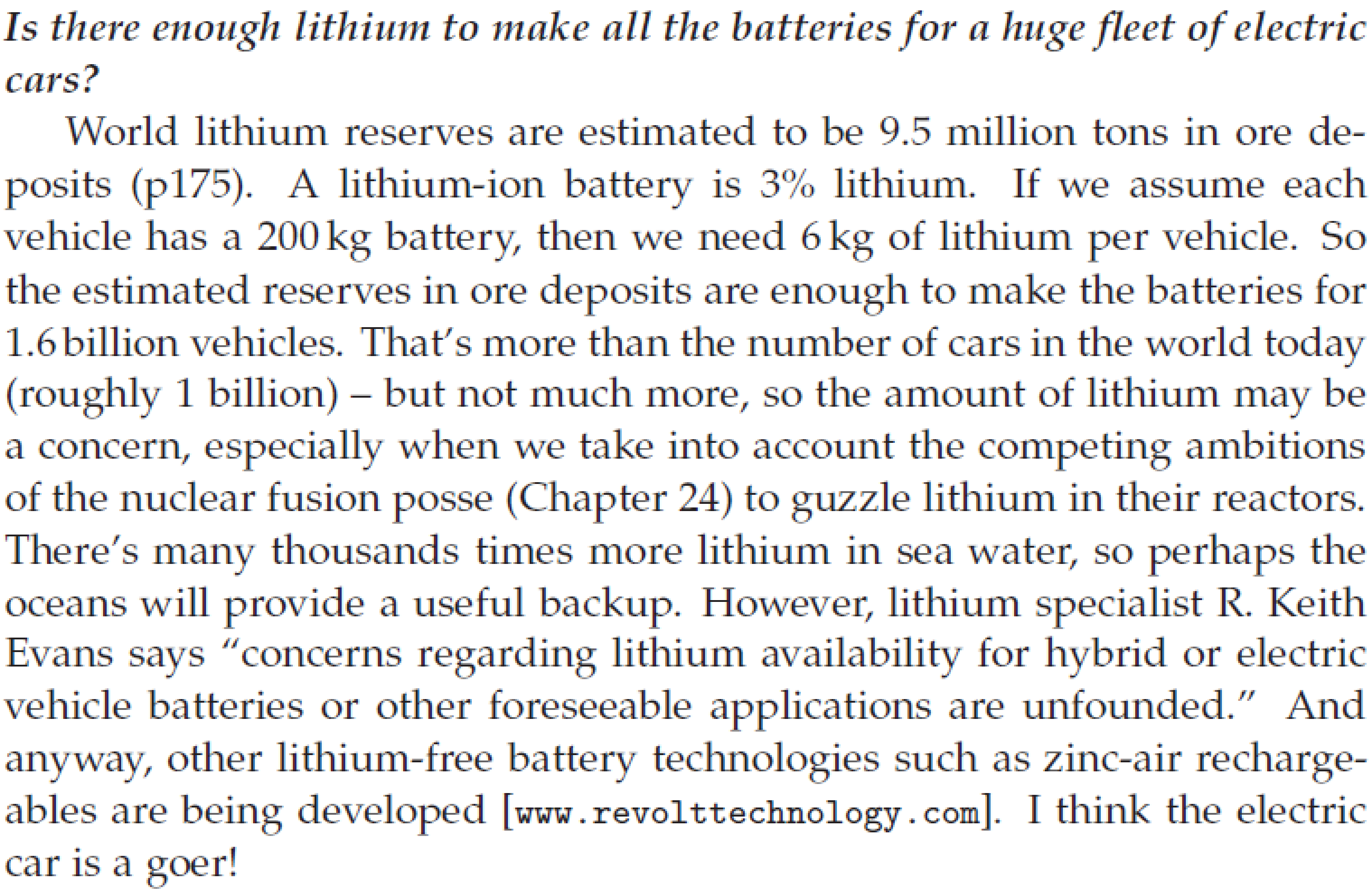


I live in a cold place. How could I drive an electric car? I demand power-hungry heating!

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.

3. Consumption: Cars

Opportunities for Reducing Energy Consumption by Cars (Chapter 20)

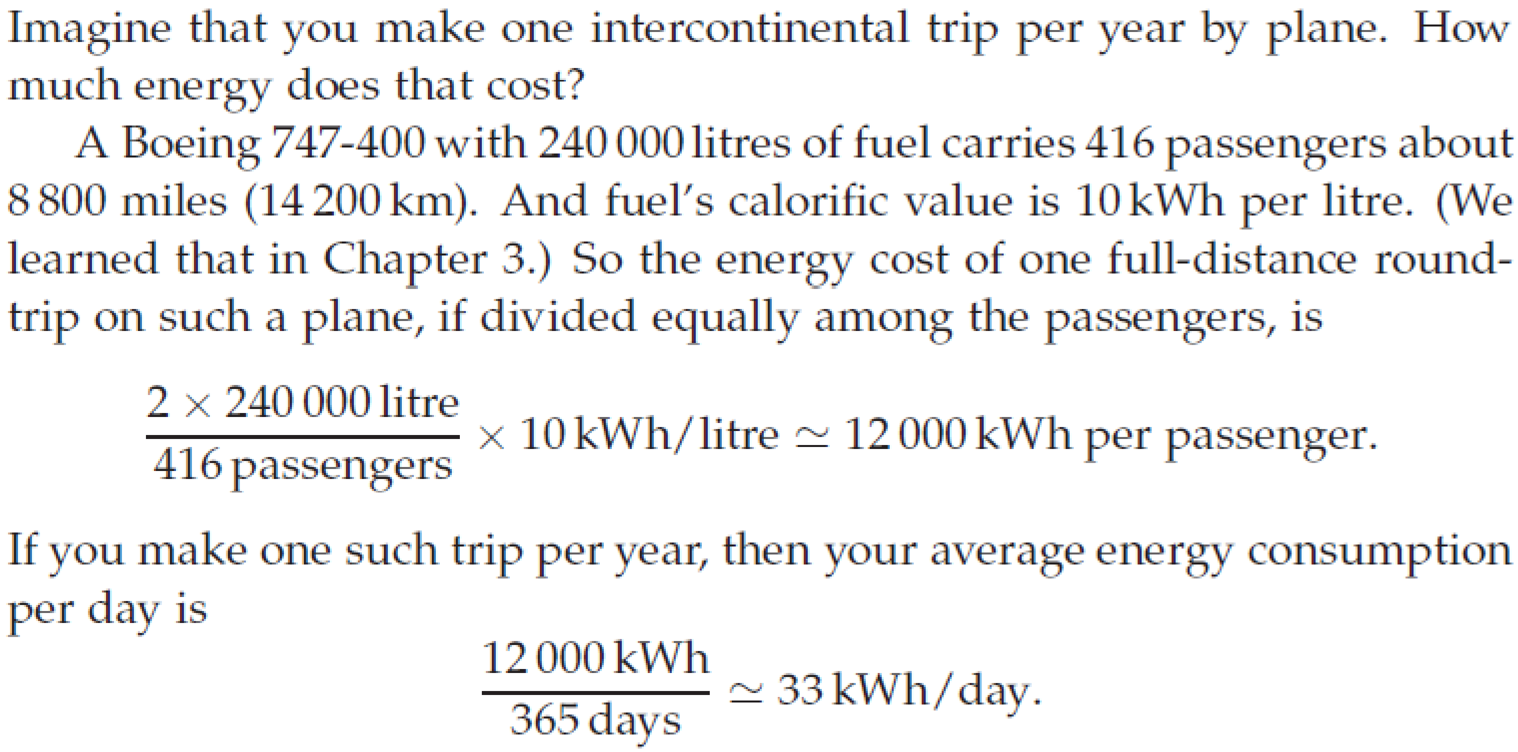


Is there enough lithium to make all the batteries for a huge fleet of electric cars?

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

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

Estimating Energy Consumption by Airplanes (Chapter 5)

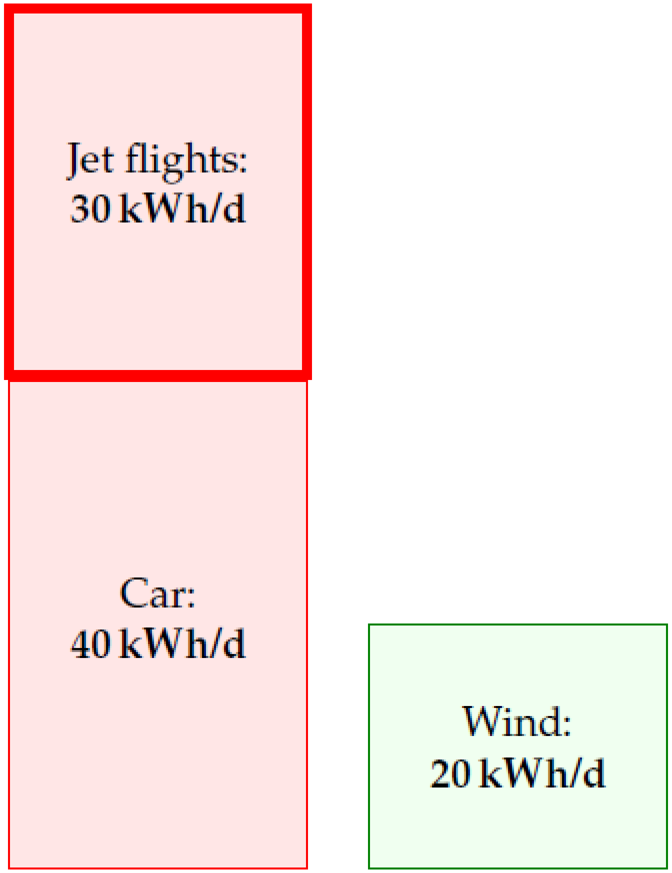


Figure 5.1. Taking one intercontinental trip per year uses about 30 kWh per day.

Flying

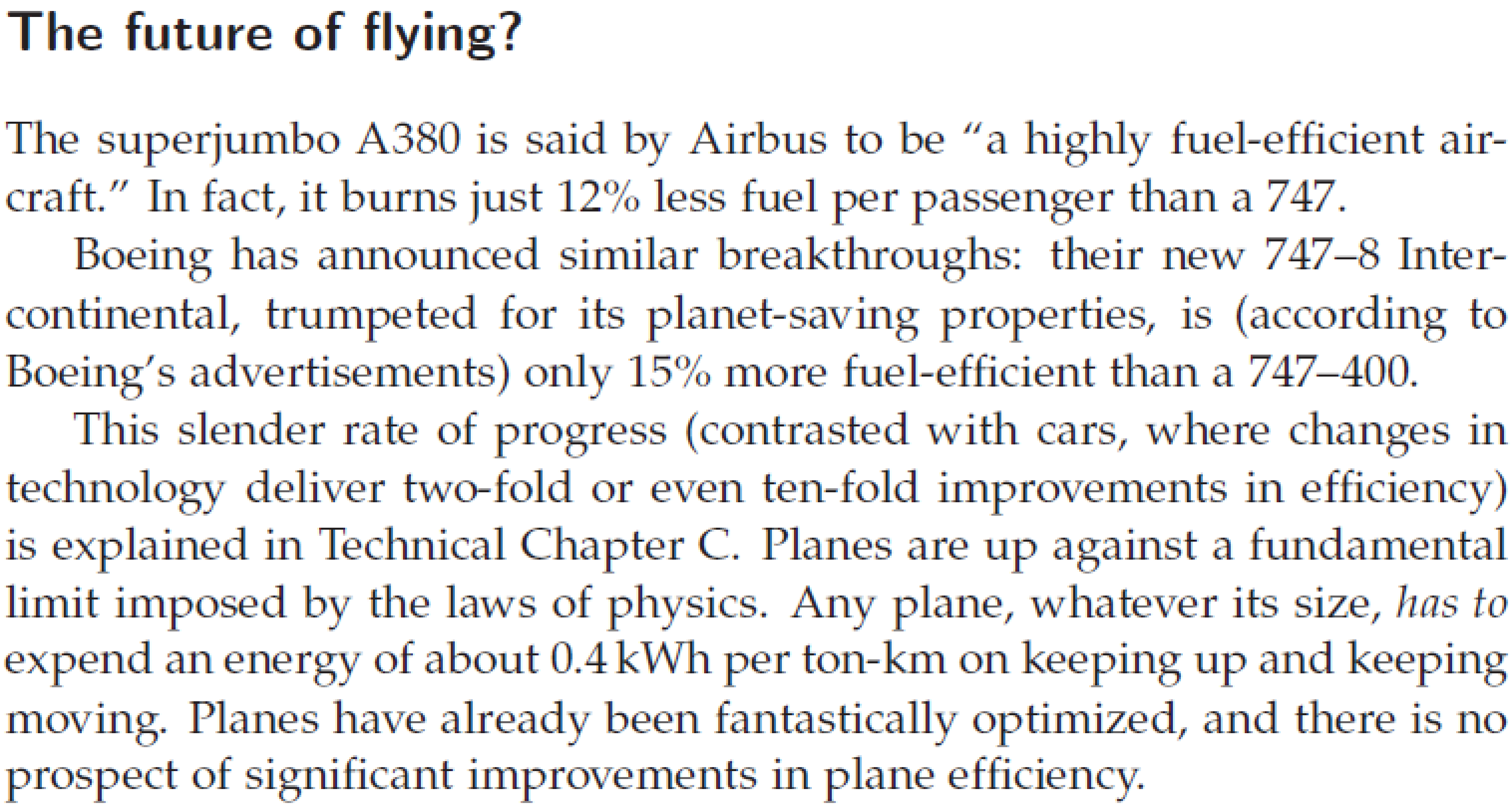
- requires a lot of energy
- is especially damaging to the environment because it ejects GHG directly into the upper atmosphere

“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

Estimating Energy Consumption by Airplanes (Chapter 20)



The future of flying?

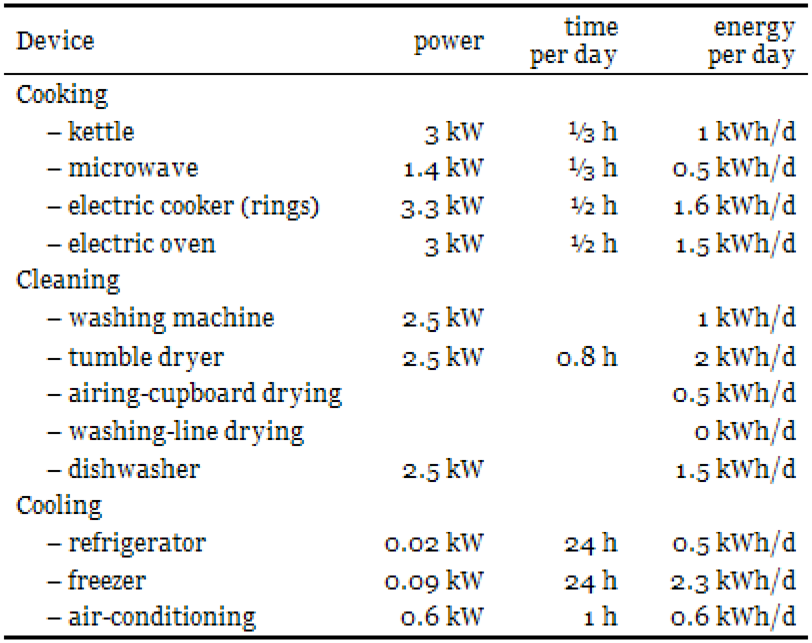
The superjumbo A380 is said by Airbus to be "a highly fuel-efficient aircraft." In fact, it burns just 12% less fuel per passenger than a 747.

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.

7. Consumption: Heating/Cooling

Estimating Energy Consumption by Heating and Cooling



Device	power	time per day	energy per day
Cooking			
– kettle	3 kW	⅓ h	1 kWh/d
– microwave	1.4 kW	⅓ h	0.5 kWh/d
– electric cooker (rings)	3.3 kW	½ h	1.6 kWh/d
– electric oven	3 kW	½ h	1.5 kWh/d
Cleaning			
– washing machine	2.5 kW		1 kWh/d
– tumble dryer	2.5 kW	0.8 h	2 kWh/d
– airing-cupboard drying			0.5 kWh/d
– washing-line drying			0 kWh/d
– dishwasher	2.5 kW		1.5 kWh/d
Cooling			
– refrigerator	0.02 kW	24 h	0.5 kWh/d
– freezer	0.09 kW	24 h	2.3 kWh/d
– air-conditioning	0.6 kW	1 h	0.6 kWh/d

- bath = 5 kWh
- shower = 1.4 kWh

Total usage:

heating water = 12 kWh/day
heating air = 24 kWh/day
cooling = 1 kWh/day (no AC needed in the UK)
total = 37 kWh/day

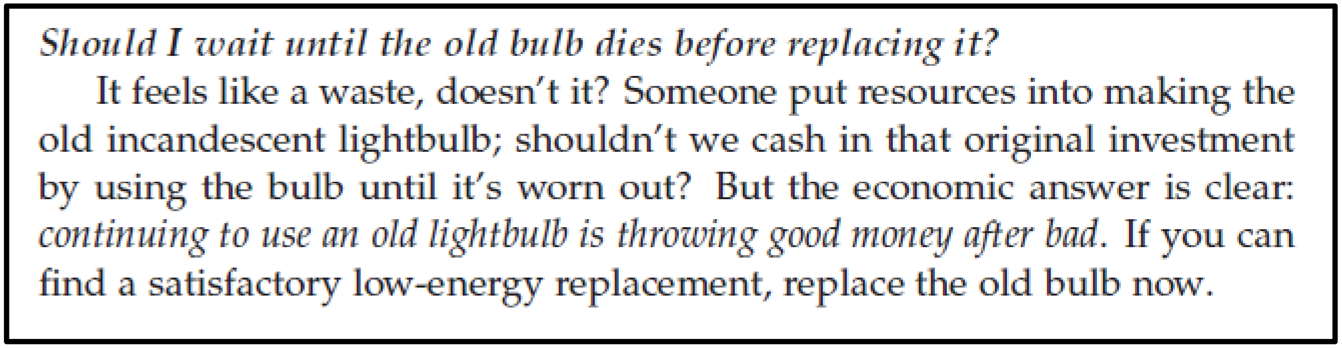
9. Consumption: Light

Estimating Energy Consumption by Lighting

total = 4 kWh/day

Incandescent vs compact fluorescent light bulbs

- incandescent = 10 lumens per W
- compact fluorescent = 55 lumens per W



Should I wait until the old bulb dies before replacing it?

It feels like a waste, doesn't it? Someone put resources into making the old incandescent lightbulb; shouldn't we cash in that original investment by using the bulb until it's worn out? But the economic answer is clear: *continuing to use an old lightbulb is throwing good money after bad.* If you can find a satisfactory low-energy replacement, replace the old bulb now.

Light: 4 kWh/d

Heating, cooling: 37 kWh/d

Jet flights: 30 kWh/d

Car: 40 kWh/d

11. Consumption: Gadgets

Estimating Energy Consumption by Gadgets (electronics)

total = 5 kWh/day

Table 11.4. Power consumptions of various gadgets, in watts. 40 W is 1 kWh/d.

Laptop: 16 W

Computer: 80 W

LCD 31 W CRT 108 W

Printer: 17 W (on, idle)

Projector: 150 W

Digital radio: 8 W

Gadget	Power consumption (W)			
	on and active	on but inactive	standby	off
Computer and peripherals:				
computer box	80	55		2
cathode-ray display	110		3	0
LCD display	34		2	1
projector	150		5	
laser printer	500	17		
wireless & cable-modem	9			
Laptop computer	16	9		0.5
Portable CD player	2			
Bedside clock-radio	1.1	1		
Bedside clock-radio	1.9	1.4		
Digital radio	9.1		3	
Radio cassette-player	3	1.2		1.2
Stereo amplifier	6			6
Stereo amplifier II	13			0
Home cinema sound	7	7	4	
DVD player	7	6		
DVD player II	12	10	5	
TV	100		10	
Video recorder	13		1	
Digital TV set top box	6		5	
Clock on microwave oven	2			
Xbox	160		2.4	
Sony Playstation 3	190		2	
Nintendo Wii	18		2	
Answering machine		2		
Answering machine II		3		
Cordless telephone		1.7		
Mobile phone charger	5	0.5		
Vacuum cleaner	1600			

Gadgets: 5

Light: 4 kWh/d

Heating, cooling: 37 kWh/d

Jet flights: 30 kWh/d

Car: 40 kWh/d

13. Consumption: Food & Farming

Estimating Energy Consumption by Food & Farming

The minimum energy required by an active human being is on average about 2600 calories or 3 kWh/day

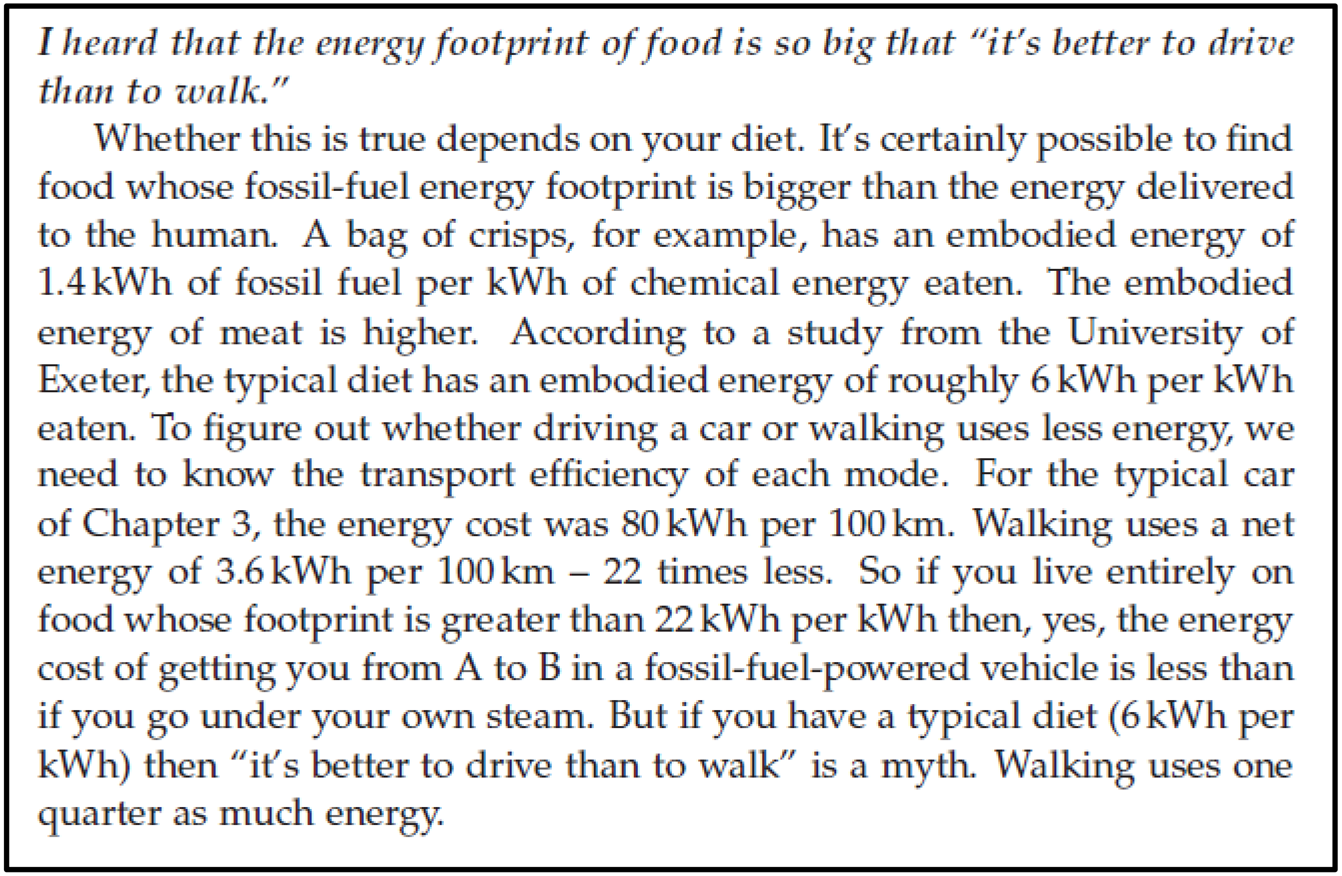
- vegetables = 1.5 kWh/d
- milk = 1.5 kWh/d (includes feeding the dairy cow)
- 2 eggs = 1 kWh/d (includes feeding the chicken)
- meat = 8 kWh/d (includes feeding the chicken, pig, cow)
- fertilizer = 2 kWh/d
- energy on the farm = 1 kWh/d (tractors, heating greenhouses)

total = 15 kWh/day

Pets

- pet cat = 2 kWh/d
- pet dog = 9 kWh/d
- pet horse = 17 kWh/d

13. Consumption: Food & Farming



I heard that the energy footprint of food is so big that "it's better to drive than to walk."

Whether this is true depends on your diet. It's certainly possible to find food whose fossil-fuel energy footprint is bigger than the energy delivered to the human. A bag of crisps, for example, has an embodied energy of 1.4 kWh of fossil fuel per kWh of chemical energy eaten. The embodied energy of meat is higher. According to a study from the University of Exeter, the typical diet has an embodied energy of roughly 6 kWh per kWh eaten. To figure out whether driving a car or walking uses less energy, we need to know the transport efficiency of each mode. For the typical car of Chapter 3, the energy cost was 80 kWh per 100 km. Walking uses a net energy of 3.6 kWh per 100 km – 22 times less. So if you live entirely on food whose footprint is greater than 22 kWh per kWh then, yes, the energy cost of getting you from A to B in a fossil-fuel-powered vehicle is less than if you go under your own steam. But if you have a typical diet (6 kWh per kWh) then "it's better to drive than to walk" is a myth. Walking uses one quarter as much energy.

15. Consumption: Stuff

Estimating Energy Consumption by Stuff

stuff = material goods

The Life Cycle of stuff

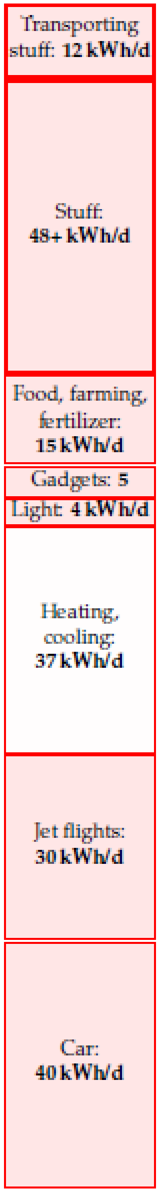
- extraction of raw materials
- production: processing of raw materials into products
- use by the consumer
- disposal (landfill, recycling)

This chapter focuses on the first two phases.

Examples

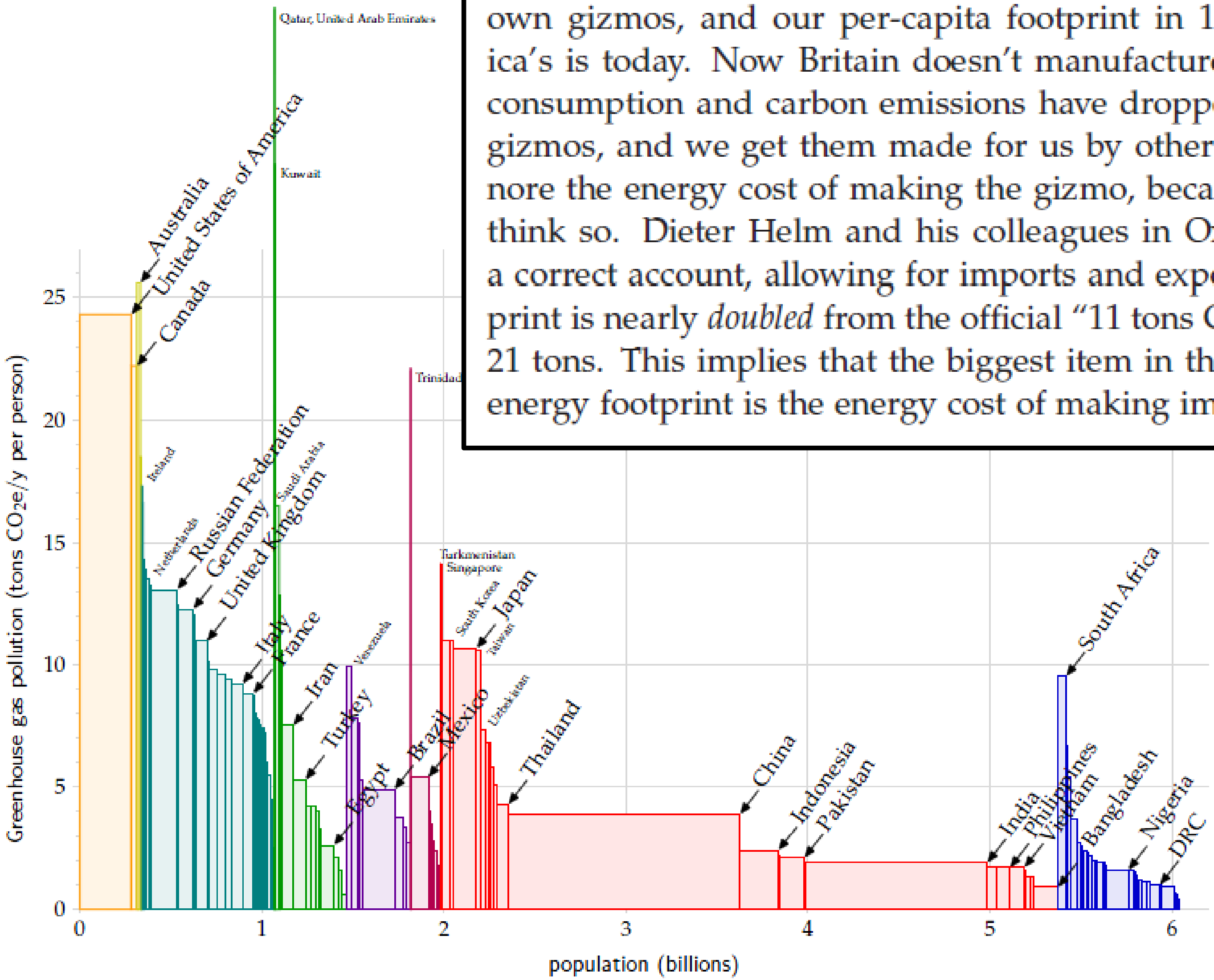
- 1 aluminum can = 0.6 kWh/d
- 400 g of packaging = 4 kWh/d
- new computer every two years = 2.5 kWh/d
- 200 g of newspaper/mail per day = 2 kWh/d
- 1 house (used for 100 years) = 1 kWh/d/person
- new car every 15 years = 14 kWh/d
- roads = 2 kWh/d/person
- television, furniture, clothes, shoes, etc.
- imported stuff = 1.3 tons stuff/person/year @ 10 kWh/kg = 40 kWh/d

Total = 48 kWh/d



15. Consumption: Stuff

In standard accounts of "Britain's energy consumption" or "Britain's carbon footprint," imported goods are *not* counted. Britain used to make its own gizmos, and our per-capita footprint in 1910 was as big as America's is today. Now Britain doesn't manufacture so much (so our energy consumption and carbon emissions have dropped a bit), but we still love gizmos, and we get them made for us by other countries. Should we ignore the energy cost of making the gizmo, because it's imported? I don't think so. Dieter Helm and his colleagues in Oxford estimate that under a correct account, allowing for imports and exports, Britain's carbon footprint is nearly *doubled* from the official "11 tons CO_2e per person" to about 21 tons. This implies that the biggest item in the average British person's energy footprint is the energy cost of making imported stuff.



15. Consumption: Stuff

Estimating Energy Consumption by Stuff
stuff = material goods

Transporting stuff

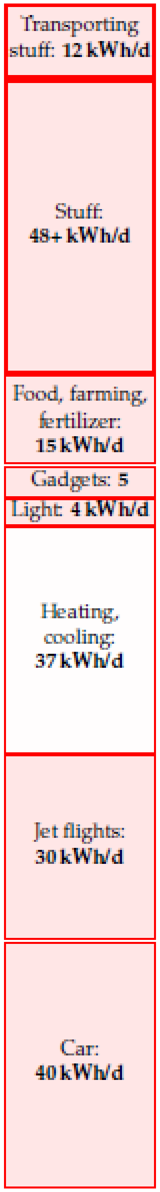
- 1 kWh will transport one ton of freight one kilometer on the road
- 0.015 kWh will transport one ton of freight one kilometer by ship

In the UK in 2006, 156 billion t-km of freight on the road shared between 60 million people comes to 7 t-km/day/person = 7 kWh/d/person

560 million tons of freight in British ports = 4 kWh/d/person

pumping water/treating sewage = 0.4 kWh/d/person

Transportation of stuff total = 12 kWh/d



17. Consumption Public Services

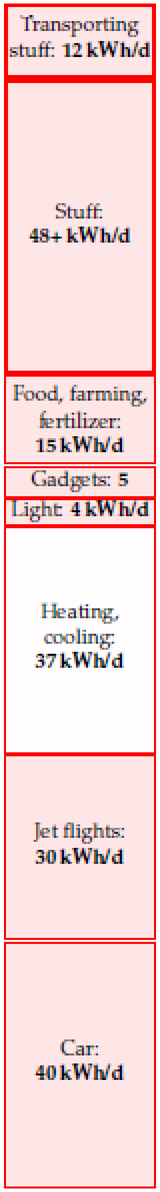
Estimating Energy Consumption by Public Services

6% of the British government expenses went to the military = 33 billion pounds
6% of the gross domestic product (GDP) went to energy

If 6% (fraction of energy) of the 6% (fraction of military) is billed at 2.7p/kWh,
Then we have 80 TWh per year in the military. This is 4 kWh/d/person.

Total = 4 kWh/d/person, ignoring everything except the military!

universities = 0.24 kWh/d/person



18. Total Consumption

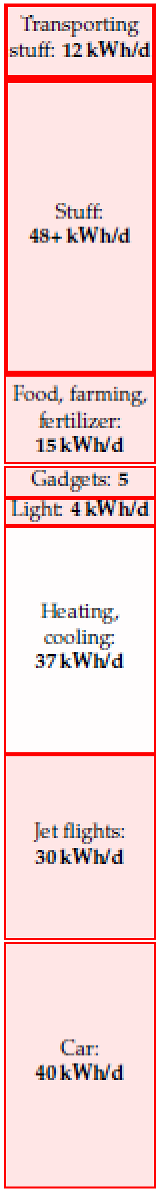
Consumption Grand Total = 195 kWh/day/person

Official consumption in the UK is 125 kWh/day/person.

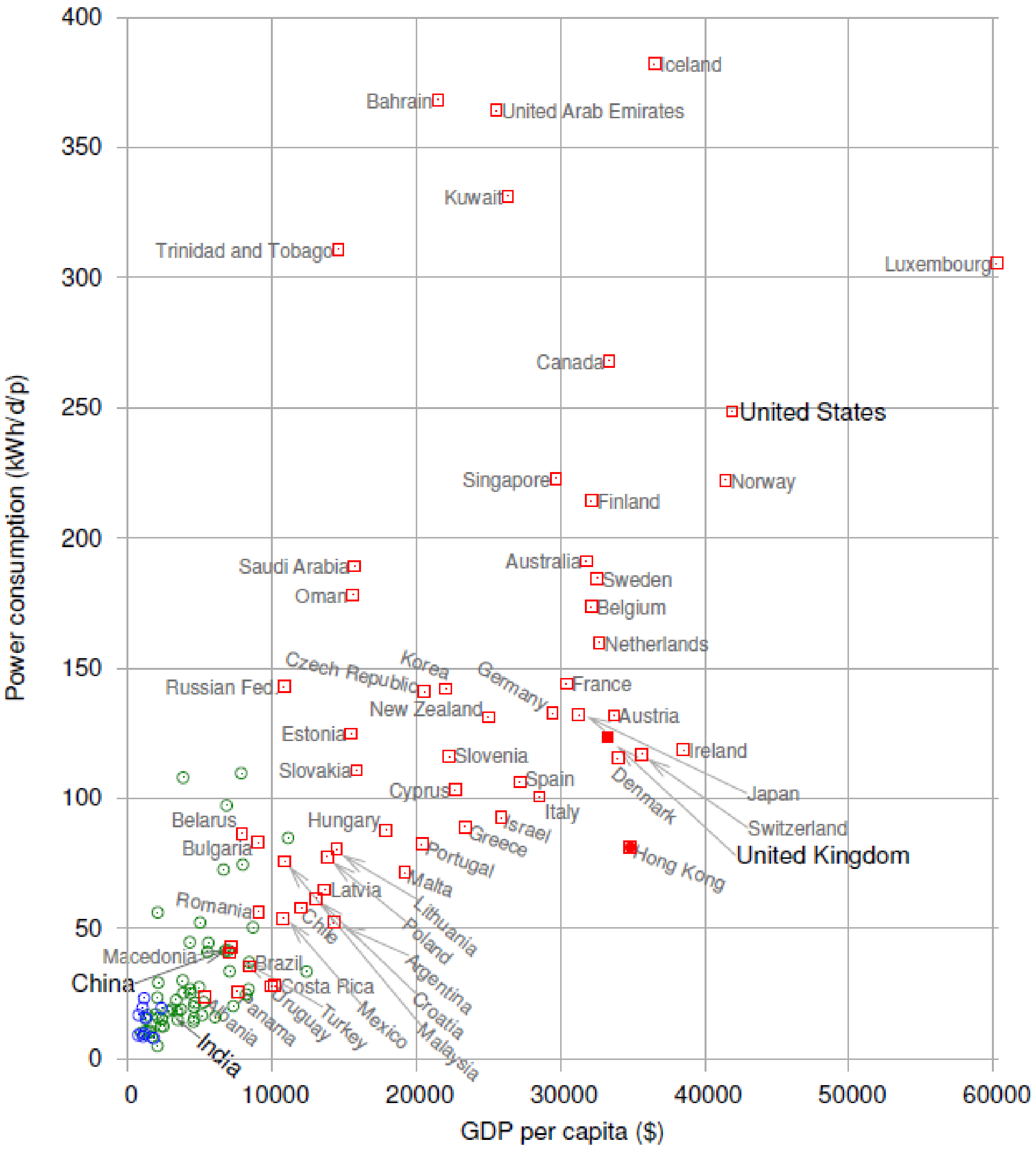
What is the difference?

If you don’t count the energy to make imported stuff, you lose 40 kWh/d/p.

The resulting 155 kWh/day/person is higher than the UK average. (Perhaps the average UK citizen doesn’t take 1 transcontinental flight each year—subtract another 30 kWh/day/person.)



18. Total Consumption



18. Improvements: Heating

Comparison: Knoxville, Tennessee, USA 3 new homes

Home 2:
Built by Contractor
w/ conventional materials
w/ conventional design
immediately retrofit to be energy efficient

Home 1:
Built by Contractor
with conventional materials
with conventional design

Home 3:
Built by from the beginning to be energy efficient
Energy efficient design
Energy efficient materials

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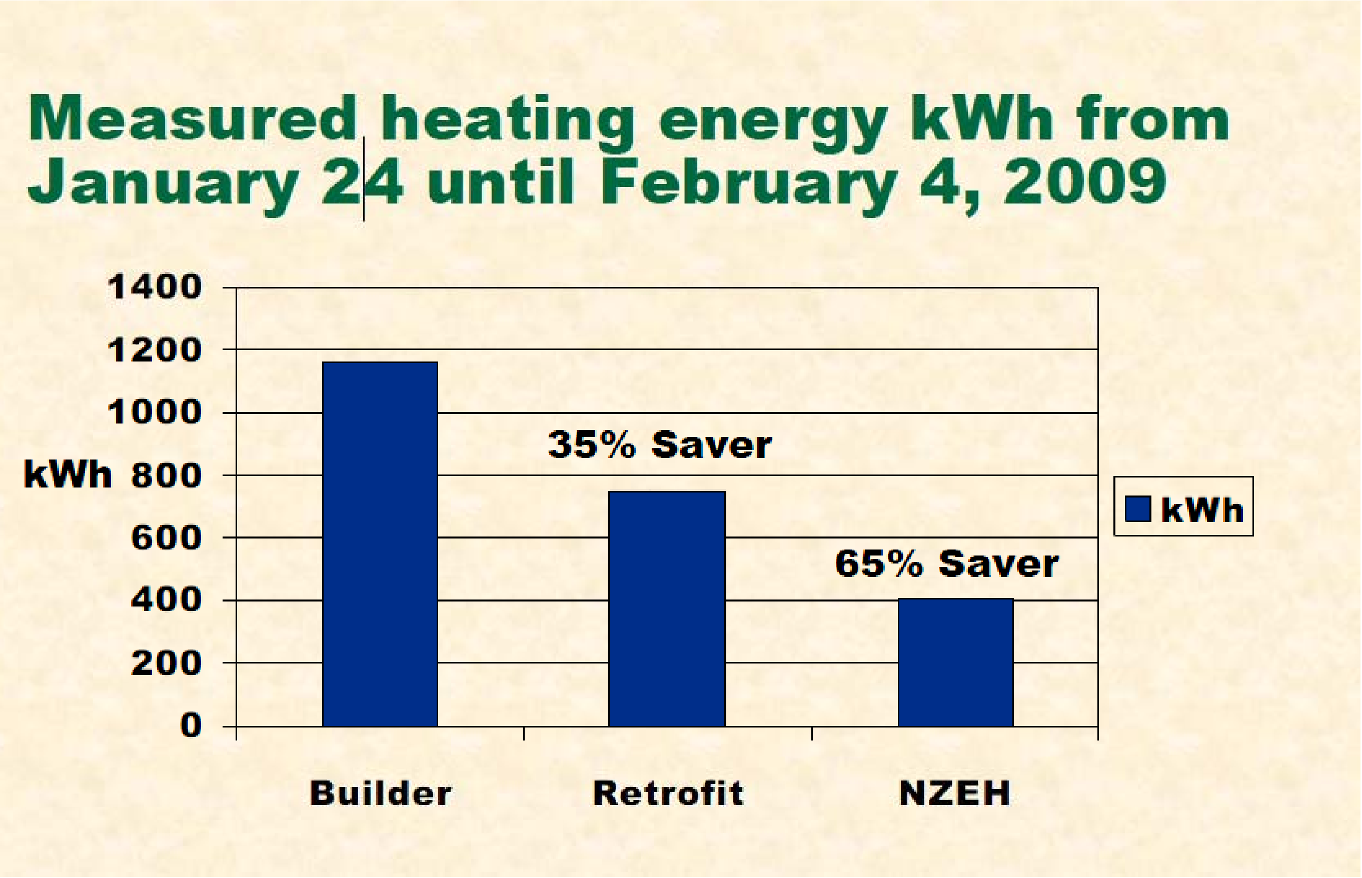
18. Improvements: Heating

Comparison: Knoxville, Tennessee, USA 3 new homes



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Note: NZEH = near zero energy house

18. Improvements: Heating

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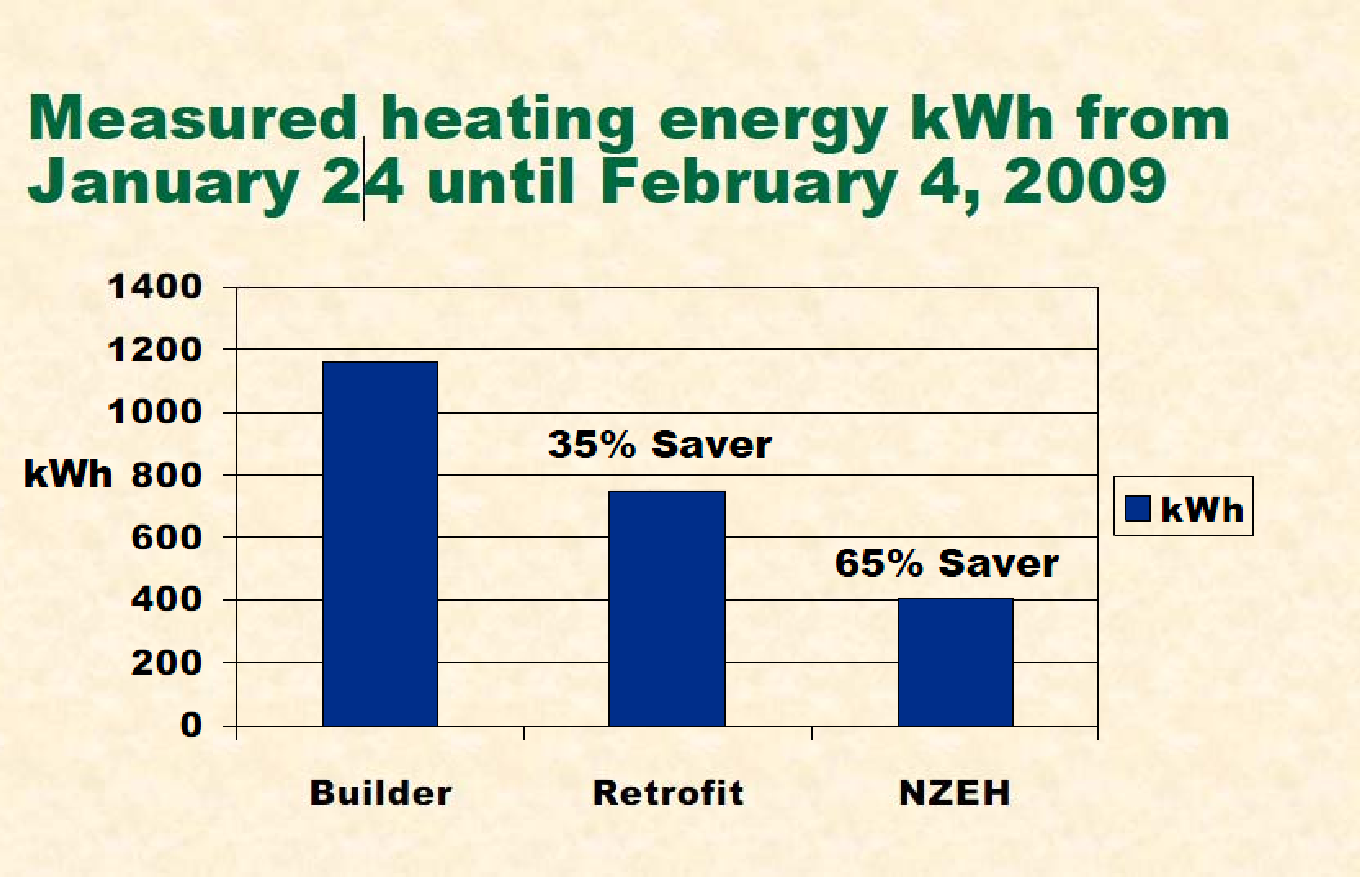

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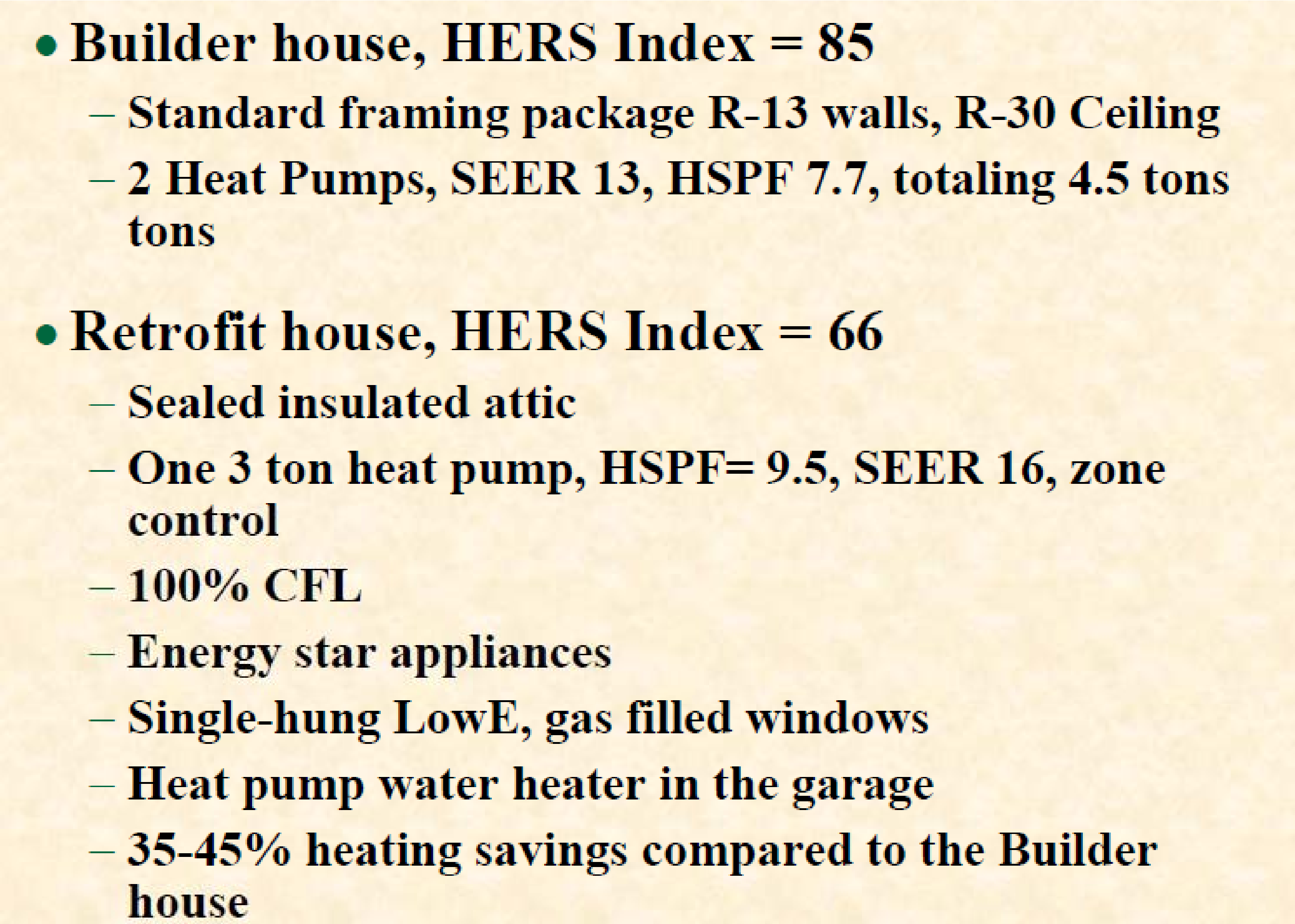

- Builder house, HERS Index = 85
  - Standard framing package R-13 walls, R-30 Ceiling
  - 2 Heat Pumps, SEER 13, HSPF 7.7, totaling 4.5 tons tons
- Retrofit house, HERS Index = 66
  - Sealed insulated attic
  - One 3 ton heat pump, HSPF= 9.5, SEER 16, zone control
  - 100% CFL
  - Energy star appliances
  - Single-hung LowE, gas filled windows
  - Heat pump water heater in the garage
  - 35-45% heating savings compared to the Builder house

Note: HERS = home energy rating system

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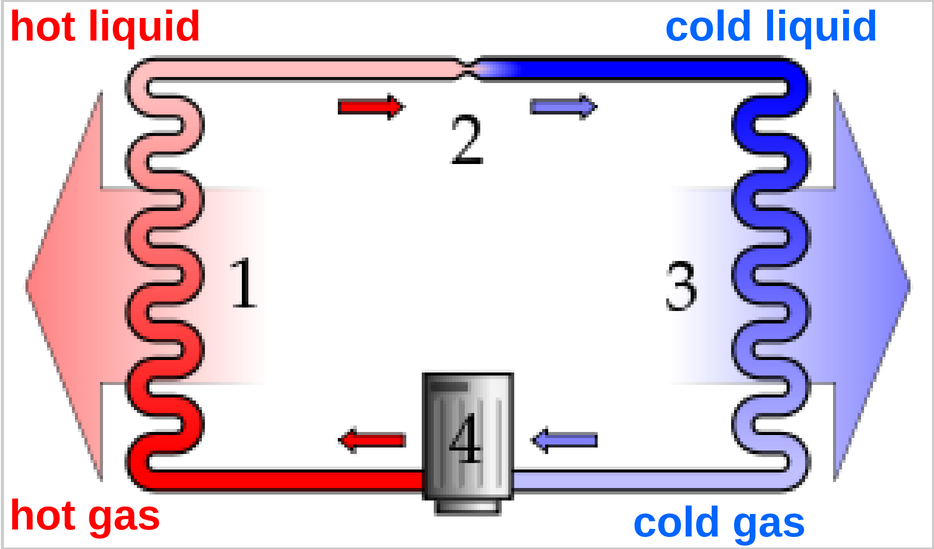
18. Improvements: Heating

All modern houses use heat pumps

with electrical heating, 1 kWh electricity creates 1 kWh of heat

with a heat pump, 1 kWh of electricity creates 3-4 kWh of heat

ant.



A simple stylized diagram of a heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

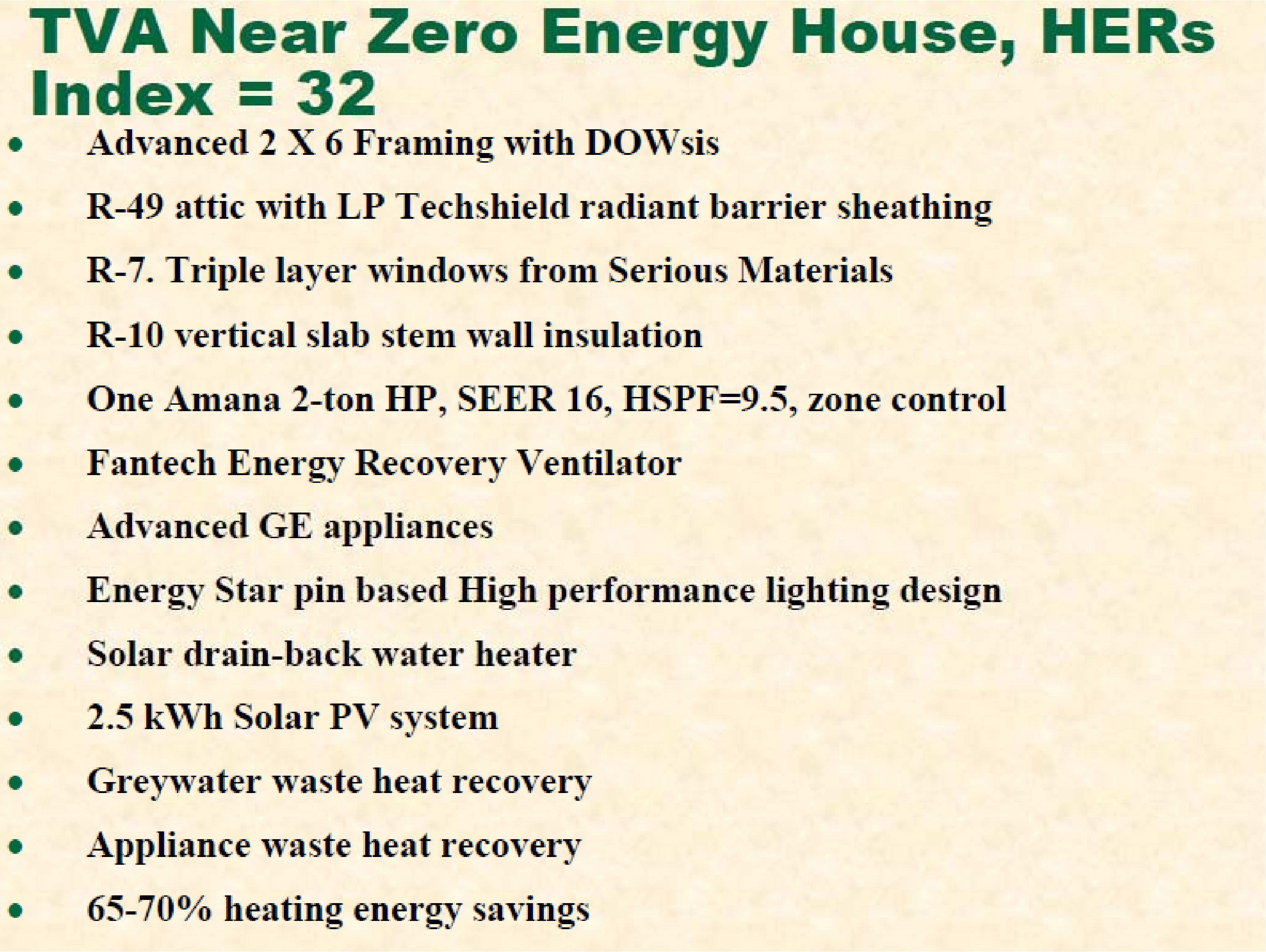
Heat pumps use energy from an outside source (air or ground).

Heat pumps are reversible (heat in winter, cool in summer).

Heat pumps become less efficient as the temperature difference becomes greater.

18. Improvements: Heating

Comparison: Knoxville, Tennessee, USA 3 new homes



TVA Near Zero Energy House, HERs Index = 32

- Advanced 2 X 6 Framing with DOWsis
- R-49 attic with LP Techshield radiant barrier sheathing
- R-7. Triple layer windows from Serious Materials
- R-10 vertical slab stem wall insulation
- One Amana 2-ton HP, SEER 16, HSPF=9.5, zone control
- Fantech Energy Recovery Ventilator
- Advanced GE appliances
- Energy Star pin based High performance lighting design
- Solar drain-back water heater
- 2.5 kWh Solar PV system
- Greywater waste heat recovery
- Appliance waste heat recovery
- 65-70% heating energy savings

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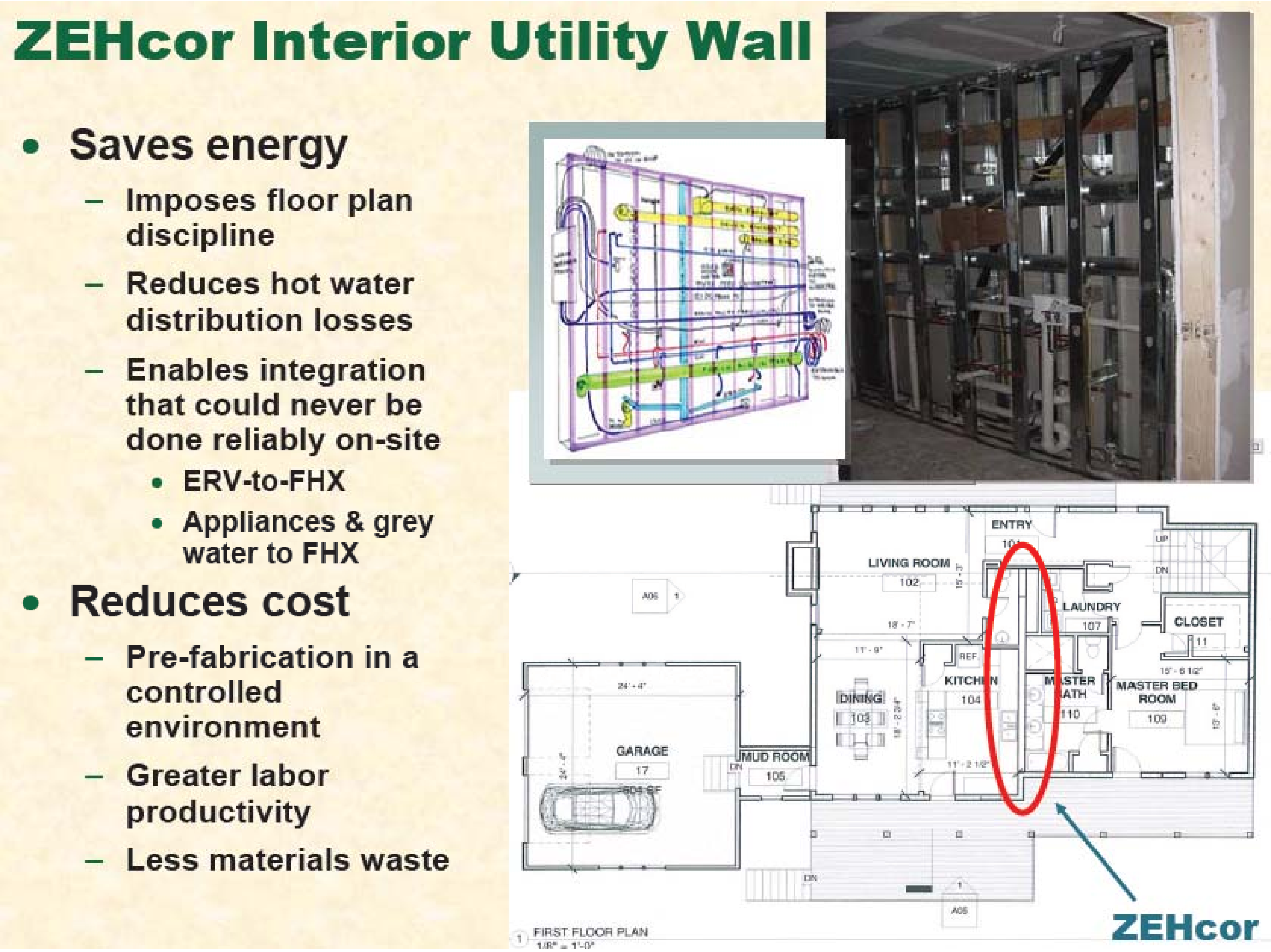
18. Improvements: Heating

Improvements
In Design



ZEHcor Interior Utility Wall

- Saves energy
  - Imposes floor plan discipline
  - Reduces hot water distribution losses
  - Enables integration that could never be done reliably on-site
    - ERV-to-FHX
    - Appliances & grey water to FHX
- Reduces cost
  - Pre-fabrication in a controlled environment
  - Greater labor productivity
  - Less materials waste

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18. Improvements: Heating

Improvements
In Materials

Triple layer windows R-6.7

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18. Improvements: Heating

Ducts all inside the conditioned space, except 6 ft run out to bonus

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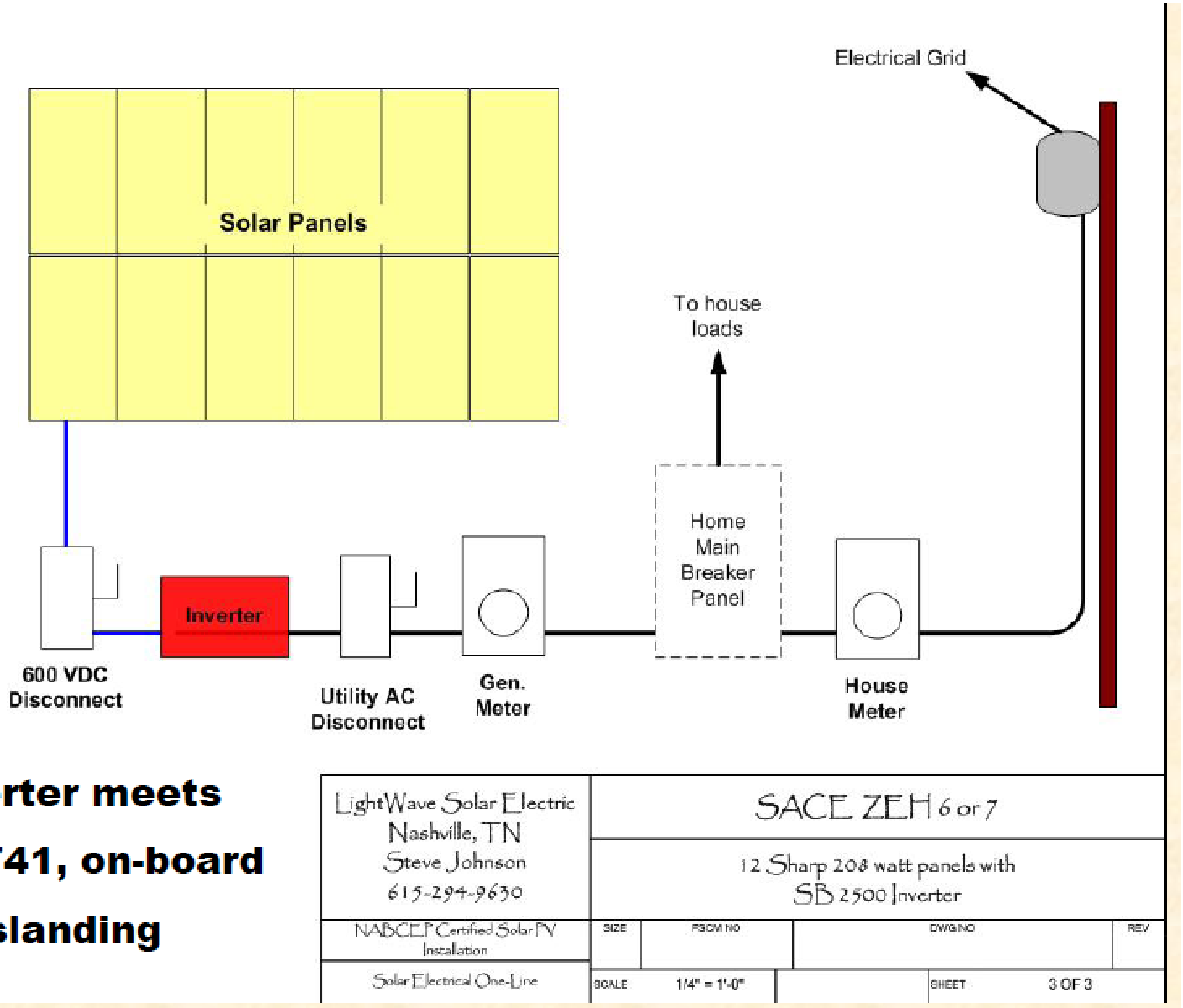
18. Improvements: Heating

Improvements in energy generation



Inverter meets UL 1741, on-board islanding

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18. Improvements: Heating

Improvements in economics due to local policy on green energy

First TVA Solar Generation Partner collecting $0.12/kWh above residential rate

New TVA feed-in tarriff

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