Greening your life with a little physics (and chemistry)

Chris Waltham
UBC Physics & Astronomy
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A Confession…

My attachment to fossil fuels runs deep. Born and raised on the South Yorkshire Coalfield, a few of my close relatives were coal miners. As an experimental physicist, I worked for 35 years in multinational collaborations whose lifeblood is jet fuel. Since realizing rather late (2003) that we, humanity, have a big carbon problem, I have been trying to wrest some kind of control over my super-sized ecological footprint. In the year 2007 I avoided flying altogether by travelling to conferences and vacation on Amtrak, which may not have been a brilliant idea, environmentally speaking…

In a world drowning in Greenwash and Sustainababble, how can I make things better without simply being duped into useless feel-good exercises?

Let's use some very basic physics and chemistry to cut to the chase:

For example:

Airlines:

"Save your earphones for your next flight and help protect the environment"

International Conferences:

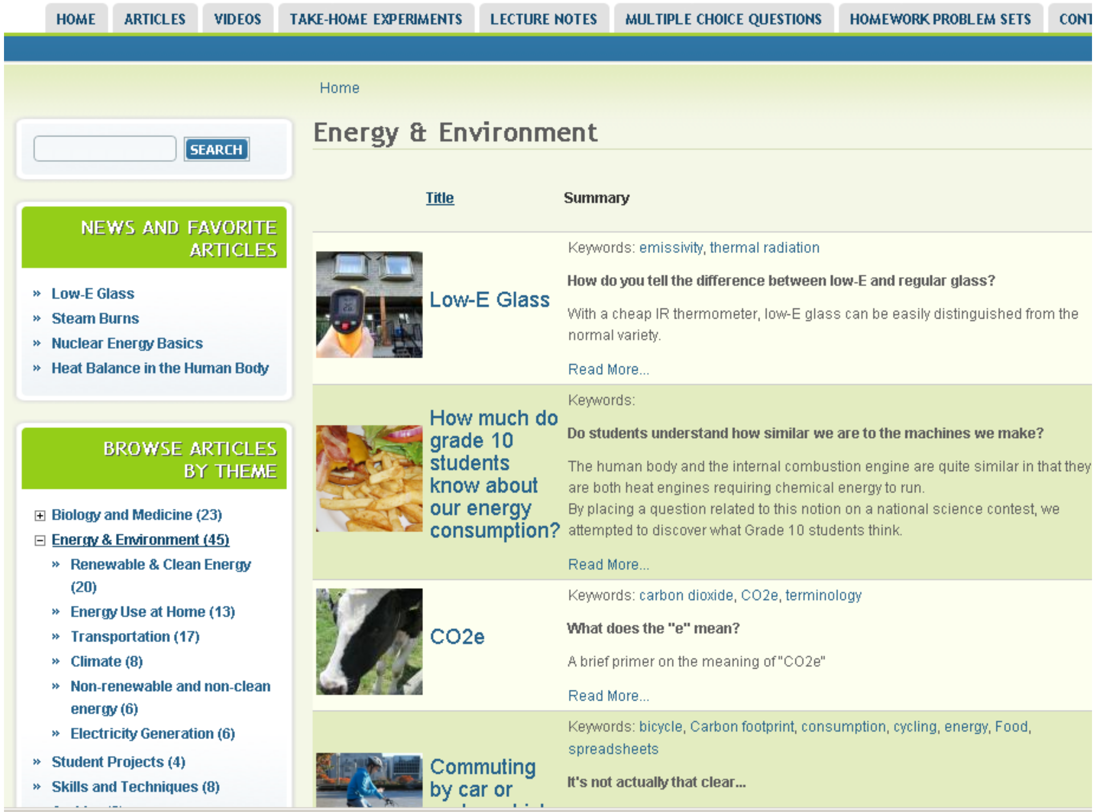
"We respect the environment, so we have not mailed you a paper copy of the program"

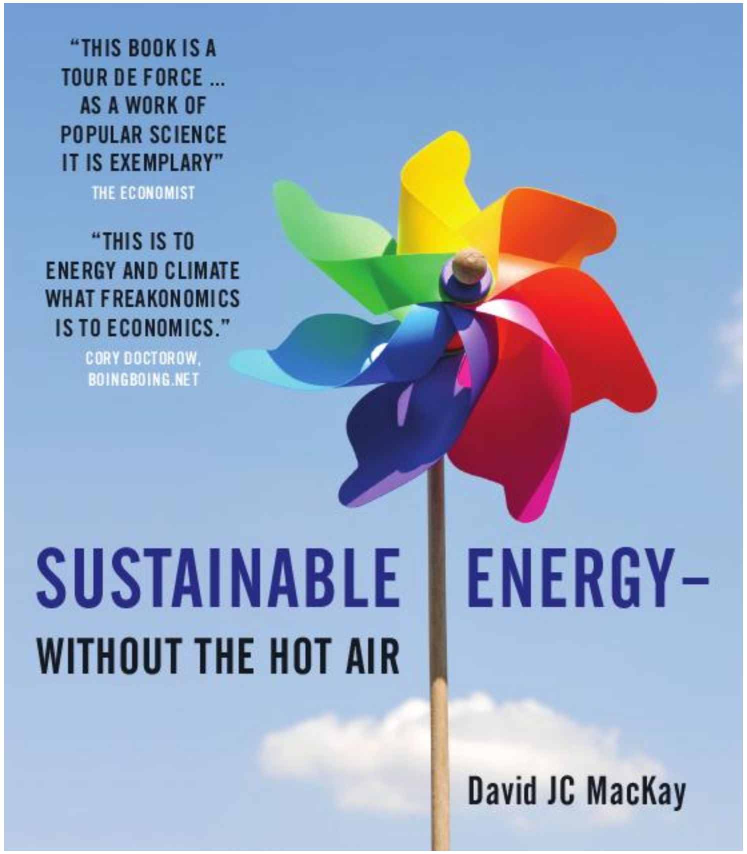
"Bailing out the Titanic with a teaspoon" – David MacKay

References

c21.phas.ubc.ca

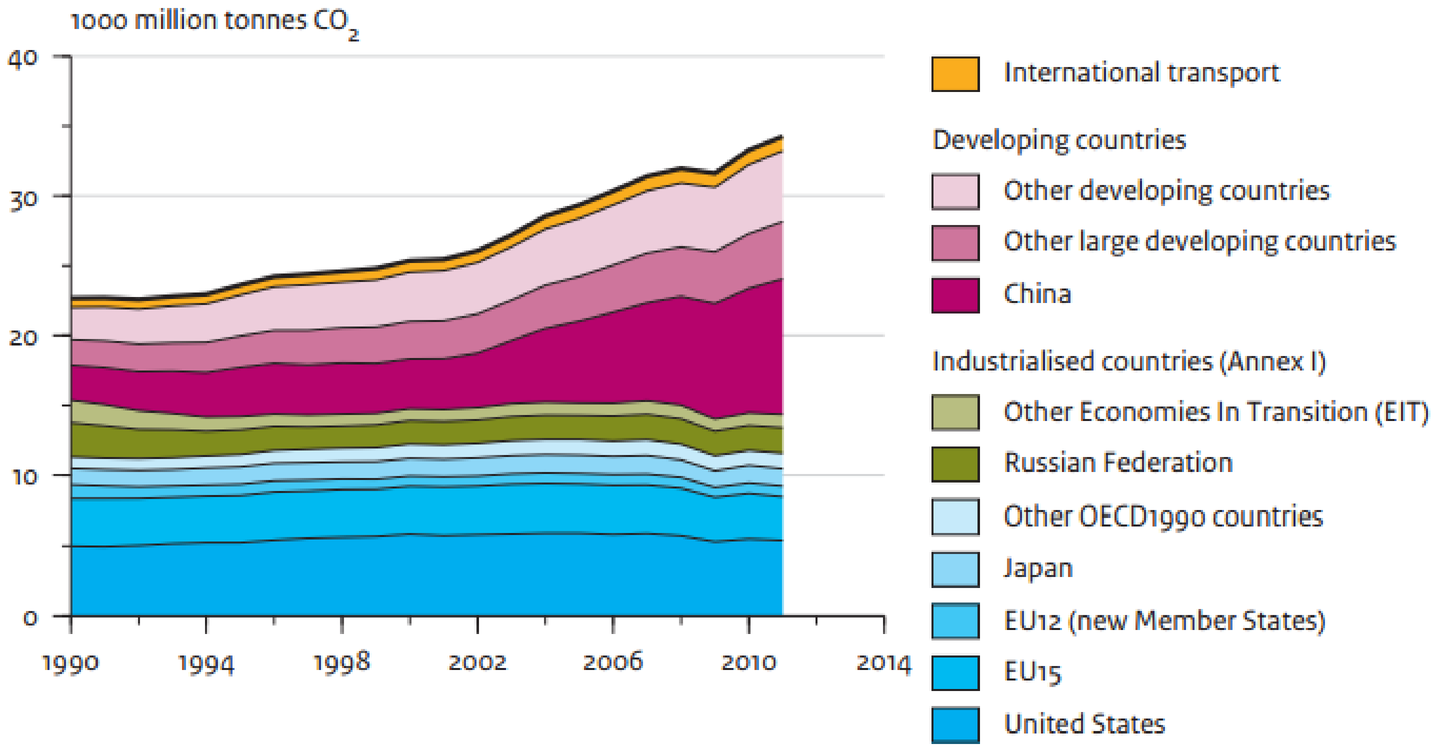
withouthotair.com





What is the main problem?

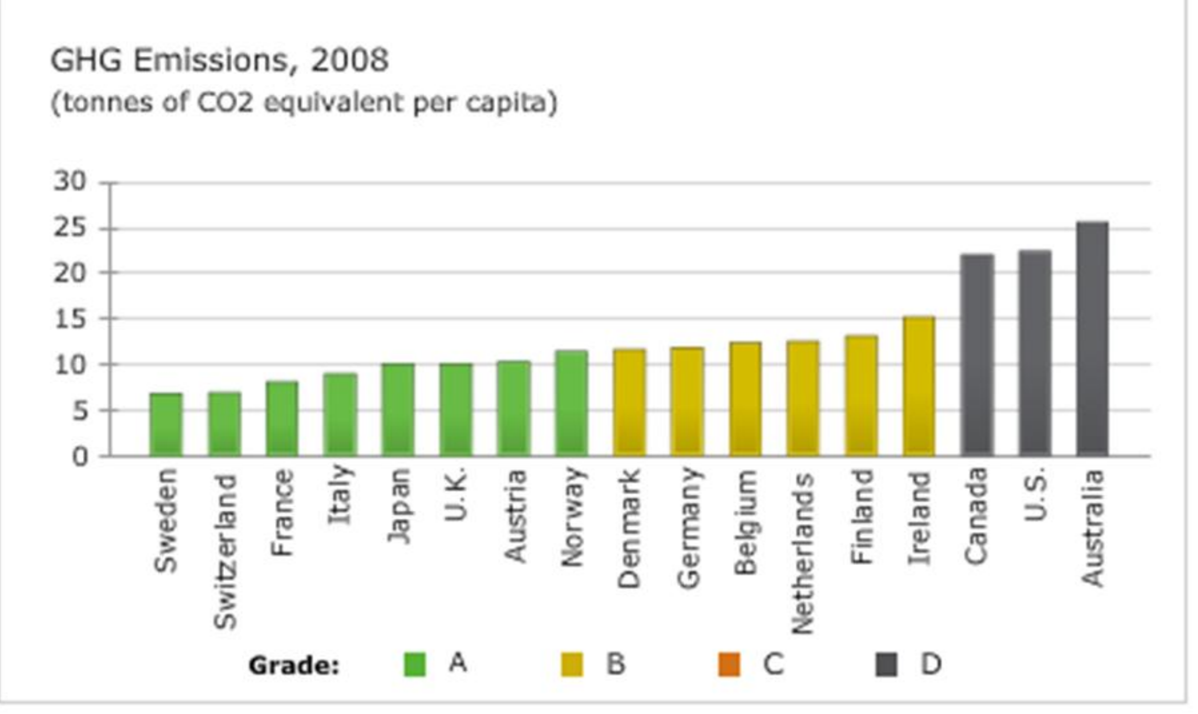
Global CO_2 emissions per region from fossil fuel use and cement production



Source: EDGAR 4.2 (1970–2008); IEA, 2011; USGS, 2012; WSA, 2012; NOAA, 2012

Canada

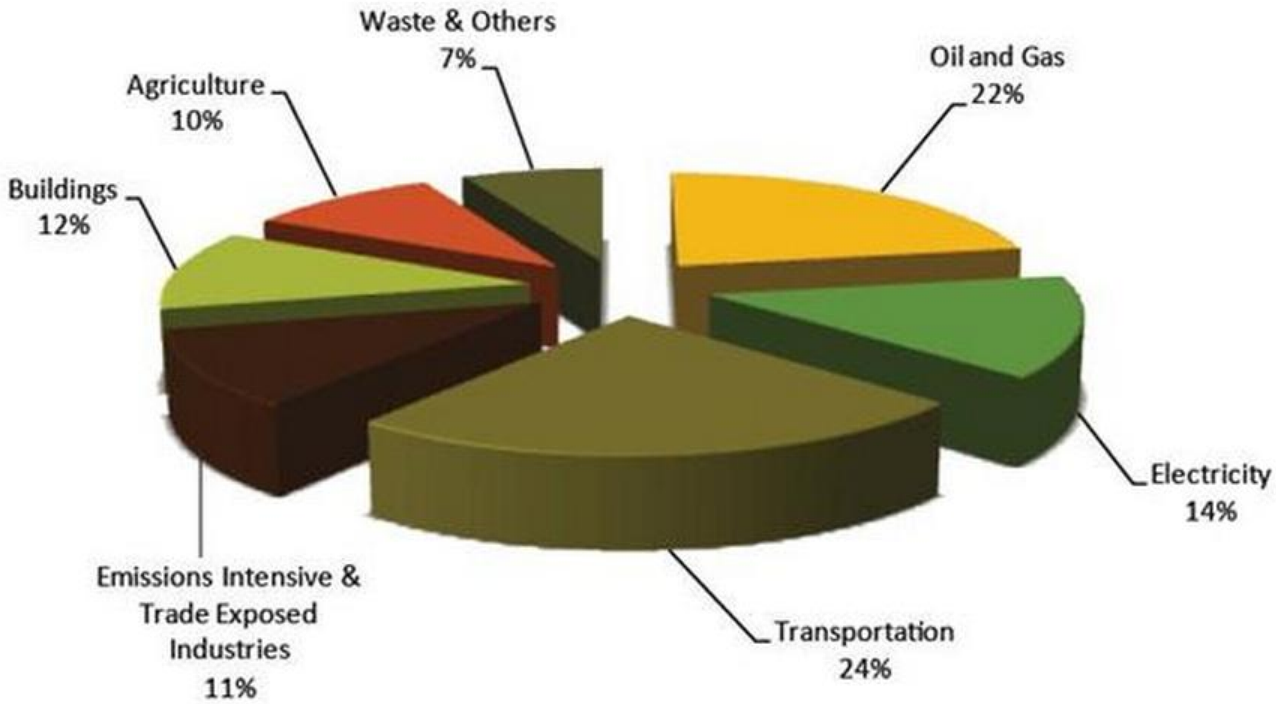
- 17 tonnes CO_2 per capita per year
- 23 tonnes CO_2e per capita per year
  - "e" means "equivalent", i.e. includes other GHGs



http://www.conferenceboard.ca/hcp/details/environment/greenhouse-gas-emissions.aspx

Where does it all come from?

Figure S-6: Canada's Emissions Breakdown 2010, by Economic Sector



http://www.ec.gc.ca

Let’s not footle around at the edges, let’s try and cut *tonnes* off our individual footprints

- Transportation
- Food
- Buildings (heating and electricity)
- Stuff

A note of realism here: we’re not aiming at *solving* the problem, we’re just trying to show the way to leave less of a mess for succeeding generations to clean up.

You must be the change you wish to see in the world

Mahatma Gandhi

A note on methods

- Broad brush only – don't get hung up on details
- No scientific notation!
  - Prefix notation: k, M, G… (x10^3, 10^6, 10^9…)
- Units
  - Energy: Joule (J) (1 Cal = 4184 J, 1 kWh = 3.6 MJ)
  - Velocity: m/s (= 3.6 km/h)
  - Mass: kg (1 tonne = 1000 kg, 1L gas ~ 0.7 kg)
  - Fuel economy: 15 L/100km = 15 mpg (US)
    - but one goes up while the other goes down!

Transportation

- A physicist's approach:
  - Energy required for transport best expressed in units: J/kg/m
  - Unit of energy J = $kg.m^2/s^2$
  - So J/kg/m = m/s^2 - an acceleration: suggests g!
  - Also J/kg/m = MJ/tonne/km in practical units
  - Gasoline: 36 MJ/L
  - Car mass: a tonne or two
  - Typical journeys: a few km

Typical energy costs per tonne per km

Energy cost of transport per total mass of laden vehicle (direct fuel consumption only)	
Mode of Transport	**Energy cost (MJ/tonne/km)**
Walking (5 km/h)	3
Boeing 747-300	1.8
Cycling (human powered, 20 km/h)	1.5
2005 Honda Civic (2 persons)	1.4
Electric bicycle	0.4

All remarkably similar! – a least from a physicist's viewpoint

http://c21.phas.ubc.ca/article/energy-cost-transport

Typical values per passenger

Energy cost of transport per passenger (direct fuel consumption only)

Mode of Transport	Energy cost (MJ/passenger/km)
Electric bicycle	0.06
Cycling (human powered)	0.16
BC Transit Skytrain (Mark 1, 80 pass - 100% full)	0.11
BC Transit Bus (Trolley, 55 pass - 100% full)	0.18
Walking	0.2
BC Transit Bus (Diesel, 60 pass - 100% full)	0.4
2005 Honda Civic (2 persons - 40% full)	1.0
Boeing 747-300 (400 pass - 100% full)	1.4
Boeing 747-300 (240 pass - 60% full)	2.3
Intercity rail	0.2 (Shinkansen)-1.7 (Amtrak)
Ship	2 (freight)-10 (cruise ship)

Energy - CO_2 relationship

We need a conversion factor, in $kgCO_2/MJ$

- Which will depend on the energy source:
  - Hydro
  - Nuclear
  - Wind
  - Natural gas
  - Oil (gasoline, diesel)
  - Coal
  - Food

Chem 11

- Fossil fuels are the easiest, because most of the emissions occur when they are burnt, with relatively little coming from extraction/processing (except bitumen)
- Look up the enthalpy (heat) of combustion a.k.a higher heating value (HHV):
  - Methane (natural gas) CH_4: 55 MJ/kg; molecular weight 16
  - Oils ~CH_2: 40s MJ/kg; molecular weight ~14 per carbon atom
  - Coal ~CH: 20-30 MJ/kg; molecular weight ~13 per carbon atom
- All remarkably similar, and determined by the strength of the hydrogen-oxygen and carbon-oxygen bonds.

http://c21.phas.ubc.ca/article/energy-and-greenhouse-gas-ghg-calculations

e.g. Gasoline: how much CO_2 per L?

CH_2 + …O_2 -> CO_2 + ….

14 44

- 1 kg CH_2 burns to 44/14 = 3.14… kg CO_2
- 1 L gasoline burns to 2.2 kg CO_2
- On highway my Honda Civic: 5.8 L/100 km
- Translates to 130 g CO_2 per km

Can physics give us an idea what fuel consumption (L/100 km) to expect?

Of course.

Energy E (J) required to move a given distance x (m):

μ_r: coefficient of rolling friction
mg: weight of vehicle [N]
C_D: coefficient of (air) drag
A: frontal area [m^2]
ρ: air density [kg/m^3]
v: speed [m/s]

- Assume constant speed
  - $E = F_{drag}.x$ (total drag force times distance)
  - $E/x = F_{drag}$ (energy per unit distance is just the drag force)
  - $F_{drag} = \mu_r mg + ½ (C_D A)\rho v^2$ (rolling friction + air drag)
  - All quantities straightforward to look up and not that hard to measure http://c21.phas.ubc.ca/article/bicycle-power
  - F_{drag} increases with mass*, size, bluff shape, speed.

* and especially in stop-go traffic and going up hills, think kinetic (½ mv^2) and potential energy (mgh). Coming down hill you lose potential energy if you have to use the brakes.

730 kg
3.4 L/100 km
75 gCO_2/km

2500 kg
17 L/100 km
370 gCO_2/km

Going long distances

- Water
- Rail
- Flying

Water transport sounds a good bet

- No rolling resistance in water (zero velocity, zero drag)
- Slow
- So why is the energy cost of transport per person the highest of all? Worse than flying, which is the fastest.

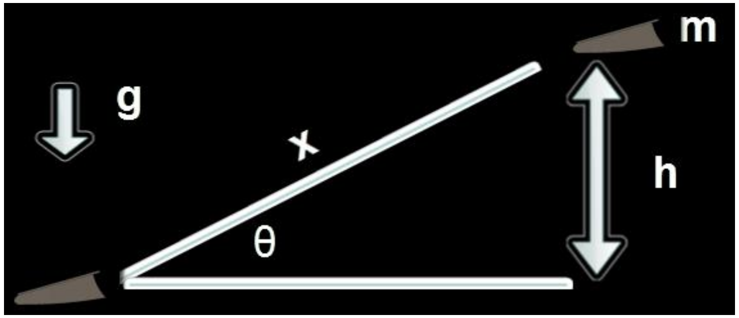
Floating global warming

- A laden Boeing 747 weighs 400 tonnes, and carries about 40 tonnes of passengers and luggage*: 10% useful load.
- The Costa Concordia displaced 114,000 tonnes and carried 380 tonnes of passengers and luggage*: 0.3% useful load.

* Assuming 100 kg for each passenger and luggage

Flying

- You can easily estimate the energy required to get an airliner from A to B by noting its mass, speed and glide-slope
- Boeing 747
  - 400 tonnes
  - Glide slope 1 in 15
  - Thermal efficiency of (all) engines ~1/3
  - *E* = (*mgx*)(3/15) ~ 800 kJ/m = 800 GJ/(1000 km)*
  - Aviation fuel ~45 GJ/tonne: 18 tonnes/(1000 km)
  - Multiply by 44/14 : 57 tonnes CO_2 /(1000 km)
  - 400 passengers for 10,000 km: 1.4 tonnes CO_2 each



http://c21.phas.ubc.ca/article/energy-cost-flying

* From first principles:

$$E \approx \frac{1}{\eta}\sqrt{\frac{C_D}{AR}}\,g \qquad \text{J/kg/m}$$

And that's not counting:

- The 22 tonnes of water (18/14) – itself a potent GHG – being pumped out at altitude where there shouldn't be any.
- Night flights are worse (contrails impede Earth's radiation without impeding incoming solar radiation).
- I'm only counting fuel burnt in the planes, not all the ancillary airline activity.

150 tonnes fuel x 44/14 = 470 tonnes CO_2

x 18/14 = 190 tonnes H_2O

Rail

- Recall $F_{drag} = \mu_r mg + \frac{1}{2} C_D \rho A v^2$
- For low rolling resistance, you can't beat steel on steel:

Tire Type	Coefficient of Rolling Friction
Low rolling resistance car tire	0.006 - 0.01
Ordinary car tire	0.015
Truck tire	0.006 - 0.01
Train wheel	0.001

- 0.2 MJ/pass/km (Shinkansen and other high speed networks)
- 1.7 MJ/pass/km (Amtrak)
- Watch where the electricity is coming from: e.g. nuclear (France), coal (China)

http://c21.phas.ubc.ca/article/energy-use-cars-3-rolling-resistance
US DoE Transportation Energy Data Book http://cta.ornl.gov/data/index.shtml

Now to food: Bicycling and Walking

- Human body is a thermodynamic engine like any other, and reasonably efficient (20-25%)
- But…the fuel source (i.e. food), in terms of $kgCO_2/MJ$, can be horribly inefficient

”Modern agriculture is the use of land to convert petroleum into food”

Albert Bartlett

- Meat: 2.7 $kgCO_2e/MJ$ (gasoline is ~0.07 $kgCO_2e/MJ$)
- Vegetables: 0.6 $kgCO_2e/MJ$
- So even a vegan makes ~10x the GHGs per MJ of energy than a car engine does.
- Mass of me + bicycle: 90 kg
- Mass of me + Honda Civic: 1400 kg
- Even if I was a vegan, its going to be a tight race between cycling and driving…

http://c21.phas.ubc.ca/article/commuting-car-or-cycle-which-better

Detailed calculation

- Easy but long winded (spreadsheet available on web http://c21.phas.ubc.ca/article/commuting-car-or-cycle-which-better)
  - The person in question weighs 70kg, is 180cm tall, 25 years old
  - The person loses 1kg in weight by biking to work instead of driving
  - Cycling speed is 20km/h
  - The commute is 10 km (one way) and is done 200 days per year
  - The comparison vehicle is a Honda Civic
- Conclusion:
  - A vegan cyclist commuter produces 300 kg less CO_2e than a vegan Civic driver
  - A carnivorous (exclusively) cyclist commuter produces 600 kg MORE CO_2e than a carnivorous Civic driver
- BUT…

If, by cycling, you OWN one less car:

- Cars need servicing and eventually replacing, even if left in the driveway.
- Do life-cycle analysis assuming 10y between buying new cars…
- Cycling wins hands-down, no matter what you eat.
- Even considering that exclusive carnivores produce 11 tonnes CO_2e per year just feeding themselves (compared to a vegan's 2.5 tonnes, and an average Canadian's 6 tonnes).

Conclusion

- Try to arrange your life so you can walk/cycle to work (this is needs some planning ahead).
- Eat mostly vegetables!
  - Better for your health
  - Better for your wallet
  - Better for the environment
  - Better for the animals you would have eaten

CH_2O in one end, CO_2e out the other.

Heating (and cooling) buildings

- Buildings loose (gain) heat from the inside wall to the outside wall through conduction.
- Thereafter the heat is lost to the environment by convection and radiation.
- Power lost through conduction:
- $P = kA\Delta T/x$: conductivity x area x temp difference/thickness

6 tonnes of CO_2 p.a. just to heat my 33’ lot house.

Heating/Cooling Conclusion

- Decrease k: insulate, double-glaze (low-E)
- Decrease A: choose a smaller home, reduce outside wall area (condo)
- Reduce average ΔT:
  - put a sweater (shorts) on.
  - don't leave the heat on if you are not in. (The inability to do this with a heat pump reduces its apparent advantage).
- Don't pump heat up the chimney (use a high efficiency furnace).
- Beware of power sources that are horribly expensive (PV) and/or eccentric (urban wind turbines): why?

Stuff: a rough calculation

- Canada’s GDP \$1.3 trillion
- National annual emissions 690 Mtonnes CO_2e
- In the absence of more detailed information, reckon on about ½ tonne per \$1,000
  - Some economic activity worse (e.g. flying)
  - Some economic activity better (e.g. insulating your home)

http://www.ec.gc.ca

Final Conclusion

- With a little thought and effort we can knock several tonnes off our personal annual CO_2 emission total (and save money in the process)
- However, most emissions remain out of our immediate control
- But don’t blame others; we’re all in this together
- Don’t yield to lazy fatalism
- Vote