Module I: energy basics
Module II: hydro-carbon energy
Module III: Energy in Canada
Module IV: Energy, History & Politics
Module V: Our Energy Future

- *renewable energy: any future out there?*
- *Conservation: can we cut spending by a factor of 10?*
- *Recycling: a little left-over topic*

Renewable Energy

- *food*
- *the game-changer*
- *what about the other renewables?*

Reading: Muller (Energy for future presidents) Chapter 8 , 9, 13 & 15

Summary: our energy endowment (last term)

. our good fortune with 'fossil fuel'

-- woody plants 360-300 million yrs ago made coal
-- coal was instrumental for industrial revolution
-- coal still heavily used in developing worlds

-- marine planktons made oil/gas
-- current transportation relies heavily on oil
-- technology developments avail us of shale gas/oil, oil-sand...

. our 'fossil fuel' dependency may come to an end?

-- reserve-to-production ratio 50-100 yrs
-- environmental issues

. with the major exception of nuclear energy, all our energy reserves come eventually from the Sun (coal, oil, gas, hydro, solar, wind, biofuel...)

Solar Energy

The Earth is the third planet from the Sun. At our distance, we receive a power of ~ **1000 Watt/square metre**.

.Human body ~ 100 Watt light-bulb. Solar energy can potentially support a very large population.

.Total solar power on Earth: ~ 200,000 TW (terawatt)
.total human consumption power: ~ 20 TW (electricity: ~ 8TW)

Reductions: …… and, efficiency of converting solar energy to useable forms (food, electricity, heating/cooling, transportation…)

Together with nuclear energy, solar energy will be an important part of our energy package:

nearly infinite, no CO_2 footprint, shine @ daytime

Just how powerful is 1000 watt/square metre?

unfocussed, the Sun heats the Earth up to 20^{o}C (300 K)

focussed, it can set alight to anything on Earth

http://www.youtube.com/watch?v=z0_nuvPKIi8
http://www.youtube.com/watch?v=jrje73EyKag

Catching sun-light: the biological path

Photosynthesis: plants and other organisms convert light energy into chemical energy that can be later released to fuel the organisms' activities — wiki

Photo-synthesis has been our main access to solar energy.

. bacteria evolved to perform photosynthesis ~ 3 Gyrs ago; before then?

Crops convert only ~ 5% sunlight into plant mass, and only ~ **0.5%** into food (potato, corn kernel, wheat grain…) — our food security.

by-products (corn stalks…) may be turned into **bio-fuel**, fed to animals, or burned for heat (**biomass**)— 'renewable', but burning releases CO2

— efficiency limited by the efficiency of photosynthesis

— **unlikely** to be an important part of future energy package

Our energy use (last term)

Historically, the yield of photo-synthesis determines the size of villages, cities….

— Food intake of a typical Canadian ~ 2500 kcal/day

— "food security"

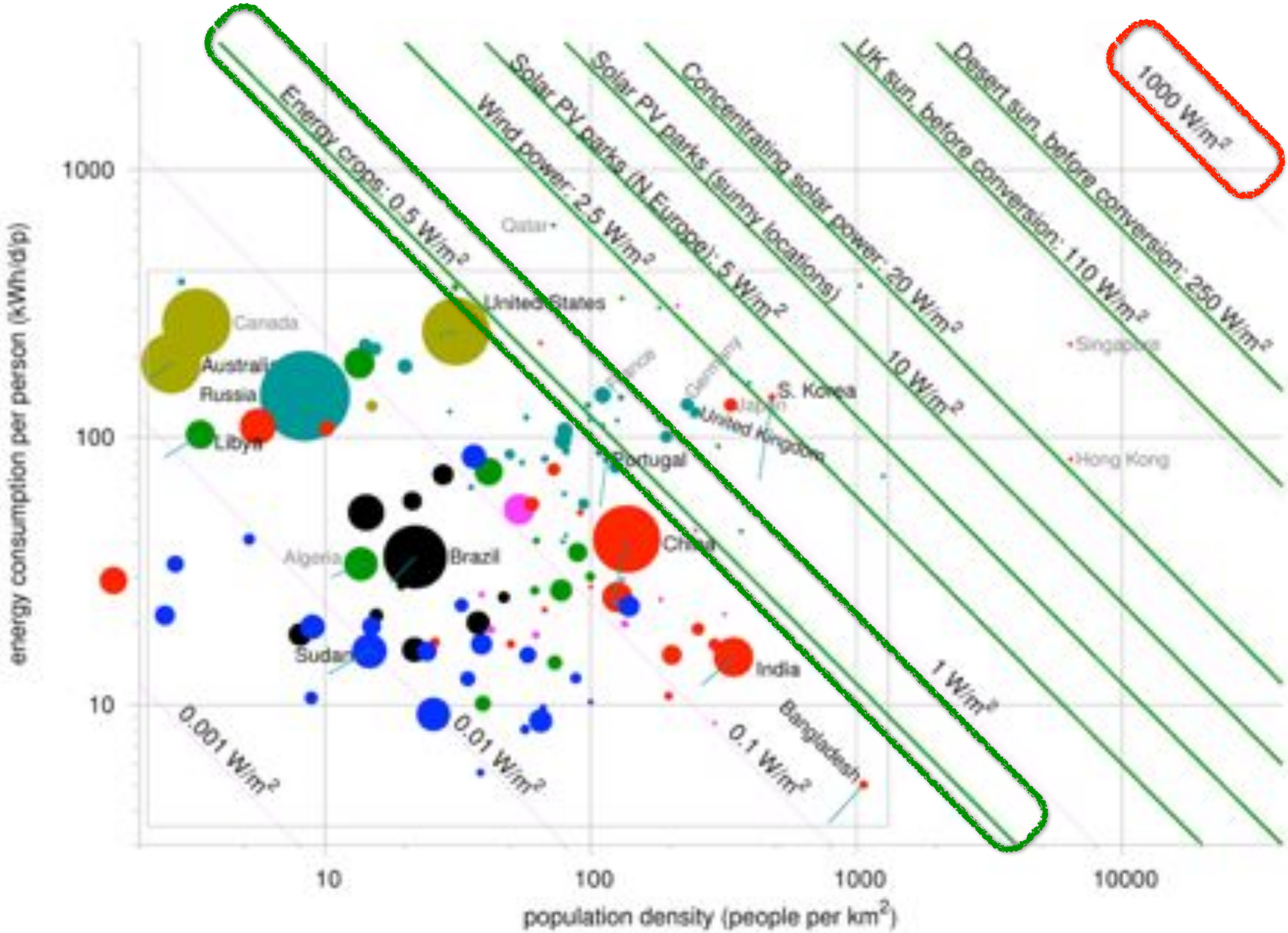
However, a post-industrial human uses **100x** more energy than in food

— energy security has evolved beyond food security.

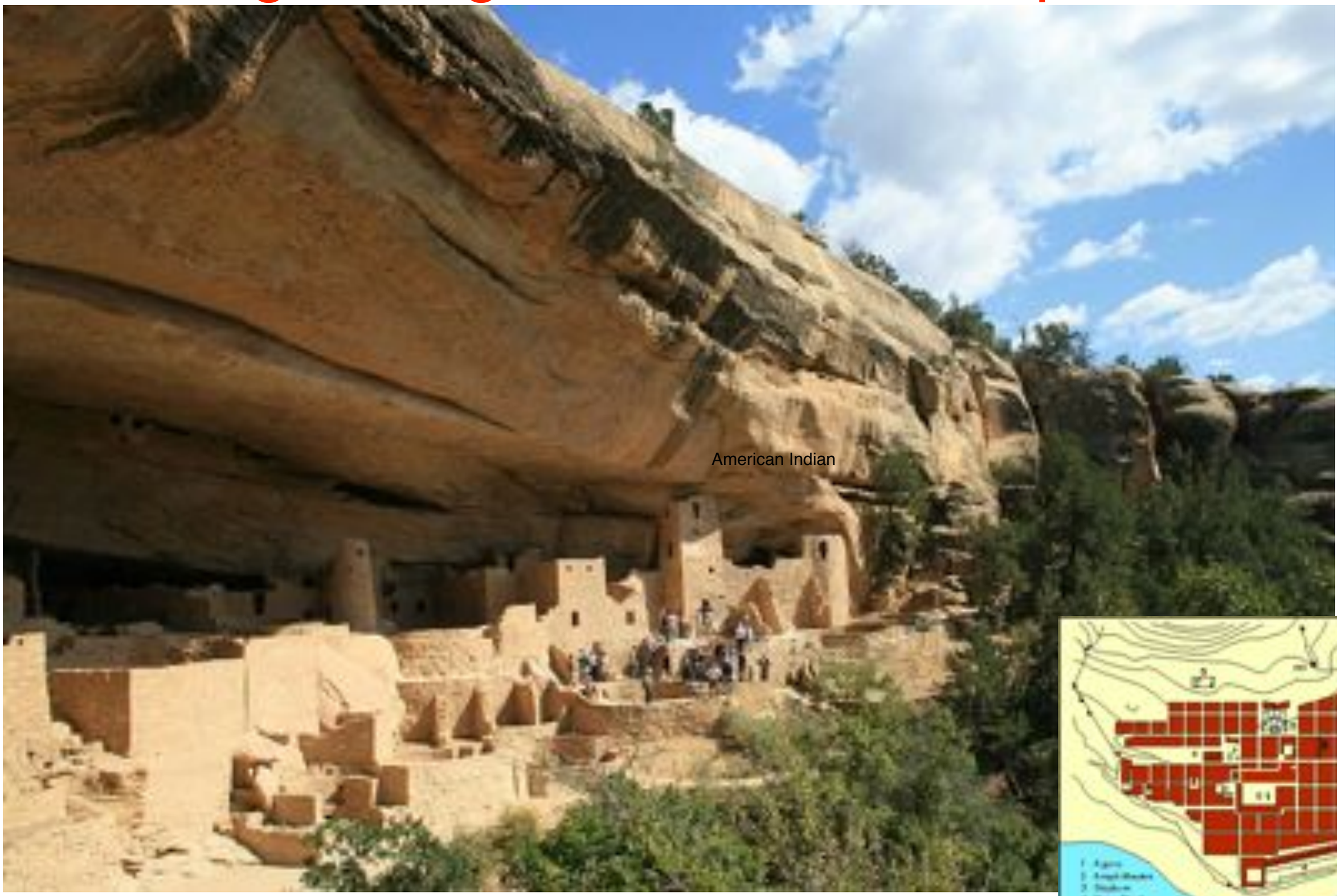
This is made possible by the use of fossil fuels.

the big Question: Could solar energy replace fossil fuels?

Energy Density: source and consumption



Catching sun-light: historical examples



Mesa Verde Indian remain, south facing with overhanging cliff

city run on North-South grid

Catching sun-light: solar thermal

.use solar energy to boil water, to heat building, to drive steam engine
.solar thermal power generation has not been commercially viable
.but solar thermal for residential has been (at least in some countries)

Catching sun-light: photo-voltics

light —> electricity

Solar PV technology is based on the physical phenomenon called the photo-electric effect (generating electricity out of light):

. first observed by French physicist Becquerel, 1839

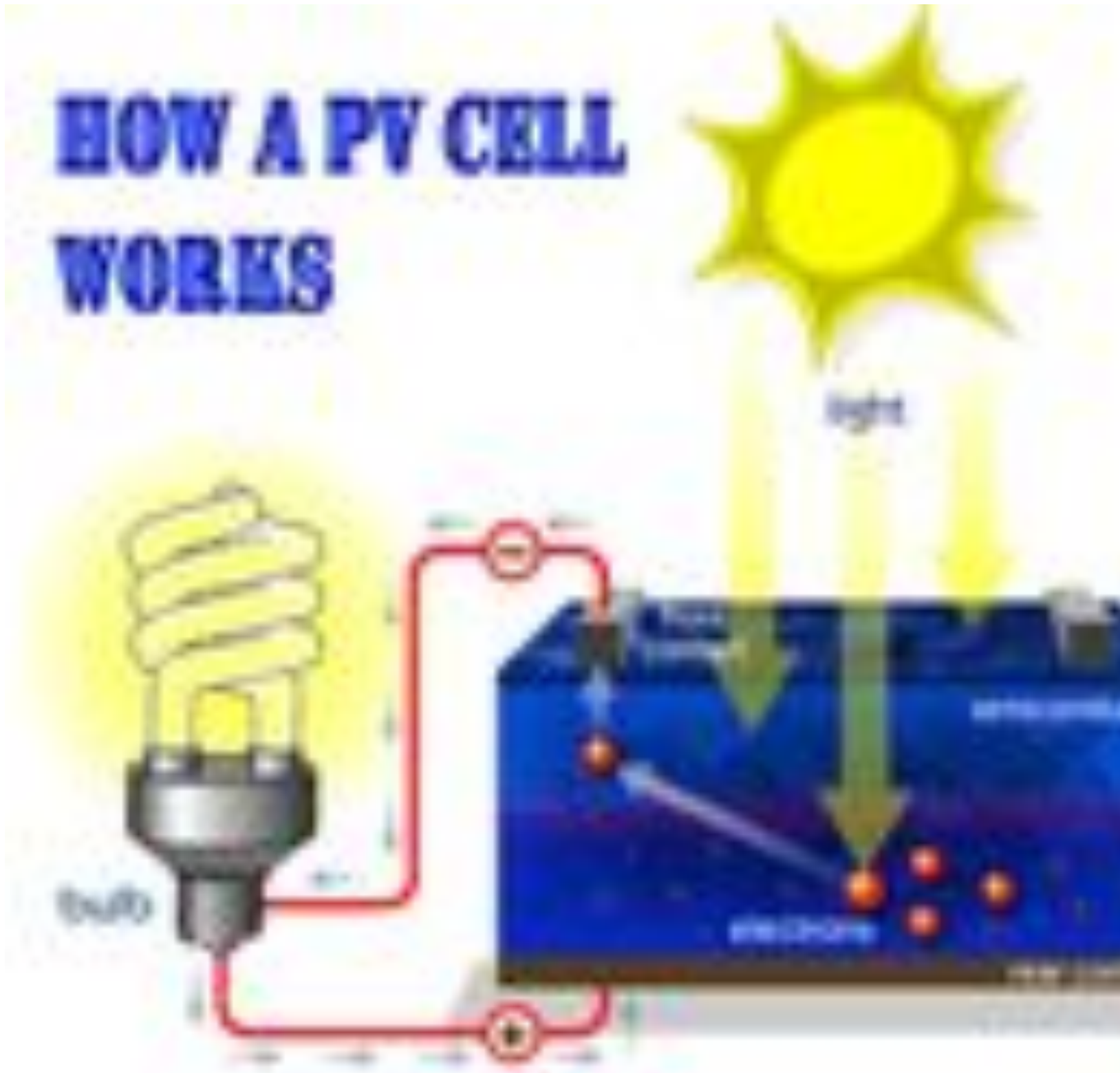
. first explained by Albert Einstein (Nobel prize in physics: 1921)

— light consists of little packets called photons,

. an example of curiosity-based fundamental research leading to revolution

— ‘necessity the mother of invention’?

Catching sun-light: photo-voltics



silicon wafer

Catching sun-light: photo-voltics

Efficiency: the fraction of solar energy that can be transformed into electrical energy is limited.

.Only photons of high enough energy can strike out the electrons

. this efficiency is not related to the Carnot law (for heat engines)

. current commercial products ~ 14-19%

— world record 45%

— material engineers' big task

Install PV panels on all roofs in Toronto?

(ignore cost, an area of 630km^2)

Supply:

- direct sunlight (peak) ~ 1000 W/m^2, —630,000 MW
- averaged over year ~ 200 W/m^2 —126,000 MW
- PV panel efficiency: take 16% —20,000 MW
- ~10% land area covered by roof —2000 MW

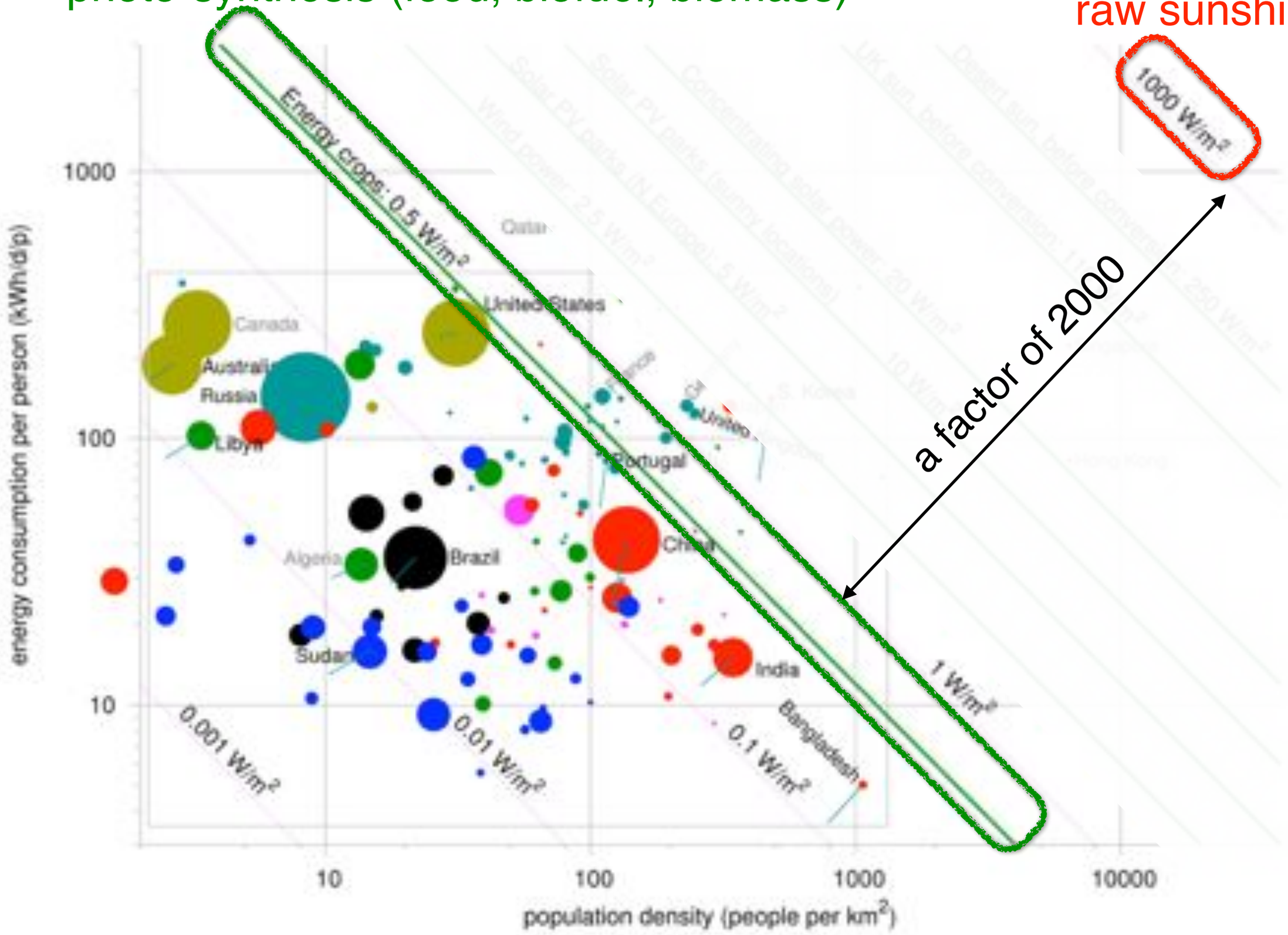
Consumption: Toronto average electricity demand ~ 4000 MW

What about the cost?

Summary of last lecture — energy density

photo-synthesis (food, biofuel, biomass)

raw sunshine



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Too good to be true?

Ontario FIT Program

"Feed-in-tariff"

- Pays premium prices for various renewable sources of electricity
  - solar 33-40¢/kwh
  - wind 12¢/kwh
  - hydro 15¢/kwh
  - biomass 16¢/kwh

http://fit.powerauthority.on.ca/fit-program/fit-program-pricing/fit-price-schedule

- Compared to 4-8¢/kwh for conventional sources such as coal, natural gas, nuclear…

The Business Case for Pure Energies

- Parts + Installation ~ $30,000 for a 6 kW system.
- Generating electricity: ~ 12,000 kWH/yr (~2000 hrs of sunshine/yr in Toronto)
- Ontario FIT buy-back: ~ $0.39/kWH, so $4680/yr gain
- Payback in ~ 6.5 years
- FIT contract for 20 years

Perfectly good business case (under Ontario's FIT programme); government incentives/rebates have done much to promote the solar industry.

But can we do away with government support?

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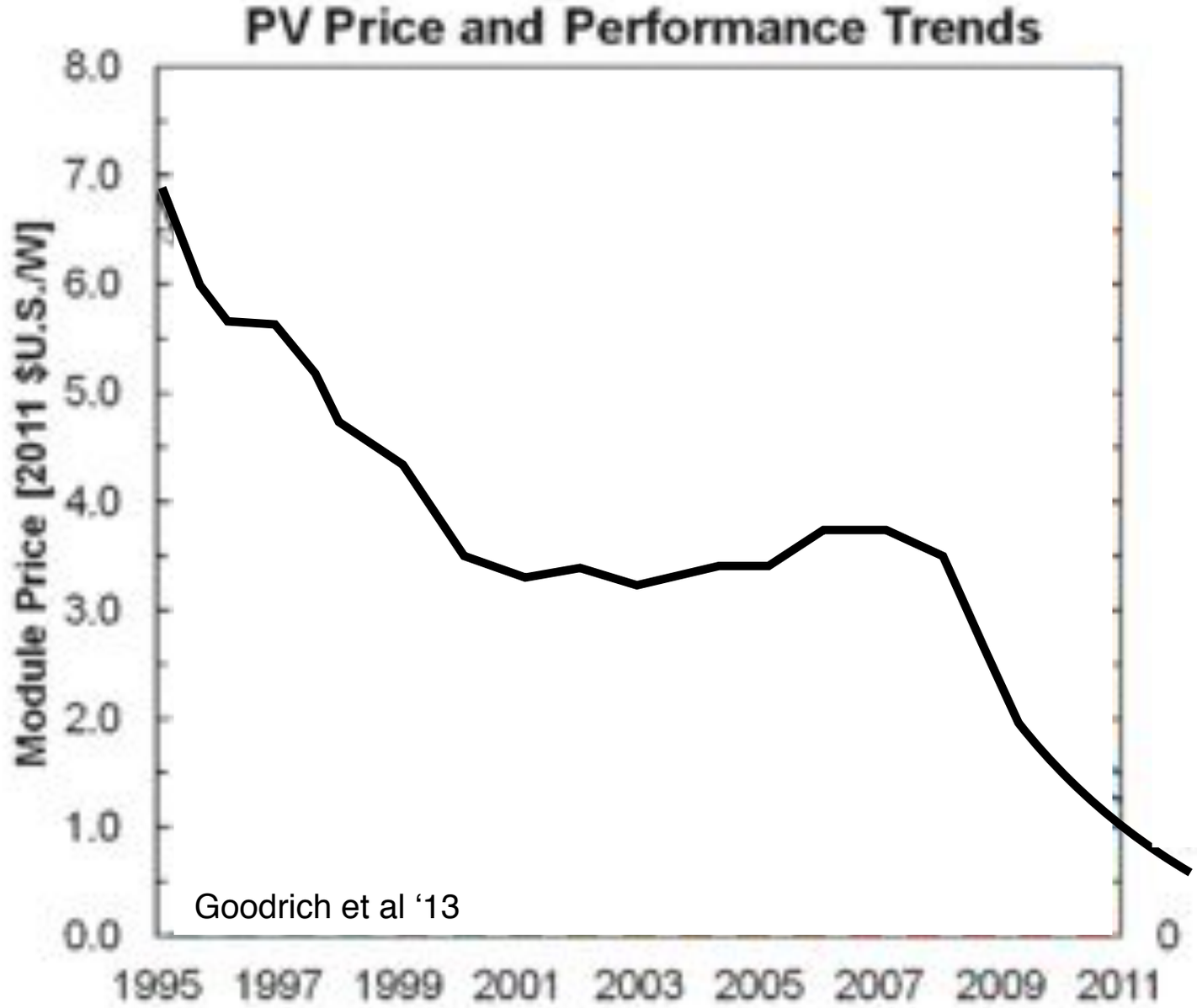
PURE is a team of smart, dedicated, fun and open-minded individuals who are working together to solve one of the biggest challenges of the 21st century.

We're Hiring!

“Solar is too expensive!” ?

— the price for solar panels (the most expensive part in PV system) has plummeted over the past few years.

.Ontario Micro-FIT buy-back: $0.80/kWh (2004); $0.39/kWh (2014);
.solar PV is now almost reaching “grid-parity”
.in sunny regions, it is already economical to go solar



Why are the solar panel prices plummeting?

subsidy?
labour?
technology?
scale?

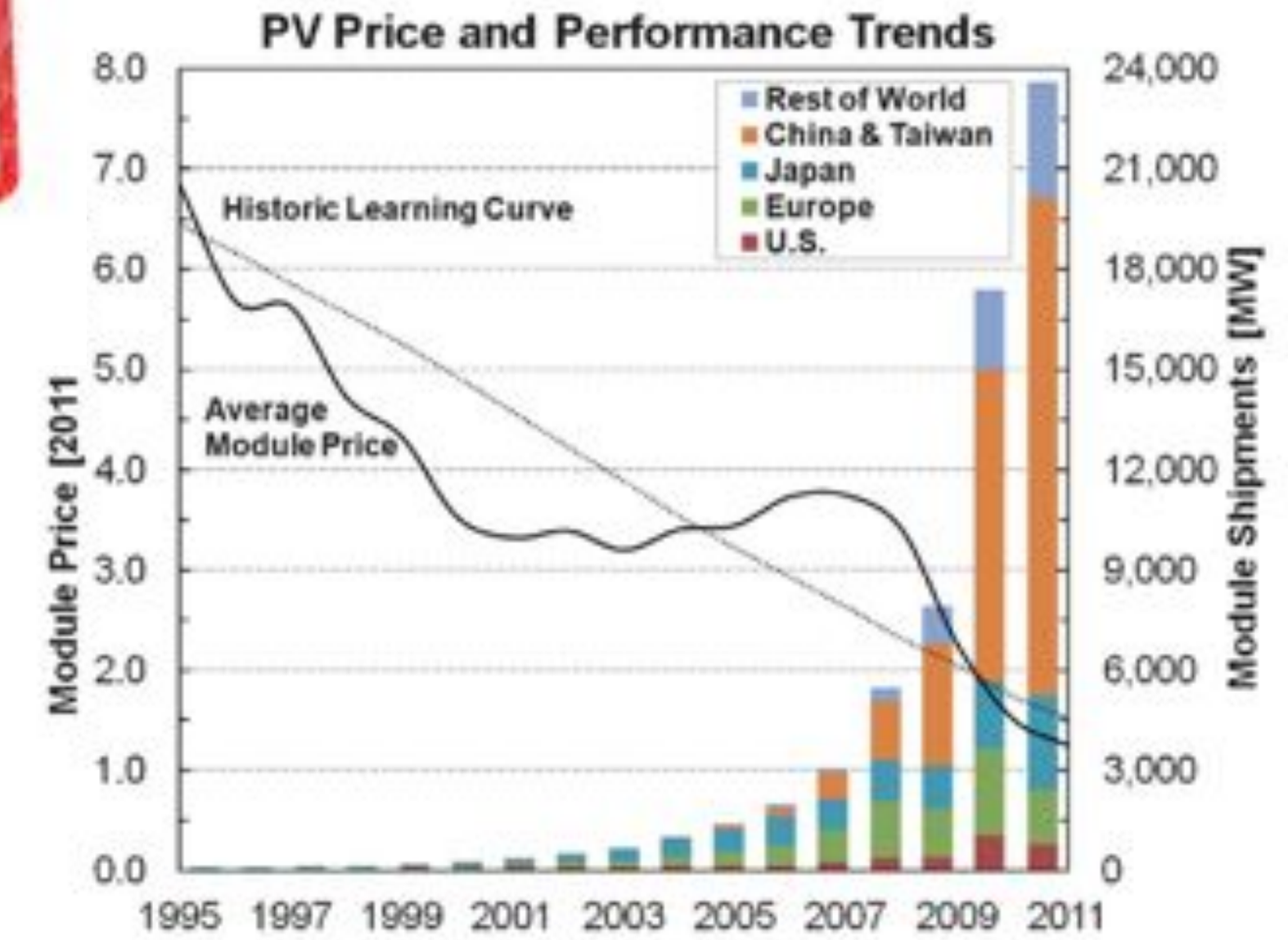
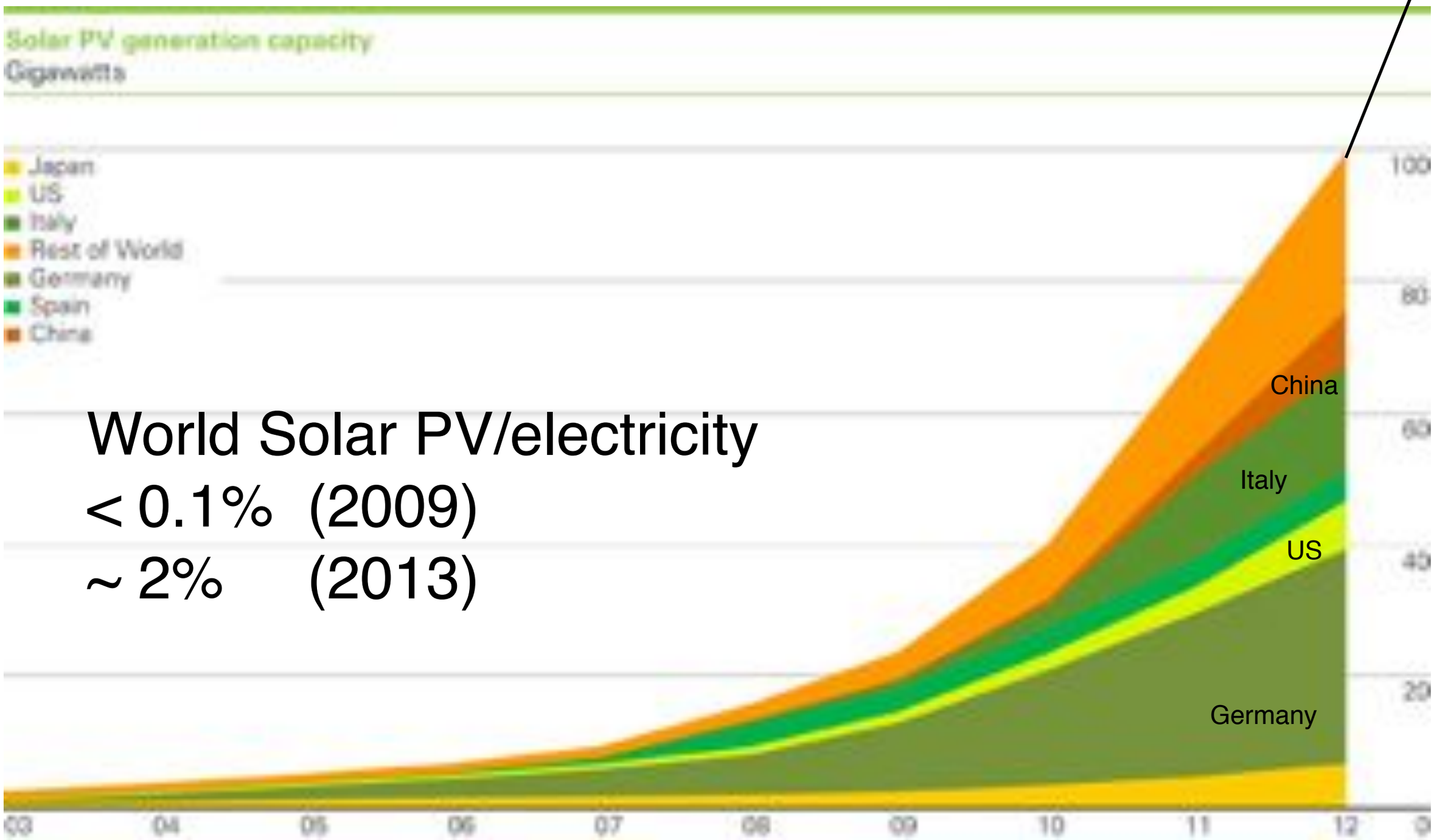


Fig. 1 From 2008 to 2011, reductions in the average global prices of c-Si PV modules have been in line with experience, but the rise of module manufacturing in China and Taiwan has been striking.[6]

Goodrich et al ’13: http://pubs.rsc.org/en/content/articlehtml/2013/ee/c3ee40701b

Catching sun-light: photo-voltics

Solar Concentrators — a good business model?



World Solar PV/electricity

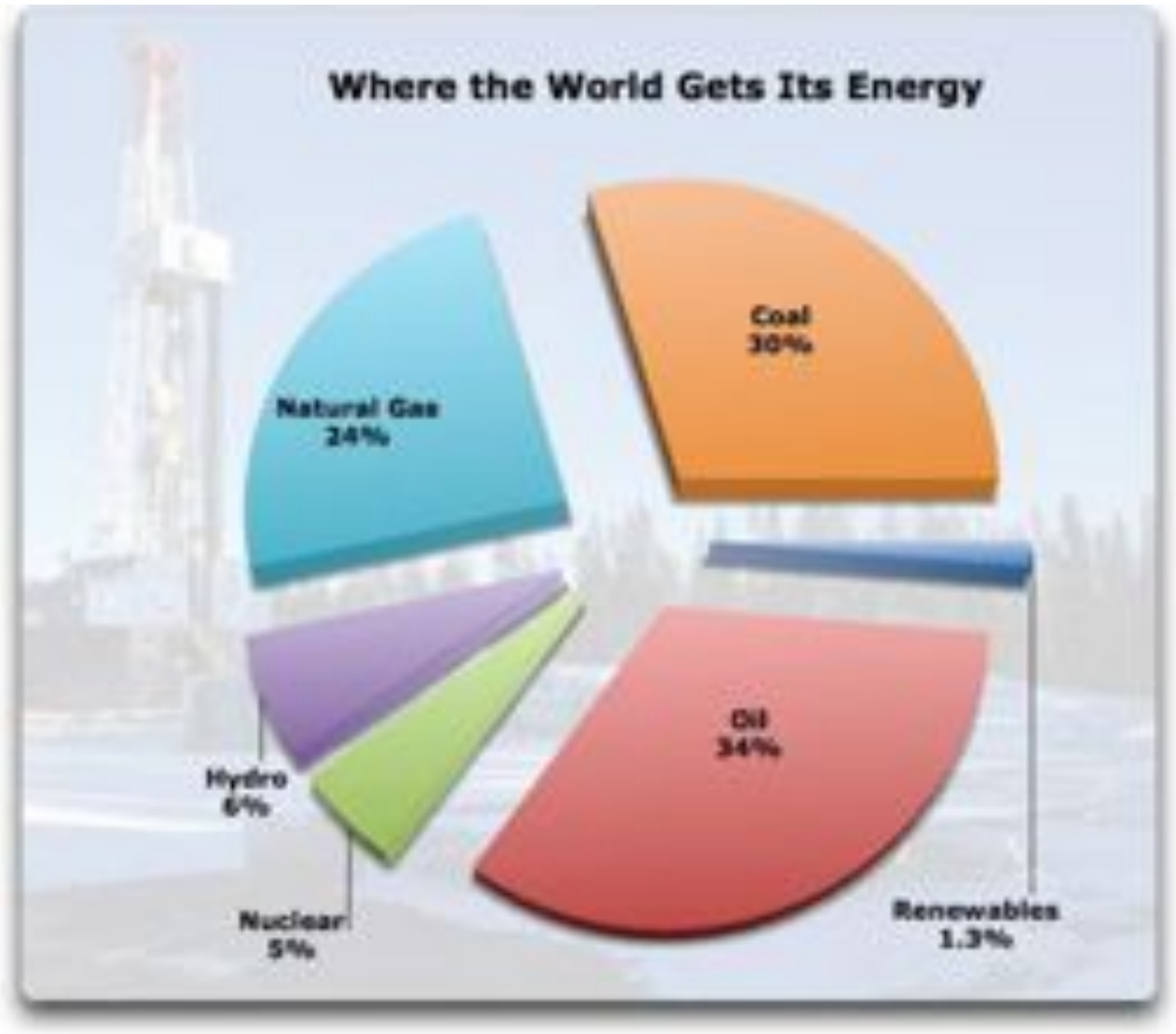
< 0.1% (2009)

~ 2% (2013)

- World total installed capacity (@2013): 140 GW = 35x Toronto
- Stratospheric growth rate of ~ 30% each year; **doubling every 3 yrs**
- extrapolate boldly, reach 8 TW installed capacity in ~ 15 yrs

First Solar PV project in Jordan!

Will Solar PV supplant other electricity generation method?



What should be taken into account?

Will Solar PV supplant other electricity generation method?

Land-area requirement for solar PV

Solar Land Requirements: 6 boxes at 3.3 TWatts Each (Source: Powering the Planet, Lewis et al.)

to supply US: assume 10% efficiency of PV panels; 160km x 160km

Will Solar PV supplant other electricity generation method?

What about the cost?

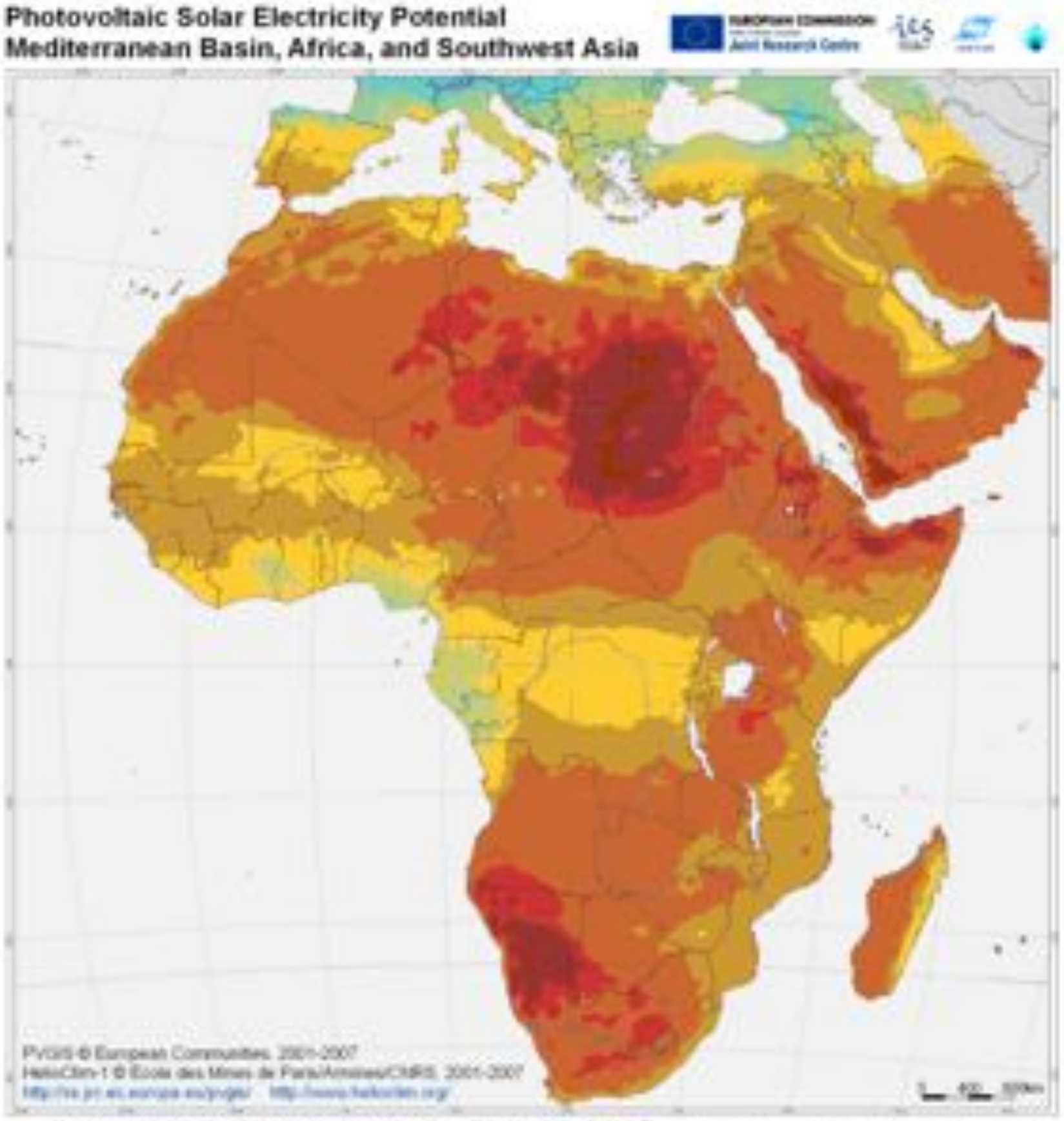
- solar has no fuel cost, but significant capital investment
    - this includes cost of PV panels, inverter, installation…

- solar is already reaching ‘grid-parity’ at:
    - sunny places: Colorado, California, southern Europe…
    - regions of high electricity price: Carribeans…
    - regions of low labour cost: Asia, Africa

- but in Canada, ~ a factor 2 above
  — more Government rebates/incentives?
  — solar panel/inverter price may continue to drop?

“The future is around the corner?”

The most suitable continent for solar PV



Will Solar PV supplant other electricity generation method?

What(else) should be taken into account?

storage
intermittency (need back-up)
....

Electricity Demand Follows Wide Cycles

- Electricity demand follows wide cycles
  - morning/afternoon/evening/night
  - weekdays/weekends
  - spring/summer/fall/winter

- And it always has to be available…

Other Alternative Energy Sources

missing ones:

biomass — CO_2

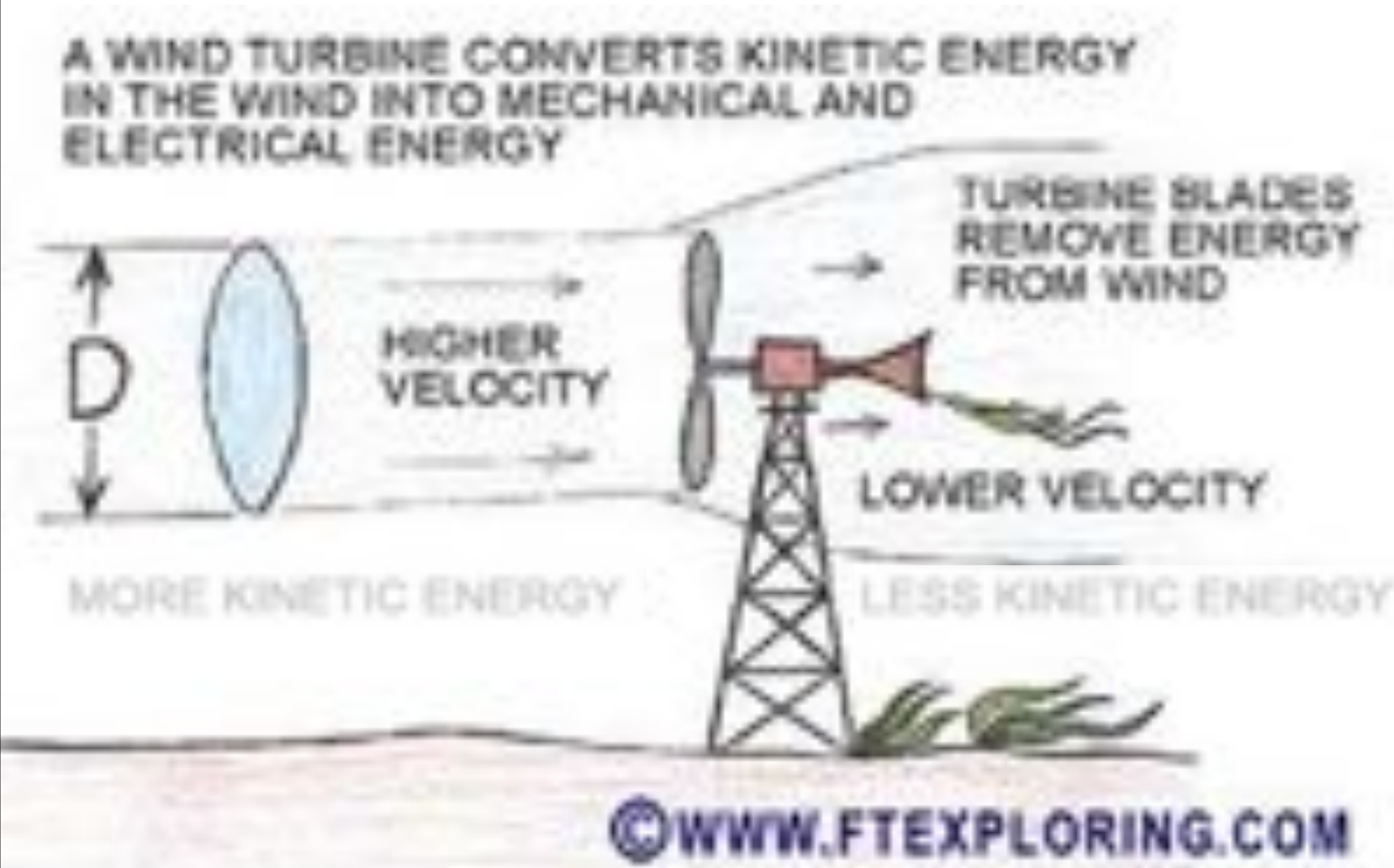
biofuel — CO_2

hydro — already in heavy use

geothermal — economical only some locales,

tidal — total ~ 3 TW, economical only some locales

Wind Power


A WIND TURBINE CONVERTS KINETIC ENERGY IN THE WIND INTO MECHANICAL AND ELECTRICAL ENERGY
D
HIGHER VELOCITY
TURBINE BLADES REMOVE ENERGY FROM WIND
LOWER VELOCITY
MORE KINETIC ENERGY
LESS KINETIC ENERGY
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POWER IN THE WIND = (DENSITY OF AIR) x (TURBINE BLADE DIAMETER)^2 x (VELOCITY OF WIND)^3 x (A CONSTANT)
POWER IN THE WIND = d x D^2 x V^3 x C
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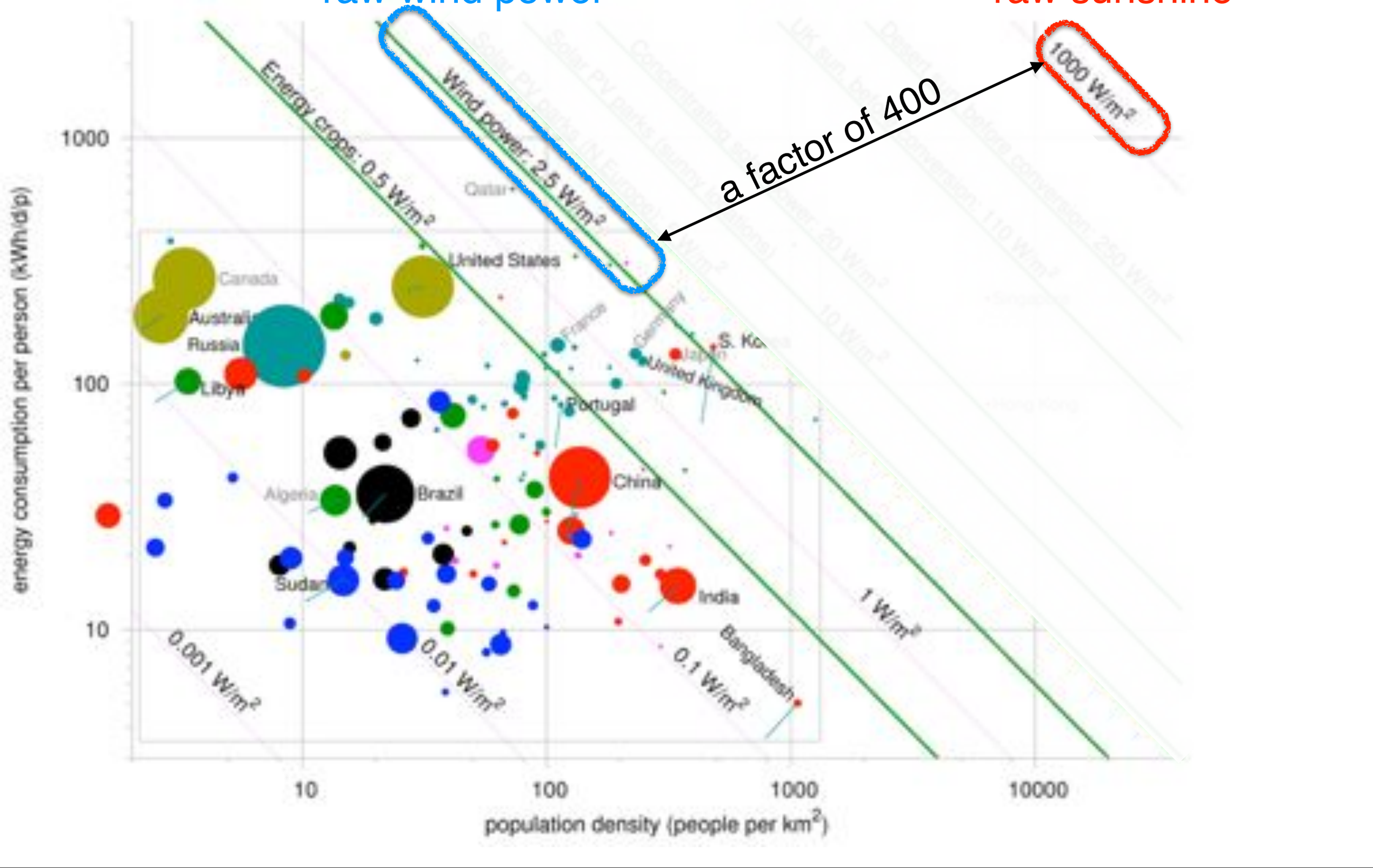
Wind energy density — compare with solar

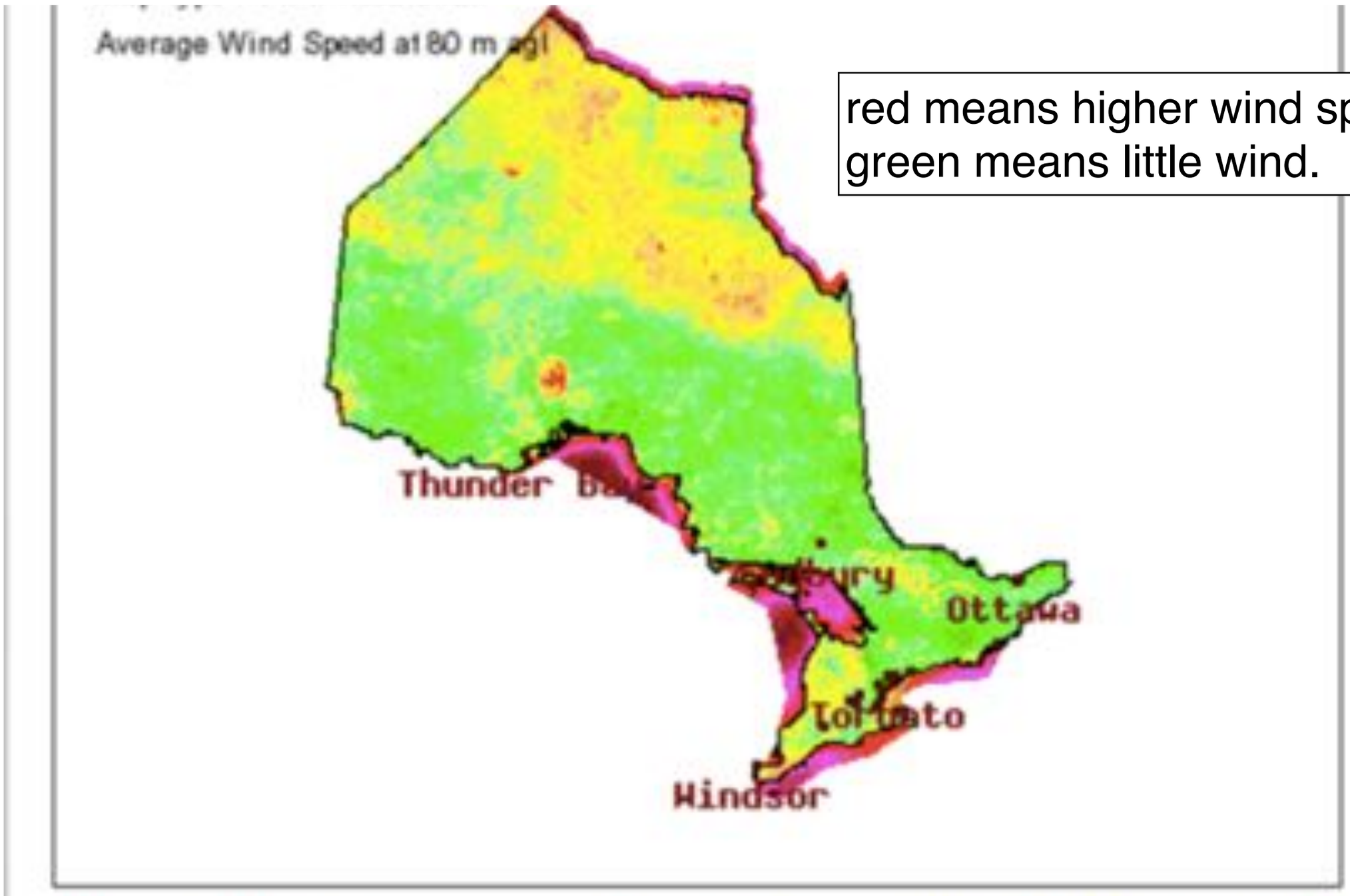
raw wind power

raw sunshine



Will Wind energy ever be the dominant player?

Fortunately, wind power is highly concentrated in… windy areas.
Mostly off-shore.



red means higher wind speed
green means little wind.

Figure 3: Ontario wind resource atlas. © Queen's Printer for Ontario, 2005.

Will Wind energy ever be the dominant player?

.no fuel cost, mostly initial investment/maintenance/back-up

.levelized cost approaches that of conventional fuel
— Ontario FIT for wind is $0.12/kWH (electricity $0.1/kWH)

.2013 world installed capacity: 300 GW (2x solar),

. doubling time every 3 years;

. wind energy faces many of the same hurdles as solar
— storage, intermittency (need back-up)

Summary: renewables

. We focus on solar and wind energy for electricity generation. — Ignore biomass/biofuel.

. Solar has the largest energy density among all. Solar electricity almost reaching ‘grid parity’.

. Wind has a much smaller energy density, but concentrated. Price for Wind energy is at ‘grid parity’.

. solar & wind capacities double every 3 year.
— Reach 8 TW in 15 years?

. Will solar + wind + nuclear halt the global warming trend?

EIA prediction for non-hydro renewable electricity generation