Energy (actually Power): How can we think about alternatives?

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Quick thought?

- Progression of thinking
  - You are approaching the time of most growth and expansion of your intellectual capabilities
  - What could be happening?

Engineering!

- Knowledge ⟶ Understanding (College)
- Novel creation + quantitative skills

Outline

- Energy (Power if we want to use it!)
  - How can we think of different technologies?
    - Underlying chemistry
    - Cost
    - Energy density
    - Clean or not?
    - Sustainable or not?

Rise of oxygen (why we breath air!)

Two classes of reactions that use glucose

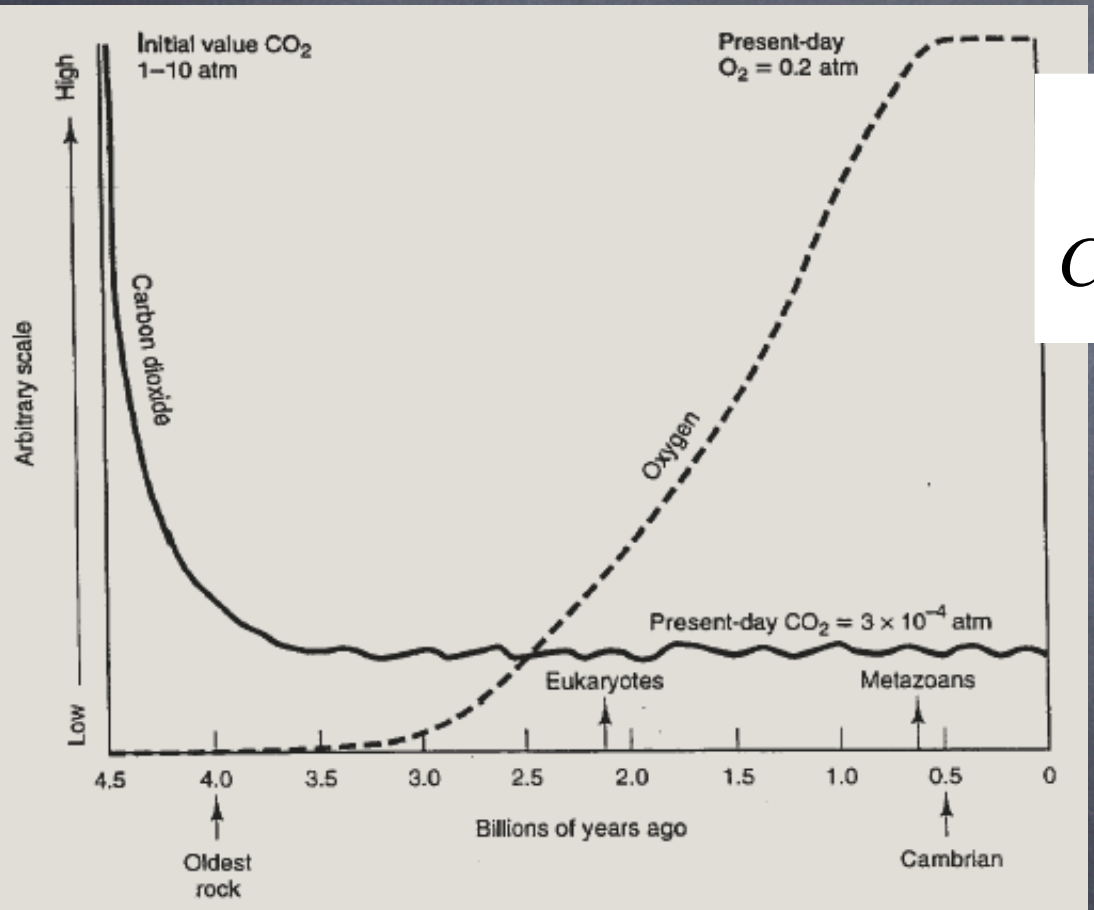

FIGURE 3–10 The history of oxygen and carbon dioxide in the atmosphere during Earth history.

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Aerobic digestion is 17 times more energetic than anaerobic digestion

All of this oxygen comes from various kinds of plant growth

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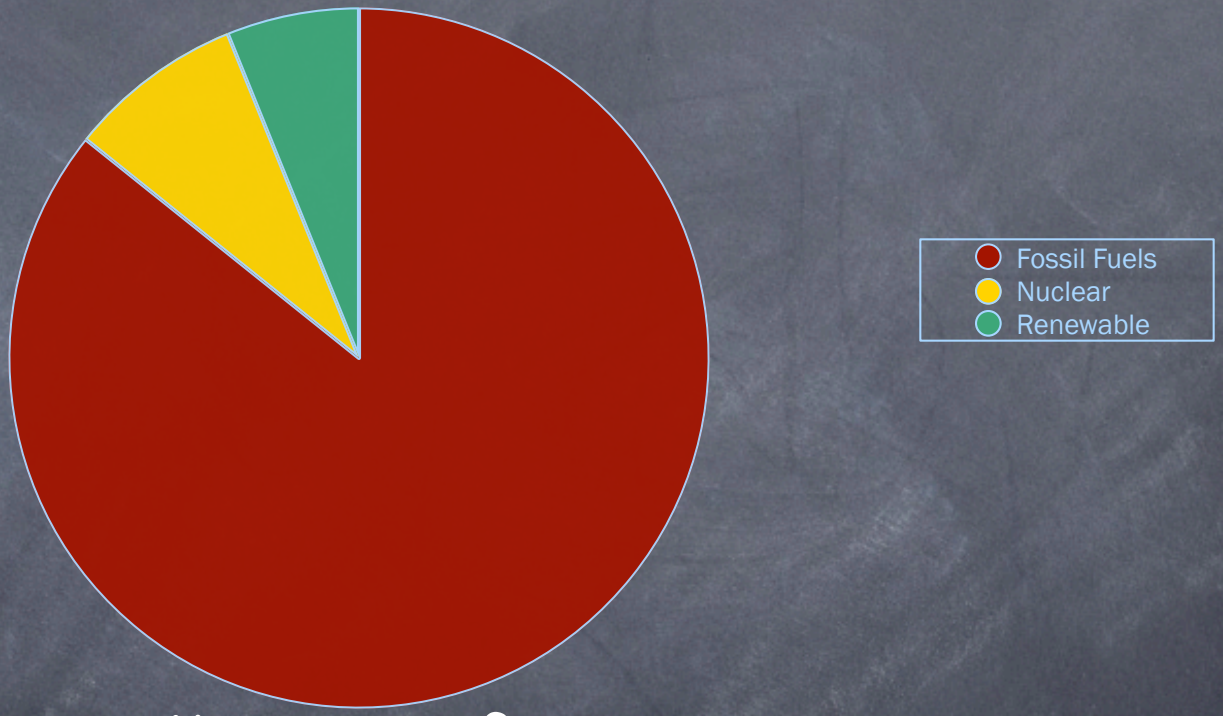
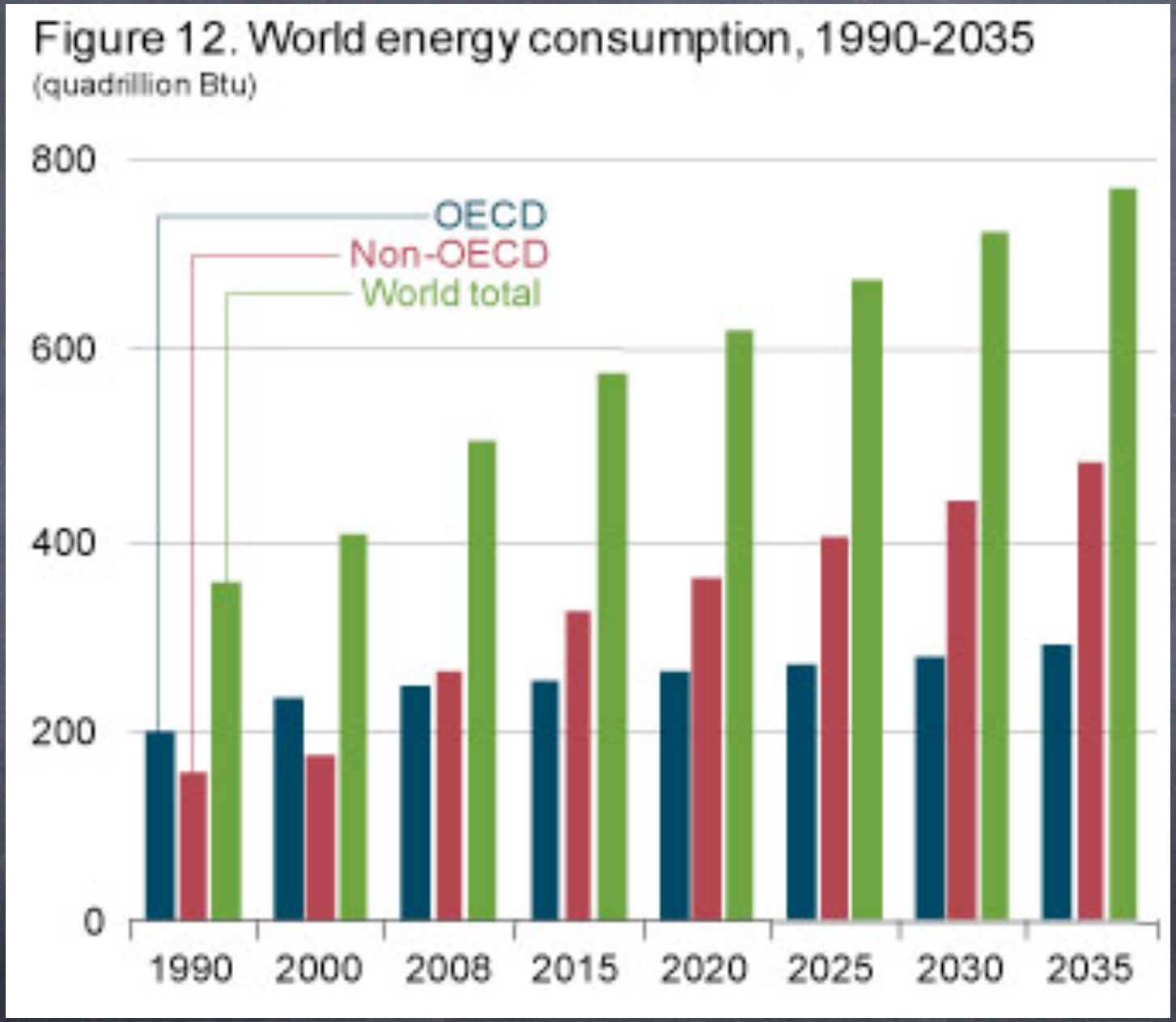
"Oxidation States" of Carbon

- -4 Methane
- -2 Hydrocarbons, Alcohols, Oil
- -1 Aromatics, Lipids
- 0 Carbohydrates, Coal
- +2 Carbon Monoxide
- +4 Carbon Dioxide

Energy for society



- Where it comes from now!
- Will it change?



Growth is about 2.5%/yr

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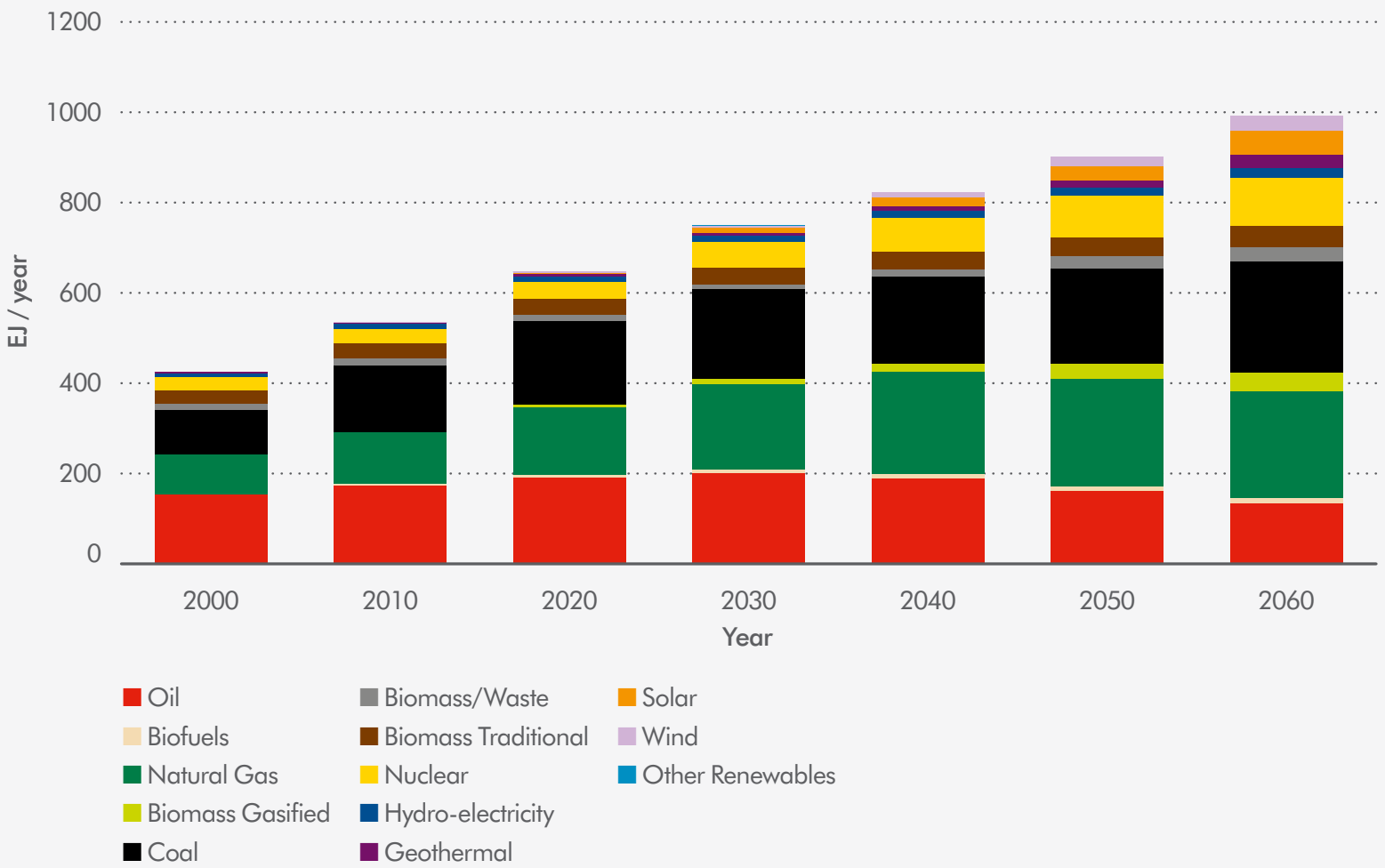
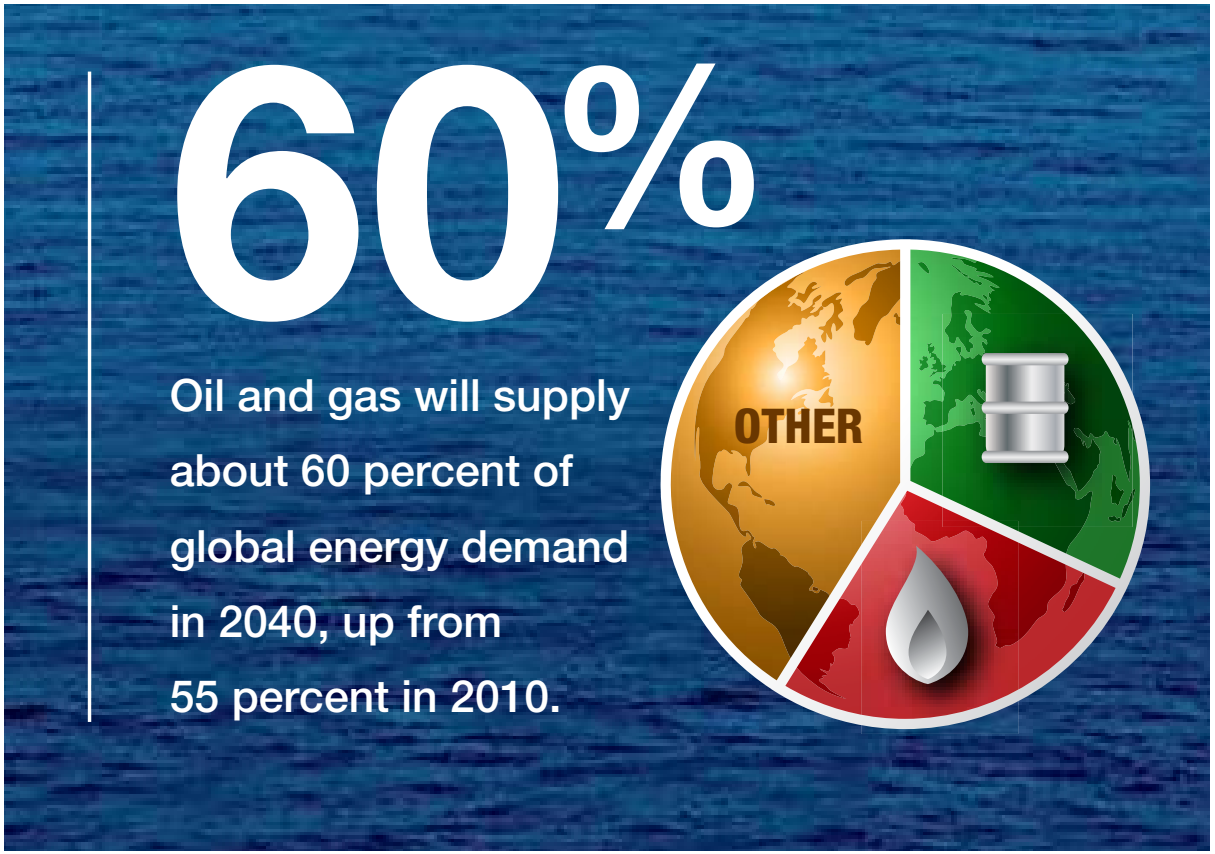
TOTAL PRIMARY ENERGY BY SOURCE



Really!!



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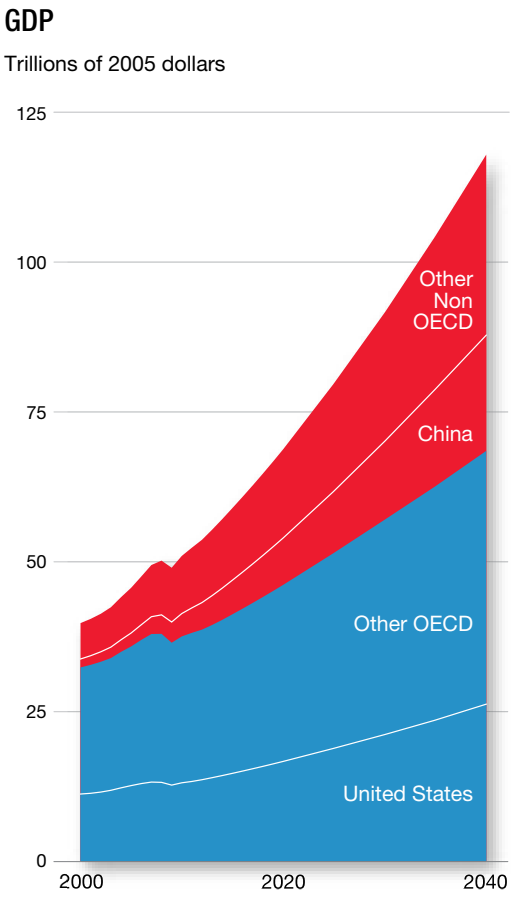
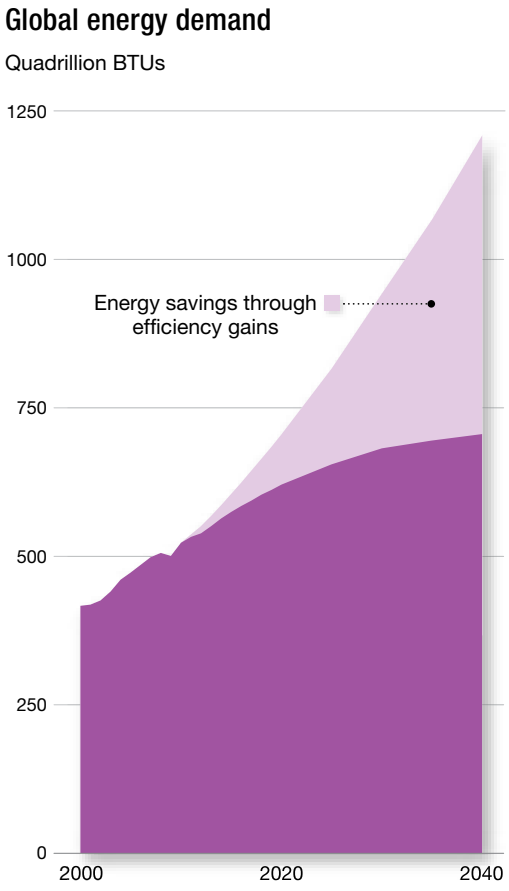
Best "new" energy source?





500 quadrillion

Businesses and consumers will help generate energy savings of about 500 quadrillion BTUs across our economies in 2040. The greatest source of energy for the future is continuing to use it more efficiently.

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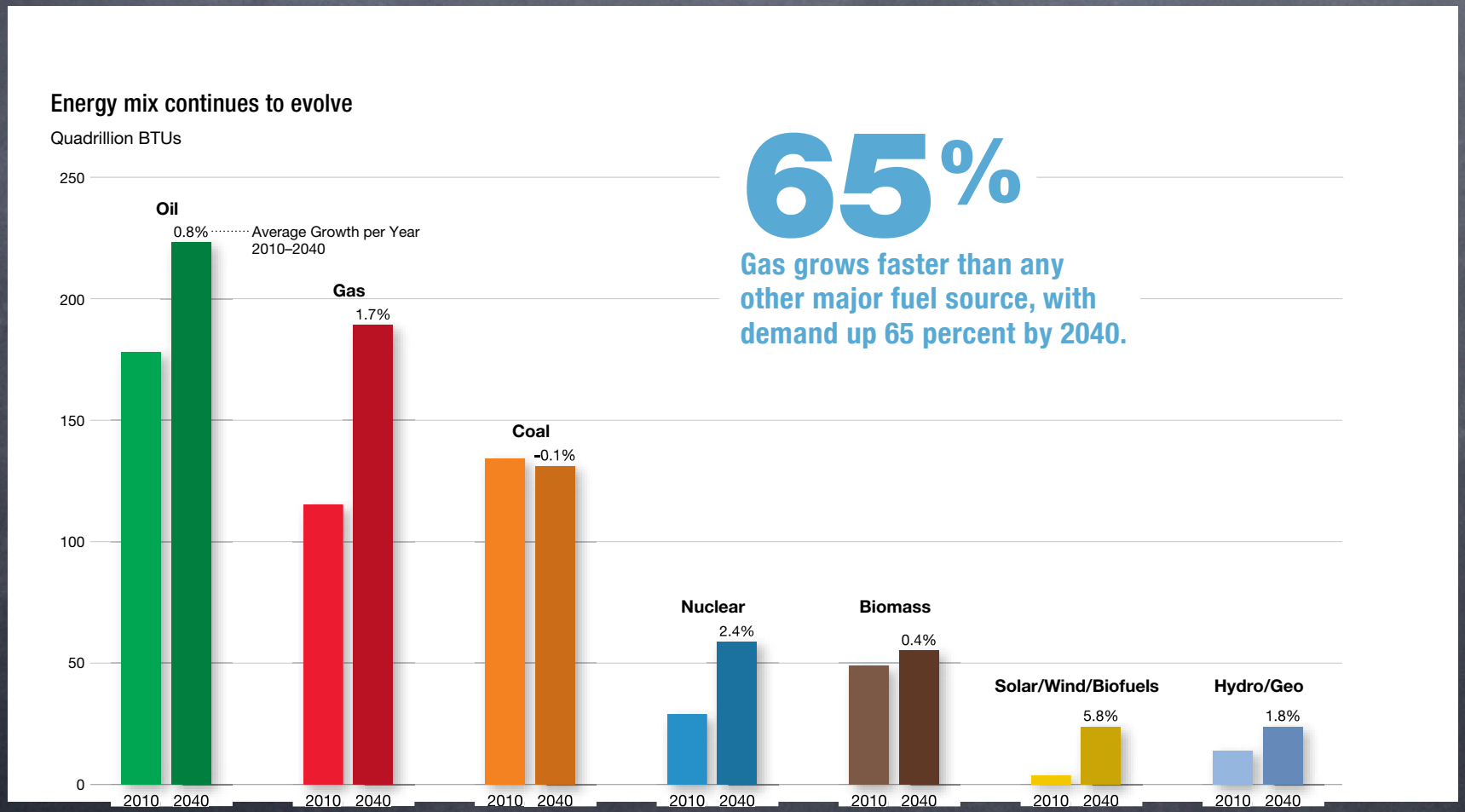
Changing energy mix



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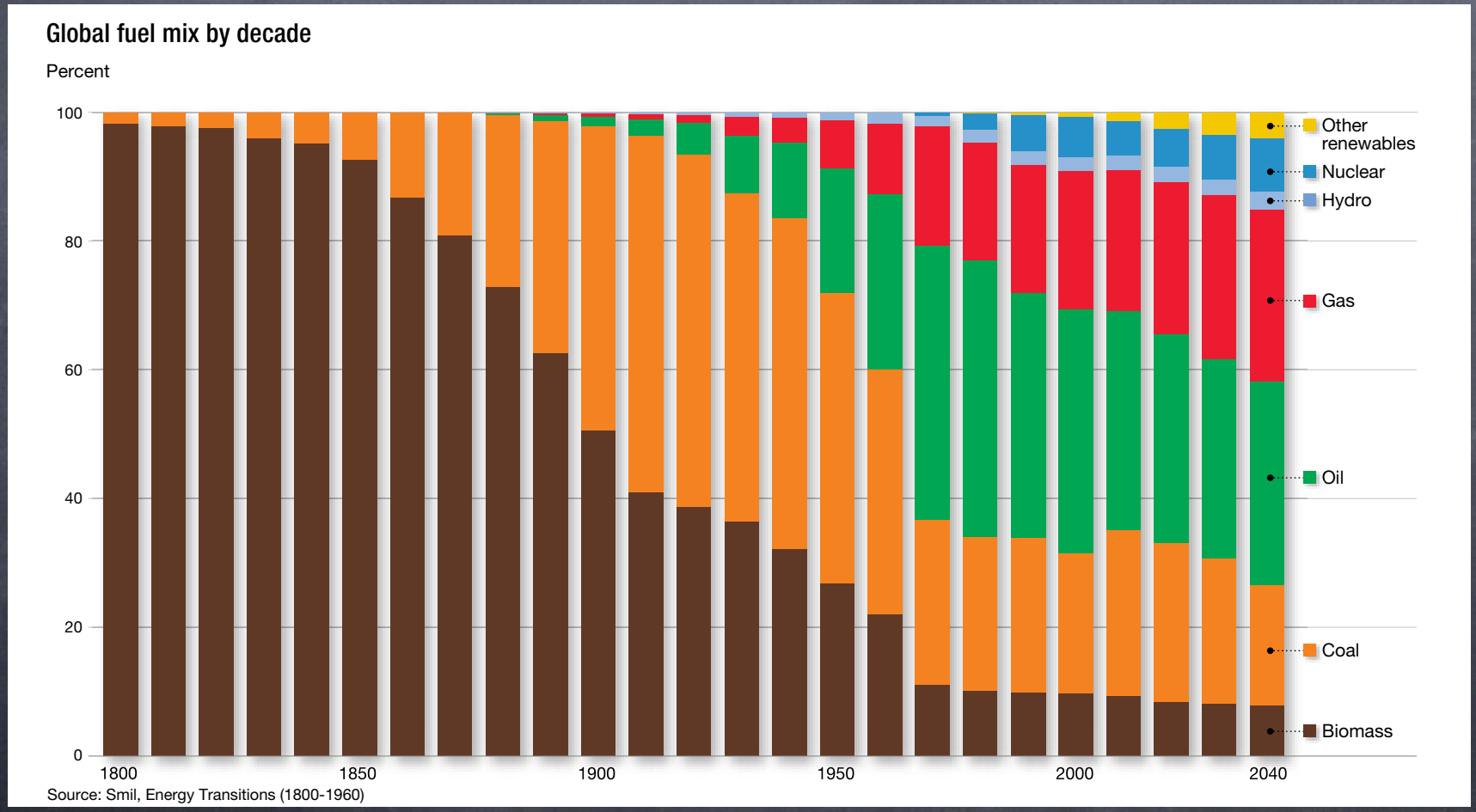
Changing energy mix



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Power by "cost"

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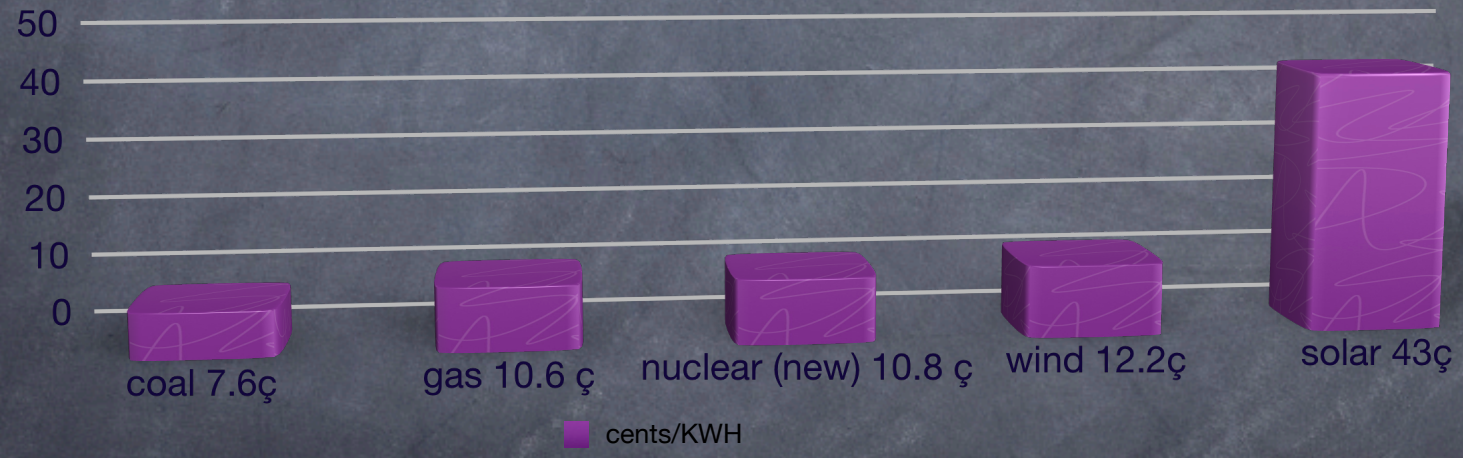
New construction: Electricity Cost

Solar is too High

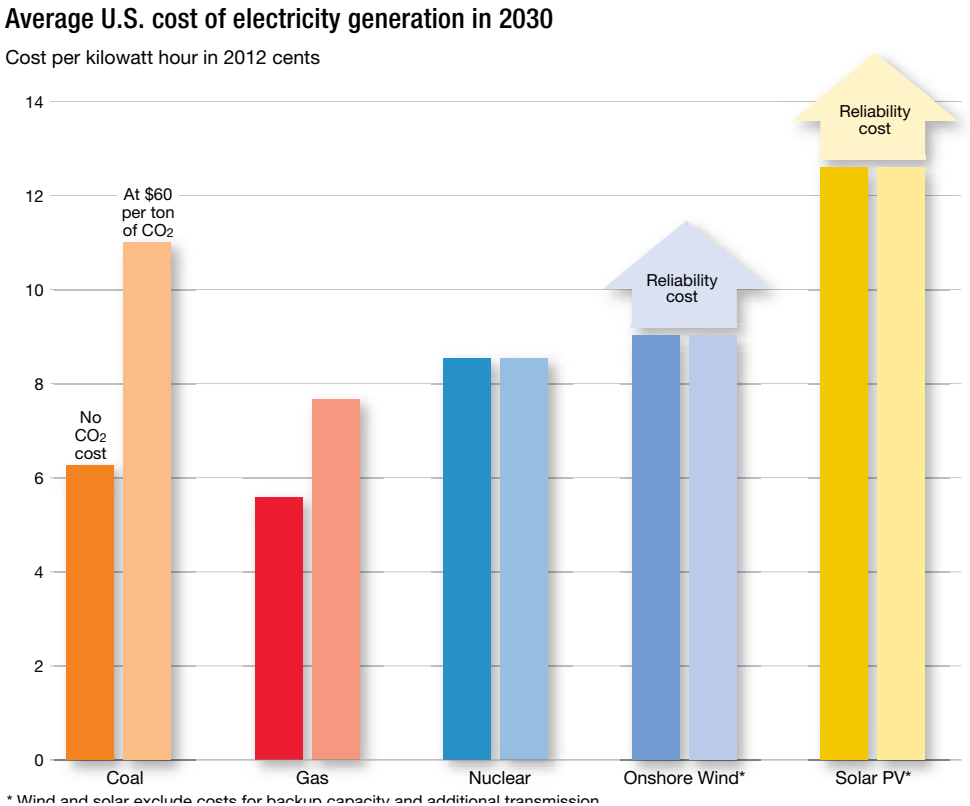
Wind is higher than Coal



Loaded Cost of Electricity

(Cents per kWh)

Future cost of electricity



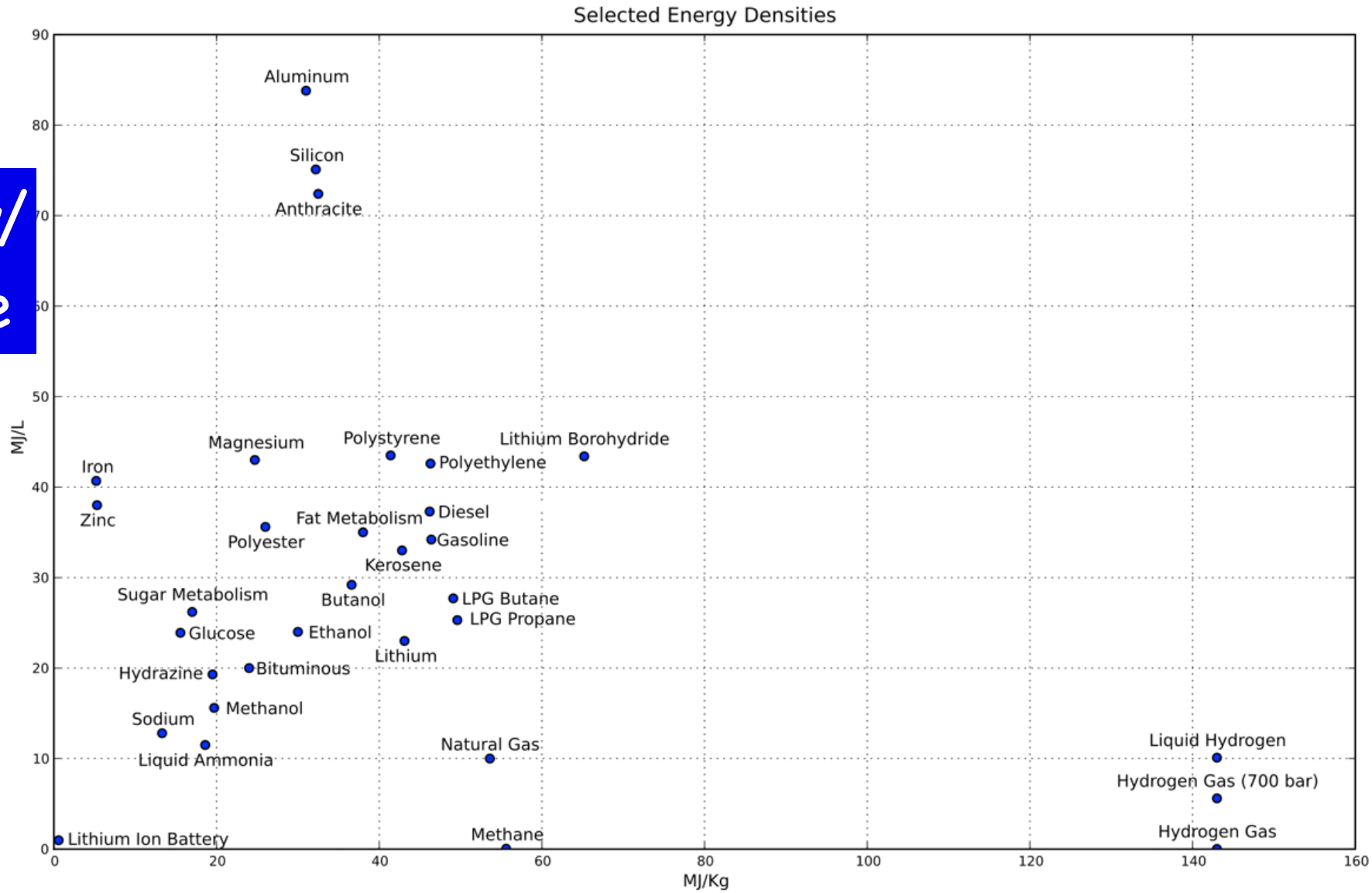
60%

Natural gas, which emits up to 60 percent less CO_2 than coal when used for electricity generation, will gain the most. By 2040, natural gas will account for 30 percent of global electricity generation, compared to just over 20 percent today.

Power Density

- How much power can be produced from:
  - A fixed weight of fuel
    - important for transportation
  - A fixed volume of fuel
    - a real problem for a small vehicle
  - On a given amount of land area

Energy/ volume



Energy/mass

Major Challenges

Energy density of hydrogen

	kWh/kg	kWh/gal	Eq. vol.(gal) (5 kg H
H	33.3	5.0	33
Liquid H	33.3	8.9	18
Gasoline	11	33.6	8.3

PURDUE UNIVERSITY

Challenges of renewable Energy: Land area use

- Let's consider
  - Wind
  - Solar
  - Biomass

Wind

- Roughly, it takes 350-450 square miles of windmills (approximately 13000 wind turbines) to produce the electrical equivalent of a large coal or nuclear plant: 1000MW.
- This is the size of St. Joseph Co. IN
- 300,000 people live here and we use about 600 MW
- We don't have very good wind here (so it would not work) and it would seem a bit inconvenient to cover 1/2 of the county with windmills

Energy Density of Wind and solar

- If we work out the numbers, the power density of wind is about
  - 0.004 MW/acre
- What could we compare this to (Engineers always want to make comparisons!)
- How about solar flux?
  - We can capture only part of the solar flux for useful heat, much less for electricity
    - What are these numbers?
- Solar flux averaged over the earth is ~350 W/m^2
- While nothing more energetic than a tree "runs" directly on solar, this gives a value of about
  - 0.3 MW/acre

Solar Land Area Requirements

Energy Density of Ethanol from corn

- About 2.7 gallons of ethanol can be obtained from a bushel of corn
- Iowa can average about 160 bu/acre, which gives us about 400 gallons per acre
- This is about 1200 W/acre or 0.001 MW/acre

More about Ethanol?

- Ethanol, mostly from corn, provides about 1.5% of highway fuels in the US.
  - The cost is subsidized….
  - EtOH production from corn has a ERoEI that is estimated to range from .7 to ~1.3.
    - So ethanol may be an energy source, just not a very high density one.
  - There is no apparent pollution or green house gas benefit
  - There is not enough land area to greatly change the 1.5% number and there is definitely an effect on food prices
- Ethanol from cellulose would be a better alternative

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What Else to Compare

- 1000 MW power plant using coal might occupy 100 acres
  - This is enough power for 1 Million people in the US
- 1 really good oil well could produce 100,000 bbl/day
  - This is an equivalent amount of power

On a 100 acre Site:

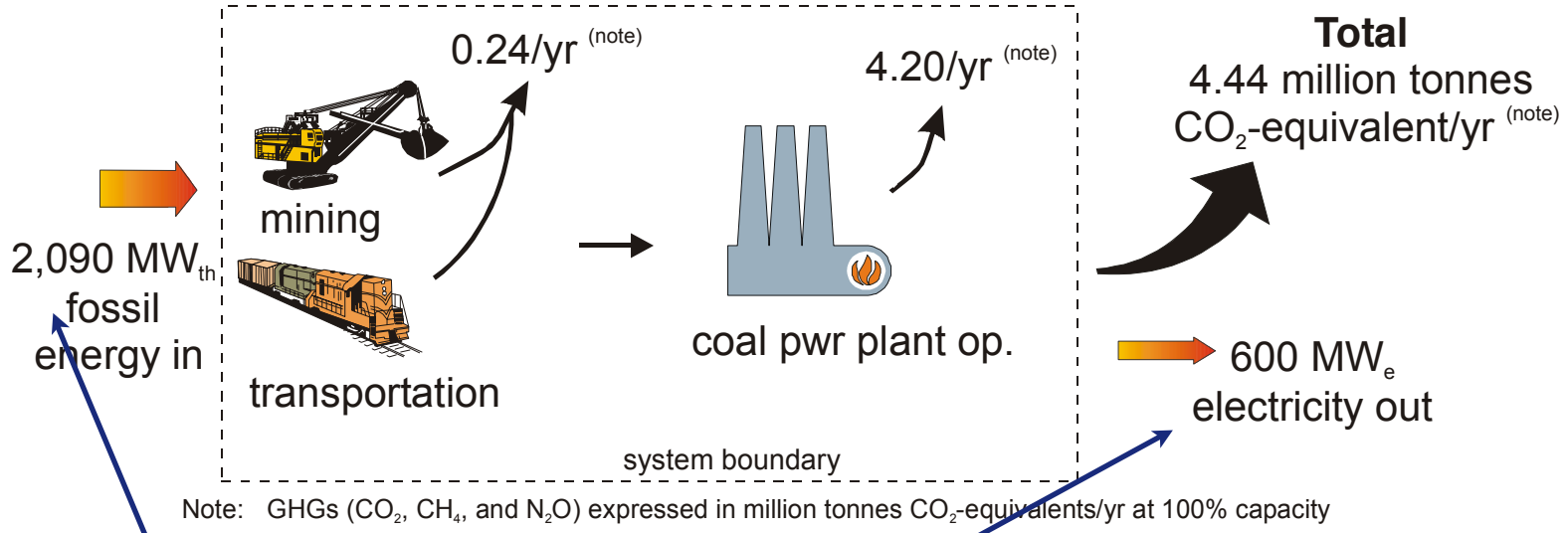
- Coal to Electricity: 1000 MW
- Solar to Electricity: 30 MW
- Wind to Electricity: 0.4MW
- Corn to liquid fuel: 0.1 MW
- 10 oil wells (surface footprint): 10 GW

Power:
Sustainable?
Clean?

- Nuclear
  - Could be...
- Solar
  - Should be...
- Biomass
  - Only if cellulosic and even then it takes a lot of land
- Wind
  - Should be
- Coal

Coal and Carbon Sequestration

Figure 1: Coal-fired Power Plant Prior to CO_2 Sequestration (600 MW)



Note: GHGs (CO_2, CH_4, and N_2O) expressed in million tonnes CO_2-equivalents/yr at 100% capacity

< 30% efficiency !

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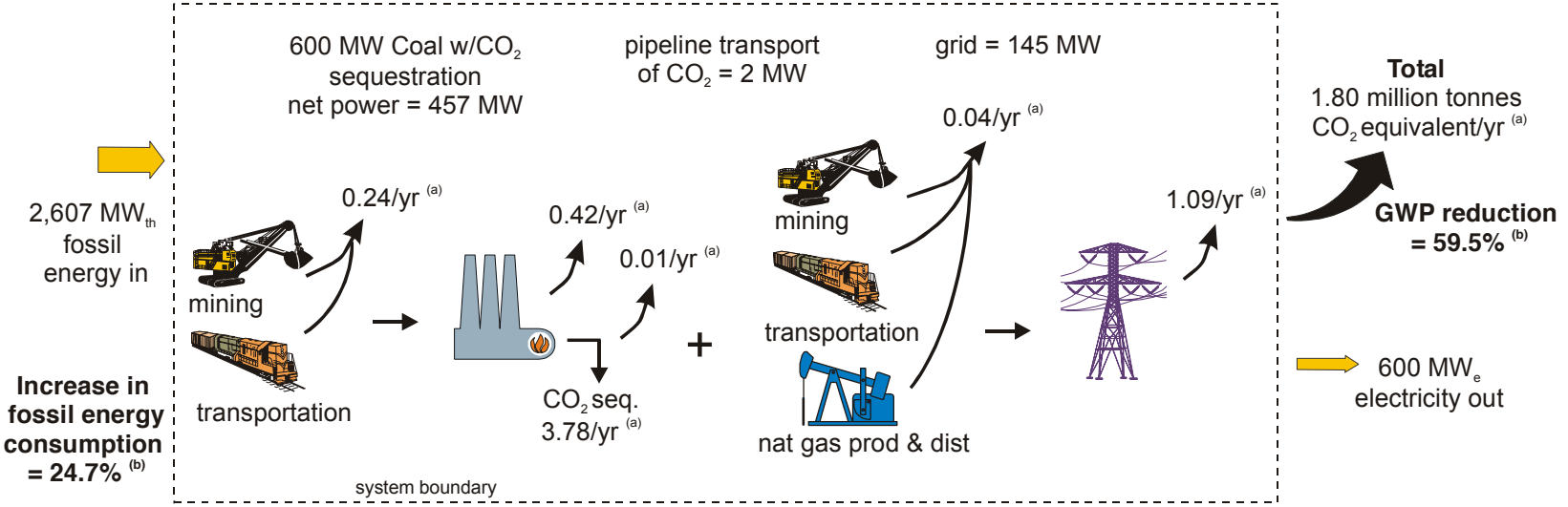
Capture and Sequester carbon

Figure 3: Coal-fired Power Plant with CO_2 Sequestration and 145 MW of Grid Capacity Added to Maintain 600 MW

(U.S. mid-continental grid mix is 64.7% coal, 5.1% lignite, 18.4% nuclear, 10.3% hydro, 1.4% natural gas, and 0.1% oil)



Notes: (a) GHGs (CO_2, CH_4, and N_2O) expressed in million tonnes CO_2-equivalents/yr at 100% capacity; (b) Change in GWP and change in fossil energy consumption compared to reference

Now even less efficient, but much less CO2 into atmosphere

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ISSUES WITH SOLAR

Los Angeles Times

Problems cast shadows of doubt on solar project

The unexpected deaths of kit foxes and discovery of ancient human settlements threaten to delay or even cancel a $1-billion, 250-megawatt installation on federal land in the desert near Blythe.

February 11, 2012 | By Louis Sahagun, Los Angeles Times

Reporting from Blythe, Calif. -- One of California's showcase solar energy projects, under construction in the desert east of Los Angeles, is being threatened by a deadly outbreak of distemper among kit foxes and the discovery of a prehistoric human settlement on the work site.

The $1-billion Genesis Solar Energy Project has been expedited by state and federal regulatory agencies that are eager to demonstrate that the nation can build solar plants quickly to ease dependence on fossil fuels and curb global warming.

A worker surveys a site where pylons are being installed on federal land... (Irfan Khan / Los Angeles Times)

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Impact of Genesis solar project on local desert kit foxes

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December 3, 2008

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A noble pursuit, but keep your eyes open!

Solar to liquid fuel

$$CO_2 + 2H_2O \xrightarrow{h\nu} CH_3OH + \frac{3}{2}O_2$$

Germany's sunshine daydream

FEBRUARY 16, 2012 - 4:39PM

Bjørn Lomborg

About the Author

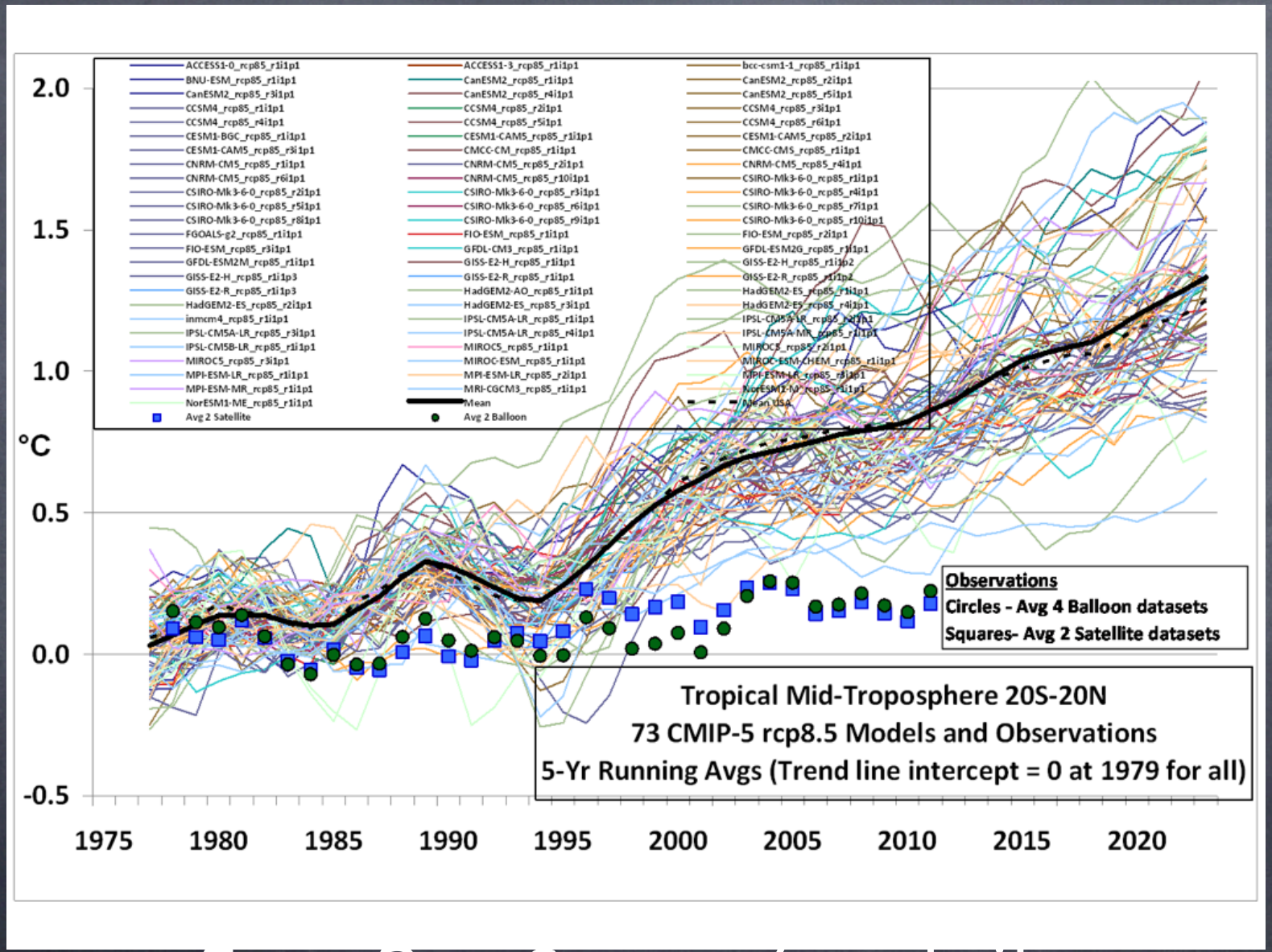
COPENHAGEN – One of the world's biggest green-energy public-policy experiments is coming to a bitter end in Germany, with important lessons for policymakers elsewhere.

Germany once prided itself on being the 'photovoltaic world champion', doling out generous subsidies – totaling more than $130bn, according to research from Germany's Ruhr University – to citizens to invest in solar energy.

Solar Energy Storage

- In atmospheric pressure gradients (wind) and terrestrial elevation gradients (hydro)
- In carbon in the zero oxidation state (biomass or coal)
- In carbon in other oxidation states (via disproportionation, digestion, fermentation)
- In other redox systems (batteries)

Climate models and data



From Roy Spencer's website

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Recap

- One way to compare potential utility of energy systems is to look at power produced per acre of land
  - Coal to Electricity: 1000 MW
  - Solar to Electricity: 30 MW
  - Wind to Electricity: 0.4MW
  - Corn to liquid fuel: 0.1 MW
  - 10 oil wells (surface footprint): 10 GW
- We breath air and use oxygen in metabolism because this is 17 times more energetic than a non-aerobic digestion reaction

Recap continued

- Current energy sources are ultimately unsustainable and cause at least some degree of extra forcing on climate stability
- Solar could provide all of the power society needs, but current costs are much too high and current storage technologies inadequate

Engineers like to compare things

- If I asked: ".. how far is it to Chicago?"
  - would you answer
    - "a couple of hours" or...
    - "about 90 miles"
- If I asked: ".. is a meter a long distance?" what would you say
  - "No", compared to the distance to Chicago
  - "Yes", compared to a micron

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Importance of dimensionless numbers

- Reynolds number: $\frac{Inertia\ \ forces}{Viscous\ \ forces}$
- Another number
- $$Cr \equiv \frac{How\ \ Smart\ \ You\ Are}{How\ \ Smart\ \ You\ \ Think\ \ You\ \ Are}$$

Dimensionless Confucius Proverb

$$Cr \equiv \frac{How\ \ Smart\ \ You\ Are}{How\ \ Smart\ \ You\ \ Think\ \ You\ \ Are}$$

- He who knows not and knows he knows not is a child, teach him, Cr~1
- He who knows not and knows not he knows not is a fool, shun him, Cr<<1
- He who knows and knows not he knows is asleep, awaken him, Cr>>1
- He who knows and knows he knows is wise, follow him Cr~1

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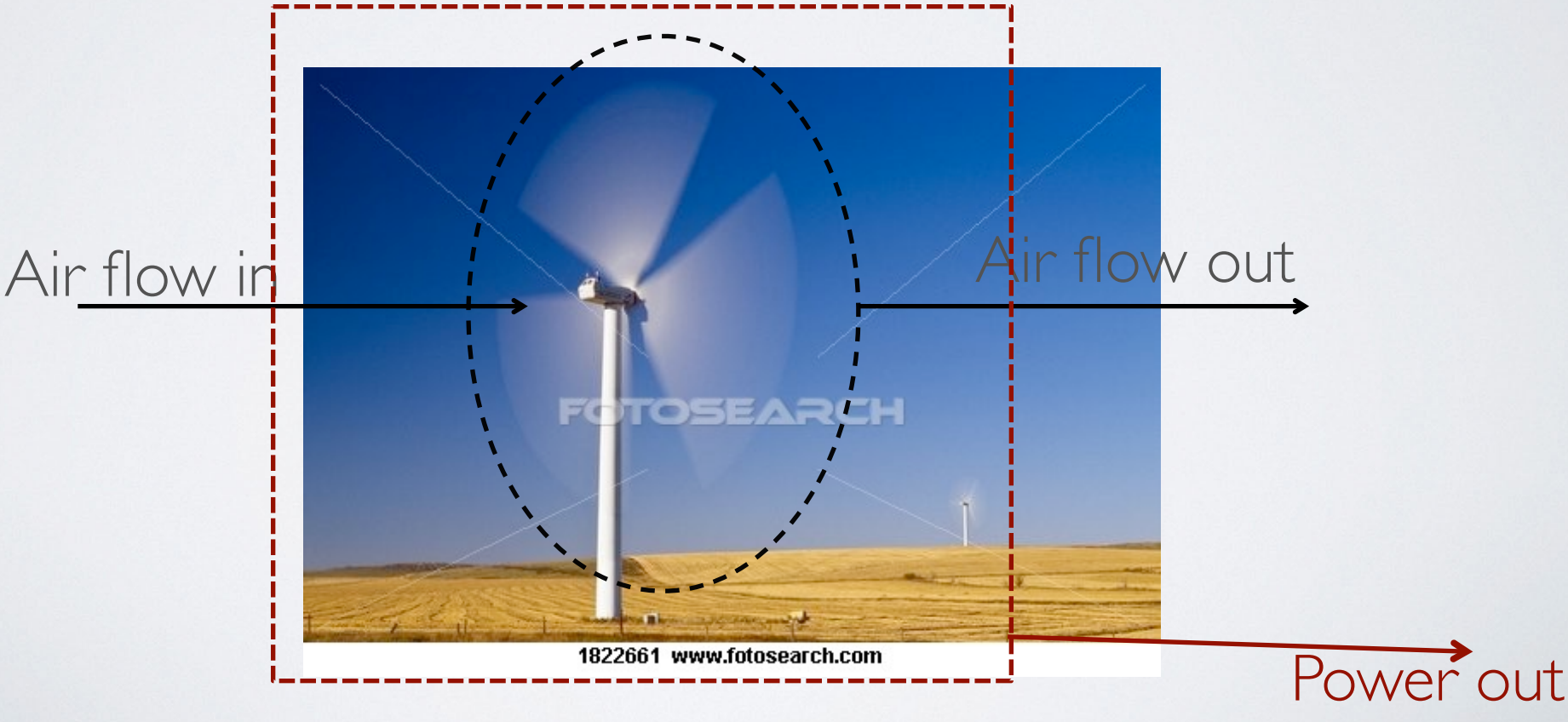
Mathematical analysis

- Could be pretty simple:
- What if we read the Wall Street Journal
  - Wind power
  - http://online.wsj.com/article/SB10001424127887324310104578507242336481504.html?KEYWORDS=wind+energy

POWER AND WIND SPEED?

- How does the power generated by the windmill change with wind speed?
  - How is power being generated?
    - Wind flows through area swept by blades
    - Windmill converts this kinetic energy to electric power



POWER AND WIND SPEED?

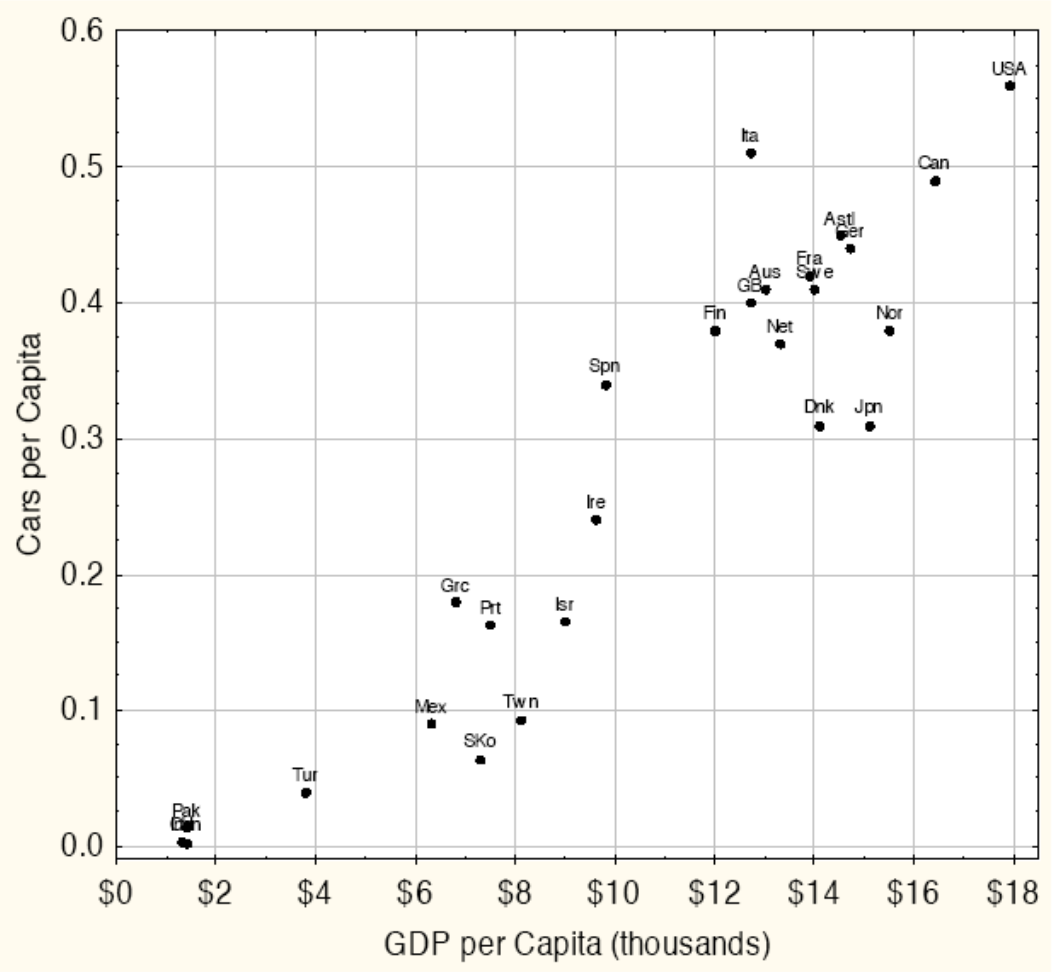
- How does the power generated by the windmill change with wind speed?
  - Let's see if we can figure this out based on dimensional reasoning
    - Power is work/time which is force * distance/time which is mass* acceleration *distance/time
    - Thus we could write

$$power = m\ \ l / t^2 l / t = \frac{ml^2}{t^3}$$

    - What variables could be used?

We can predict numbers of cars

Cars/capita vs. GDP/capita by country, 1992



GDP in $1990 at PPP

Source: Dargay & Gately, NYU, 1997

Joel Schwartz
Visiting Fellow
American Enterprise Institute

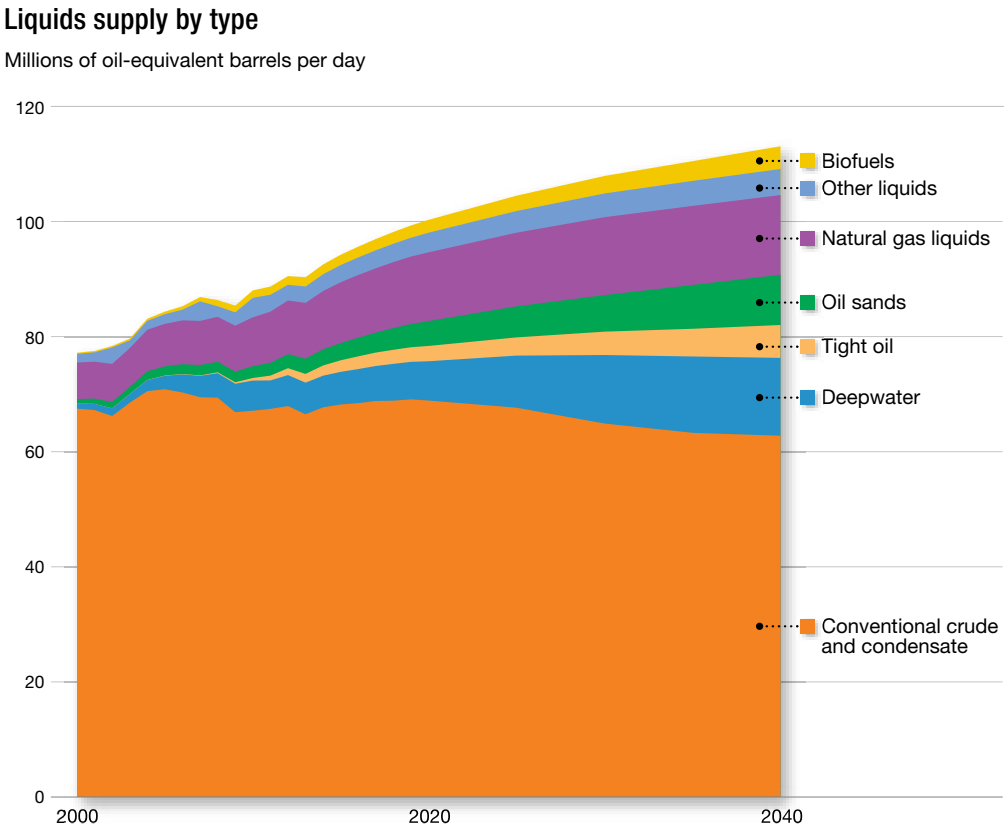
EQUATION FOR POWER FROM WIND

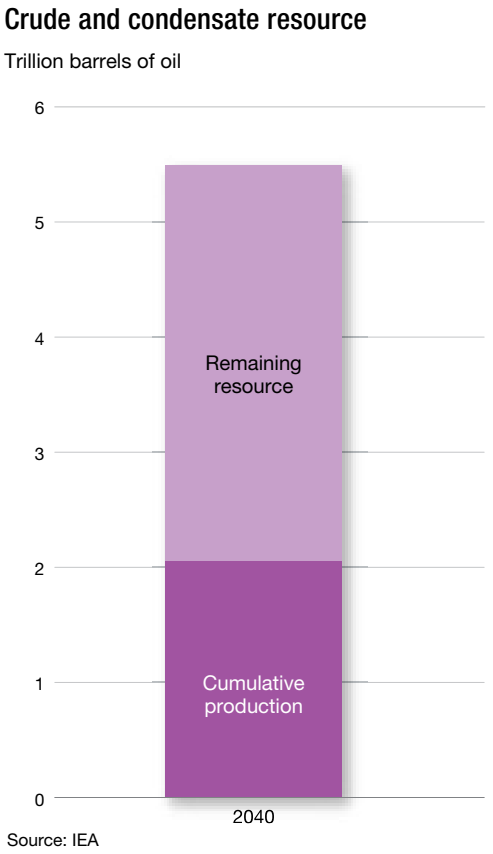
- Windspeed, blade diameter, air density
  - v [=] l/t
  - d, r [=] l
  - Density of air ρ [=] m/l^3
  - Arrange these variables to get dimensions of power:

$$power \sim \rho v^3 d^2 [=] \frac{ml^2}{t^3}$$

  - If the wind speed doubles, the power increases by a factor of 8!

Liquid fuels





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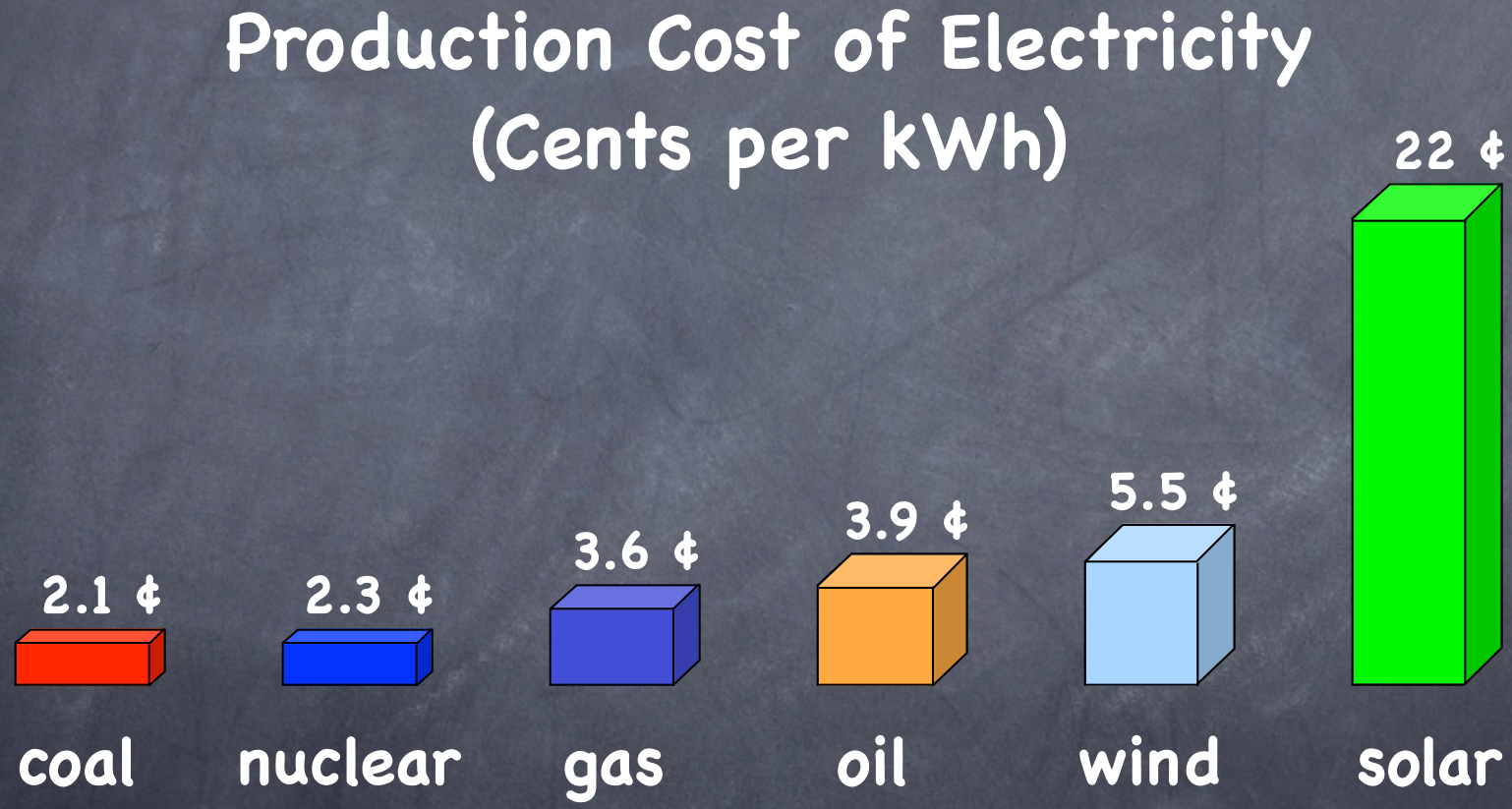
Is cost the best way to think about energy?



Source: N. Lewis