Engineering: How can we define it?

Mark J. McCready

Professor of Chemical and Biomolecular Engineering

Senior Associate Dean for Research and Graduate Studies

College of Engineering

http://ndcbechair.blogspot.com/

Outline

- Part of your interest here is to decide if you want to major in engineering in college and...
  - If you want to be an engineer
- Thoughts about what engineering is
  - A definition and some context
  - Use of mathematical analysis: Ultimate engineering tool
  - How engineers think
    - We practice engineering in society so we need to understand people!

Definitions of engineering

en·gi·neer [en-*juh*-**neer**] [?] Show IPA *Dictionary.com Unabridged*

noun

1. a person trained and skilled in the design, construction, and use of engines or machines, or in any of various branches of engineering: *a mechanical engineer; a civil engineer.*

engineering Use **Engineering** in a sentence Like

en·gi·neer·ing [en-*juh*-**neer**-ing] [?] Show IPA

noun

1. the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, buildings, mines, ships, and chemical plants.

2. the action, work, or profession of an engineer.

3. skillful or artful contrivance; maneuvering.

Origin:
1710–20; engineer + -ing[1]

en·gi·neer·ing

/ˌenjəˈni(ə)riNG/

noun

noun: **engineering**

the branch of science and technology concerned with the design, building, and use of engines, machines, and structures.

- the work done by, or the occupation of, an engineer.
- the action of working artfully to bring something about.
  "if not for Keegan's shrewd engineering, the election would have been lost"

en·gi·neer

/ˌenjəˈni(ə)r/

verb

gerund or present participle: **engineering**

design and build (a machine or structure).
"the men who engineered the tunnel"

- skillfully or artfully arrange for (an event or situation) to occur.
  "she engineered another meeting with him"
  synonyms: bring about, arrange, pull off, bring off, contrive, maneuver, manipulate, negotiate, organize, orchestrate, choreograph, mount, stage, mastermind, originate, manage, stage-manage, coordinate, control, superintend, direct, conduct; More
- modify (an organism) by manipulating its genetic material.
  "genetically engineered plants"

en·gi·neer·ing ***noun*** \-ˈnir-iŋ\

: the work of designing and creating large structures (such as roads and bridges) or new products or systems by using scientific methods

: the control or direction of something (such as behavior)

Full Definition of ENGINEERING Cite! g+1 Like

1 : the activities or function of an engineer

2 a : the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people

b : the design and manufacture of complex products <software *engineering*>

3 : calculated manipulation or direction (as of behavior) <social *engineering*> — compare GENETIC ENGINEERING

See engineering defined for English-language learners »
See engineering defined for kids »

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What do engineers do?

- Or, you may have heard it stated that "engineers solve problems..."
- What engineers really do is:
- *Engineers understand how to use techniques of engineering analysis to design (i. e., synthesize) substances, devices and processes even though they have an imperfect understanding of important physical, chemical or biological issues. Furthermore engineers operate under constraints caused by a need to produce a product or service that is timely, competitive, reliable, and consistent with the philosophy and within the financial means of their company.*
- *We need to use all that we know to produce the best answer to a problem!!*

Underlined words

- 1. Engineering analysis

- Engineers use "mathematical models" to describe reality in sufficient detail to produce quantitative results.

- (It is not engineering until we produce some numbers!!)

Underlined words

- 2. Imperfect understanding

- Most significant engineering problems cannot be analyzed and solved exactly.

-

- Thus we need our models or our understanding of phenomena gained by experiment to capture the important features and (usually) ignore a lot of unessential detail.

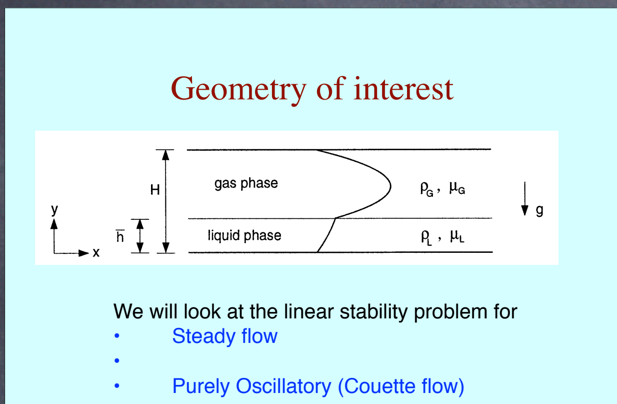
Curveball vs. knuckle ball

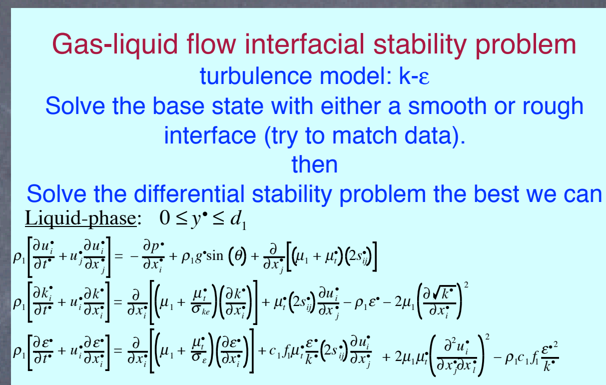
- We tried to make the argument that the imperfectness of a baseball is important to the pitching of a knuckleball, which does not spin and not important in the pitching of a curveball which spins fast. The same effect can either be important or incidental. This is because important issues always as ratios between competing effects. Engineers need to make the decision about what is important!!

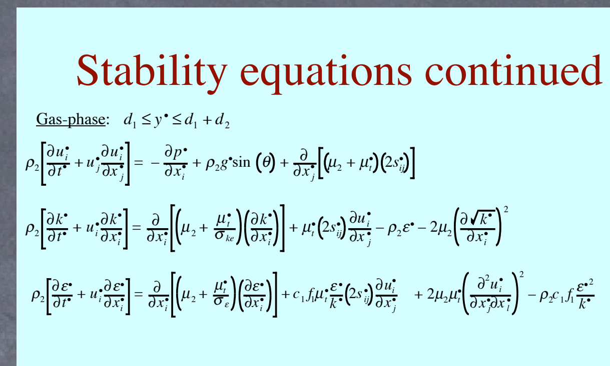
Mathematical Analysis

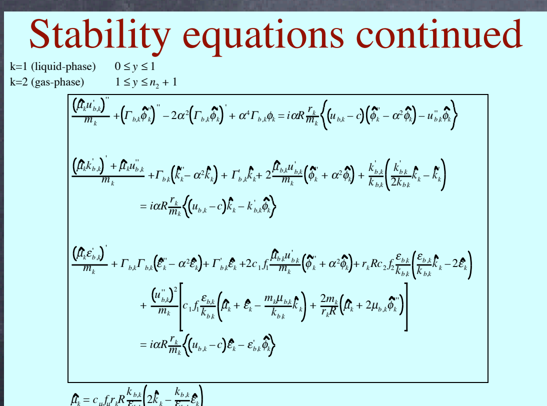
- We would like to know how a device, process or system behaves "before" we build it
  - The only way that this is possible is with accurate mathematical "models" (collections of mathematical equations, that could be based on physical laws or verified observations that represent **reality** sufficiently well)

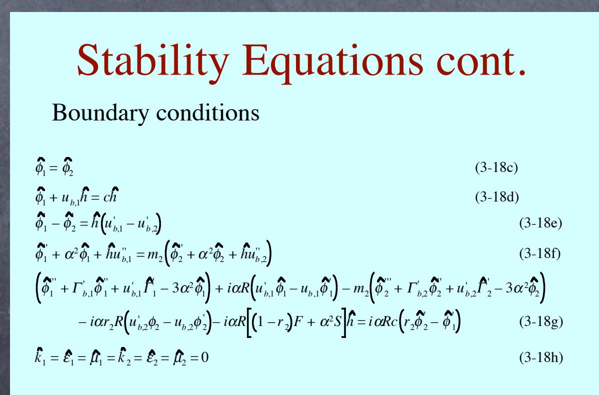
Mathematical modeling can be complex

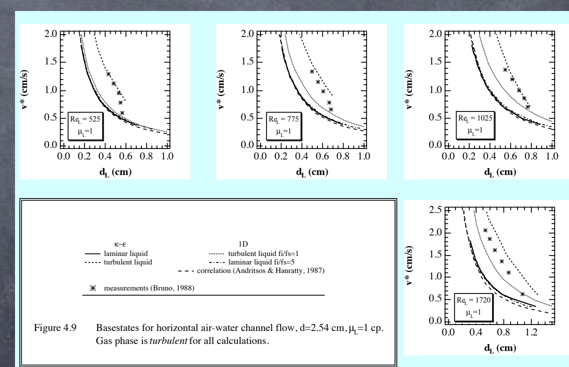










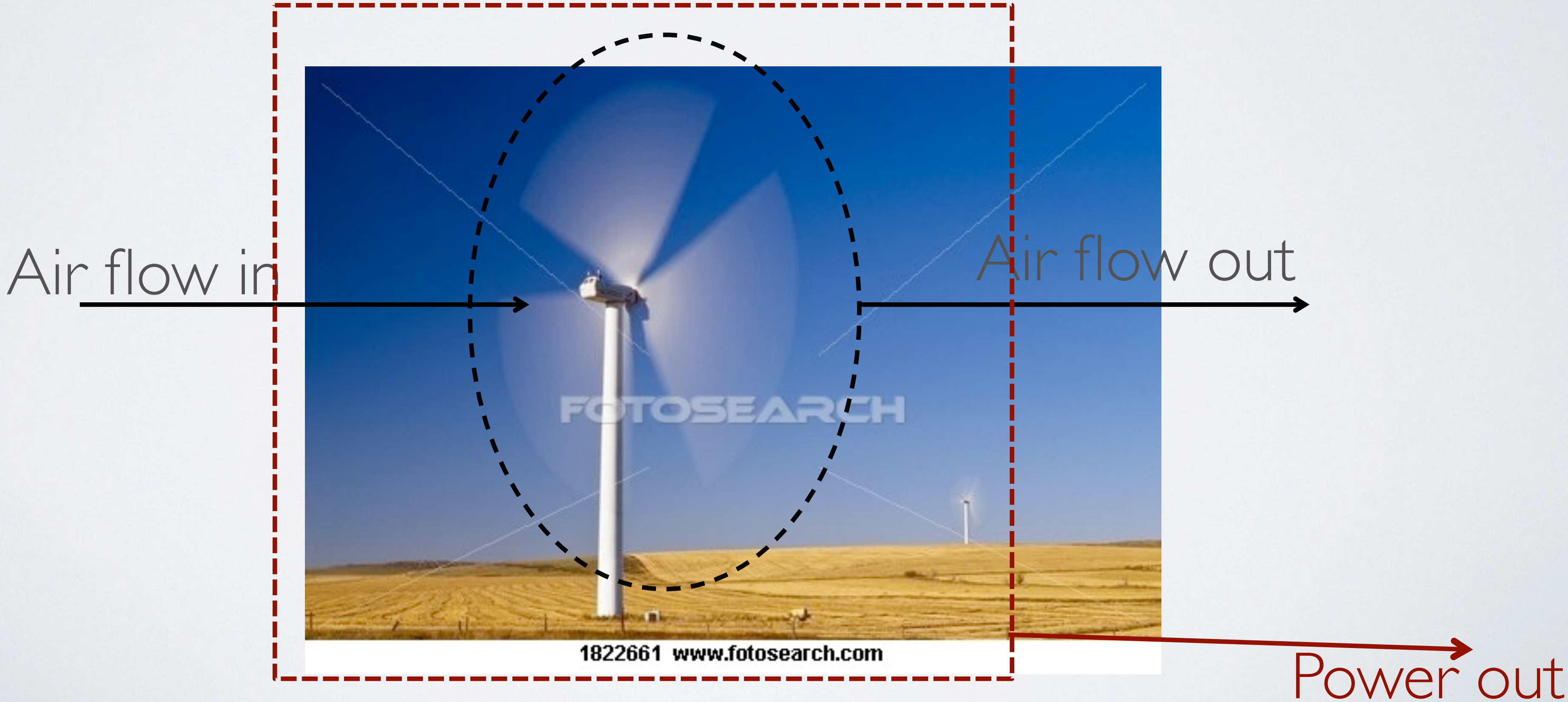


Mathematical analysis

- 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?

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!

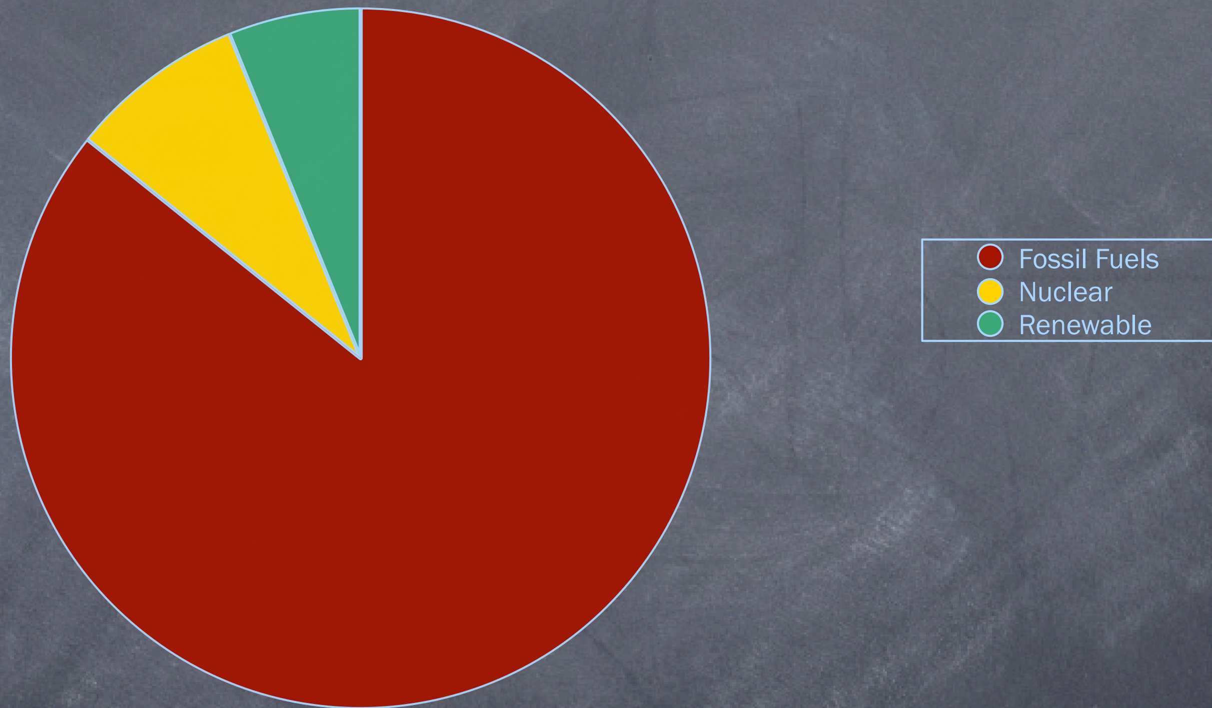
Topics of the moment

- Healthcare
- Energy
- The Environment
- The Economy
- Engineers are critically involved in all of these and will chart the future course
- "Society" may call these issues "problems", engineers see these as challenges to be met!
    - Major advances in all of these areas will require engineering!

Engineering in Medicine

- http://www.flukebiomedical.com/Biomedical/usen/products/default.htm
- http://www.washingtonpost.com/blogs/innovations/wp/2014/06/17/google-and-apple-want-to-be-your-doctor-and-thats-a-good-thing/

Energy for society



- Where it comes from now!!

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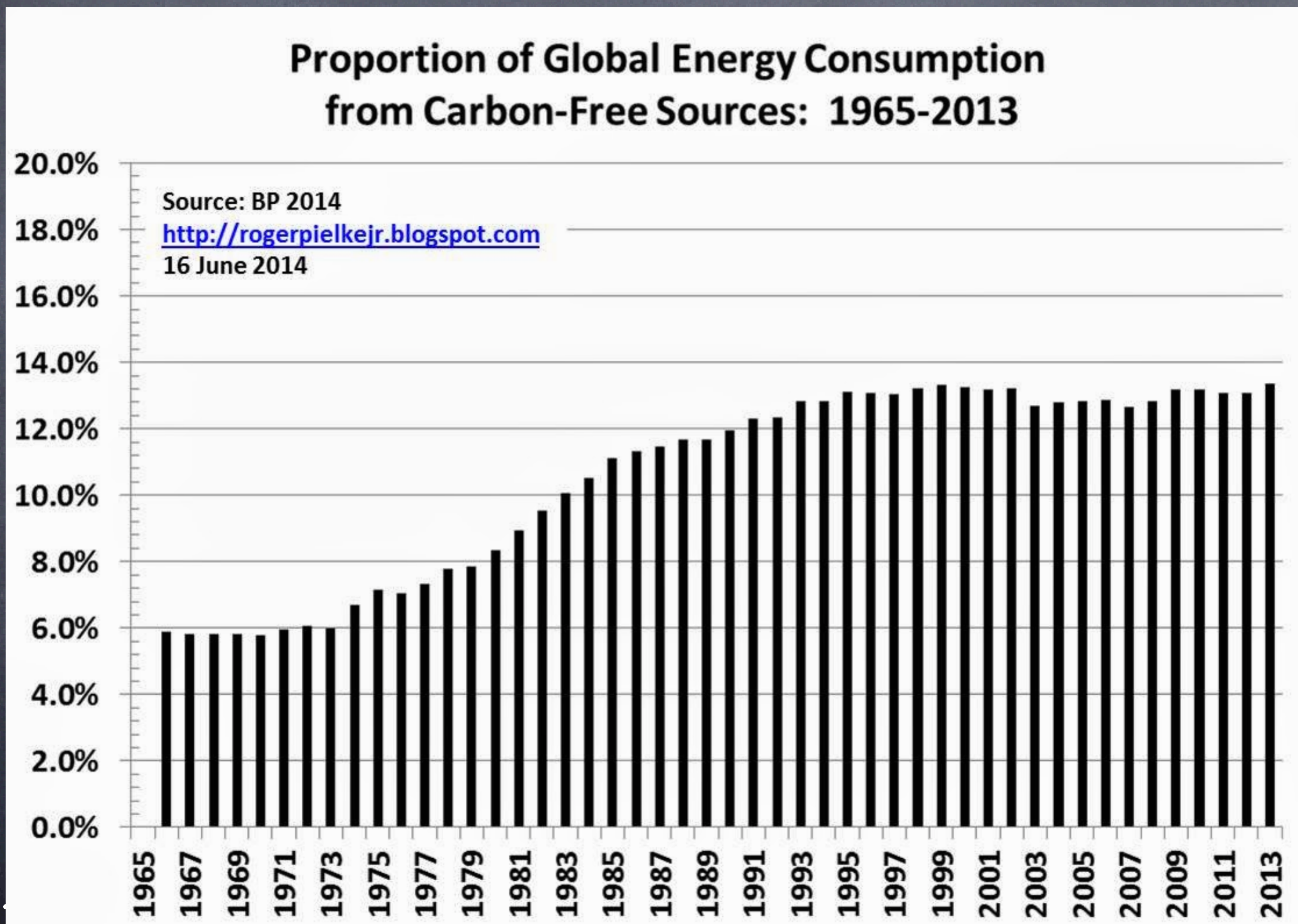
“Renewables” are not gaining ground



Energy per pound

substance	food calories	kW-hours	compared to TNT
bullet (1000 ft/s)	4.5	0.005	0.015
car battery	14	0.016	0.046
computer battery	45	0.053	0.15
alkaline battery	68	0.079	0.23
TNT	295	0.343	1
PETN	454	0.538	1.5
Chocolate chip cookie	2,269	2.6	7.7
Coal	2,723	3.2	9.2
Butter	3,176	3.7	11
Ethanol	2,723	3.2	9
Gasoline	4,538	5.3	15
Natural gas	5,899	6.9	20

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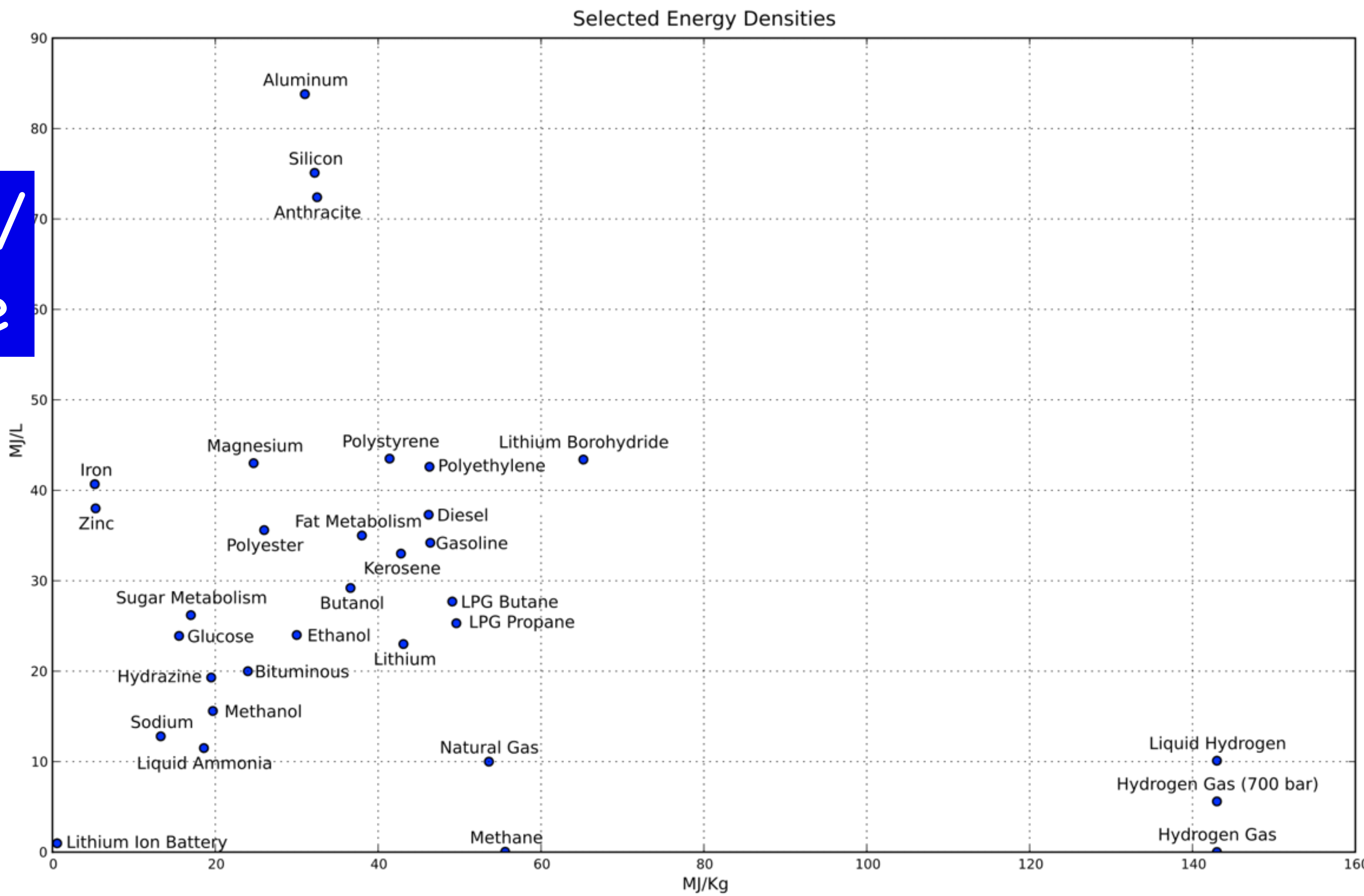
Energy/
volume



Energy/mass

Filling a gas tank

- Gasoline pumped at 4 gallons / minute; what is the rate of power transfer?
- Answer: Equivalent to 8 megawatts of power!
- Engines are 20-25% efficient
- Useful energy transfer rate: 2 MW
  - Electric power of 2000 small homes!

5 MW offshore wind turbine

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New construction: Electricity Cost

Type	Cost per megawatt-hour
Coal	100.1
Natural Gas[16]	65.6
Nuclear	108.4
Geothermal	89.6
Biomass	111.0
Non-dispatchable Technologies	
Wind (Onshore)	86.6
Wind (Offshore)	221.5
Solar Photovoltaic	144.3
Solar Thermal	261.5
Hydroelectric	90.3

When all costs are factored in—transmission, capital, operations and maintenance, etc.—natural gas continues to be the fuel of choice for electricity production in the United States because it is Cheaper than other sources. *Source*: Energy Information Administration, Annual Energy Outlook 2013.[17]

Challenges of renewable Energy

- 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

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To replace just the coal...

If You Want to Replace US Coal-fired Capacity with Wind, Then Find a Land Area the Size of Italy

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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

To get 20% of energy from biomass

From: Smaller, Faster, Lighter, Denser, Cheaper:How Innovation Keeps Proving the Catastrophists Wrong: Robert Bryce

Source: Author calculations, based on land-productivity calculations for biofuels published by Oak Ridge National Laboratory.

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

Rise of oxygen (why we breath air!)

Two classes of reactions that use glucose

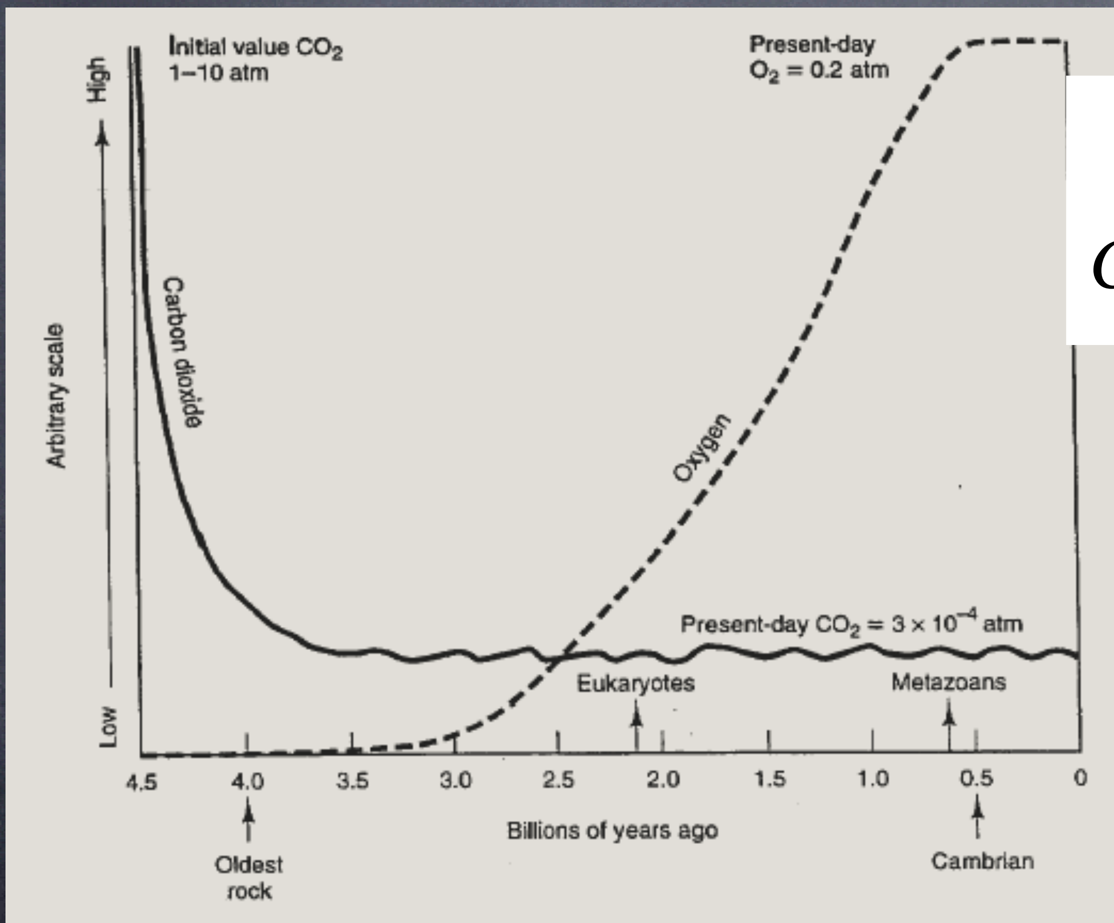

FIGURE 3–10 The history of oxygen and carbon dioxide in the atmosphere during Earth history.

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

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

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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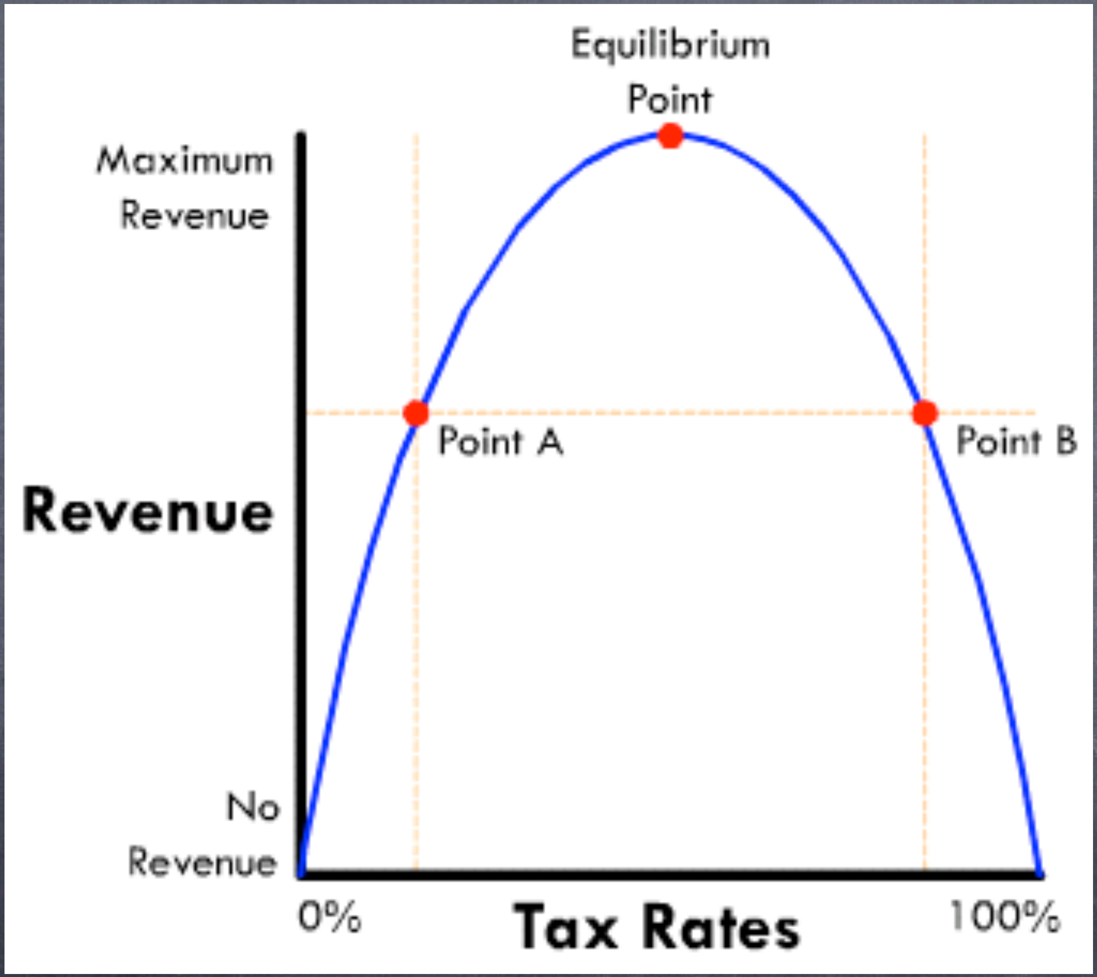
Success in life

- Skills, knowledge and ability to learn
- dedicated to task and career
- have the capacity and inclination to determine how "other people" will think and why

Taxes: Look at limits...



Recall "Extreme value theorem" or Rolle's Theorem from Calculus

Laffer tax-revenue curve

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For many years, we have been told to raise our HDL levels but..

- http://www.nytimes.com/2012/05/17/health/research/hdl-good-cholesterol-found-not-to-cut-heart-risk.html
- http://www.cbn.com/health/naturalhealth/drsears_heartattack.aspx

Relationship between salt and health?

- http://www.nytimes.com/2011/07/12/health/research/12nostrums.html?ref=health
- http://www.nytimes.com/2013/05/15/health/panel-finds-no-benefit-in-sharply-restricting-sodium.html?pagewanted=all

It is OK to challenge accepted thinking!

- Some things we thought we knew:
  - Margarine was considered a health food
  - Left-handed people die sooner because of the hazards of the right-handed word
  - Stomach Ulcers are caused by stress
  - Plants absorb CO2 and emit O2
  - The adult brain has no capacity to regenerate itself
  - Komodo Dragons bit their prey and waited for them to succumb to bacterial infections

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Recap

- Engineers use understanding of the situation and mathematical analysis to get quantitative answers that can tell how to design and build all of the technologies of the world

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

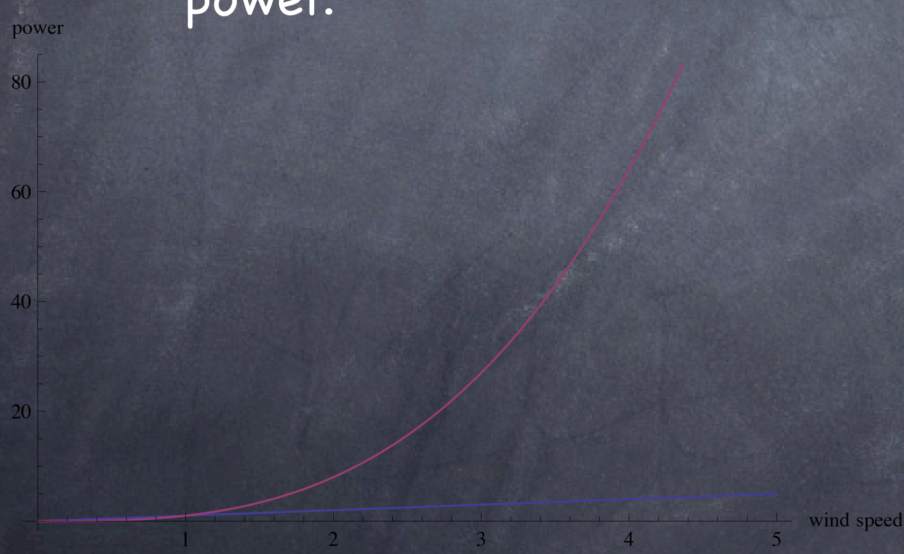
- Successful engineering requires an understanding of the detailed device or process but must be practiced in the larger context of all of society
- This general knowledge and understanding is also important for engineers.

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
- This is just one critical technology that needs more new ideas and people to push the efforts forward
  - It is a good time to be an engineer!

Wind power (homework)

- Suppose that I design a wind turbine to work perfectly for 25 mph wind
- If the wind speed drops to 15 mph, I get only 22% of the power!
- This is because power varies as the cube of the wind speed
- If this relation were linear, then we would get 60% of the power.



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Problem definition

- Every aspect of engineering relies on us knowing what problem we are trying to solve
- We may have to produce an “answer” (design) when we don’t know a lot about the fundamental science or other underlying phenomena, but
- We can never produce a result when we don’t know the problem!
- This is not the case in society in general!

Imperfect understanding

- **6.1 The Ideal solution**
- The history of modern science has shown repeatedly that a quantitative description of nature can often be achieved most successfully by first idealizing natural phenomena, i.e. by setting up a simplified model, either physical or mathematical, which crudely describes the essential behavior while neglecting details. **(In fact, one of the outstanding characteristics of great contributors to modern science has been their ability to distinguish between what is essential from what is incidental)** ..."

- From: Molecular Thermodynamics of Fluid Phase Equilibria
- John M. Prausnitz 1969.
-
- **This statement describes how an engineer often must do her job. You cannot waste your time on details that don't matter !!!!**

Medal of science ceremony

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Bob Langer, MIT,

Brain cancer "patch", skin replacement, tissue engineering for heart, liver

Adam Heller, U Texas

Artificial pancreas, technology will generalize to other diseases

Mark Davis, Caltech

Totally synthetic construct for gene delivery and molecular design of catalysts

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Some realities of the world

- I am wont to say, "I hate it when facts get in the way of my opinions!", but this is what we must face as engineers
  - Let's do green energy!
- Let's do the simplest analysis to quantify our thinking

This one will be interesting?

- http://www.telegraph.co.uk/foodanddrink/foodanddrinknews/9340712/Coca-Cola-not-to-blame-for-US-obesity.html
- http://www.advisory.com/Daily-Briefing/2013/03/20/Pepsi-health-challenge-Sugary-drinks-linked-to-obesity-related-deaths

It is OK (sometimes) to change your mind

Corporations act in their own best interest

Clifton Garvin

CEO Exxon circa 1980

Garvin and Exxon were enthusiastic proponents and participants in "synfuels" in the 1970's

In a stunning reversal of thinking, at the last minute, Garvin pulled the plug and stopped the project before it was built!

He saved Exxon and other oil companies Billions of dollars!

Leadership Matters!

Since 2000:
64.78% Win Percentage
7 Playoff Appearances (12-5)
2 Super Bowl Victories

Since 2000:
42.77% Win Percentage
2 Playoff Appearances (0-2)
No Super Bowl

"Qui tacet consentiret"

"Silence gives consent"

Saint Thomas Moore

Lord Chancellor of England

when

Henry VIII was king

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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

Importance of dimensionless numbers

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

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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RECAP

- Engineering involves defining a problem or situation of interest
- Engineering involves some degree of mathematical analysis based on physical laws or empirical understanding
- All problems of real importance have some degree of uncertainty and so judgement is needed
- Two global thoughts are to consider the limits of a possible range for a given variable and to try to make sure what effects are important as compared to what is incidental