

Engineering: How can we define it?

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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!

Rise of oxygen (why we breath air!)

Two classes of reactions that use glucose

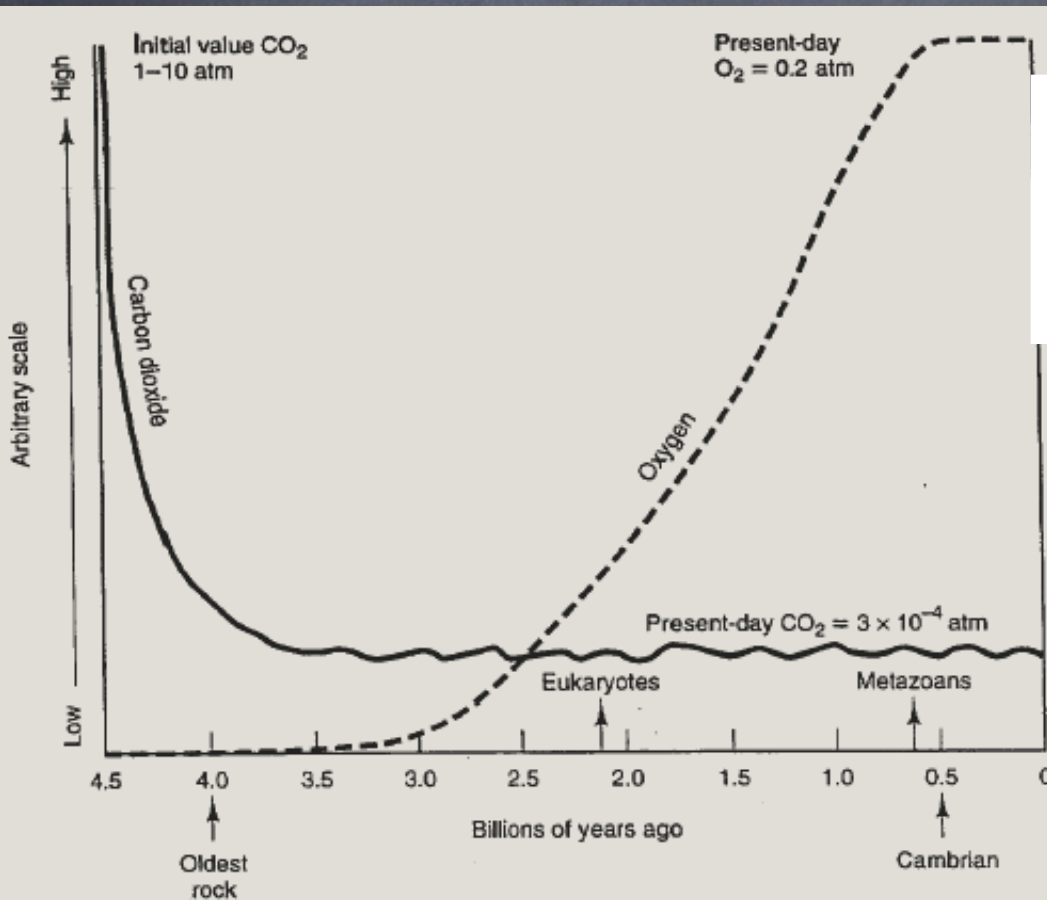
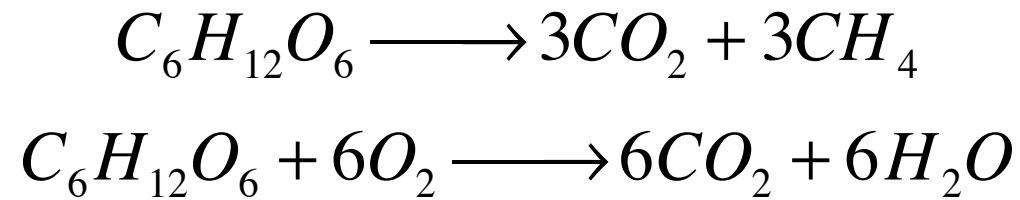


FIGURE 3-10 The history of oxygen and carbon dioxide in the atmosphere during Earth history.



Aerobic digestion is 17 times more energetic than anaerobic digestion

All of this oxygen comes from various kinds of plant growth

What do engineers do?

- 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

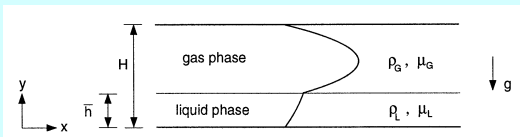
- We tried to make the argument that the imperfectness of a baseball is important to the pitching of a knuckleball, which does not spin and not important in the pitching of a curveball which spins fast. The same effect can either be important or incidental. This is because important issues always as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

Geometry of interest



We will look at the linear stability problem for

- Steady flow
- Purely Oscillatory (Couette flow)

Gas-liquid flow interfacial stability problem turbulence model: k-ε

Solve the base state with either a smooth or rough interface (try to match data).
then

Solve the differential stability problem the best we can
Liquid-phase: $0 \leq y^* \leq d_1$

$$\rho_l \left[\frac{\partial u_1'}{\partial t} + u_1' \frac{\partial u_1'}{\partial x_1} \right] = -\frac{\partial p'}{\partial x_1} + \rho_l g' \sin(\theta) + \frac{\partial}{\partial x_1} \left[(\mu_1 + \mu') (2s_1') \right]$$

$$\rho_l \left[\frac{\partial k_1'}{\partial t} + u_1' \frac{\partial k_1'}{\partial x_1} \right] = \frac{\partial}{\partial x_1} \left[\left(\mu_1 + \frac{\mu'}{\sigma_k} \right) \left(\frac{\partial k_1'}{\partial x_1} \right) \right] + \mu' (2s_1') \frac{\partial u_1'}{\partial x_1} - \rho_l \epsilon' - 2\mu_1 \left(\frac{\partial \sqrt{k_1'}}{\partial x_1} \right)^2$$

$$\rho_l \left[\frac{\partial \epsilon_1'}{\partial t} + u_1' \frac{\partial \epsilon_1'}{\partial x_1} \right] = \frac{\partial}{\partial x_1} \left[\left(\mu_1 + \frac{\mu'}{\sigma_\epsilon} \right) \left(\frac{\partial \epsilon_1'}{\partial x_1} \right) \right] + c_1 f_1 \mu_1' \frac{\epsilon_1'}{k_1'} (2s_1') \frac{\partial u_1'}{\partial x_1} + 2\mu_1 \mu_1' \left(\frac{\partial^2 u_1'}{\partial x_1^2} \right)^2 - \rho_l c_2 f_1 \frac{\epsilon_1'^2}{k_1'}$$

Stability equations continued

Gas-phase: $d_1 \leq y^* \leq d_1 + d_2$

$$\rho_2 \left[\frac{\partial u_2'}{\partial t} + u_2' \frac{\partial u_2'}{\partial x_1} \right] = -\frac{\partial p'}{\partial x_1} + \rho_2 g' \sin(\theta) + \frac{\partial}{\partial x_1} \left[(\mu_2 + \mu') (2s_2') \right]$$

$$\rho_2 \left[\frac{\partial k_2'}{\partial t} + u_2' \frac{\partial k_2'}{\partial x_1} \right] = \frac{\partial}{\partial x_1} \left[\left(\mu_2 + \frac{\mu'}{\sigma_k} \right) \left(\frac{\partial k_2'}{\partial x_1} \right) \right] + \mu' (2s_2') \frac{\partial u_2'}{\partial x_1} - \rho_2 \epsilon_2' - 2\mu_2 \left(\frac{\partial \sqrt{k_2'}}{\partial x_1} \right)^2$$

$$\rho_2 \left[\frac{\partial \epsilon_2'}{\partial t} + u_2' \frac{\partial \epsilon_2'}{\partial x_1} \right] = \frac{\partial}{\partial x_1} \left[\left(\mu_2 + \frac{\mu'}{\sigma_\epsilon} \right) \left(\frac{\partial \epsilon_2'}{\partial x_1} \right) \right] + c_1 f_2 \mu_2' \frac{\epsilon_2'}{k_2'} (2s_2') \frac{\partial u_2'}{\partial x_1} + 2\mu_2 \mu_2' \left(\frac{\partial^2 u_2'}{\partial x_1^2} \right)^2 - \rho_2 c_2 f_2 \frac{\epsilon_2'^2}{k_2'}$$

Stability equations continued

k=1 (liquid-phase) $0 \leq y \leq 1$
k=2 (gas-phase) $1 \leq y \leq n_2 + 1$

$$\frac{(\hat{h}_1 u_1)'}{m_1} + (\Gamma_{11} \hat{\phi}_1)' - 2\alpha' (\Gamma_{11} \hat{\phi}_1)' + \alpha' \Gamma_{11} \hat{\phi}_1 = i \alpha R \frac{(\hat{u}_1 u_1)'}{m_1} \left((u_{11} - c) (\hat{\phi}_1 - \alpha' \hat{\phi}_1) - u_{11} \hat{\phi}_1 \right)$$

$$\frac{(\hat{h}_1 k_1)'}{m_1} + \hat{h}_1 u_1' \frac{(\hat{k}_1 - \alpha' \hat{k}_1)'}{k_1} + \Gamma_{11} (\hat{k}_1 - \alpha' \hat{k}_1)' + \Gamma_{11} \hat{k}_1 + 2 \frac{(\hat{h}_1 u_1)'}{m_1} (\hat{\phi}_1 + \alpha' \hat{\phi}_1) + \frac{k_1'}{k_{11}} \left(\frac{\hat{k}_1 - \alpha' \hat{k}_1}{2k_{11}} - \hat{k}_1 \right) = i \alpha R \frac{(\hat{u}_1 k_1)'}{m_1} \left((u_{11} - c) \hat{k}_1 - k_{11} \hat{\phi}_1 \right)$$

$$\frac{(\hat{h}_1 \epsilon_1)'}{m_1} + \Gamma_{11} \Gamma_{11} (\hat{\epsilon}_1 - \alpha' \hat{\epsilon}_1)' + \Gamma_{11} \hat{\epsilon}_1 + 2 c_1 f_1 \frac{(\hat{h}_1 u_1)'}{m_1} (\hat{\phi}_1 + \alpha' \hat{\phi}_1) + \Gamma_{11} R c_2 f_2 \frac{(\hat{\epsilon}_1 - \alpha' \hat{\epsilon}_1)'}{k_{11}} (\hat{k}_1 - 2\hat{\epsilon}_1) + \frac{(\hat{u}_1)'}{m_1} \left[c_1 f_1 \frac{(\hat{h}_1)'}{k_{11}} \left(\hat{k}_1 + \hat{\epsilon}_1 - \frac{m_1 \mu_1 k_1'}{k_{11}} \right) + \frac{2 \mu_1}{r_1 R} (\hat{k}_1 + 2 \mu_1 \hat{\phi}_1) \right] = i \alpha R \frac{(\hat{u}_1 \epsilon_1)'}{m_1} \left((u_{11} - c) \hat{\epsilon}_1 - \epsilon_{11} \hat{\phi}_1 \right)$$

$$\hat{k}_1 = c_1 f_1 R \frac{k_1'}{k_{11}} \left(2 \hat{k}_1 - \frac{k_{11} \hat{\epsilon}_1}{k_{11}} \right)$$

Stability Equations cont.

Boundary conditions

$$\hat{\phi}_1 = \hat{\phi}_2 \quad (3-18c)$$

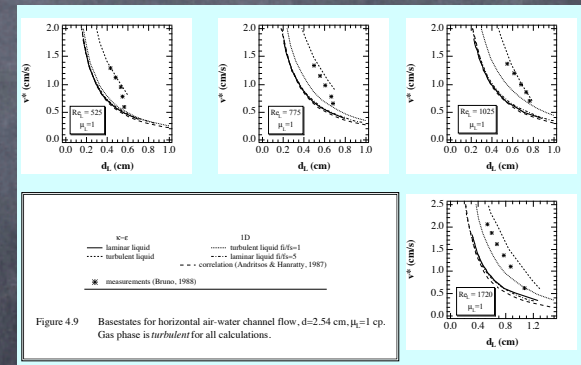
$$\hat{\phi}_1 + u_{b1} \hat{h} = c \hat{h} \quad (3-18d)$$

$$\hat{\phi}_1 - \hat{\phi}_2 = \hat{h} (u_{b1} - u_{b2}) \quad (3-18e)$$

$$\hat{\phi}_1 + \alpha' \hat{\phi}_1 + \hat{h} u_{b1}' = m_2 (\hat{\phi}_2 + \alpha' \hat{\phi}_2 + \hat{h} u_{b2}') \quad (3-18f)$$

$$\left(\hat{\phi}_1' + \Gamma_{b1} \hat{\phi}_1 + u_{b1}' \hat{k}_1 - 3\alpha' \hat{\phi}_1 \right) + i \alpha R (u_{b1}' \hat{\phi}_1 - u_{b1} \hat{\phi}_1) - m_2 (\hat{\phi}_2' + \Gamma_{b2} \hat{\phi}_2 + u_{b2}' \hat{k}_2 - 3\alpha' \hat{\phi}_2) - i \alpha R (u_{b2}' \hat{\phi}_2 - u_{b2} \hat{\phi}_2) - i \alpha r [(1-r)F + \alpha' S] \hat{h} = i \alpha R c (r_2 \hat{\phi}_2 - \hat{\phi}_1) \quad (3-18g)$$

$$\hat{k}_1 = \hat{\epsilon}_1 = \hat{k}_2 = \hat{\epsilon}_2 = \hat{h} = 0 \quad (3-18h)$$

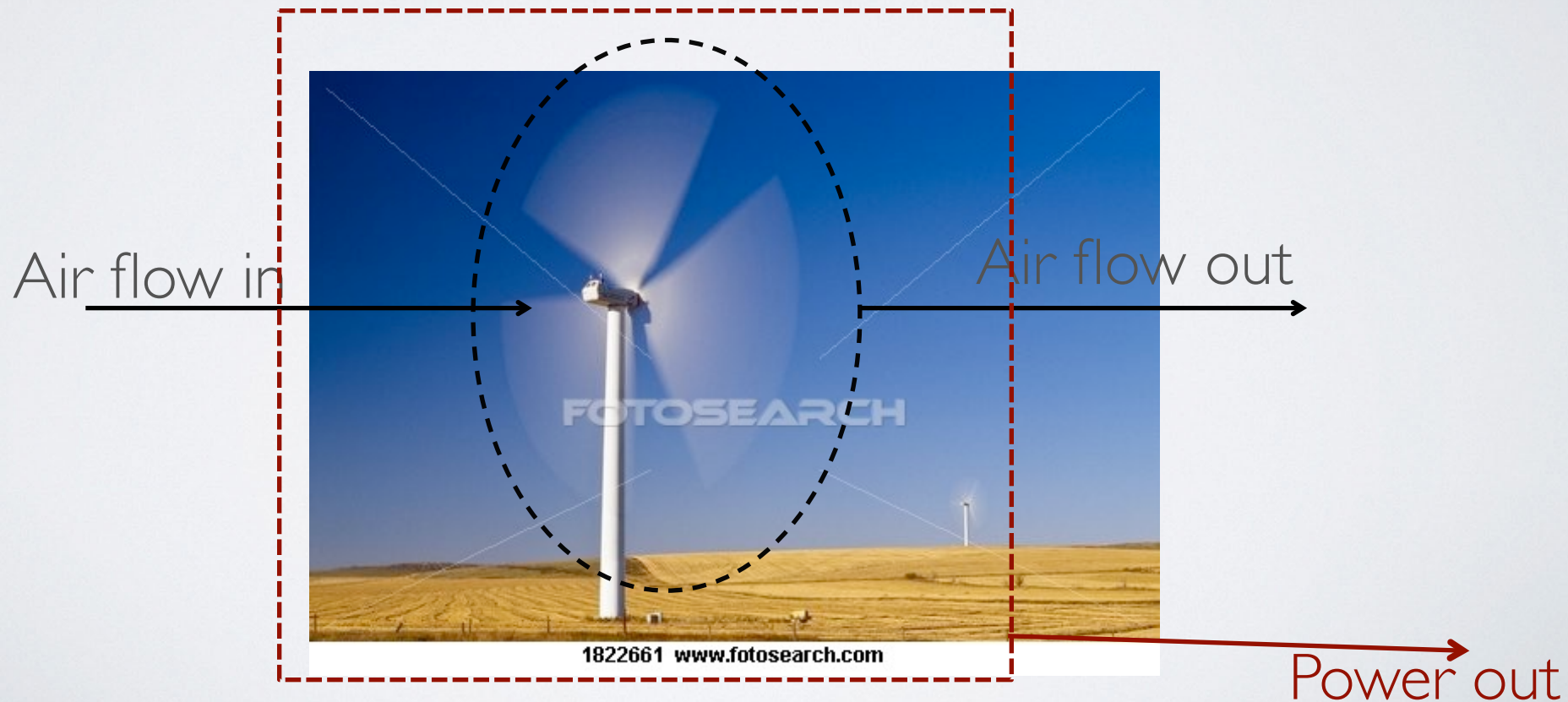


Mathematical analysis

- 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

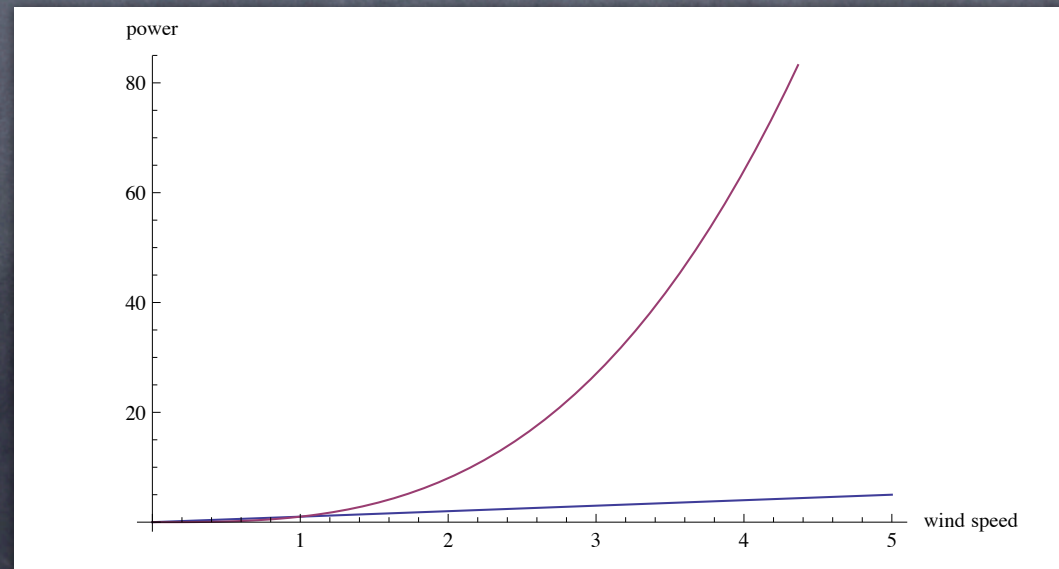
- Windspeed, blade diameter, air density
 - v [=] l/t
 - d, r [=] l
 - Density of air ρ [=] m/l³
 - Arrange these variables to get dimensions of power:

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

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

Wind power

- 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.



Topics of the moment

- Healthcare
- Energy
- The Environment
- The Economy
- Engineers are critically involved in all of these and will chart the future course
 - Major advances towards solutions of problems in all of these areas will require engineering!

Engineering in Medicine

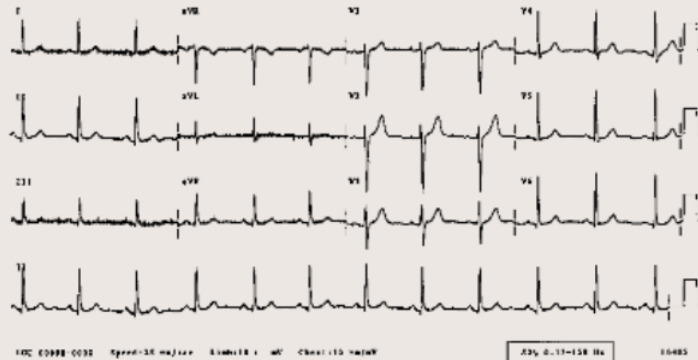
- <http://www.flukebiomedical.com/Biomedical/usen/products/default.htm>
- <http://www.washingtonpost.com/blogs/innovations/wp/2014/06/17/google-and-apple-want-to-be-your-doctor-and-thats-a-good-thing/>

Sudden Cardiac Death Prediction using ECG Signal Derivative (Heart Rate Variability): A Review

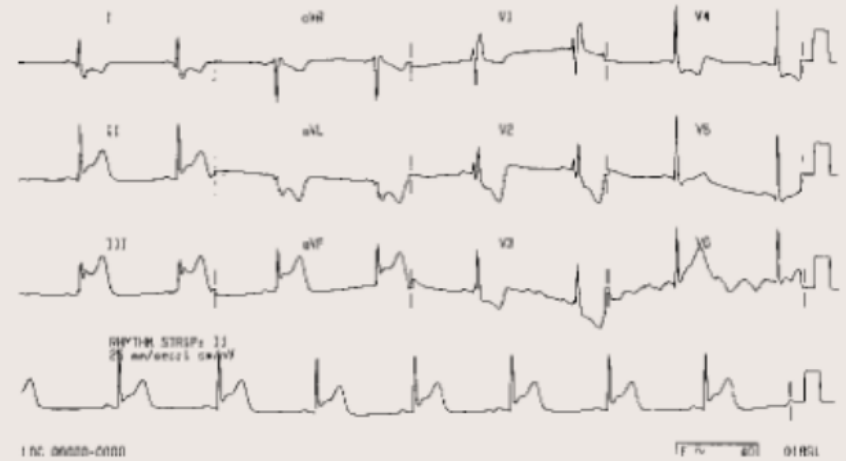
L Murugesan , M Murugappan , M Iqbal
School of Mechatronic Engineering,Universiti Malaysia Perlis (UniMAP)
Campus Putra Pauh, Perlis, Malaysia

Interpreting a "time series" is engineering

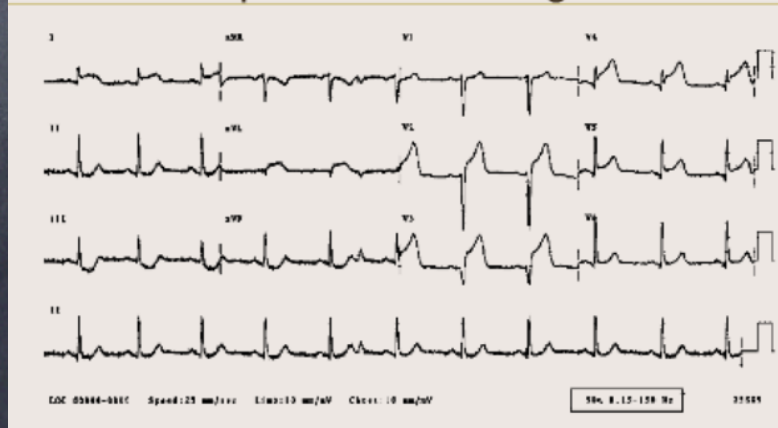
Normal ECG



A 55 year old man with 4 hours of "crushing" chest pain

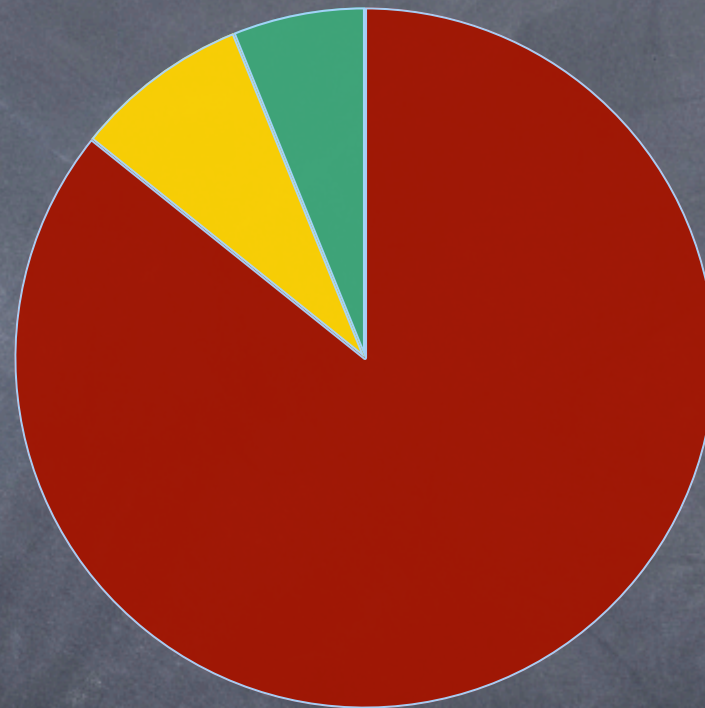


A 63 year old woman with 10 hours of chest pain and sweating



From: <http://www.docstoc.com/docs/75224507>

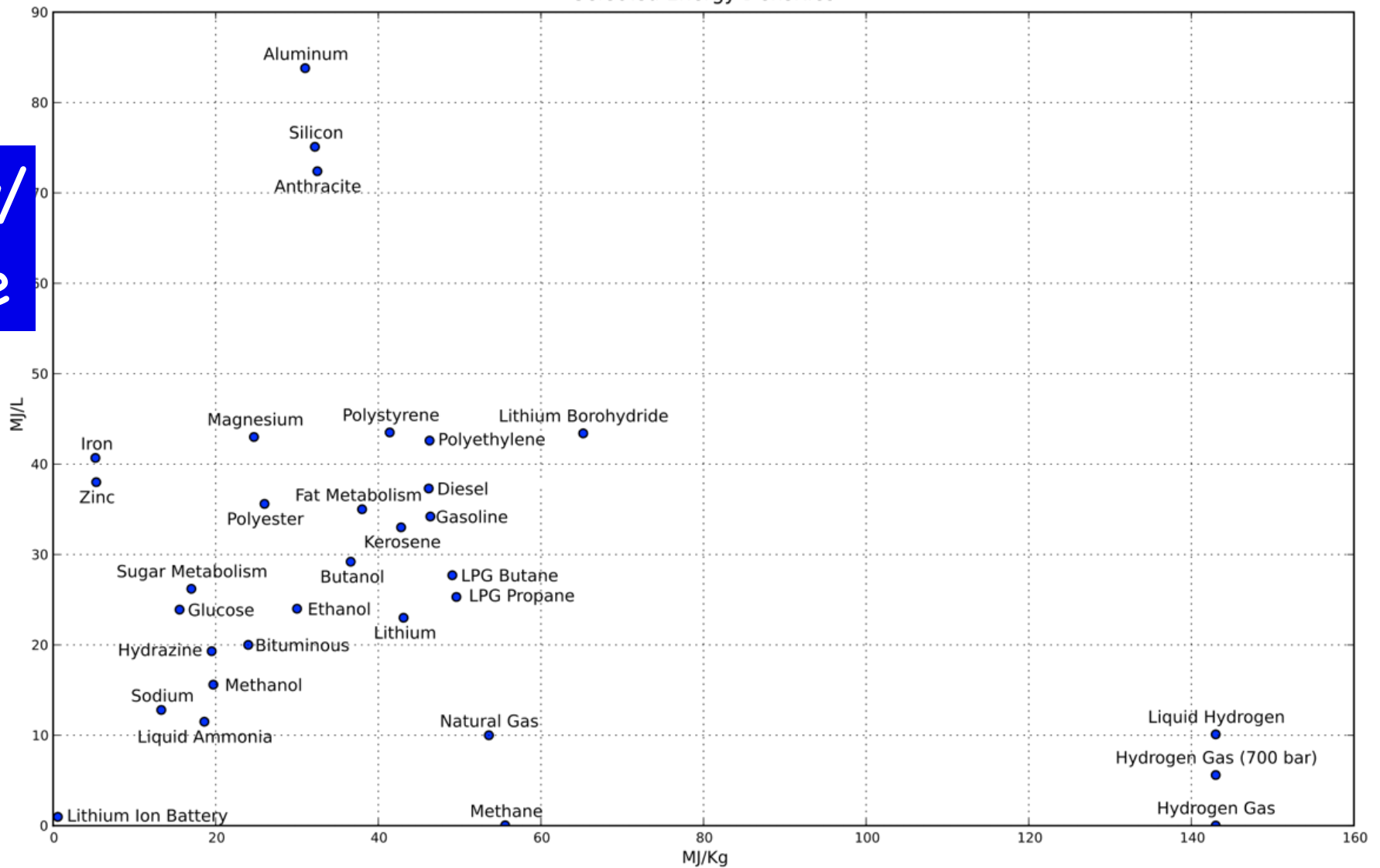
Energy for society



• Where it comes from now!!

Why aren't all cars electric?

Selected Energy Densities

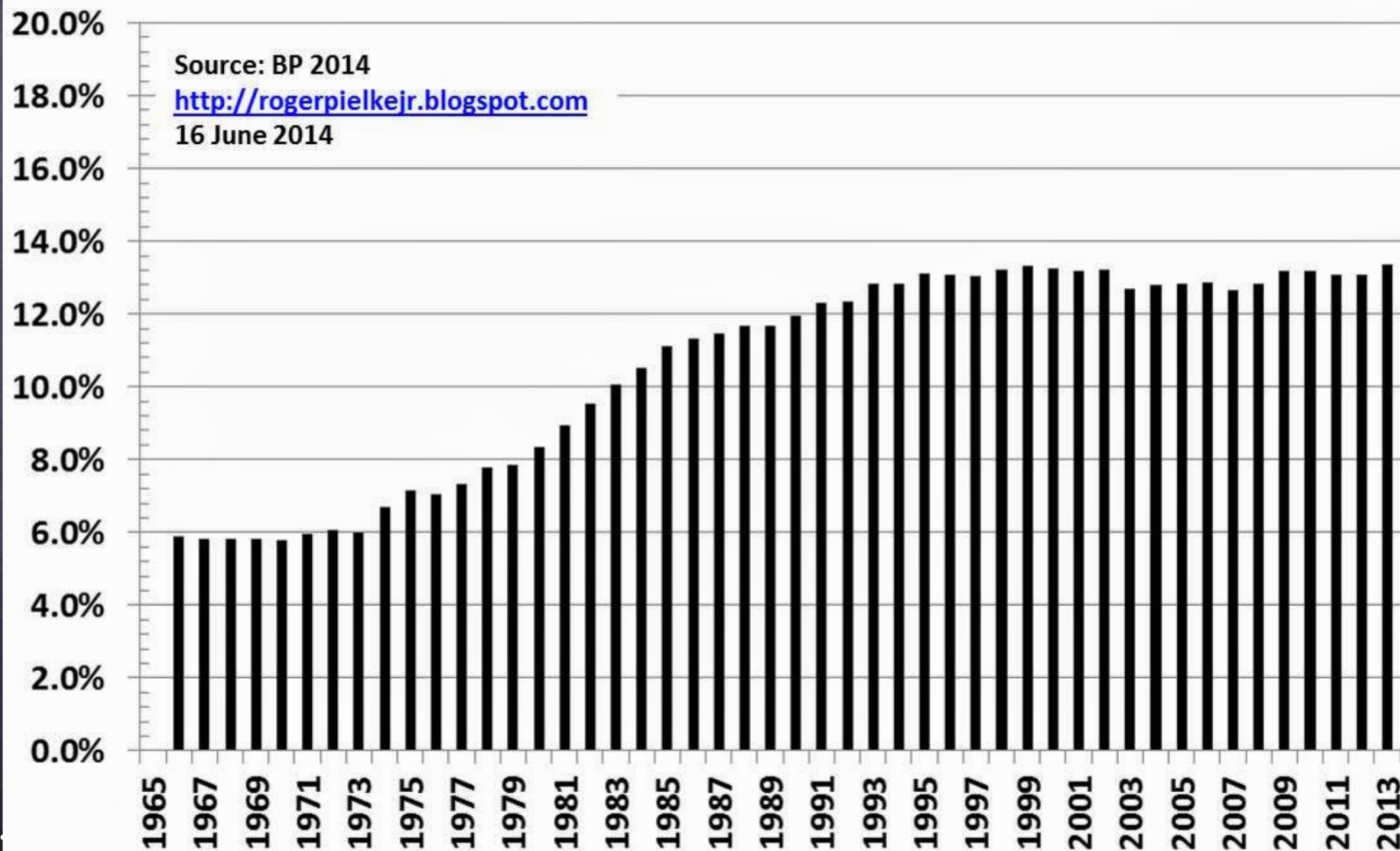


Energy/
volume

Energy/mass

"Renewables" are not gaining ground

Proportion of Global Energy Consumption
from Carbon-Free Sources: 1965-2013



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

Require energy storage

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



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



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 $\sim 350 \text{ W/m}^2$
- While nothing more energetic than a tree "runs" directly on solar, this gives a value of about
 - 0.3 MW/acre

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, but...

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

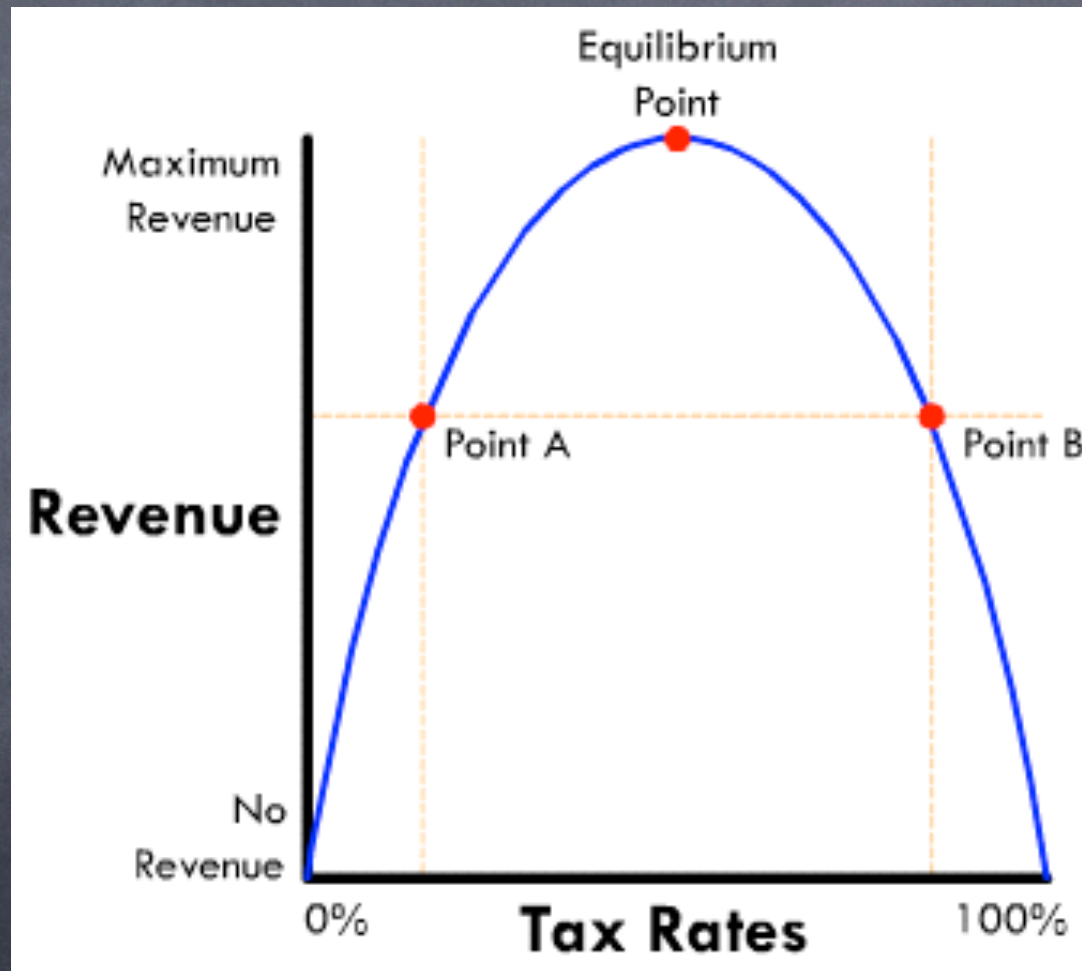
On a 100 acre Site:

- 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

More topics..

- Don't have time to solve these today
 - except that you know some calculus...
 - we can look at limits..

Taxes: Look at limits...



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

Laffer tax-revenue curve

<http://chemeprof.com/>

<http://ndcbechair.blogspot.com/>

How about traffic flow?

- $\text{Cars/time} = \text{cars}/(\text{length of highway}) * \text{length/time}$
- $\text{Cars/time} = \text{traffic density} * \text{average speed}$
- $\text{traffic density} = \text{Cars/time}/\text{average speed}$
 - Just go faster!

Engineering

- We need to deal with REALITY
 - much of the political and societal talk you hear is fantasy
- It is critical to determine what “problem” you will be trying to solve
- Don't be afraid to challenge traditional thinking

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

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>

Use of statins

- Statins are a class of drugs that lower the levels of cholesterol (hopefully the bad components) in blood.
- The guidelines for use have recently been changed so that many more people will be treated with these...
- <http://www.medscape.com/viewarticle/822210>

Final Thought

- Why be an engineer?
 - to help people and society:
 - <http://newsinfo.nd.edu/news/31468-multifunctional-nanoparticles-promise-to-improve-blood-cancer-treatment/>

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.

End

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

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 still 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!

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 !!!!



<http://chemeprof.com/>

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<http://ndbachair.blogspot.com/>

Medal of science ceremony





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

<http://chemepro.com/>

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

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

<http://chemeprof.com/>

<http://ndcbechair.blogspot.com/>

Importance of dimensionless numbers

• Reynolds number: $\frac{\text{Inertia forces}}{\text{Viscous forces}}$

• Another number

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

Dimensionless Confucius Proverb

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

- He who knows not and knows he knows not is a child, teach him, $Cr \sim 1$
- He who knows not and knows not he knows not is a fool, shun him, $Cr \ll 1$
- He who knows and knows not he knows is asleep, awaken him, $Cr \gg 1$
- He who knows and knows he knows is wise, follow him $Cr \sim 1$

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