SUSTAINABILITY and Industrial Hygiene

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OVERVIEW

- SUSTAINABILITY
- THE PROBLEMS
- THE ETHICS
- THE HOPE FOR THE FUTURE
  - THE ROLE FOR INDUSTRIAL HYGIENE

Sustainable

"Rates of use of renewable resources do not exceed regeneration rates;

rates of use of nonrenewable resources do not exceed rates of development of renewable substitutes;

rates of pollution emission do not exceed assimilative capacities of the environment."

Herman Daly
(1996)

LIMITS ON DEVELOPMENT

- STANDARD OF LIVING IS PROPORTIONAL TO ENERGY CONSUMPTION
- ENERGY CONSUMPTION IS ***THE*** FOCUS OF SUSTAINABILITY
- IMPLEMENTATION MUST APPEAR ETHICAL FOR PEOPLE TO ACCEPT IT
- IMPLEMENTATION MUST FOLLOW:
  - LAWS OF NATURE
  - CONSERVATION LAWS
    - ENERGY, MOMENTUM, and CHARGE

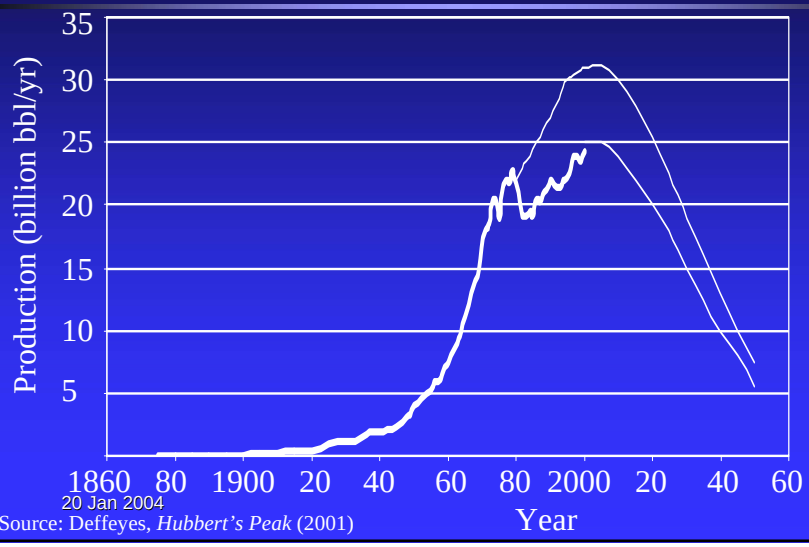
POPULATION OF EARTH

- 2003 POPULATION ~ 6 billion
- Population may plateau in 2060, ~ 10 billion
- Today, richest 20% of population (1.2 billion)
  - Consume 75% of energy and resources
  - Median member of top 20% consumes 20 x that of median member of poorest 50% of population
- We are in top 20%, for each of us:
  - It remains less expensive to purchase energy efficient appliances to cut consumption by 100 kW-hr per year than to buy wind or solar plants

Consumable Energy (fossil)

- Oil Consumption 3x faster than discovery
- Bring all people up to top 20% lifestyle?
  - Exhaust coal, oil, shale, natural gas by 2050
  - Then, exhaust Methane clathrates (CH_4 ice) or ???
- Keep CO below 540 ppm
  - Limit emissions to less than 9 GT / yr
  - Reduce top 20% emissions from 16 to 1 T / yr
- Can NOT bring 10 billion to USA lifestyle with fossil fueled economy

World Oil Production
Deffeyes Prediction (2001)



Source: Deffeyes, *Hubbert's Peak* (2001)

Methane Clathrates may exceed all other Fossil Reserves

- 300 feet deep in cold oceans
  - Methane from decaying sediment
  - Freezes into methane ice
- + 4 deg would release huge quantities
  - destabilize ocean floor
  - probably happened 10k yrs ago on earth
- Energy to harvest may exceed energy in fuel
- Seafloor disasters may preclude deep drilling
  - gtresearchnews.gatech.edu/newsrelease/HYDRATES.htm
  - released 11 Jul 2002, Georgia Institute of Technology

Consumable Energy (nuclear)

- Fission power plants exist, fusion plants not yet.
- Bring 10 billion people up to top 20% lifestyle?
  - Need 8,000 additional uranium plants
  - Exhaust all uranium fuel in 10 years
- If we use breeder reactors
  - Uranium then adds plutonium and thorium to fuel cycle
  - Uranium will last 700 years (2x life of coal)
- Fusion plants would last for millennia if burning H
  - No technology demonstration, as of 2003
  - We should have this as a priority, and we will

RENEWABLE ENERGY - 1

- Solar power density = 1.36 kW/m^2
  - Exo-atmospheric incident power density
- Max biomass = 26 gal ethanol/ha
  - US not yet harvesting all waste biomass
  - US energy use = 1.3X all biomass per year
- Solar Electric costs 10X fossil electric
  - Price competition due to tax credits today
  - Large Solar Plant reduces Biomass
  - Large Solar Plant does not harvest Carbon

RENEWABLE ENERGY - 2

- Water power is developed in US
  - Produces 1 to 6% of energy in US
- Wind power is developing
  - Capable of ~ 1 to 12% of US base load
    - Hawaii now has wind capacity = 20% of base load
    - Peak capacity unusable due to inability to control
- Dynamic load shifting expected by 2015
- Off Peak Storage remains a challenge
  - Pumped water, air pressure, flywheel
  - Quantum Spin Flip in Advanced Magnetic materials
  - Reversible chemical reactions
    - The hydrogen economy vs hydrocarbon economy

Space, Shelter, Food

- For 10 billion to live as 1.2 billion do now
  - Need 3.5x more forest area
  - Need 5 billion ha cropland (now 1.4 billion ha)
  - Need 100 billion ha support land for all the new cities
- For energy, food and water
  - Need 14x total productive land on earth
  - Additional land needed for disposal

Limits to Growth Summary

- To bring Earth's sustainable population up to top 20% standard of living, with technology as we know it
  - 0.5 to 2.0 billion people
- If 5 to 20-fold improvement in efficiency
  - Earth is sustainable with 10 billion people
- Must pursue such technology quickly to preserve fossil fuel
  - Must also find other energy sources within a decade
  - Otherwise, earth is overloaded with people and 80 to 90% die
- Energy efficiency in base load, automotive and building systems is an essential future industrial activity, and Industrial Hygiene insight is needed. Get ready, get set, GO.

NAE Ethics Discussion

- *Engineers face complex moral issues that cannot be resolved by codes of professional behavior.*
- Ethics, to use the felicitous words Lord Bank uttered three-quarters of a century ago, can be called the

  "observance of the unenforceable."
- In Lawrence Durrel's Justine, Balthazar says,

  "morality is nothing if it is merely a form of good behavior."
- These two definitions provide as good a preamble as any to a discussion of engineering ethics.
- Ethics falls in the middle of the spectrum, with laws, norms, and codes at one extreme and good manners at the other.

Bugliarello, George, "Machines, Modifications of Nature, and Engineering Ethics" , *The Bridge*, 30:3-Fall 2002.
http://www.nae.edu/NAE/naehome.nsf/weblinks/MKEZ-5F8L4U?OpenDocument

NAE Engineering Ethics

- Engineers create and use artifacts
  - artifacts are machines to extend biological capabilities
  - dams, engines, radios, computers, automotive vehicles
- Every artifact modifies pre-existing nature
- Engineering Ethics are the Ethics of Modification
- All living organisms modify nature
    - man by conscious design, others primarily by instinct
    - man may be causing unprecedented global changes

NAE Scientific Ethics

- Scientists strive to understand nature
  - Ethical problems are epistomological
  - Big ethical lapse is misconduct in research
    - falsify data
- Engineers strive to modify nature with artifacts
  - Ethical problems are more nebulous than in science
  - False sense of security about machine performance
    - overlooking dangerous consequences & side effects
- JCR note: Industrial Hygiene is NEEDED here!

NAE -- Grouping Ethical Issues

- Modification of Nature
  - Are humans immune from extinction?
- Cui Bonum (Who benefits? Who pays?)
  - intergenerational payments, unsustainable processes
  - waste disposal, air pollution, noise mitigation
- Methods and Designs
  - Should we allow unpredictable artifacts?
  - Software cannot be fully tested
  - Unintended consequences from genetic engineering
- Control of Technology
  - Ethics needed to provide control unreachable by legal means

NAE--Future of Engineering Ethics

- Perhaps, "do no harm" or "maximize the good"
  - But, no simple definition of "good" or of "harm"
- Today, engineering, as the motive force for technology, is raising pressing new ethical questions
  - Blurred boundaries between machines & living organisms
  - Enhanced destructiveness of weapons
    - Is this an application of science that benefits human kind?
    - Are humans the most violent species?
  - Must we limit per capita energy consumption?

NAE -- Intertwined Ethical Issues Looks Like the IH mission

- Seek Intelligent modifications of nature
- Technological determinism
- Access to the profession
- Conflicts & inequities in technology application
- Balance global risk, local safety, & quality of life
- Seek global sustainability
- Careful with artifacts whose performance is unpredictable

NAE Conclusion

- Engineers [and Industrial Hygienists] face an enormous and urgent challenge.
- "A comprehensive engineering ethic will have to be built patiently, stone by stone, case by case, and then continuously tested and reexamined in the context of very rapid technological and social change."

Industrial Hygienists Role

- Anticipate
  - Trends in science & feasible technology
- Recognize
  - Laws v. Hypotheses of Nature
- Evaluate
  - Usable Laws of Nature
- Control (Substitution)
  - Apply Laws of Nature to Present Problems

LAWS OF NATURE - Anticipate

- Dynamic Theory derives standard model
  - Search Web under Pharis Williams Dynamic Theory
  - State laws of thermodyanamics in precise mathematical form
  - Solutions exist only in Weyl Geometry (hyperbolic)
  - No general solution known; special solutions fascinate me
- Different solutions appear with different assumptions
  - Solve in 3-D: find Newton's Laws
  - Solve in 4-D: find Maxwell's Electromagnetism
  - Solve in 4-D: find Einstein's General Relativity
  - Solve in 4-D: find Schroedinger's Wave Equation (Quantum Theory)
  - Solutions in are emerging 5-D and higher D

LAWS OF NATURE - Recognize

- Williams Dynamic Theory
  - Promises a Unification of Physics as we know it
  - Existing Standard Theory is derived from Thermodynamics
  - No need to assume a geometry for space time
  - So far, no testable new predictions.
- String Theory
  - A leading candidate for theory of everything
  - Energy is intrinsically quantized into flexible strings
  - Our world is one set of string configurations
  - Replaces prior science, rather than unify it
  - So far, No testable new predictions.
- The Standard Model
  - All components have been tested & can be used now

LAWS OF NATURE - Evaluate

- NEWTON'S LAWS
  - 3-D Cartesian Geometry
- MAXWELL'S ELECTROMAGNETICS
  - 4-D space time Cartesian Geometry
- EINSTEIN'S RELATIVITY
  - 4-D Parabolic or Hyperbolic Curved Geometry
- THERMODYNAMICS
  - Initially free of geometric assumptions
- SCHROEDINGER'S QUANTUM MECHANICS
  - Fits experiments in 4-D space time Cartesian Geometry

LAWS OF NATURE - Control

- Use what we know to improve human life
  - Thermodynamics
  - Electromagnetics and Relativity
  - Quantum Mechanics
- IH, as multi-disciplinary professionals, can bring good science to decision makers
- We can help society avoid seriously misguided and unduly expensive tactics offered by extremists of all types

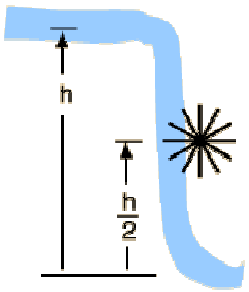
Thermodynamics: basis for action

- 1st Law. Energy is Conserved
  - Reject fanciful proposals that do not conserve energy.
- 2nd Law. Entropy is monotonic increasing in a closed system and represents energy that has lost its ability to do useful work.
  - Reject proposals that offer more work output than conditions allow.
  - Find REVERSIBLE systems that minimize entropy while doing usable work.

First Law of Thermodynamics

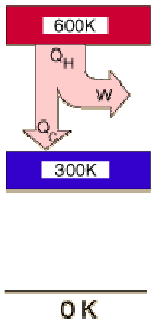
- **The total quantity of energy in an isolated system remains constant.**
  - Energy is the potential to do work:
    - Hot Matter, Mass in gravitational field, Pressure in Matter, charge in E-field, current in B-field
    - Molecular Bond Energy, Nuclear bond energy
  - Work occurs in many macroscopic forms and may be converted between those forms :
    - FORCE * DISTANCE
    - PRESSURE * VOLUME
    - TORQUE * ANGLE
    - CURRENT * VOLTAGE * TIME
    - CURRENT * CURRENT * INDUCTANCE
    - VOLTAGE * VOLTAGE * CAPACITANCE
  - Force is gravitational, electromagnetic, inertial or nuclear (for now)
    - Fg = MASS * GRAVITATIONAL FIELD
    - Fe = CHARGE * ELECTRIC FIELD
    - Fm = CURRENT * MAGNETIC FIELD
    - Fi = MASS * ACCELERATION

Intuitive Second Law



If you are constrained to put your waterwheel half-way up the waterfall, then you can extract at most half of the available energy.

If a 600K heat engine must exhaust heat at 300K, then it can be at most 50% efficient.

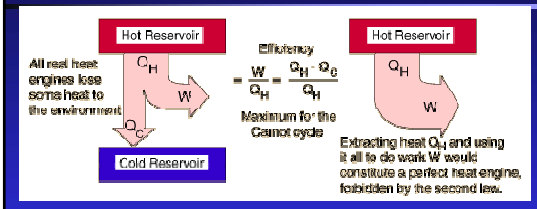


$$Eff_{maximum} = (h_{up} - h_{lo})/h_{up} = (T_{hot} - T_{cold})/ T_{hot}$$

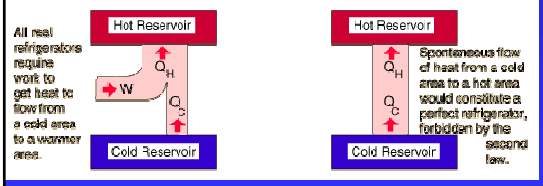
In any cyclic process the entropy will either increase or remain the same.

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclaw.html#c1

Thermal Versions of 2nd Law



It is impossible to extract heat from a hot reservoir and convert it entirely into work. Some energy must move to a cold reservoir.



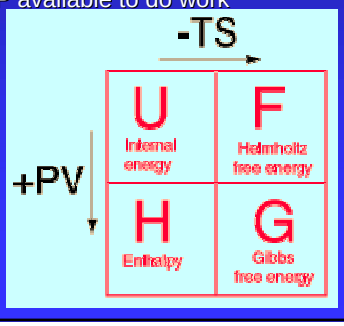
It is impossible for heat to flow from a cold reservoir to a hot reservoir without doing some work. Heat does not flow spontaneously from a cold to a hot reservoir.

Chemical or nuclear free energy is < reaction energy change.

Thermodynamic Chemistry

- Energy of a chemical reaction, is
  - (products' energy of formation) - (reactants' energy of formation)
- H = U + PV, Enthalpy is a measure of reaction energy
- F = U – TS, Helmholtz free energy (reaction at const V)
- G = H – TS = U + PV – TS, Gibbs free energy (const P)
  - Portion of reaction energy at constant P available to do work

The four thermodynamic potentials are related by offsets of the "energy from the environment" = TS, and the "expansion work" = PV. A mnemonic diagram suggested by Schroeder can help keep track of the relationships between the four thermodynamic potentials.



Two Sustainable Fuel Cycles

- Reversible Reactions for a Gaseous & a Liquid Fuel
  - Hydrogen: $2\ H_2 + O_2 \rightleftarrows 2\ H_2O$
    - 285 kJ/mol = 143 kJ/g
  - Ethanol: $C_2H_6O + 3\ O_2 \rightleftarrows 3\ H_2O + 2\ CO_2$
    - 1082 kJ/mol = 24.6 kJ/g
- Enthalpies of Formation for all compounds
  - H_2 = 0 kJ/mol, C_2H_6O = - 277 kJ/mol
  - H_2O = -286 kJ/mol , CO_2 = -393 kJ/mol
- Enthalpies of Reaction per mol or g of fuel
  - To Synthesize Fuel from combustion products: add energy
  - To use energy, burn fuels in appropriate equipment
  - Free Energy from fuel < Energy to reverse the cycle

Energy Needed to Sustain

- Free energy released during combustion < Energy of Formation
- Forward reaction releases less energy than reverse reaction
- Plants in biosphere release oxygen and sequester carbon
- As already pointed out, earth will not sustain carbon projected release rates
- Need a new primary source of energy, or lower standard of living, or fewer people

Rock's Energy Proposal

- Maximize Solar, Wind, Hydro and Geothermal Sources
- Use fission power plants (breeders)
  - to maximize free energy from Uranium
  - Provide centuries of energy with modest volumes of nuclear waste
- Develop Fusion Power
  - B Freeman & J Rock developing Dense Plasma Focus at TAMU
  - Deuterium provides millenia of energy, no nuclear waste
- Adopt chemical fuels for automative and off peak storage
  - Methanol: $2\ CO_2 + 4\ H_2O \rightarrow 2\ CH_4O + 3\ O_2$
  - **Ethanol**: $C_2H_6O + 3\ O_2 \rightleftarrows 3\ H_2O + 2\ CO_2$
  - Methane: $2\ CO_2 + 4\ H_2O \rightarrow 2\ CH_4 + 4\ O_2$
  - Ammonia: $N_2 + 3\ H_2 \rightarrow 2\ NH_3$
  - Hydrogen: $2\ H_2O \rightarrow 2\ H_2 + O_2$

Paths to Fusion

- TAMU Dense Plasma Focus
- Princeton Tokamok
- Lawrence Livermore National Ignition Facility

Dense Plasma Focus

Dense Plasma Focus (DPF):

An intense, pulsed source of x-rays, neutrons and ions.

Design Parameters:

465 kJ

3-5 MA

5 µs rise time

Current research:

Feasibility studies using the DPF for fusion.

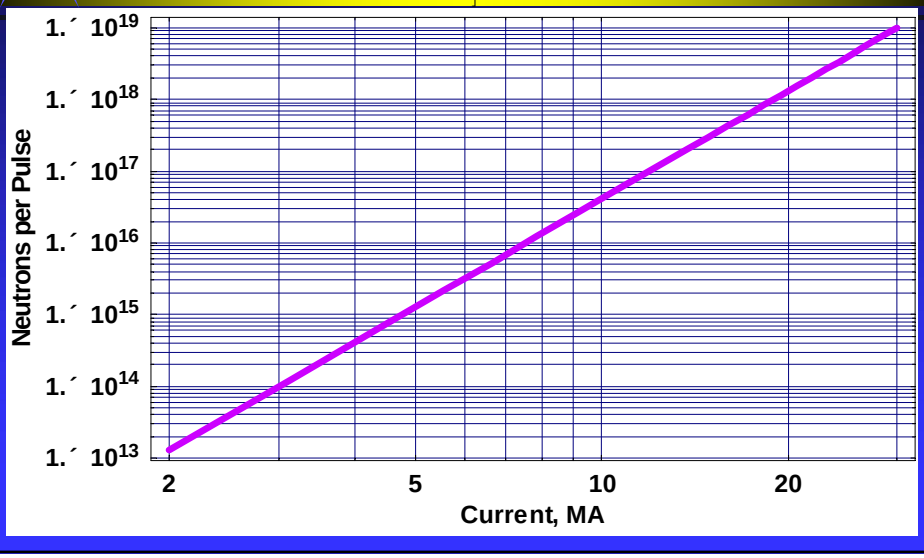
Non Destructive Inspection.

Deep Space propulsion by means of ion-thruster with 10 to 100x the specific impulse of present technology.

DPF Deuterium Scaling Law

Present Capability is 1 to 4 MA

Power Generation predicted at 25+ MA

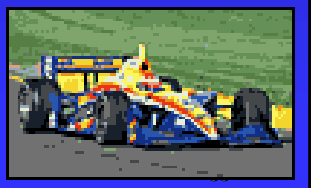


Rock's History of Energy

- Pre-History
- Biomass was used for millenia during pre-history
- Stored Biomass in use for centuries as coal and peat
- Stored biomass in use for decades as oil and natural gas
- Nuclear Fission burning Uranium in use for years
- We are here in 2004 on this putative timeline
- Nuclear Fission in use for decades to centuries
  - Edward Teller said two things in the 1950s
    - Bury all reactors; keep actinides in reactors to boil water
- Nuclear Fusion promises millenia as deuterium and tritium
- Allow 10 billion people to achieve US lifestyle
- Bright Future

Sustainable Development -Energy

- Methanol, CH_4O, "wood alcohol", a liquid fuel?
  - CH_4O via Proton Exchange Membranes (NASA – JPL invention)
  - CH_4O is the Only fuel used for Indianapolis Race Cars
- Synthesis Gas from waste, then to Methanol
  - Destructive distillation of plant tissue (from waste)
- Natural Gas is steam-reformed to Syngas (H_2 + CO)
  - Syngas heated with catalyst to form methanol
  - Reaction Products: water and carbon dioxide
- Need to supply



Methanol Fuel Cells are Possible

Courtesy DaimlerChrysler

- 18 March1999.
- DaimlerChrysler Chairmen Robert J. Eaton and Juergen E. Schrempp Wednesday unveiled the first drivable, zero-emission, methanol fuel-cell car.
- ACGIH TLV = 200 ppm.
- Methanol vapor causes neuropathy, vision loss and CNS damage. It is a skin irritant

The first zero-emission, fuel-cell vehicle with space for a driver and passengers. The car, on display in Washington, D.C., Wednesday, has a top speed of 90 miles per hour, travels nearly 280 miles on a methanol fill up and can carry 5 passengers.

The federal government is sponsoring research to commercialize this technology.

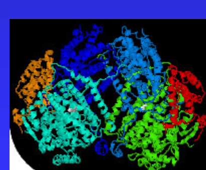
http://www.enn.com/enn-news-archive/1999/03/031899/necar4_2203.asp

http://www.lanl.gov/energy/est/transportation/trans/pdfs/workshop/narayanan.pdf

Norway: Sustainable (?) Energy

- Methanol from Natural Gas
  - Fish grown in oxygenated warm cooling water from methanol plant.

- Protein grown by *Methylococcus capsulatus* feeding on warm natural gas. It is fish food.



- Tomatoes grown from waste carbon dioxide, solar heat, and waste heat.
- Farming closer to arctic circle than otherwise possible.

Tjeldbergodden is located a bit south of the arctic circle.

http://www.conoco.com/pa/special/norway.asp

Is Methanol Energy Sustainable? The Present & Future Debate

- Is it ethical to “burn” fossil feedstock rather than save it for polymers to be used by future generations?
- Perhaps it is OK, if methanol is derived from waste streams.
- Not sustainable if derived from plants grown for the purpose
  - energy to grow, harvest and distill exceeds energy value of the fuel.
  - US energy consumption 1.3x energy value of all plant life each year
- Energy budget for methanol from natural gas
  - Not sustainable when geologic deposits of fossil fuel fail
  - Use of waste heat, as in Norway, improves value of CH_4

Near Term Options

- Define Industries needing IH support
- Reversible Engines that minimize entropy to maximize free energy:
  - Starrotor, Weisman, Erickson Cycle, Brayton Cycle, Carnot Cycle,
- LN2 Superconductors for Transmission Lines, Transformers, Motors & Generators
  - Save 10% of US electricity, enough to provide initial supply of electricity to all of Africa

The Human Carbon Cycle

- Liquid hydrocarbon fuel for automotive use
- Increasing automotive demand
- Increasing [CO_2] in air, a greenhouse gas
- If all fossil fuel burned, [CO_2] ~ 4700 ppm
  - [CO_2] was <300 ppm, now nearly ~400 ppm
- EEC is funding CO_2 deep injection technology
- DOE is funding Carbonate Salt Adsorption
  - Allows CO_2 removal distant from source
  - Permits sequestration industry in developing nations

The Geo-Carbon Cycle

- Huge reservoir of methane clathrate ice in deep, cold ocean water
- Hydrogen clathrate ice, too?
- A bit of planetary warming will release methane, the strongest of the greenhouse gases (other than water, which seems to be OK)
- This probably happened during the warm period 10 to 11 thousand years ago.
- If it happens now, global warming will accelerate.

Methane Clathrate Ecology

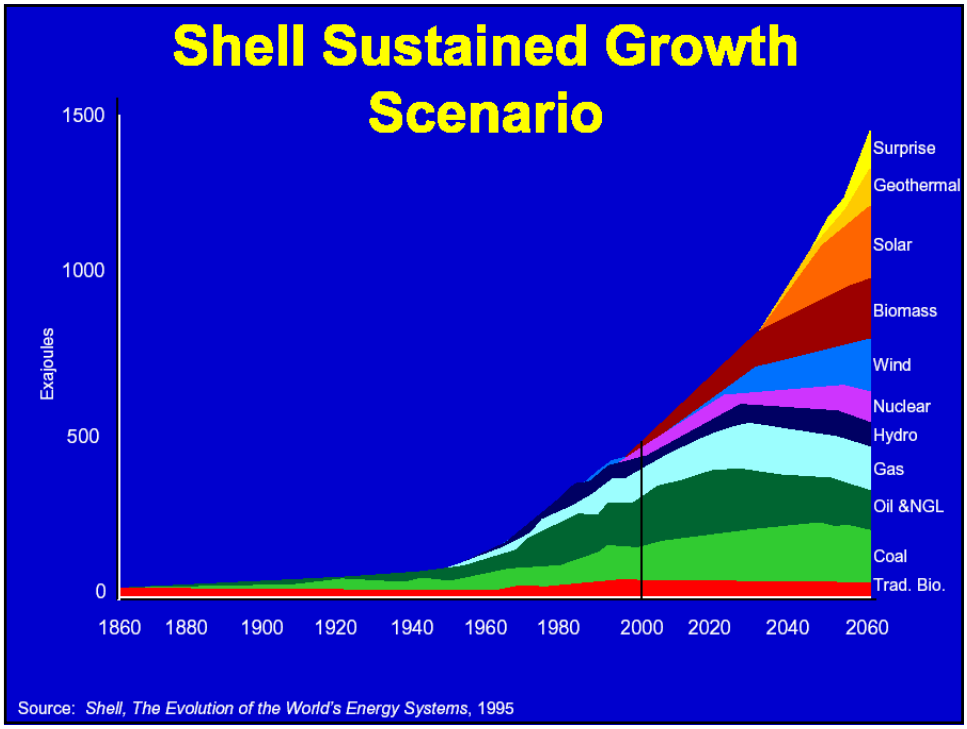
This close-up photo shows a dense colony of one-to-two inch-long polychaete worms living on and in the surface of the methane hydrate. These worms were discovered on July 15th 1997, by Penn State Associate Professor of Biology Charles Fisher and his research team, which is just beginning to study them. they speculate that the worms may colonize the hydrates even when they are buried and that the worm's nutrition is tightly tied to the hydrate itself. (Photo credit: Charles Fisher, Penn State)

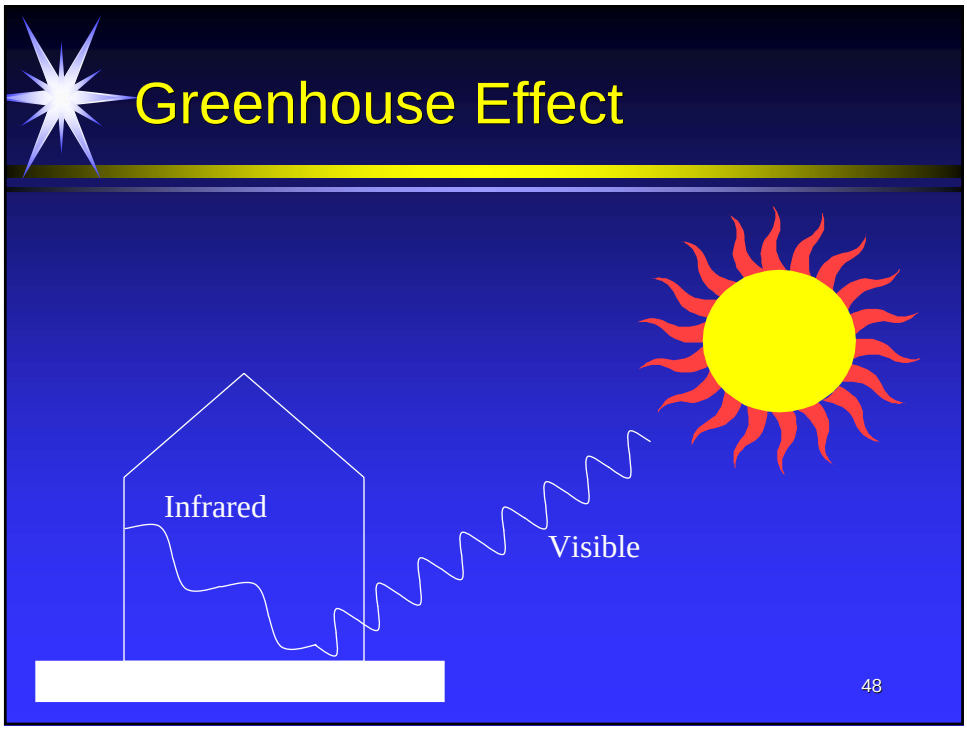
Where will we get our energy?

Study by Shell Group Planning

Georges Dupont-Roc
Alexon Khor
Chris Anastasi

The Evolution of the World's Energy Systems - 1996

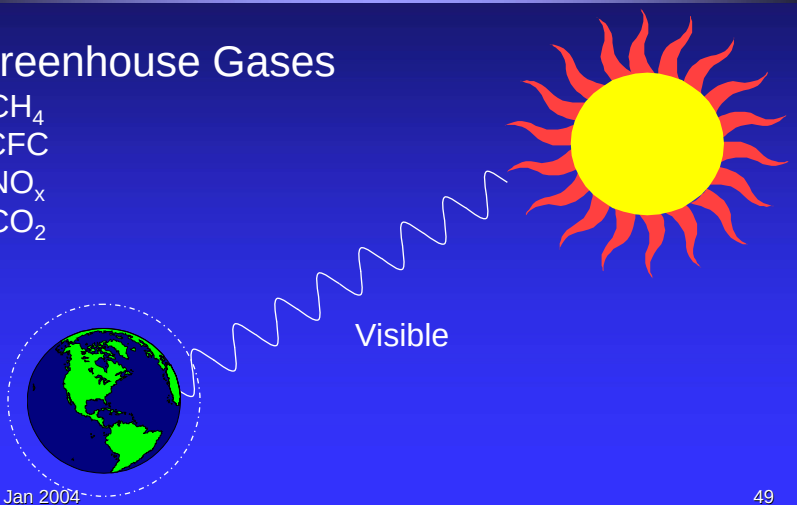

Shell Sustained Growth Scenario
1500
1000
500
0
Exajoules
1860
1880
1900
1920
1940
1960
1980
2000
2020
2040
2060
Surprise
Geothermal
Solar
Biomass
Wind
Nuclear
Hydro
Gas
Oil &NGL
Coal
Trad. Bio.
Source: Shell, The Evolution of the World's Energy Systems, 1995


Greenhouse Effect
Infrared
Visible
48

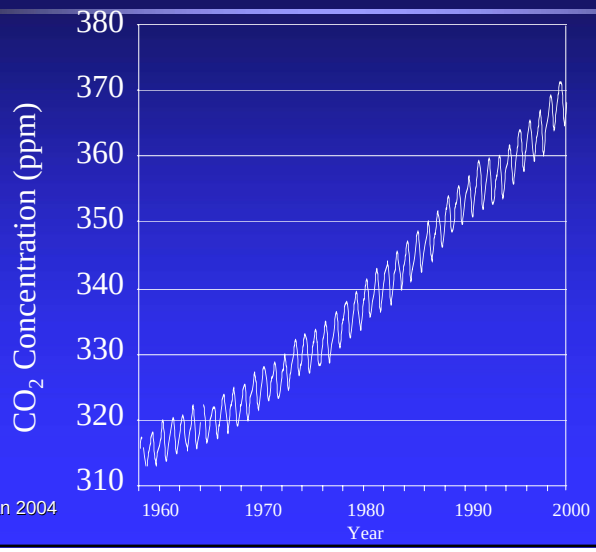
Greenhouse Gases

Greenhouse Gases

- CH_4
- CFC
- NO_x
- CO_2

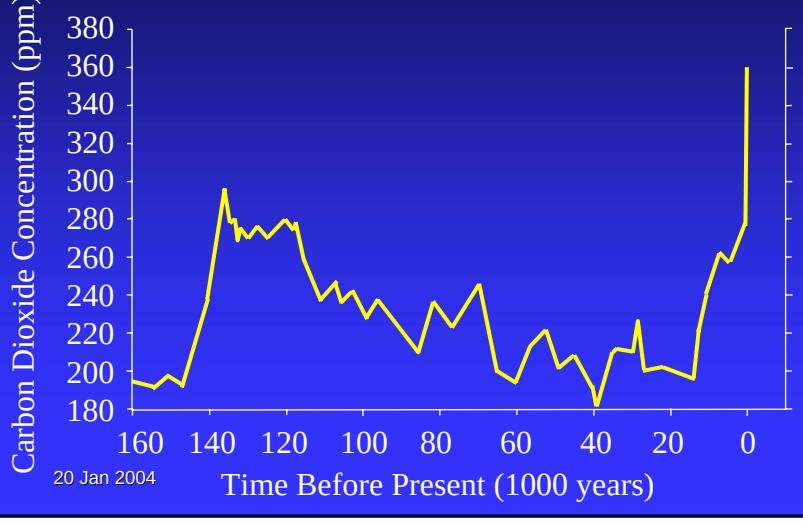


Recent CO_2 Concentration

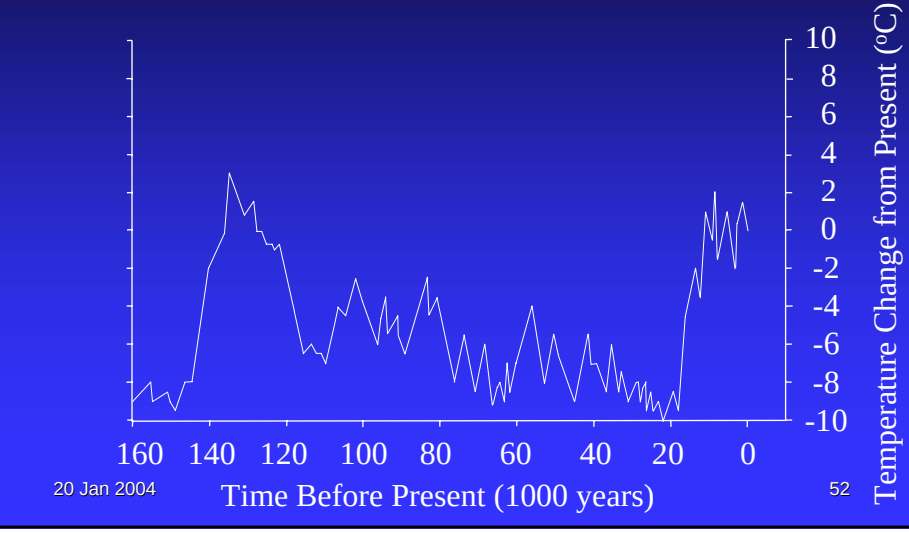


Mauna Loa Observatory

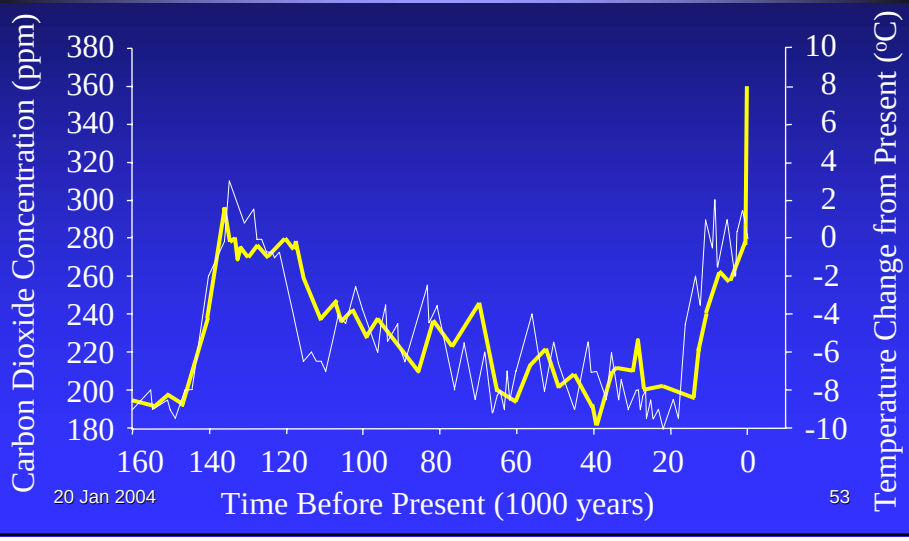
Historical CO_2 Concentration



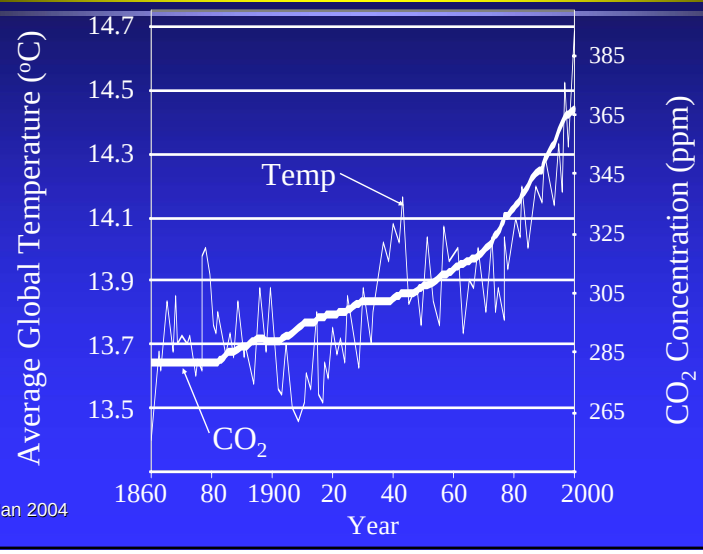
Temperature Change



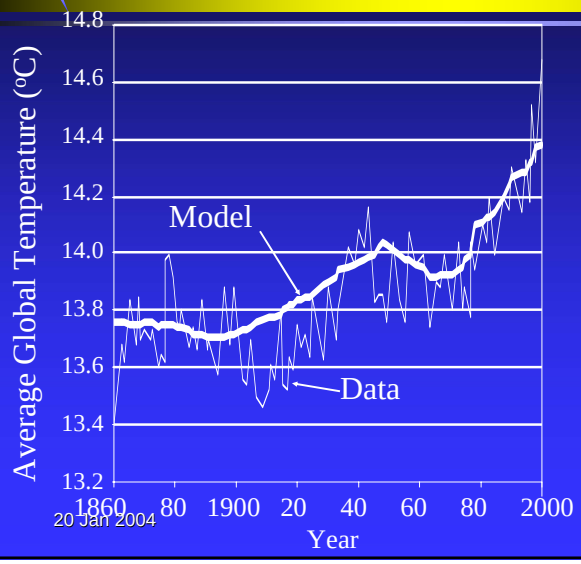
Combined



Recent Correlation



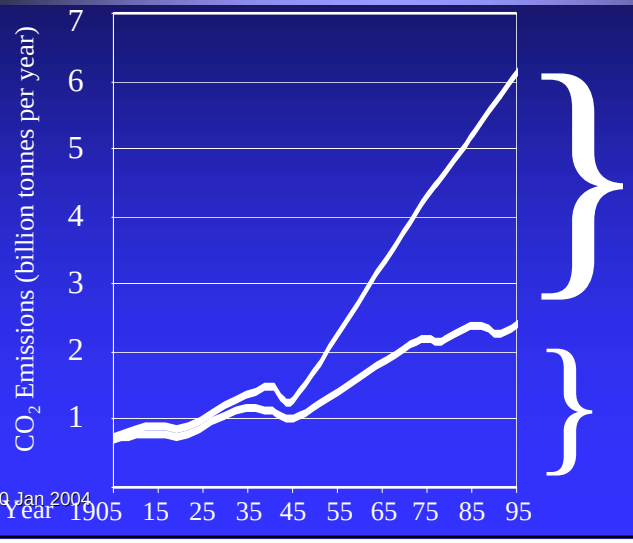
Princeton Model



Model Includes:

- CO_2
- Aerosols
- Solar Radiation

Carbon Emissions



Rest of World

Developed World
(US, Canada, Western Europe)

Potential Negative Effects

- rapid extinctions
- tropical diseases moving north
- Grain Belt becomes Dust Belt
- more insects
- rising ocean levels
- increased heat-related deaths
- Gulf Stream shuts down, chilling Europe
- increased storms/floods/hurricanes
- droughts and floods more common
- more forest fires due to drought
- weakened coral reefs

Exacerbating Effects

- extended thaw in tundra
- polar ice caps melt
- methane clathrates melt

Biofuels

REFERENCES

- Lackner, K.S., P. Grimes, H-J Ziock: "Carbon Dioxide Extraction from Air: Is it an Option?" Proceedings of the 24th Annual Technical Conference on Coal Utilization and Fuel Systems, Mar 8-11, 1999.

REFERENCES (cont'd)

- "Sustainable Manufacturing Roadmap," Center for Waste Reduction Technologies of the AIChE, July 2002.
- "Call for Network Proposals on the Sustainable Use of Materials", Engineering and Physical Sciences Research Council (EPSRC)

Another Proposal For Hydrogen

- Store and transport H_2 as liquid Ammonia
  - ammonia is 75% hydrogen, or 1.45 kWhr/L — power density = 1.87 kWhr/kg
  - Methanol is 67% hydrogen, or 1.15 kWhr/L — power density = 1.45 kWhr/kg
- Use in proton exchange membrane fuel cell
- As for sustainable methanol cycle, one needs primary power to create a sustainable ammonia-based automotive fuel cycle
- Reaction at the heart of the fuel cycle:
  - Catalytically Decompose NH_3 at 1180 K to N_2 and H_2

$$2\ NH_3 \rightarrow N_2 + 3\ H_2$$

http://www.electricauto.com/HighDensity_STOR.htm

Setting the Stage

- Oil shortage
- Greenhouse Effect

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