Sustainable energy in undergraduate chemistry courses

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Chemistry for a Sustainable World

"*recruiting and educating the next generation of chemists to pursue sustainable solutions*"

ACS Sustainability Stakeholders

FOR CHEMISTRY: attracting and retaining students

FOR STUDENTS: green jobs, personal values and interests

FOR FACULTY: teaching what we care about and what we research

sustainability in chemistry education

Chemistry for a Sustainable World	materials	water food soil	energy	green chemistry
liberal arts	science majors	Chemistry for a Sustainable World	vocational	graduate education
units & labs	revised courses	new courses	degree programs	Chemistry for a Sustainable World

Kenyon College

private liberal arts college in Gambier, OH

1650 undergraduates

~1/4 in Natural Sciences

Mathematics	Scientific Computing
Physics	Biochemistry
Chemistry	Molecular Biology
Biology	Environmental Studies
Psychology	Neuroscience

CHEM 108: *Solar Energy*

"non-majors" chemistry course at Kenyon College

- ~15-20% of all Kenyon graduates enroll
- students in every major outside of Natural Sciences, and ~30% undecided
- Environmental Studies minors (~20-30%)
- Quantitative Reasoning requirement (~50%)
- "interest in topic" (~75-80%)

This is a course <u>about</u> sustainable energy, not a course <u>about</u> chemistry.

Solar Energy syllabus

1. **Challenges of Fossil Fuels**

   population and energy use, peak oil, coal and environmental challenges

2. **Renewable Energy**

   assessing alternative energy, capacity of renewable energy, solar energy systems

3. **Molecules and Reactions**

   matter and molecules, combustion reactions, molecular structure and bonding

4. **Solar Energy**

   energy and power, light, energy quantization, absorption and color, excited states

5. **Chemical Energy and Fuels**

   molecular energy and heat, bond energies and thermochemistry of combustion, heat engines and entropy

6. **Photosynthesis and Biofuels**

   molecular components of photosynthesis, ethanol and biodiesel, capacity, land area

7. **Fossil Fuel Chemistry**

   fossil fuels, petroleum refining, coal gasification & liquification

Solar Energy syllabus

8. Greenhouse Gases

greenhouse effect, molecular vibrations, GHG emissions and sequestration

9. Electricity Production

electricity production and transmission, voltage and current, concentrated solar

10. Photovoltaics

sizing a PV system, semiconductors, photovoltaic design

11. Electricity Storage

electrical energy storage, redox chemistry and batteries, fuel cells

12. Which Hydrogen Economy?

hydrogen history, hydrogen economy components, H_2 from fossil fuels, catalysis

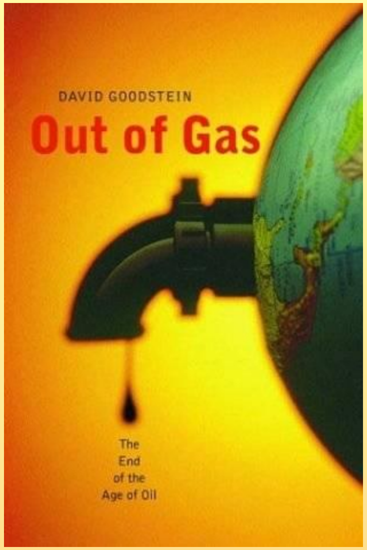
13. Sustainable Hydrogen Production

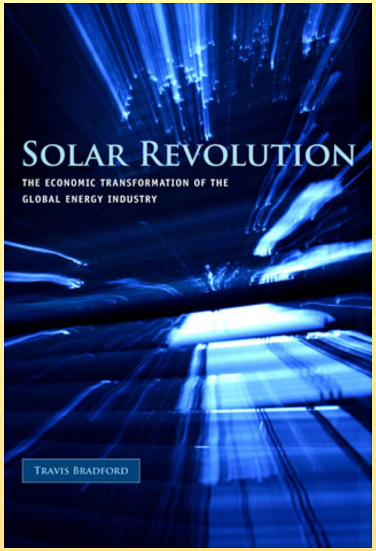
water electrolysis: thermochemical, electrochemical & photochemical methods

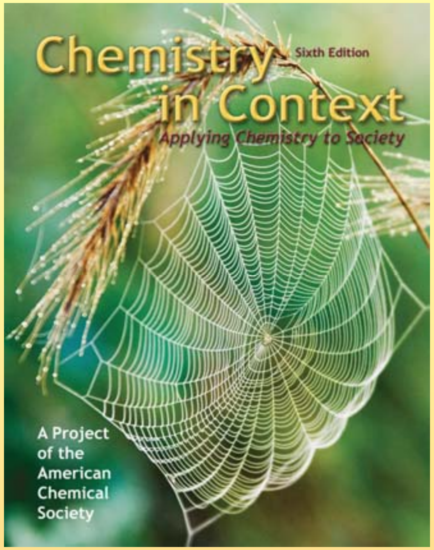
14. Conservation and Efficiency

choices about automobiles, food, electronics, and lighting

textbooks and readings







"**A Plan to Power 100 Percent of the Planet with Renewables**" by Mark Z. Jacobson and Mark A. Delucchi. *Scientific American*, November 2009, pp 58-65.

"**A Solar Grand Plan**" by Ken Zweibel, James Mason and Vasilis Fthenakis. *Scientific American*, January 2008, pp 64-73.

"**Is Ethanol for the Long Haul?**" by Matthew L. Wald. *Scientific American*, January 2007, pp. 42-49

theme: critical thinking to evaluate claims about energy systems

1. capacity and availability of primary energy source
2. capacity and availability of needed materials
3. energy return on energy investment (EROEI)
4. land area needs
5. environmental impact of an energy system

What land area would be needed if all U.S. electricity came from solar?

"A 92-by-92-mile square grid in the Southwest could generate electricity for the entire United States." - Joseph Romm

insolation in southwest U.S.:

~6 kWh/m^2day x (1 day/24 h) x (1000 W/kW) **= <u>250 W/m^2</u>**

U.S. electrical power = 450 GW:

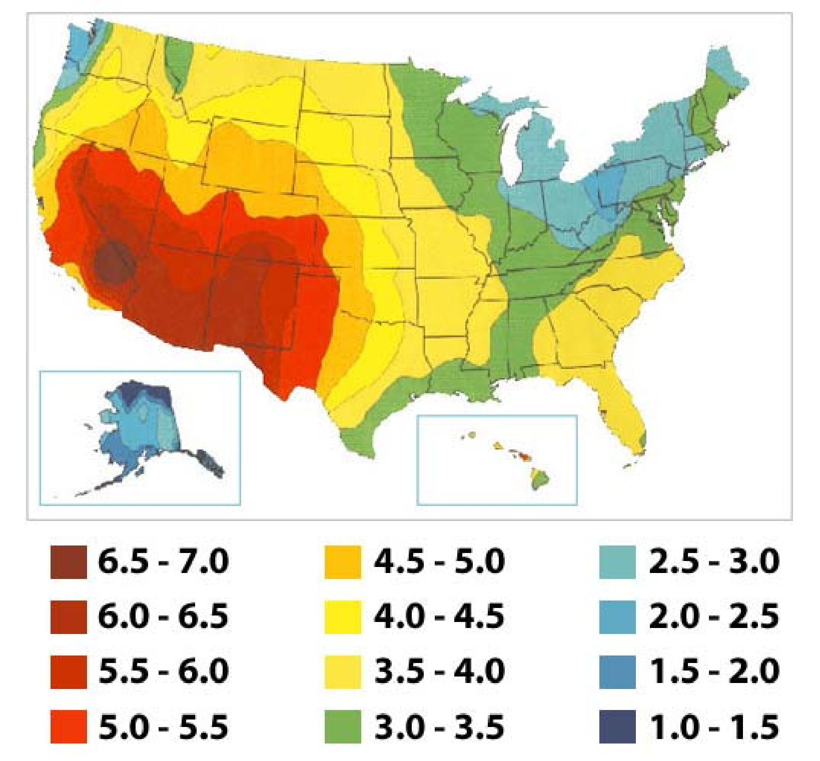
(4.5×10^{11} W) x (1 m^2 / 250 W)

= **1.8×10^9 m^2**

If 10% conversion efficiency:

= 1.8×10^{10} m^2

= ~100 x 100 mile area



kWh/m^2day

What is the energy return on investment for a PV?

"Today the breakeven energy payback time [for PVs] is around 2 to 4 years, compared to an effective production life of over 20 to 30 years" - Wikipedia

Evaluate this claim, assuming:

~600 kWh to manufacture a 1 m^2 Si solar cell
12% PV efficiency
140 W/m^2 average insolation

electrical *power* production:

$$\mathbf{0.140\ kW/m^2 \times 12\% = 0.017\ kW/m^2}$$

to produce 600 kWh of electrical *energy*:

$$\mathbf{(600\ kWh / m^2) \times (1\ m^2 / 0.017\ kW) = 35{,}700\ h}$$

= ~<u>4 years</u>

Which is a better deal: gasoline or E85?

"Save 30 cents a gallon on gas. If you see E85 fuel pumps in your area, check your owners manual. Millions of drivers could use it and save a bundle."

– MSN Money

(1 gallon EtOH) x (3.79 L / 1 gallon) x (1000 mL/L) x (0.789 g/mL) x (1 mol EtOH /46.07 g) x (1281 kJ/mol)

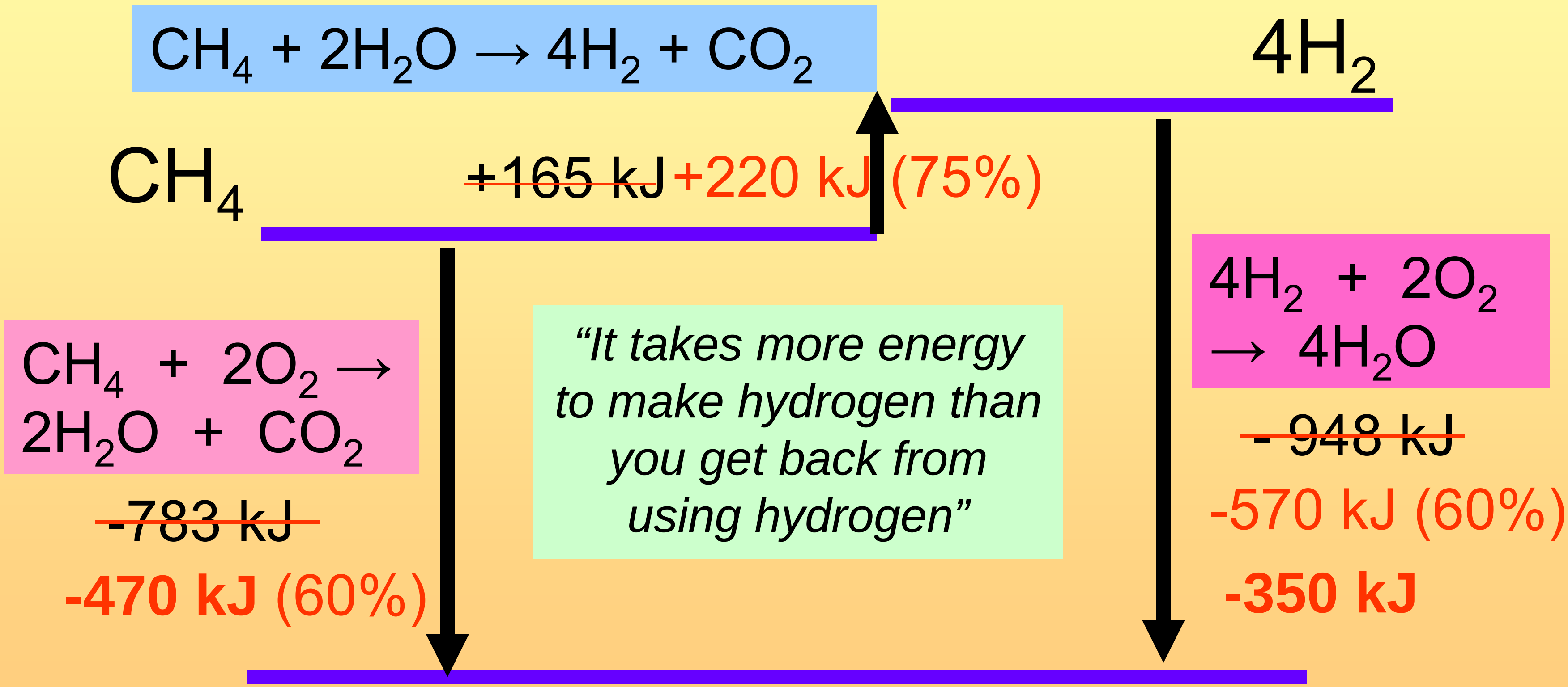
= **83,147 kJ/gallon for EtOH**

vs. **123,462 kJ/gallon for octane**

1 gallon gasoline ≅ 1.5 gallons ethanol

10 gallon E85 ($26.90) provides same energy as 7.2 gallons gasoline ($21.60)

Is hydrogen from natural gas a net energy loser?



More sustainable energy?
No more content!

standard Intro. Chem. topics

stoichiometry
quantum theory
bonding and structure
thermochemistry
entropy, free energy
electrochemistry
chemical equilibrium
acids and bases
chemical kinetics
gases
intermolecular forces, liquids, solids
chemistry in the atmosphere

sustainable energy topics

carbon emissions from combustion
solar energy and light absorption
water splitting
making and using fuels
heat and combustion engines vs. fuel cells
batteries and fuel cells
hydrogen storage materials
ocean acidification
catalysts
storing hydrogen
refining fossil fuels and biofuels
greenhouse gases and vibrations

CHEM 401: *Hydrogen Energy*

"special topics" chemistry seminar

- for CHEM majors
- stealth PChem course

texts:

- DOE *Basic Research Needs for the Hydrogen Economy* (2003)
- *Tomorrow's Energy* (2001) by Peter Hoffman
- *The Hydrogen Economy* (2002) by Jeremy Rifkin
- primary and secondary research literature

CHEM 401: *Hydrogen Energy*

TOPICS

1. Introduction to hydrogen energy systems
2. Changing visions of H_2
3. H_2 from fossil fuels
4. Sustainable H_2 production
5. H_2 from water electrolysis
6. H_2 from photoelectrochemical water splitting
7. H_2 from photocatalytic water splitting
8. H_2 from photobiological water splitting
9. H_2 from thermochemical water splitting
10. H_2 from biomass
11. H_2 storage
12. H_2 storage materials
13. H_2 fuel cells
14. Hydrogen infrastructure and research

PRINCIPLES

MO theory symmetry rules
active metals
metal hydrides
Hess's Law
T-dependence of ΔH, ΔS ΔG
T-dependent equilibrium
electrochemistry (Nernst eqn.)
band theory
excited-state reactions
catalysis and TS theory
phase changes
physisorption vs. chemisorption

reflections on teaching sustainable energy topics

- students overwhelmed by global sustainability challenges
- dealing with uncertainty and complexity
- options for textbooks to support new curriculum
- need for sustainability course/program census and faculty network

- enhancing interdisciplinary connections
    - consider a “pre-med model” for sustainability
- connecting curriculum to campus sustainability projects