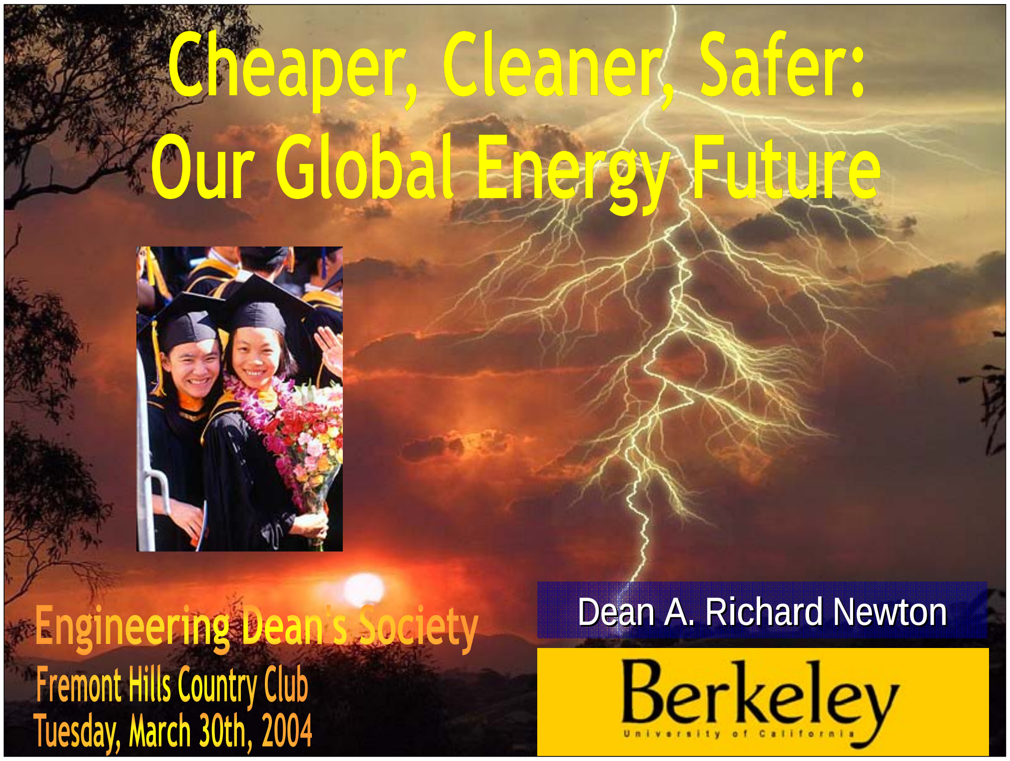


Welcome alumni, parents, friends, panelists, and other distinguished guests to our third annual Dean's Society spring program.

Most of you are here tonight as Dean's Society members who generously support the College of Engineering's work, including the energy research you'll hear about shortly.

Contributors such as you are essential in fulfilling the College's mission of *educating leaders, creating knowledge, and serving society.* This event is our way of *thanking you for your loyal support.*

First of all, however, let me acknowledge and thank *Mihir and Nancy Parikh* for sponsoring this event. Mihir and Nancy also hosted last year's Dean's Society reception here at the Fremont Hills Country Club, and we are very grateful for their continued generosity.

Why energy?

Energy is the largest industry on the planet, $3T annually. Food is about half that at $1.7T

We don't own it or control it in the US, and others are doing a much better job than we are at developing alternatives to complement fossil fuels!

Technical changes, supply shortages, environmental concerns, and rapidly changing (not always for the better!) energy markets are sweeping the globe.

UC Berkeley and our partners at LBNL have assembled the largest and most productive set of energy researchers at any university.

The nuclear, coal, solar, wind, and gas industries *all* (!) see huge market expansions in their future. This could be a sign of great opportunities, or impending market manipulations that make the recent California Energy Crisis look mild.

Energy has become one of the hot-button campaign issues for the 2004 election, largely because the democrats and republicans actually differ significantly in their positions on the issue (from energy markets, to the role of coal, nuclear, and renewable energy, and of course over climate change). Expect fireworks from both Kerry and Bush on this front over the coming months.

Panel Introductions

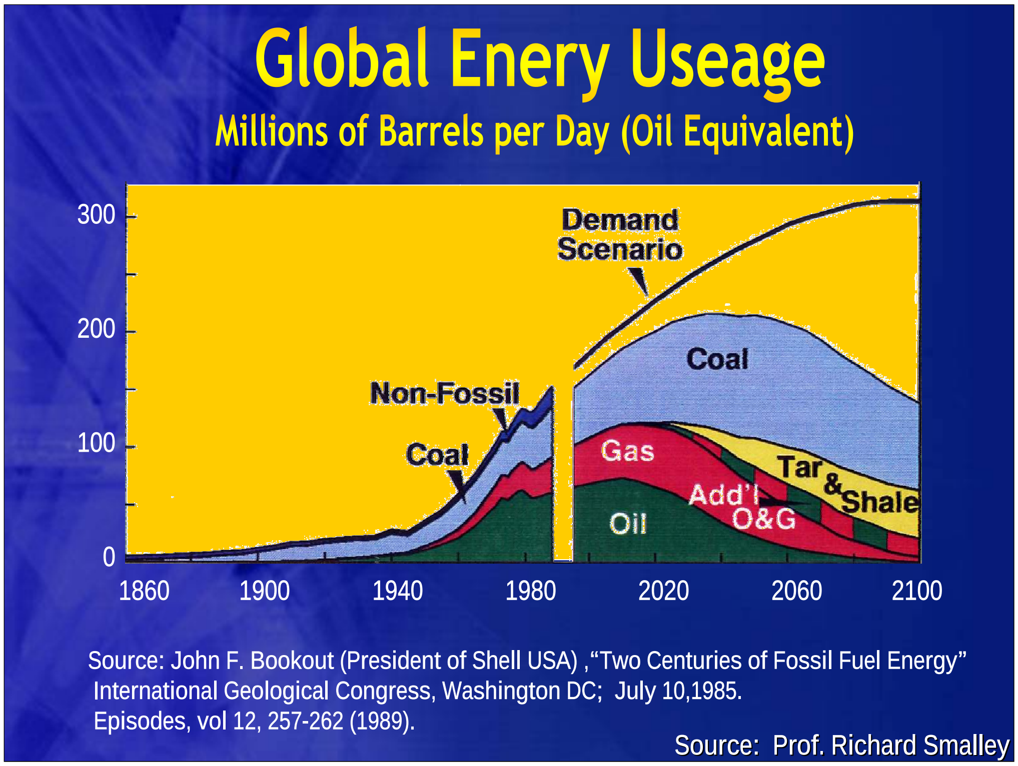
And now it's my pleasure to introduce the distinguished panelists with us tonight – each one a leading researcher in energy at Berkeley Engineering:

Dan Kammen is Professor of Nuclear Engineering and also holds appointments in Public Policy and Energy and Society. He directs the Renewable and Appropriate Energy Laboratory, based here in the College. Dan works on science, engineering, economics, and policy projects related to energy systems and the environment. He is closely tracking advances in clean, renewable technologies – from solar, wind, and biomass to fuel cells – as well as more-efficient uses of fossil fuels, all of which are starting to have a major impact on national economies and the global energy system.

Per Peterson is Professor of Nuclear Engineering and Chairman of that department. His research focuses on heat and mass transfer, thermal hydraulics, nuclear reactor design and safety, and radioactive waste and materials management. Per is currently exploring whether nuclear hydrogen could provide us not only with an inexpensive alternative to fossil fuels, but also with a gasoline additive to improve air quality.

Shmuel Oren is Professor of Industrial Engineering & Operations Research. He uses his expertise in economic modeling and mathematical analysis to engineer market mechanisms and pricing strategies for complex infrastructure systems such as electric power. Shmuel is currently combining game theory and computational methods to develop new market rules and better incentives for independent system operators.

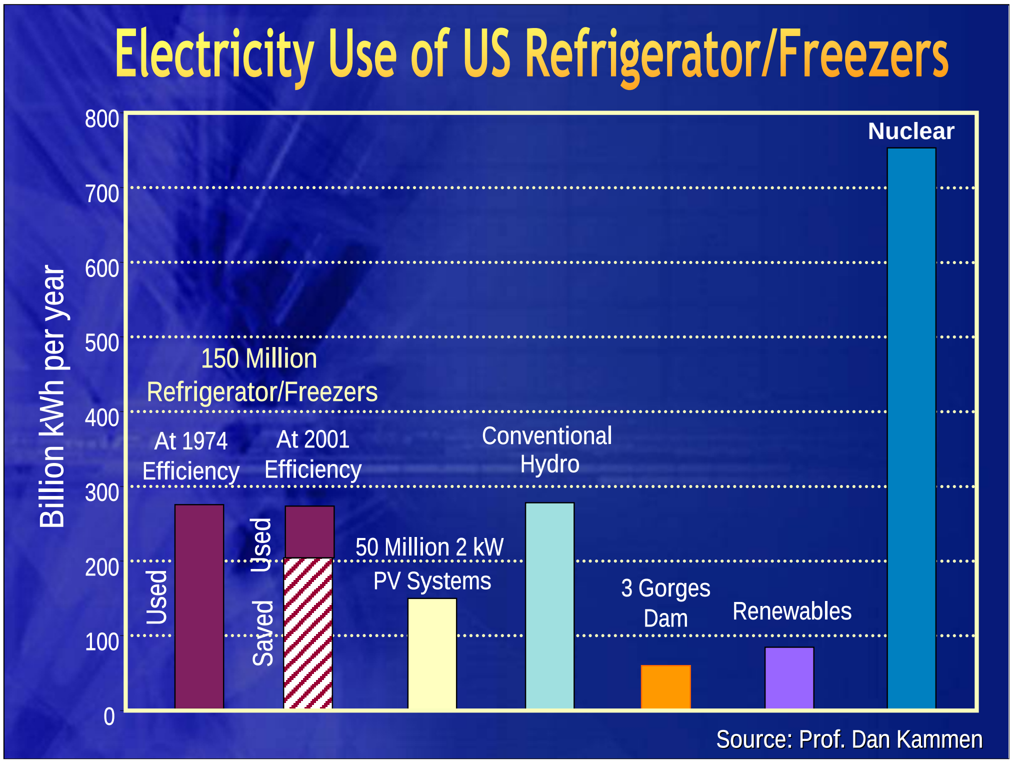
Paul Wright is the A. Martin Berlin Professor of Mechanical Engineering, as well as Associate Dean for Distance Learning and Instructional Technology and the Engineering Co-chair of Berkeley's Management of Technology Program. Paul and his students are now designing and testing thermostats that can adjust energy use to real-time fluctuations in energy prices. They are also developing self-powering batteries that scavenge energy from the environment, using solar power, ambient vibrations, and other sources.



This is a typical prediction slide—there are many I could have used to make this point. The details are a lot less important than the general trends, upon which all of the prediction slides basically agree.

At some point, we do run out of fossil fuels. The main issue is not *elimination* of our use o fossil fuels, but has much more to do with the *way* in which we uses these resources efficiently, understanding their value and their related costs.

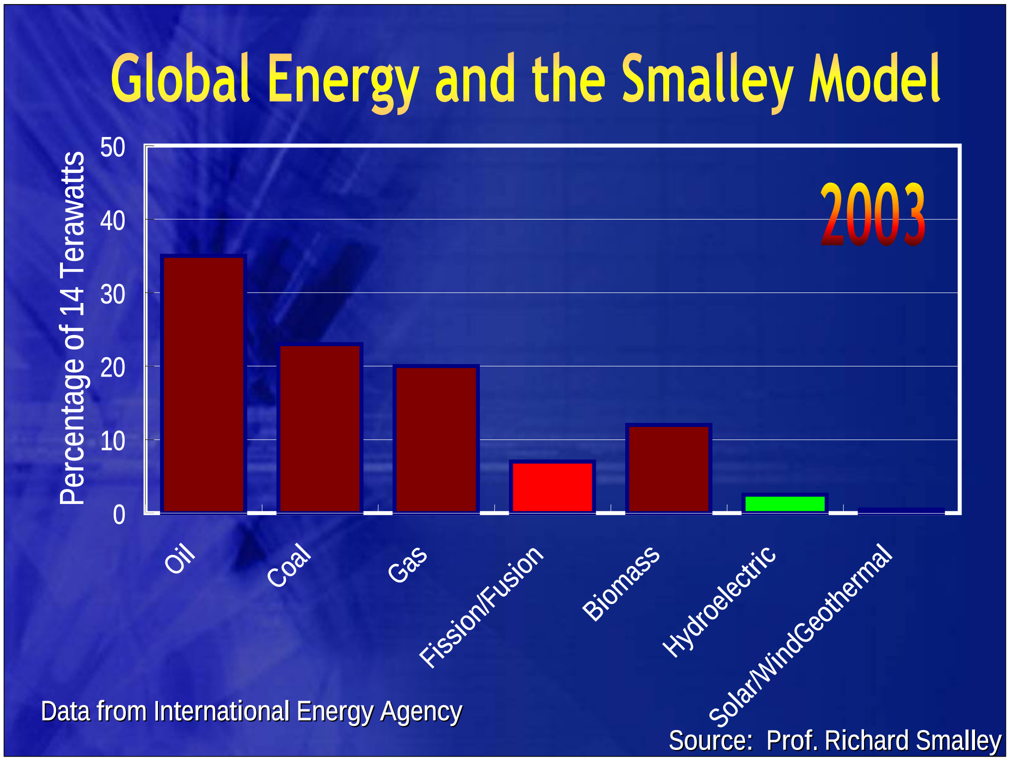
China has come on-line a lot faster than this slide predicted, and so the demand scenario is even higher than shown on this 20 year old prediction.



To get a feeling for how much energy we use in the US today, look at how much energy our refrigerators and freezers consumed in 1974. Now since then, we have improved their efficiency tremendously—but what did we do with those savings? We sold more, even bigger units and lost all the gains over the past 30 years!

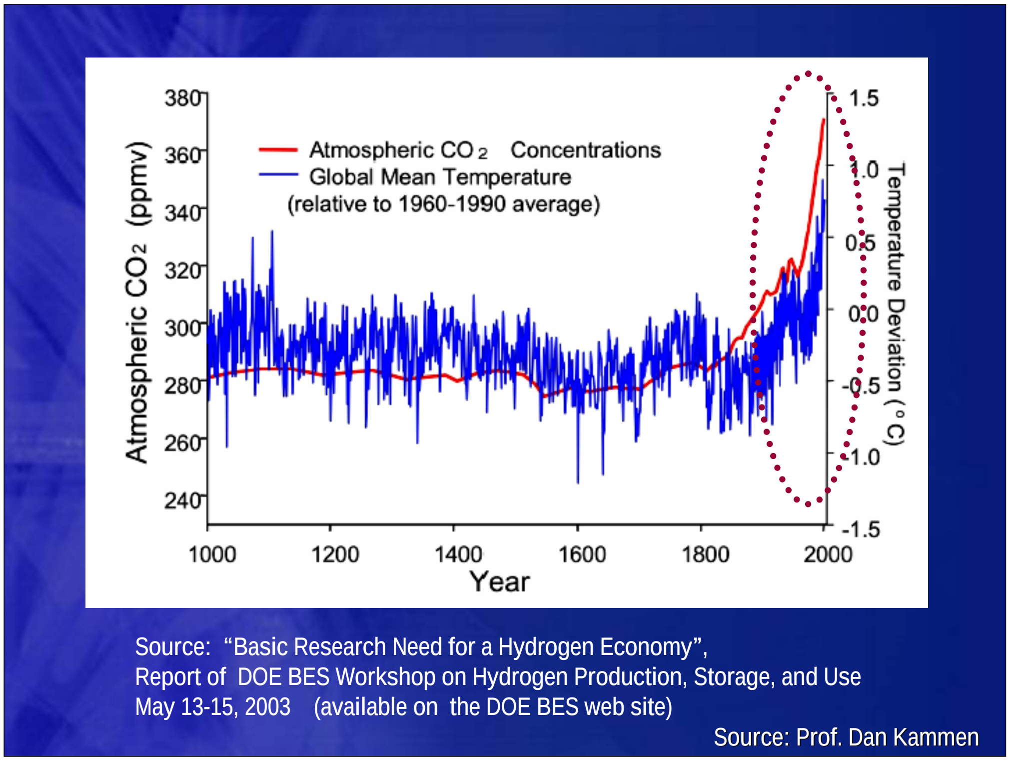
This slide shows the same gain, expressed in TeraWattHours/year, compared with all US hydro power, the Three Gorges dam, all United State’s existing renewables, and United State’s nuclear power.

And that is only refrigerators and freezers!



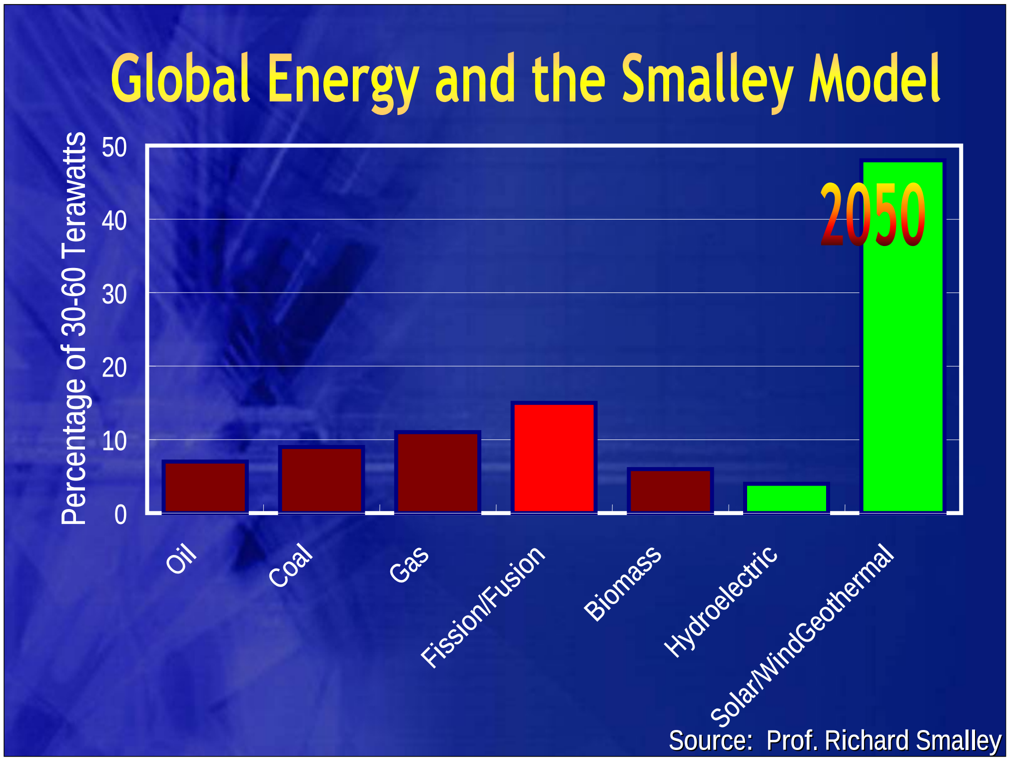
How are we generating the 14TeraWatts of power we consume on the planet today?

Brown are conventional carbon-based fuels. Solar/Wind/Geothermal around 0.5% today.

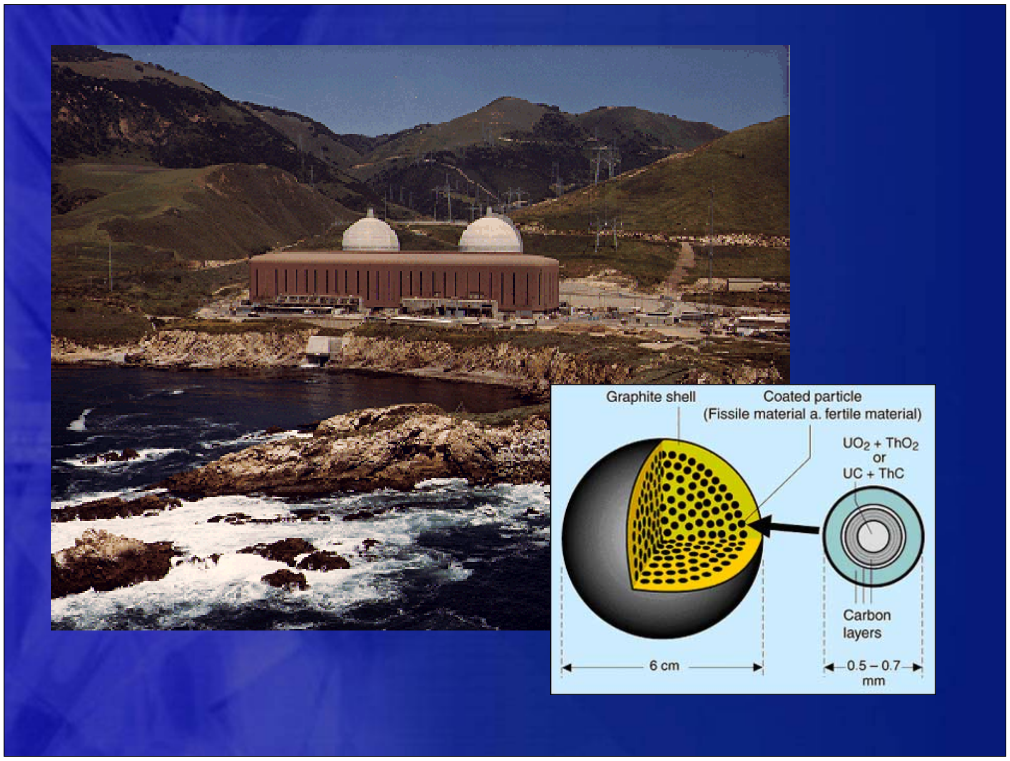


There can no longer be any doubt that man-made sources of pollution are causing the temperature of the planet to rise.

One example: Since Sir Edmund Hillary climbed Mt Everest, the glacier where he started and had his first base camp has receded 5km!

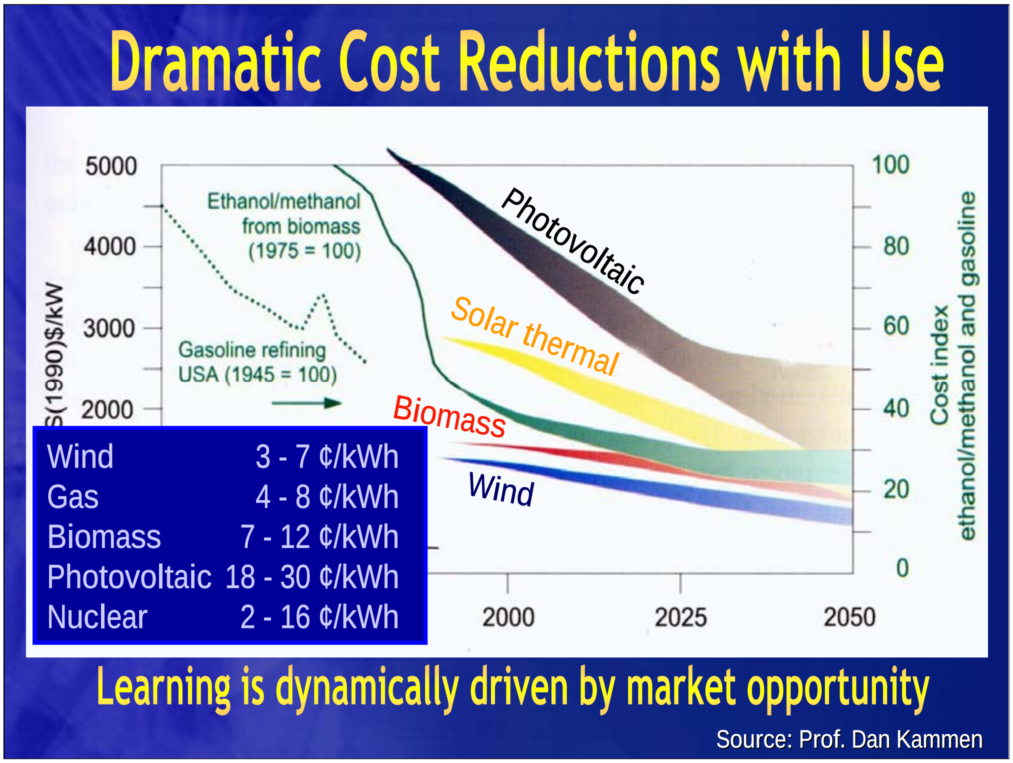


According to Rick Smalley, if we want to limit global temp. change to < 2deg. C additional by 2050, then by 2050 around half of the 30-60TWatts we will need—or 15-30TWatts—must come from “green” sources. This is equivalent to bringing on-line a 1GW green power system *every day* between now and 2050! (…of course, we would likely not implement it that way, as I will explain)



Over the past two decades, the nuclear power industry has engineered a remarkable set of technical and management innovations which have been so successful in improving the operation of nuclear power plants that the US fleet of plants – which has *decreased* in number, now produces over 20% more power today than two decades ago. This is like adding 20- 25 new plants without a single new construction license.

As a result of this, a new hydrogen producing reactor will be built at the Idaho National Engineering Laboratory, and long-dormant discussion to build a new nuclear power plant are now begin hotly debated once again.



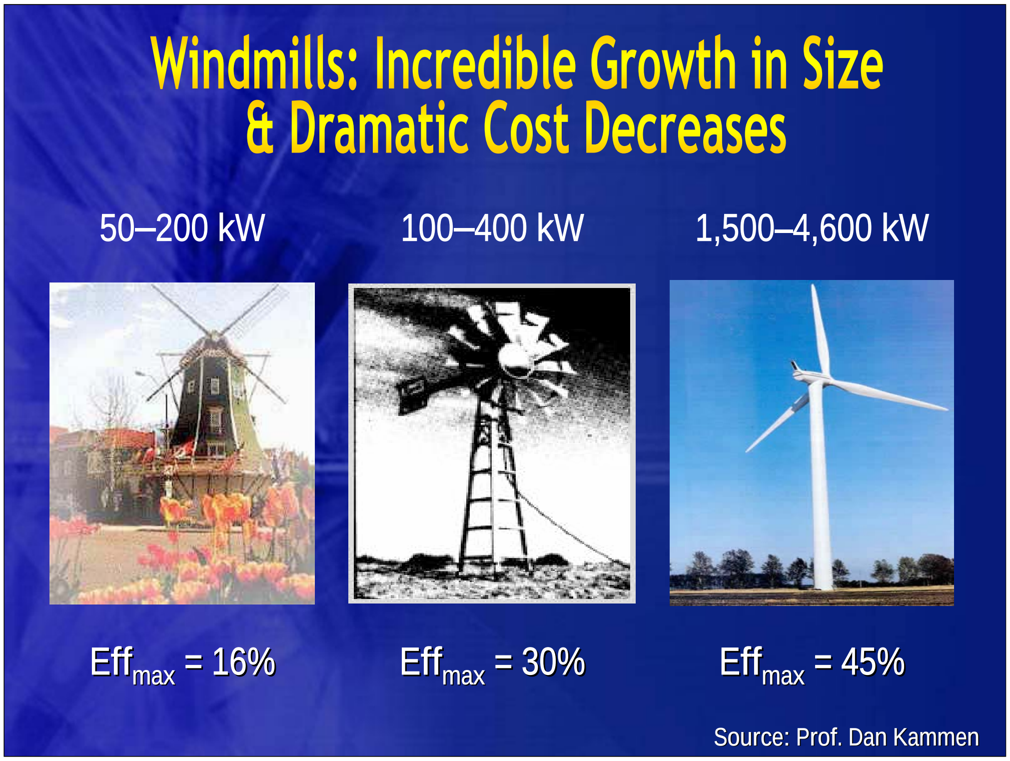
Technology cost improvements, in 1990$ per kW. Past achievements for US gasoline refining and Brazilian ethanol/methanol and range for biomass, solar and wind energy assumed for the three scenarios.

Learning and investment is dynamically driven by market opportunity…

In fact, in 1974 solar photovoltaic (PV) cost ~$40/W; today ~$5-7/W; by 2020 ~$1/W!!

Wind energy and solar photovoltaic (PV) are, respectively, the fastest and second fastest growing *(on a percentage basis)* energy technologies on the planet, with over 25% growth in installed capacity for the past five years running

Global capacity for solar photovoltaic production is now over 500 MW/year, and wind production capacity is over 7,000 MW/year



We are approaching the theoretical limit for wind efficiency at 59% (limited because the wind has to go somewhere once it passes the blades of the turbine.)

The wind energy potential of North Dakota alone is larger than that of Germany, which currently has over *three times* the installed wind capacity of the U. S.

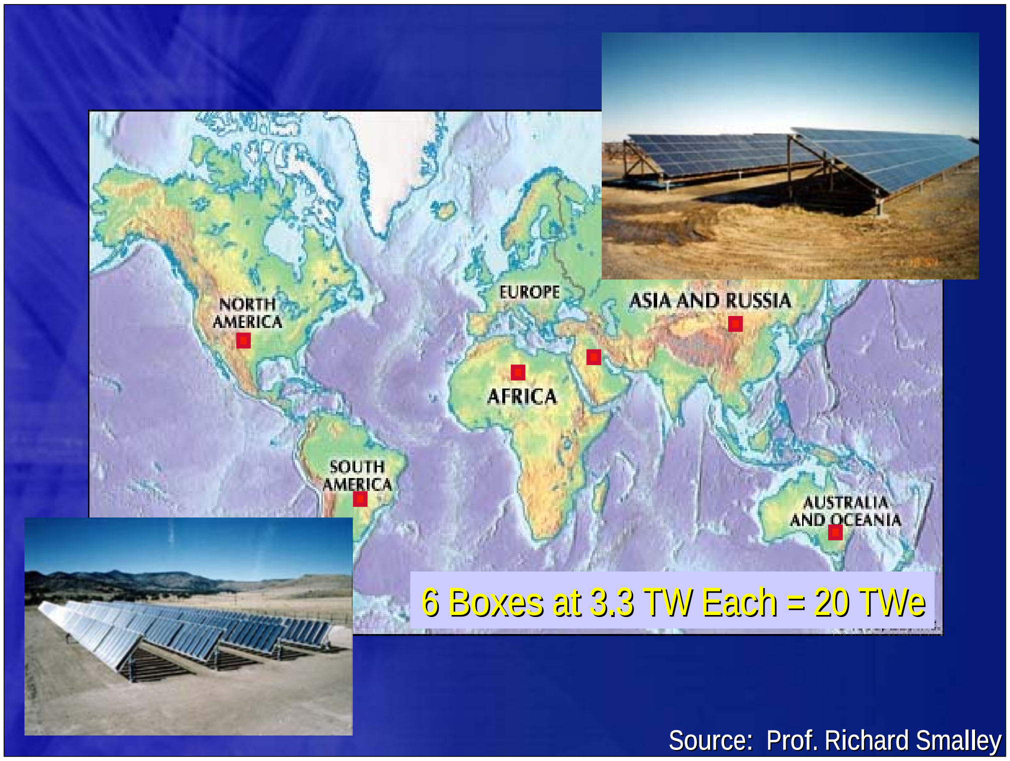
Total global installed wind capacity is over 35,000 MW with parts of northern Germany and southern Spain now obtaining over 25% of their electricity from wind (peaking in the case of northern Germany at 50%)

165,000 TWatts of sunlight hit the earth every day… Plenty for all our needs!

Electricity from solar photovoltaics (PV) now cost ~ $5/Watt (installed), but technical advances in thin film technology, nanotechnology, and from ‘exotic’ technologies like solar *paint* could dramatically accelerate the cost decline of PV from its current level to the $1 – 2/Watt level where PV will be economically competitive in all markets, without subsidies of any kind.

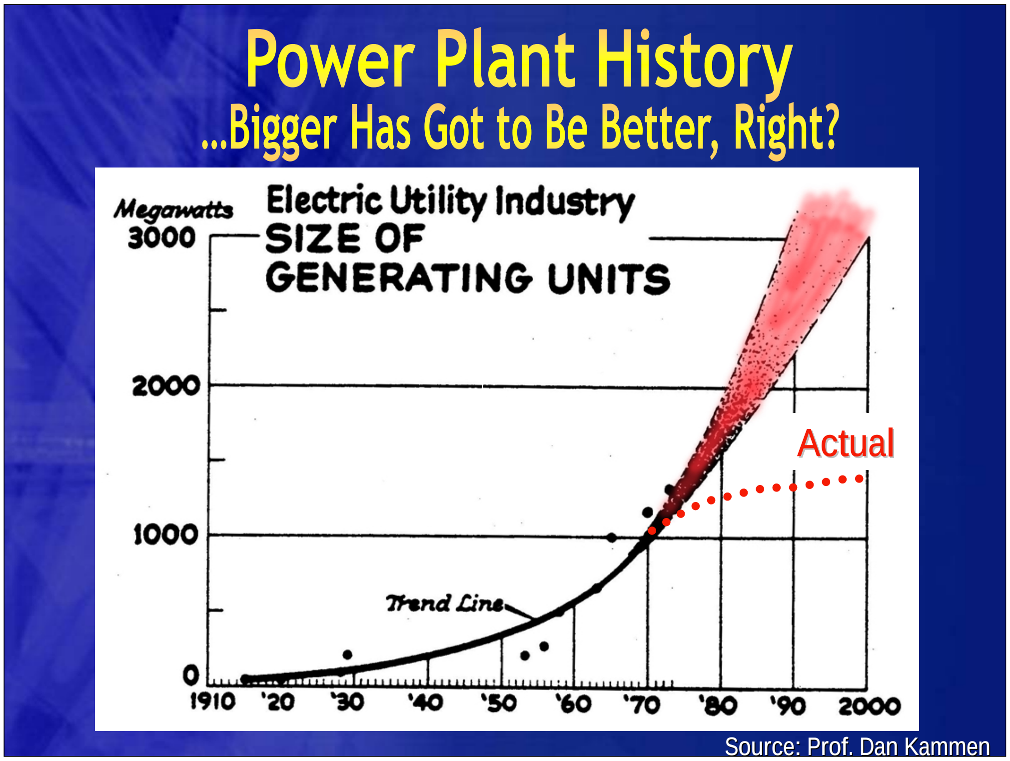
The roof areas of U. S. commercial buildings is far more than necessary to meet *total* U. S. electricity demands.

Yes, there is a storage issue of course—a role hydrogen might play, or some potentially more efficient chemical storage solution than hydrogen.



Centralized power generation with complex and expensive distribution networks is the old view! Not appropriate in today's world for a whole lot of reasons, but this slide makes the point that it would be relatively "easy" to do a lot better with solar than we do today. We don't need to cover much of the earth's surface with solar collectors to get all we need.

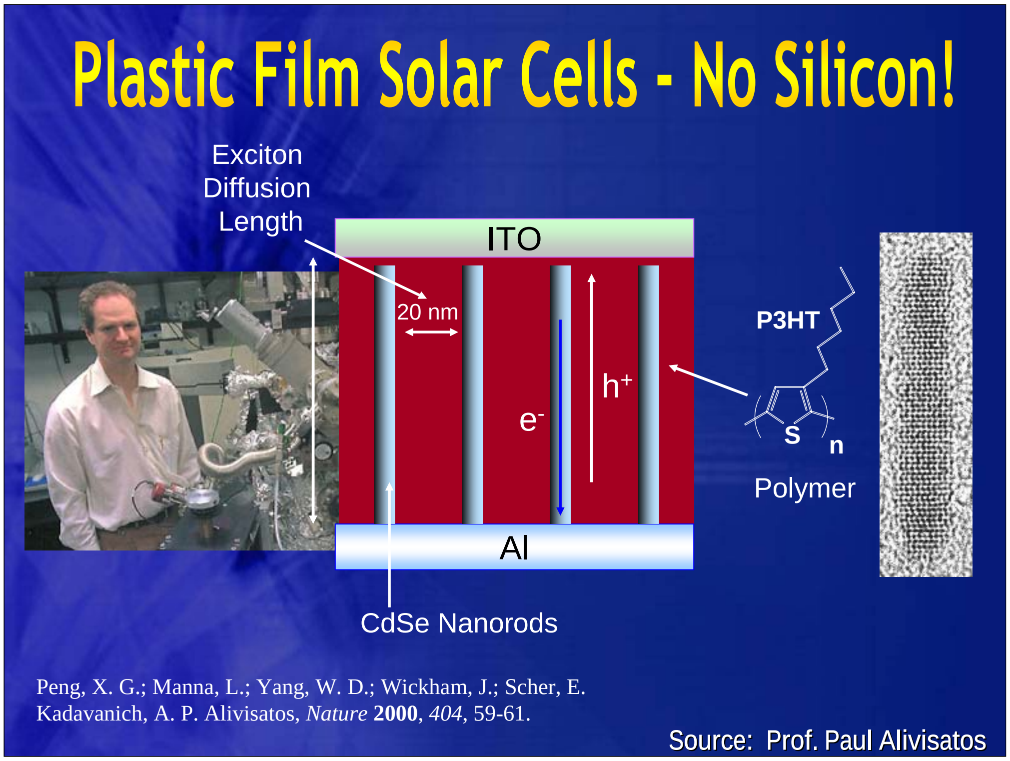
We should include passive solar in this discussion as well—like today's swimming pool heaters, for example.



Even the predications of the 1960's and 1970's did not come to pass in terms of size of generating units. Today, a 70MW jet engine is the most efficient generator of power we have available.


Dan Kammen's Home, Oakland CA: 2,400W

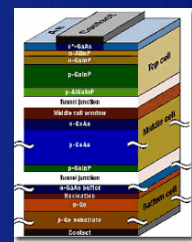

Moscone Center, San Francisco, CA: 675,000 W
Source: Professor Dan Kammen



At Berkeley, a number of researchers are working to produce low-cost and cost-effective photovotaic solutions, especially Professor Paul Alivisatos (Chemistry and Materials Science; LBNL) and his students and colleagues. By making a matrix of self-aligned cadmium selenide "nanorods" in an organic matrix, they have been able to implement a form of "plastic" solar cells that have the potential to be very inexpensive. Of course, cadmium is a toxic chemical and so they are working on alternatives, but the work is very exciting.

Our Best Result So Far!

- Low end silicon tandem cells, 12% power efficiency
- High end multi-band gap tandems 34%
- Key considerations:
  - Thermalization to band edge
  - Processing methods



AM 1.5 Efficiency

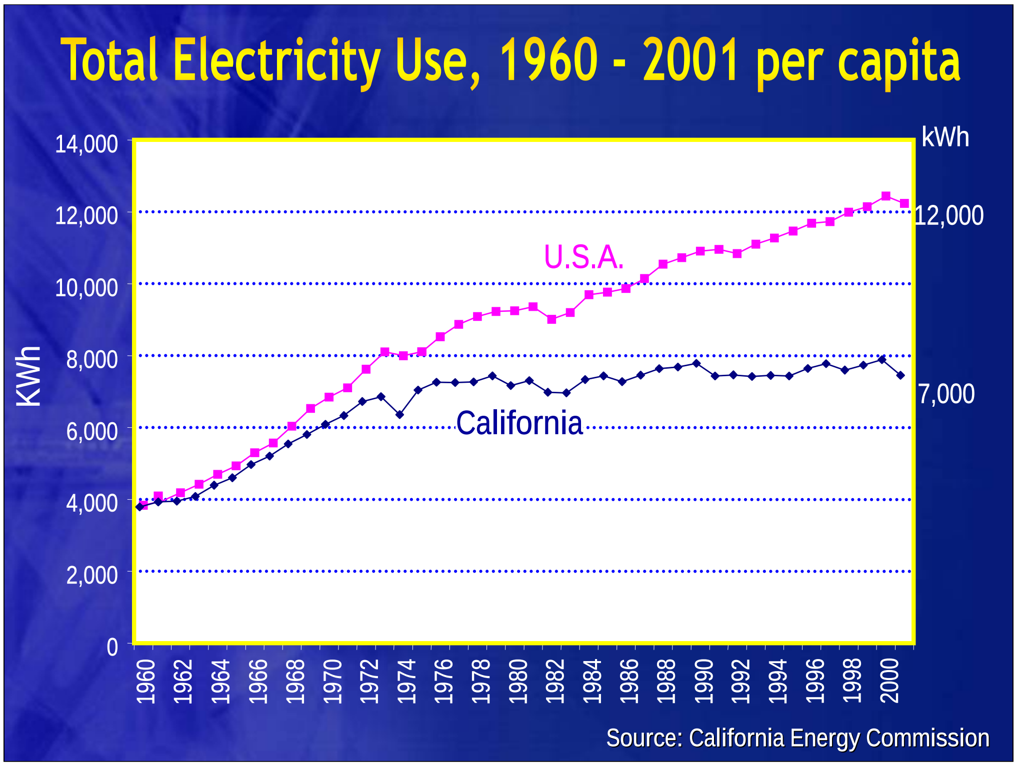
Power Conversion: 1.7%

Short Circuit Current: 5.8 mA/cm^2

Fill Factor: 0.42

Voc : 0.67 V

Source: Prof. Paul Alivisatos

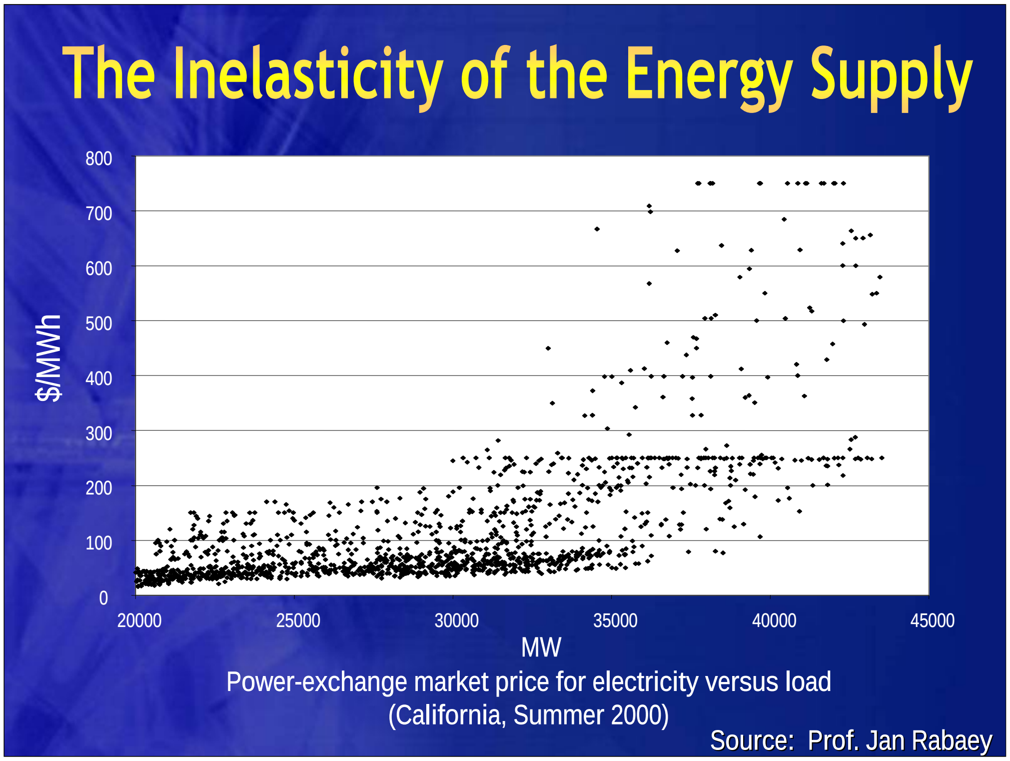


Compares kWh/capita for California, constant for 27 years, with the US, which during the same time grew 50%, i.e. 2%/year.

California has been far out in the lead in innovative energy policies, including:

- The solar revenue bond measure that San Francisco passed in 2001 that will result in 40 MW of PV to be installed in the city, and now a commitment to meet *one-half* of the base-load energy demand in the city with renewables and efficiency measures over the next decade;
- The first greenhouse gas reduction legislation from vehicles in the world (AB 1493)
- Aggressive support of the solar PV industry through rebates on installed, producing systems
- The State Treasurer has developed the 'Green Wave' plan to invest over $1.5 billion of state retirement/pension funds in clean energy and green construction businesses.

If we plotted per household domestic consumption, US versus California, we would see a similar plot. But of course Berkeley would be even considerably lower than the state average! However, the average house in Denmark is considerably more efficient a consumer than the average Berkeley house.

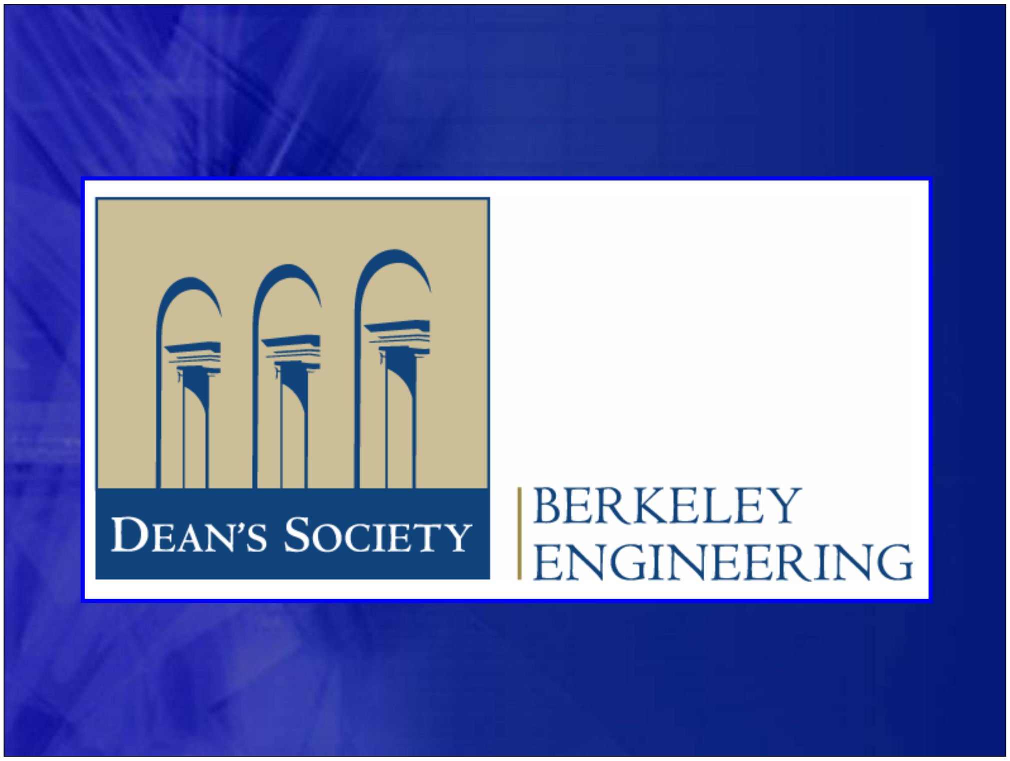

The Inelasticity of the Energy Supply
800
700
600
500
400
300
200
100
0
$/MWh
20000
25000
30000
35000
40000
45000
MW
Power-exchange market price for electricity versus load
(California, Summer 2000)
Source: Prof. Jan Rabaey

Synthetic satellite image, 10 August 1996…utilities routinely keeping the lights on.

But ~98–99% of U.S. outages are caused by failures of the grid.

For example...

35 seconds later, after an Oregon powerline sags into a tree limb, operational goofs plus poor communications black out four million people in nine Western states and parts of Canada. Local supply can prevent that—and up to 95+% of grid failures are in the distribution system.



Now I haven't talked about hydrogen much yet.

Hydrogen and fuel cell cars are being hyped today as few technologies have ever been, and California seems to be buying the hype. Yet, for all the hype, a prestigious National Academy of Sciences panel concluded in February 2004 that in the best-case scenario, the transition to a hydrogen economy would take many decades, and any reductions in oil imports and carbon dioxide emissions are likely to be minor during the next 25 years. And that's the best case.

Realistically, hydrogen cars are a post-2030 technology. They require at least three major breakthroughs before they are practical, and a premature push towards hydrogen cars would undermine efforts to reduce global warming. This is the subject of Dr. Joe Romms new book "The Hype about Hydrogen: Fact and Fiction in the Race to Save the Climate".

Summary

UC Berkeley and our partners at LBNL have assembled the largest and most productive set of energy researchers at any university. If we continue to coordinate and refine these efforts, and continue our international collaboration, we can really have a major impact over the next decade.

At the national level, a major meeting to analyze options to develop a sustainable energy future took place March 25/262004 in Washington, DC. This meeting, to explore energy opportunities one and five decades from now – the 10/50 solution – was attended by industry and academic leaders, members of the US House and Senate, and representatives from the teams of the current presidential candidates. Dan Kammen participated in the meeting as part of the renewables team and I will ask him to give us a brief report on what happened there.

Thank you!

A snapshot of energy research at UC Berkeley is included on the next two pages.

Advanced Solar Cells and Nanofabrication of Cells

A revolution is underway in the materials and fabrication techniques employed to develop new, high-efficiency, low-cost solar cells. UC Berkeley has multiple groups looking at nano-scale methods, to exotic materials, to organic solar cells. Among the research foci for these efforts are:

The Nanoengineering Laboratory

Faculty: Arun Majumder (ME), Shankar Sastry(EECS), Paul Alivisatos (Chem/MSE)

Advanced Materials Methods for High Efficiency Solar Cells

Faculty: Eicke Weber (MSE)

The Energy and Resources Group (ERG)

Interdisciplinary graduate research group with projects in all areas of energy science, systems, and social impacts. ERGs graduates are international leaders in every field of energy. To date ERG has graduated over 300 Masters and Doctorate students. ERG faculty and former students have been involved in national and international energy science and policy, and two have been awarded MacArthur ‘Genius’ Awards. Former UC Berkeley Physics professor Art Rosenfeld who was instrumental in establishing ERG, is now one of the five California Energy Commissioners.

Energy-focused faculty: Dan Kammen (ERG), Alex Farrell (ERG)

URL: http://socrates.berkeley.edu/~erg

The Renewable and Appropriate Energy Laboratory (RAEL)

RAEL was founded by Professor Kammen in 1999, and is a jointly supported by the Energy and Resources Group and the Department of Nuclear Engineering. Housed in Etcheverry Hall, RAEL supports a wide range of energy science and policy projects, with significant efforts in both sustainable energy options for developed and industrializing nations. RAEL involves over 20 students, three faculty members in addition to Professor Kammen, and three post-doctoral fellows.

Energy-focused faculty: Dan Kammen (ERG), Alex Farrell (ERG)

URL: http://socrates.berkeley.edu/~rael & http://socrates.berkeley.edu/~kammen

The Department of Nuclear Engineering

The department of nuclear engineering at UC Berkeley is rated second in the nation, and has one of the most diverse research portfolios with major research efforts on reactor design, reliability, neutronics, waste management, fusion, and nuclear medicine.

Department chair: Per Peterson (NE)

URL: http://www.nuc.berkeley.edu

Combustion Management and Pollution Mitigation

Berkeley houses a unique combination of research teams tackling engineering, monitoring, combustion science, and epidemiological aspects of emissions management.

a) Biomass in developing nations & energy/health interactions: Dan Kammen (ERG), Kirk Smith

b) Primary and secondary chemistry of pollutant formation: Rob Harley, Catherine Koshland

c) Indoor Air Quality and Pollutant Transport: Bill Nazaroff, Ashok Gadgil

d) Life-cycle methods: Arpad Horvath

Energy Market Research: Economics, Engineering and Policy

a) The University of California Energy Institute (UCEI)

This UC System-wide research and funding operation has supported work in a diverse range of energy issues, with a focus and international reputation for work on the operation of energy markets.

Faculty: Severin Borenstein (Haas), Carl Blumstein (Haas)

b) Power Systems Research Center

Research at the interface of engineering and economics on the performance of energy markets, and modeling of firms and individuals in those market systems.

Faculty: Shmuel Oren (IEOR)

c) RAEL

The barriers and opportunities for renewable energy systems in current and envisioned energy markets. Hydrogen production and use; fuel cells; fossil-fuel, nuclear, and renewable energy hydrogen production.

Faculty: Dan Kammen (ERG)

d) Energy and Public Management

Faculty: Lee Friedman (GSPP) & Tim Duane (Planning)