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Natural Gas and the Jackrabbit

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Thanks to Gary Smith and the PowerSouth Energy Cooperative for the opportunity to speak with you about the energy business viewed through a green lens. [**Slide 1**]. In the end my green lens will focus you on natural gas, methane, not so-called renewables. My task is to explain why methane is green and destiny, and why renewables are neither green nor destiny.

First, let me comment on a current temptation. The sudden crash of the US and world economies during the last year tempts us to have faith in revolutionary change. For energy systems, we should resist the belief that in a short time everything can be different. Very stable trends characterize the energy system. In fact, the stable trends finally appear to go unscathed through economic depressions, wars, and, for better or worse, fashions in public policy.

Let me begin with an extreme example of public policy, the central planning that followed a famous revolution, the Bolshevik Revolution of 1917 in Russia. The Russian Revolution and later World War II literally drove Russians back into the woods to collect their fuel. Yet, these extreme political and economic shocks were later entirely absorbed. A “business as usual” extrapolation of market substitution using logistic curves for the period 1890-1915 predicts market shares of primary fuels in the USSR in 1950 very nicely. By 1950 one sees no visible effect on the energy system of World War I, the Bolshevik Revolution, the Great Depression, or World War II. Wood was disappearing right on schedule, coal peaking, oil growing, and soon gas would be soaring, and nuclear penetrating.

I would say the energy system had arrived at its genetic destiny. Along the way, the leaders of Russia and its adversaries had made the population miserable. Yet, the so-called leaders and planners made no lasting effect on the USSR energy system.

America's experience in energy systems differs little from Soviet Russia. Consider for the US the change of four variables -- population, affluence, consumer behavior, and technological efficiency -- that together cause emissions of sulfur dioxide and carbon dioxide. **Slide 2** charts the changes of combinations of these variables against growing affluence between 1900 and 2007. In particular, look at the effect of intervals of economic depression and recession. For sulfur, in the Depression of 1930-1935 the system backtracked and then resumed its trajectories, barely affected. The chaotic fluctuations during the post-War recession of 1945-1952 were similarly soon absorbed. For sulfur, the system worked its way through a 100-year program of growing and then declining emissions. Richer was first dirtier, but then richer became cleaner, in a great arc economists call a Kuznets curve, for the American economist Simon Kuznets.

What differs between sulfur and carbon is the duration of the life or product cycle. For carbon, completing the arc, the Kuznets curve, will take three hundred rather than the one hundred years sulfur took. Carbon will weigh in the energy system for another 75 years or so.

Returning to the regressive effects of economic turmoil, a zoom into the carbon dioxide emission story during the Depression in **Slide 3** shows the effects in detail. The system darts this way and that before regaining its

long-run orientation. A 20-second animation (**Slide 4**) shows the jackrabbit behavior of the system in a depression. To summarize, periods of depression and other forms of shock such as war do not revolutionize an energy system, though they do release lots of hot air from politicians and pundits.

Here let me introduce the most important trend in the environment for the energy business, namely decarbonization. Hydrocarbons are of course a mix of hydrogen (H) and carbon (C) [**Slide 5**]. Each combines with oxygen to release energy, with the hydrogen converted to water H_2O , and the carbon mostly converted to carbon dioxide, CO_2 , which is food for plants but also a greenhouse gas that now worries a lot of people. On average, when one removes the water, biomass fuels such as wood, hay, and oats have a ratio of about 40 Cs to 4 H. Charcoal is essentially pure C. Coal comes in many shades but typically has about 8 Cs for each 4 H. Popular liquid products, like gasoline and jet fuel, average about 2 C for each 4 H. Methane, CH_4 , burns only 1 carbon for each 4 hydrogens, 1/40th the ratio of wood.

Twenty-five years ago, my colleagues and I put all the hydrocarbons humans used each year for the past two centuries in a hypothetical gigamixer and plotted the history of fuel in terms of the ratio of C to H [**Slide 6**]. To our surprise we found a monotonic trend, namely the ascent of hydrogen. We named the trend decarbonization for the concomitant descent of carbon. The history of hydrocarbons is an evolutionary progression from biomass to coal to oil to natural gas and on to hydrogen, eventually derived from non-fossil fuels in order to keep the primary mix clean of carbon. The figure shows carbon losing market share to hydrogen as horses losing to cars or typewriters losing to word processors. The slow process to get from 90% C

to 90% H in the fuel mix should take about 300 years and pass the 90% mark about 2085. Let's say 2100 so as not to appear overconfident.

Some decades have lagged and some accelerated but the inexorable decline of carbon seems clear. Times make the man. The patron of my University, John D. Rockefeller, surfed on this long wave by standardizing oil. Al Gore surfed the wave to a Nobel Peace Prize. Over the past 20 years decarbonization has entered the vernacular, and a New York money manager even has a decarbonization mutual fund. Successful people and companies ride the wave of history and arrogate fame and money. I hope people in this room do so.

A variation of decarbonization as a competition between carbon and hydrogen (**Slide 7**) shows the kilos of carbon per unit of energy, thus integrating fuel switching with increases in efficiency, that is, technical progress, for example better motors. The global kilos of carbon per joule of energy slide inexorably downward. The variation of carbon per GDP further integrates energy with consumer behavior, that is, whether consumers favor energy with their marginal dollar. The US is not an exception to the world trend. **Slide 8** shows that the US will soon celebrate its centennial of falling carbon per dollar. In summary, long-term decarbonization lines always point down for C and up for H.

One naturally asks why. The explanation is that the overall evolution of the energy system is driven by the increasing spatial density of energy consumption at the level of the end user, that is, the energy consumed per square meter, for example, in a city. Finally, fuels must conform to what the end user will accept, and constraints become more stringent as spatial density of consumption rises. The spatial density of consumption in vertical

cities like Shanghai is soaring. Such rich, dense cities accept happily only electricity and gases, now methane and later hydrogen. These are the fuels that reach consumers easily through pervasive infrastructure grids, right to the burner tip in your kitchen.

Ultimately the behavior of the end user drives the system. When the end user wants electricity and hydrogen, the primary energy sources that can produce on the needed scale while meeting the ever more stringent constraints that attend growth will eventually and inexorably win. Economies of scale are a juggernaut over the long run.

One contributor to economies of scale is the heat value of the fuel per kilo [**Slide 9**]. Replacing brown coal with methane raises the energy per ton of fuel as it decarbonizes. Thirteen railroad cars of biomass such as switchgrass equal about one railcar of coal and half a car of oil. Economies of scale match best with technologies that grow smaller even as they grow more powerful, as computer chips, electric motors, and power plants all have done (**Slide 10**). Miniaturization matters because it multiplies the potential market, as laptops show compared to main frame computers. Moreover, miniaturization is green. It shrinks our footprint.

Miniaturization also matters because, notwithstanding the present depression, over the long-turn energy use will keep rising. One reason is that computer chips could well go into 1000 objects per capita, or 10 trillion objects worldwide, as China and India log into the game. By the way, some studies suggest the total energy system demand of a cell phone is not unlike a refrigerator, because the telecom system must flood the skies with waves and always be on. PowerSouth managers probably know exactly how its

customers have increased demand by filling homes, hotels, and offices with wifi and flat screens even as lamps and appliances became more efficient.

What is the most promising way for the energy system to meet fluctuating and then again rising consumer demand amidst green fears? For electricity, the obvious and destined route is methane, and PowerSouth is about halfway there. Methane is inherently good for reasons now well-established, but it can be even better. The next big trick is to take rocket engines and turn them into power plants. One might say take a cruise missile or even the space shuttle and turn it upside down and operate it for a few hundred thousand hours. While methane consumption grows, we won't permit ourselves to dispose much of its carbon in the air. So, we will also capture the emissions and make a methane-fueled Zero Emission Power Plant or ZEPP.

Operating on methane, a ZEPP puts out electricity and carbon dioxide that can easily be sequestered. From an engineering point of view, the key is air separation or abundant cheap oxygen so that the fuel can be burned neatly with the O₂ and leave streams only of CO₂ and water (**Slide 11**). While in principle any fuel could be an input to such a machine, the theme of clean-up on the front end favors methane. Coal is a minestrone with sulfur, mercury, cadmium, and other headaches. Why buy rocks that will leave piles of these elements that will likely cause a plant site to become a regulated toxic waste dump, when one can purchase methane that is already almost purely C and H? Chemical engineers appreciate the benefits of fine feedstock.

ZEPP technology is exemplified by a company called Clean Energy Systems in Bakersfield, California, which already has operated for 4 years a

prototype ZEPP of 20 MW, which I visited myself (**Slide 12**). Some day the Kimberlina plant may become an environmental world heritage site for its contribution to decarbonization. Operating at high temperatures and pressures, the plant, or rocket one might say, is delightfully compact.

Clean Energy Systems is also working on a 200 MW generator, whose dimensions are even more striking (**Slide 13, 14, 15**). Think of a 200 MW generator or turbine as a mobile home and the power park as half a dozen trailers. The “All in” efficiency of the ZEPP including compressed CO₂ as a by-product should be about 50%. The CO₂ can be sequestered underground in a saline formation or used lucratively for enhanced oil recovery or enhanced gas recovery,

Pushing the envelope on pressure and temperature, Japanese colleagues calculate (**Slide 16**) a ZEPP a few decades hence could reach 70% efficiency, green indeed compared to the 30% of today’s coal plants. Doubling the efficiency of power plants attracts me as a way to spare carbon emission. My dream is a 5 GW ZEPP, super fast, operating at high temperatures and high pressures and thus super compact. A single machine the size of a locomotive would more than double PowerSouth capacity and fit comfortably within the existing infrastructure!

Where will the methane come from? Here let me introduce a heresy. [**Slide 17**] I reject the notion of “fossil” fuels, which implies that all or most oils and natural gases derive from the buried and chemically transformed remains of once-living cells. Think of Earth instead as a steaming plum pudding, outgassing since ever. Primordial, non-biological carbon comes in the first place from the meteorites that help form Earth and other planetary bodies. Abiogenic carbon clearly abounds on such planetary bodies as

Titan, which enjoyed no Carboniferous or Jurassic eras with giant ferns and dinosaurs. Now we sniff outgassing methane on Mars, too (**Slide 18**).

Water also abounds inside Earth, perhaps 10 times as much as in the oceans. Suppose the carbon is upwelling from the core and mantle of the planet and then, through a range of interactions with hydrogen and oxygen at high temperatures and pressures, enters the crust from below as a carbon-bearing fluid such as methane, butane, or propane. Continual loss of the very light hydrogen brings it closer to what we call petroleum or even coal. Emissions from volcanoes and earthquakes give further evidence of very deep hydrocarbons eager to outgas.

The fossil theory relies on the long unquestioned belief that life can exist only at the surface of Earth. In one of the most exciting scientific developments of recent years, science has now established the existence of a huge, deep, hot biosphere of microbes flourishing within Earth's crust, down to the deepest levels we drill. In fact, humanity has never drilled deeper than life. Mud from the deepest holes of 30,000 and 40,000 feet bears life. These deep microbes can best be explained by diffuse methane welling from the depths on which methane-loving bugs thrive. Oil, too, is very desirable to microbes.

So, the alternate concept is that the deep hot biosphere adds its products to the upwelling hydrocarbons. The bioproducts have caused us to uphold the belief that the so-called fossil fuels are the stored energy of the Sun. I believe much, maybe most, of the oil and gas is not the stored energy of the Sun but primordial hydrocarbons from deep in Earth. And they keep refilling oil and gas reservoirs from below, as reported in fields deep under the Gulf of Mexico. Alternate theories of the origins of gas, oil, and coal

may well revolutionize Earth sciences over the next 2-3 decades, and lift estimates of resource abundance. Methane may more truly be an inexhaustible and renewable fuel, generated continually deep in Earth, than forests, which humanity managed to eliminate from much of North Africa, for example, for about 2,000 years.

New theory will also help reveal methane resources in little explored places, such as the continental margins, where the sea floor slopes from a few hundred meters deep to a few thousand. **[Slide 19]**. Now frequent discoveries of communities of life that live around cold seeps of methane on continental margins suggest that margins have lots of fracture zones where gas upwells. Methane seeps are plentiful on the slopes of Powersouth's service area in the Gulf of Mexico **[Slide 20]**), near the potentially giant Jack Field touted in September 2006. A more embracing theory of the margins in which outgassing methane occurs all along their extent creates not only startling life on the margins but vast ribbons of opportunity for offshore exploration. Israel just proved the opportunity by finding deep carbon 16 thousand feet beneath 5000 feet of water on its continental margin. **(Slide 21)** The abundance of deep carbon, especially accessible offshore, and its possible explanation, is a big story for the energy industry. The big news from Brazil is not the few gallons of alcohol from sugar cane that provide less than 10% of that nation's primary energy, but the plans of Petrobras to expand offshore natural gas extraction from astonishingly rich and surprising superdeep wells from 7 million cubic meters per day in 2013 to 40 million per day in 2020.

Working in the oceans brings immense responsibility. The oceans are beautiful beyond imagination, as a selection of Arctic jellies show **[Slide**

22]. But we have already squandered many riches of the oceans, and we do not want to squander or harm more. The energy industries, including PowerSouth, should become leading stewards of marine life, supporting creation of protected areas, research, and monitoring, while operating perfectly where society does permit operation. Florida and other states in the Gulf Region can see the example of operators in places such as Norway, where gas extraction activities minimally impact the environment (**Slide 23**).

Returning to the land, shale formations such as the Barnett and Marcellus also harbor vast amounts of methane. The recent documentation of the US reserves of about 2,000 tcf, comparable or larger than the fabled Russian reserves, should limit methane price volatility, a widely cited objection to the growth of methane's market share.

Methane is compact, but uranium is 10,000 to 100,000 times more so [**Slide 24**] Small is beautiful, and nuclear is very small. It is, after all, atomic power. While the competition will take another century or so, finally nuclear energy remains the overwhelming favorite to produce the hydrogen and electricity that Alabama and Florida, not to mention Bangalore and Shanghai, will demand. The important point is nuclear's environmental superiority to so-called renewables.

The reason, as hinted already, is that efficiency must be reckoned in space as well as energy and carbon. To me the essence of green is No New Structures, or at least few new visible ones, in the Gulf of Mexico or South Alabama. I repeat that, like computers and the internet, the energy system to be deeply green should become more powerful and smaller. [Repeat slide 10 as **Slide 25**] During the 20th century, electric generators grew from 10 to 1

million kW, scaling up an astonishing 100,000 times. Yet a power station today differs little in the space it occupies from that of 50 or 100 years ago.

What about the so-called renewable forms of energy? They may be renewable, but calculating spatial density proves they are not green. The best way to understand the scale of destruction that hydro, biomass, wind, and solar promise is to denominate each in watts per square meter that the source could produce [**Slide 26**].

In a well-watered area like the Southeast, a square kilometer produces enough hydroelectricity for about a dozen Americans, while severely damaging life in its rivers. In any case, one needs catchment areas of hundreds of thousands of square kilometers to provide gigawatts of electricity, and no such areas remain in the Southeast.

The Southeast abounds in forest, more productive than the forest of New England mentioned in Slide 26, but Powersouth would need to harvest from every acre of three typical Alabama counties to provide kilowatts equal to those generated by a single 1000 MW nuclear power plant on a square kilometer or two.

Shifting from logs to corn, a biomass power plant requires about 2500 sq km of prime Iowa farmland to equal the output of a single 1000 MW nuclear power plant on few hectares. PowerSouth would need to farm every acre of Covington County to generate the kilowatts you would get from a nuclear power plant.

Windmills to equal the same nuclear plant cover almost 800 square km in a very favorable climate. (**Slide 27**)

Photovoltaics require less but still a carpet of 150 sq km to match the nuclear plant. **(Slide 26 repeated as 28)**

The spatial ratio for a Toyota rather than a large power plant is equally discouraging. A car requires a pasture of a hectare or two to run on biofuels, unwise as the world's vehicle population heads toward 1 billion.

Biofuels, wind, solar, and other so-called renewable massacre habitat. I want to spare land for nature, not burn, shave, or toast it.

No economies of scale adhere to any of the solar and renewable sources **(Slide 29)**, including by the way the sources of ocean energy, such as tides, waves, and the thermal gradient, which also suffer from combinations of dilution and intermittency. If you need another megawatt, you site and build yet another windmill, another structure. Supplying more customers or more demanding customers requires matching increases in infrastructure, indeed potentially larger areas, as one will probably have used the most fertile, wavy, windiest, sunniest, and wettest sites first.

Moreover, bridging the cloudy and dark as well as calm and gusty weather takes storage batteries and their heavy metals. The photovoltaics raise nasty problems of hazardous materials. Burning crops inflates the price of food. Wind farms irritate with low-frequency noise and thumps, blight landscapes, and whack birds and bats.

And, solar and renewables in every form require large and complex machinery to produce many megawatts. Per average MW(e), a natural-gas combined cycle plant uses 3.3 MT steel and 27 m3 concrete, while a typical wind energy system requires construction inputs of 460 MT of steel and 870 m3 of concrete per average MW(e), about 130 and 30 times as much. The

wind industry is a very heavy industry, as transporting turbines shows **(Slides 30-34)**.

Renewable energies also invoke high risk as sources of supply in a changing climate. Clouds may cover the deserts investors covered with photovoltaics. Rain may no longer fall where we built dams and planted biomass for fuel. The wind may no longer blow where we build windmills. Maybe PowerSouth should put its Iowa windmills on railcars, as Ronald Reagan wanted to put Peacekeeper intercontinental ballistic missiles on railcars rather than in silos. Without vastly improved storage, the windmills and photovoltaics are supernumeraries for the coal, methane, and uranium plants that operate reliably round the clock day after day.

We live in an era of mass delusion about solar and other renewables, which will become an embarrassing collection of stranded assets. But let's use our intelligence and resources to build what will work on the large scale that matters for decarbonization rather than to fight irrationality. Humans are not rational after all, and the environment for the energy business never will be.

What about efficiency? On efficiency, I maintain the engineer's view that improvements are embedded in the lines of development of any machine or process. In spite of market failures and other obstacles, increases in efficiency are documented for everything from aircraft and autos to air conditioners and ammonia production. We will be busy squeezing out inefficiency for at least another millennium. The overall thermodynamic efficiency of our energy system, measured from the woodchopper to the hot soup on the dinner table, advanced from only perhaps 1% in 1000 to 5% in 2000. Cars, most reviled, are perhaps 15% efficient, while homes viewed as

machines may be only 3%-5% efficient. The difficulty is no one has found a way to sustain improvements in efficiency beyond the 1-2%/yr that seem built into most processes. A big problem seems to be user's time budgets. Efficiency strategies like car-pooling that conflict by even a few minutes with people's convenience are discarded.

While we have not discovered durable ways to multiply our rate of increase of energy efficiency, the past year has reminded us broadly of the virtues of thrift. Thrift and frugality have not been prominent values in world society in recent decades. Indeed, one may attribute the present economic crisis to worldwide growth of what is aptly called the Debt Culture. Fortunately, PowerSouth, rooted in rural economy in the best sense, did not join the Debt Culture. In the USA debt soared to 3 times GDP (**Slide 35**), as individuals, households, companies of all sizes, and governments at all levels basically decided they could print money a go go. The adjustment will likely create jackrabbit behavior in the energy system, as Stalin or the Great Depression did, but does not change the fundamentals, like the destiny of natural gas. But it may make finding capital for pipelines and ZEPPs harder.

Now let me return to strategies and fate. We know during the last decade that almost all orders for new US power plants were gas, and that gas will become dominant in the next 10-20 years. In the end, the system wins. Don't forget the System; it won't forget you.

So, what is left for strategy, of businessmen or politicians? To minimize waste and unproductive debt, to be on the right side of fate. Waste in the US energy play comes, for example, from the failure to separate natural gas from oil. As an environmentalist, each time I hear "oil & gas"

talked about like Siamese twins, I hear missed opportunity. Oil and gas are very different fuels. I spend most of my time with Greens of various kinds, and I believe many Greens would accept drilling for natural gas, whether off-shore Florida or in upstate New York, if natural gas is the exclusive target, if it isn't a cover for drilling for more oil and the problems that come with oil.

Politicians could help, or could recognize reality and ratify and legitimize it, by forming state and national energy policy directly about natural gas and not "oil & gas" or "fossil energy". The rights of way for pipelines are the sorts of problems that the political system has to deal with, and should deal with. So are LNG terminals; LNG adds flexibility to the system. So are safety of transport and storage of gas, and underground sequestration of CO₂. Oil will remain a big product for another thirty or forty years, but oil is not a growth industry, whereas enormous need and room exist for growth in thoroughbred natural gas. Keep in mind that natural gas can penetrate oil's stronghold, the market for mobility. CH₄ can provide both the gigawatts to charge batteries and other forms of electrified transport and the hydrogen to power fuel cells. We might be surprised how civil the energy discussion would become if a Natural Gas First policy were decisively promoted.

Let me now summarize. Very stable trends, particularly those of decarbonization and miniaturization, appear finally to go unscathed through economic depressions, wars, and central planning. **(Slide 36)** Fortunately, the trends are green, or perhaps they persist as trends precisely because they are green, that is, they meet constraints of the system associated with increasing spatial density of energy consumption. Renewables may be

renewable but they are not green. Failing to benefit from economies of scale, they offer few watts per square meter and demand more space and volume from nature than the system finally will permit.

Planning, strategy, and R&D should essentially support the invariants in the system. Symmetrically, one should avoid the wasteful, painful excursions around the long-term trends organized by Lenin and Stalin, or the US coal and renewable interests, whom I lump together. For a trillion dollar industry like energy, jackrabbit search strategies are very costly. **(Slide 37)** For PowerSouth, the strategic green prescription is simple: with due attention to environment and safety, favor methane and compact new machines that use it efficiently.

Thanks to Cesare Marchetti, Keith Pronske, Smriti Rao, and Paul Waggoner

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Natural Gas and the Jackrabbit

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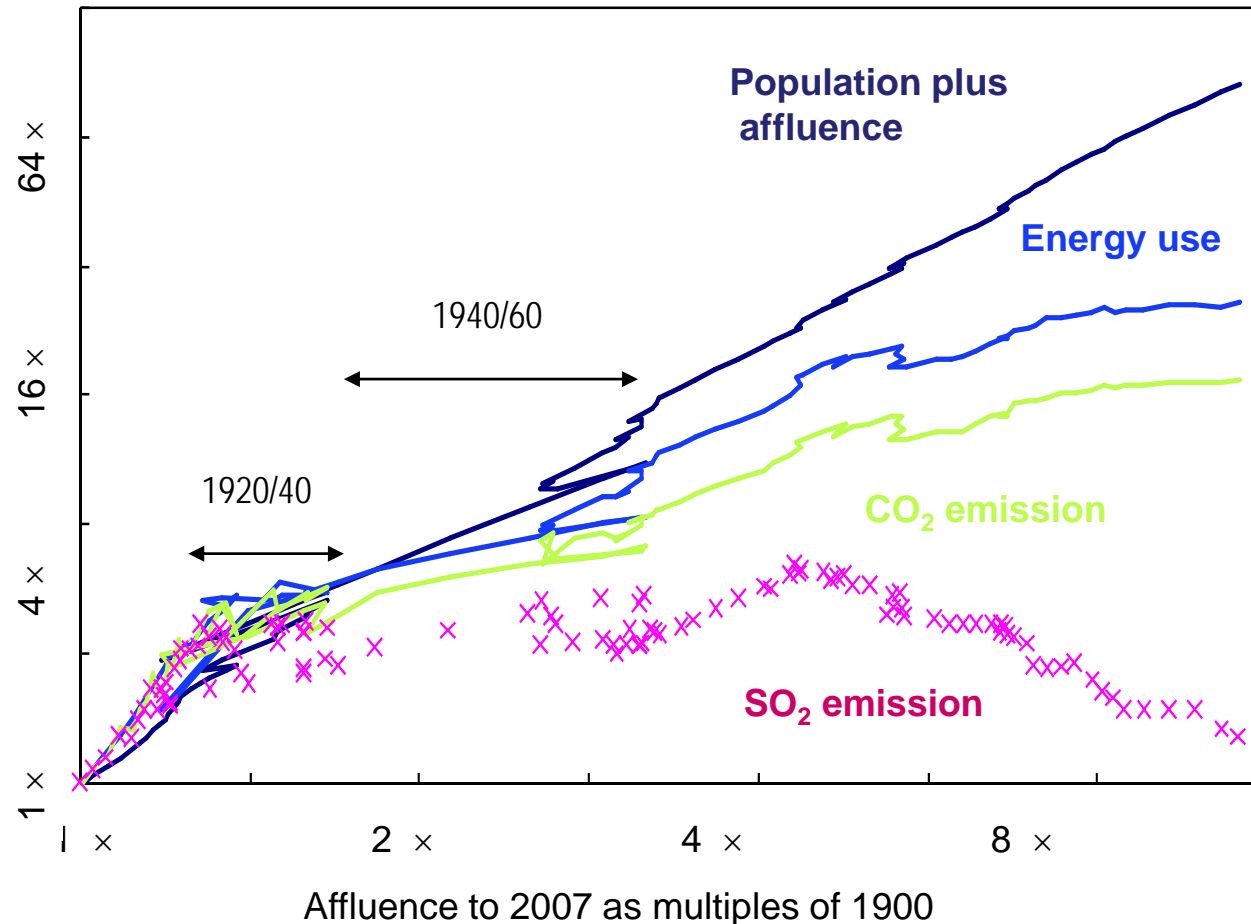
Program for the Human Environment
The Rockefeller University, New York City

<http://phe.rockefeller.edu>

Acknowledgements: C. Marchetti, K Pronske, S. Rao, P. Waggoner

Multiples of U.S. emissions, energy use & population plus affluence (GDP)

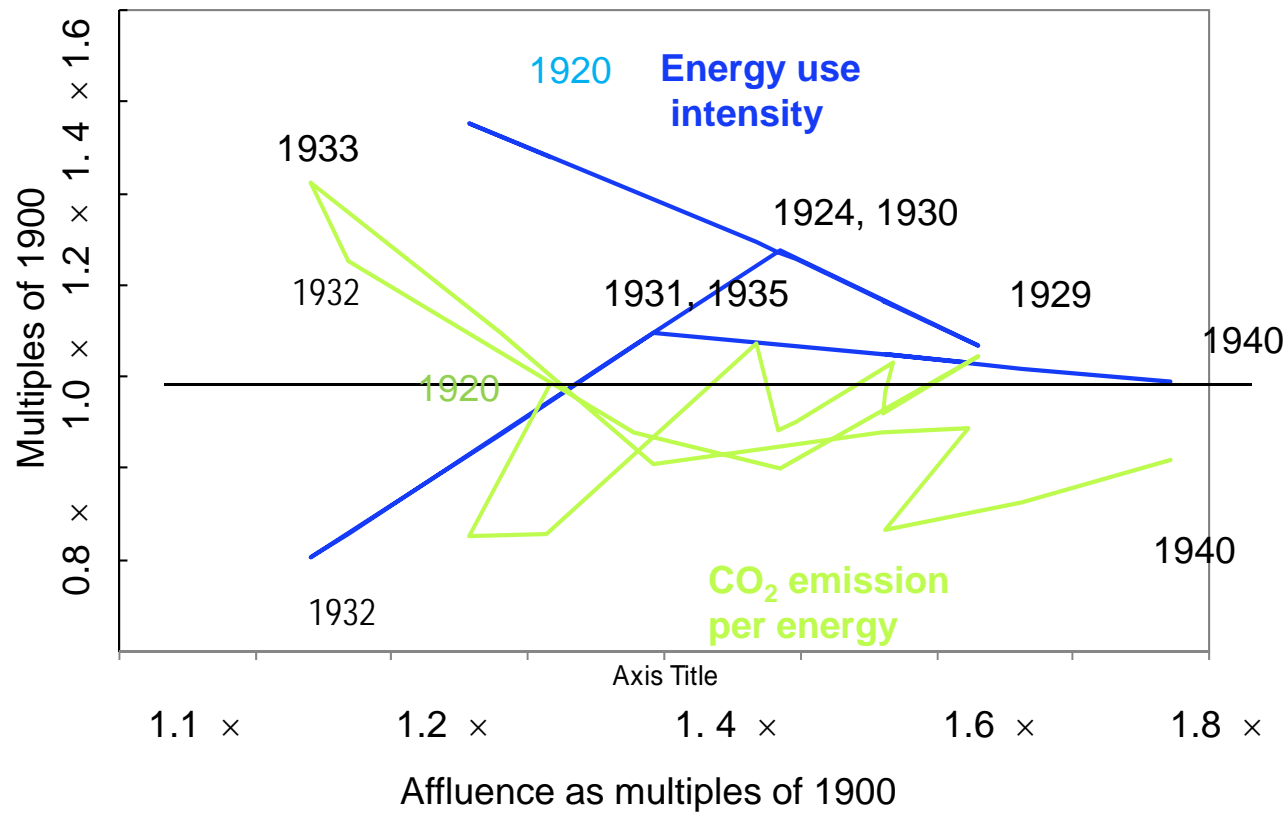
Economic slumps of the Great Depression & post World War II Recession appear as **switchbacks** that fundamentally do not change trajectories



Data Sources: U.S. Census Bureau. 1975. Historical Statistics of the U.S. and various years Statistical Abstract of the U.S.; Energy Information Agency, various years; Carbon Dioxide Information Analysis Center. 2008; and U. S. Environmental Protection Agency. 1985 and 2008.

Depression causes erratic movement

A line sloping down from left to right charts environmental progress



Data sources: Same as the previous slide

The Jackrabbit of Depression (animation)

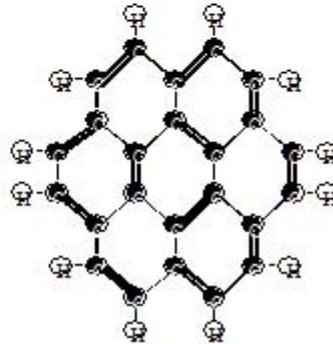


Carbon atoms per hydrogen atom in hydrocarbons

Evolution from wood to methane decarbonizes

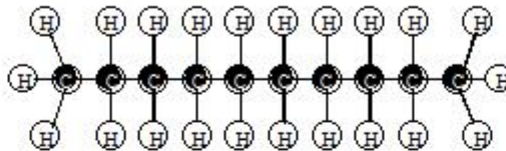
Biomass Wood & Hay C:H = 40:4 (water removed; charcoal pure C)

Typical Coal



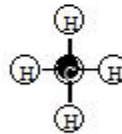
C:H = 8:4

Typical Oil



C:H = 2:4

Methane Gas

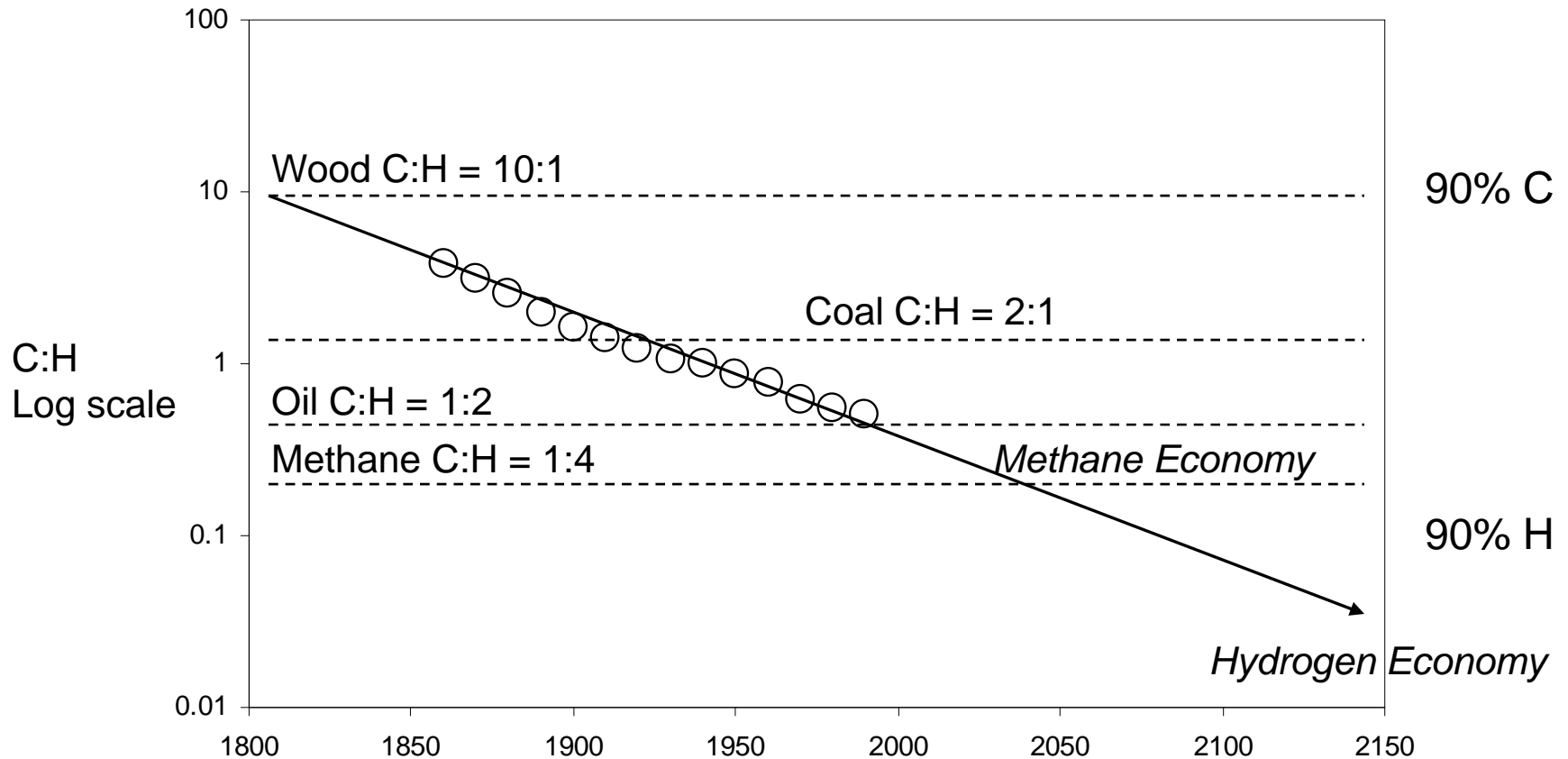


C:H = 1:4

Source: Ausubel, 2007

Global Decarbonization

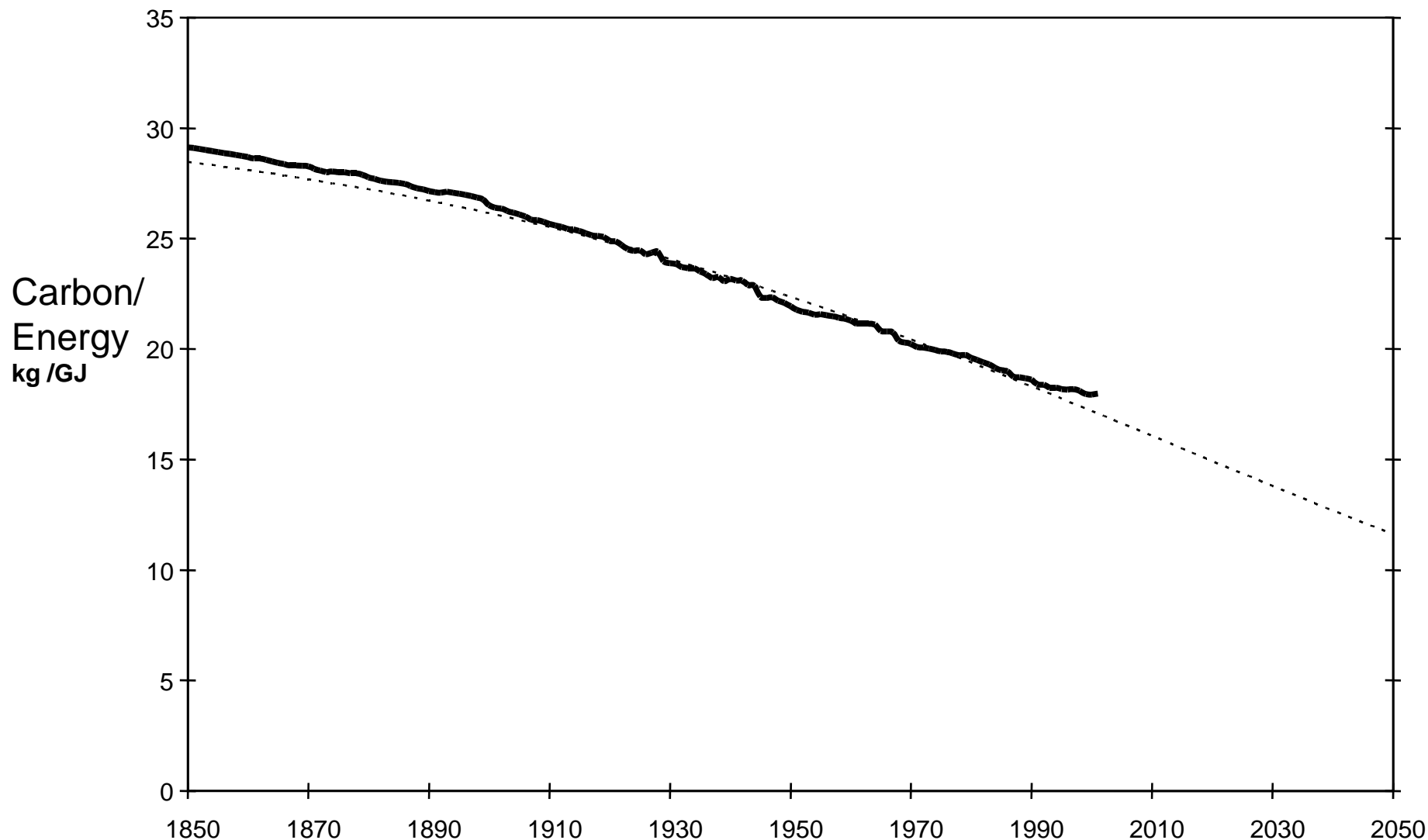
Evolution of C:H ratio in global fuel mix



Viewed as market substitution, decarbonization is a 300-year process for C to fall from 90% to 10% market share, with midpoint in year 1935

Decarbonization of **Global** Primary Energy

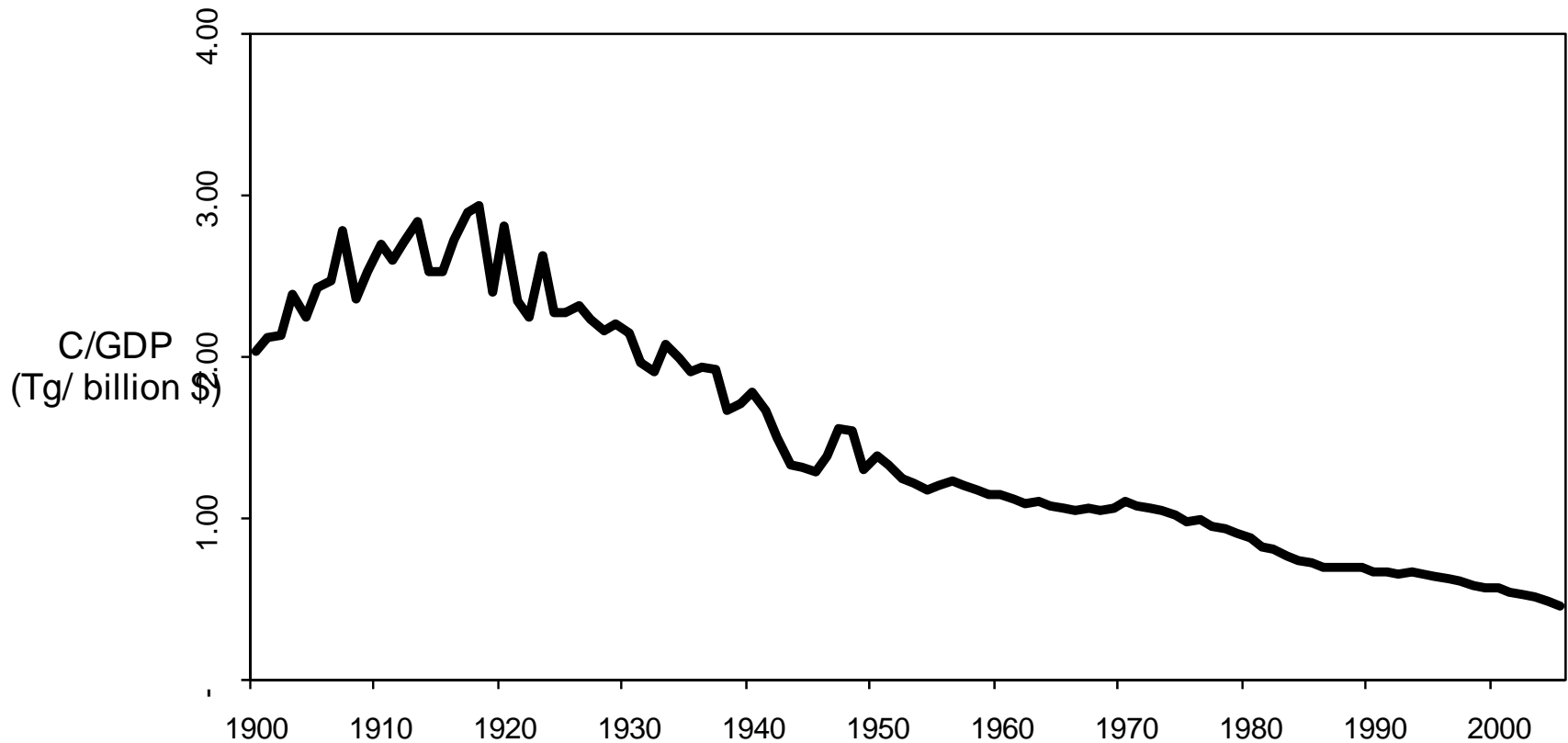
Viewed as declining carbon intensity of all primary energy



Data sources: IIASA, BP (1965-2001), CDIAC http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm

U.S. rise & fall of carbon/GDP

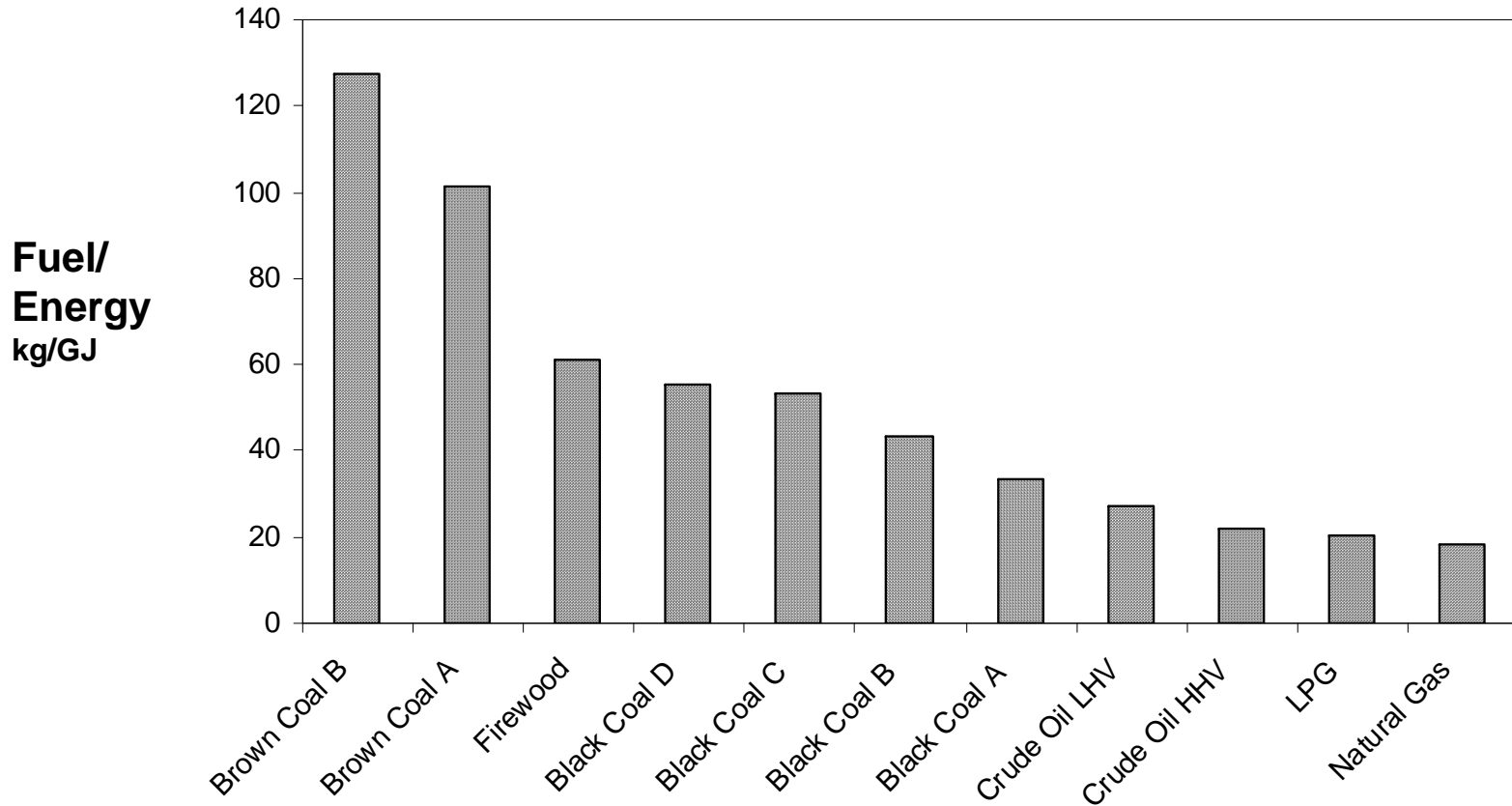
from coal, oil, gas since 1900



Data source: Carbon Dioxide Information Analysis Center

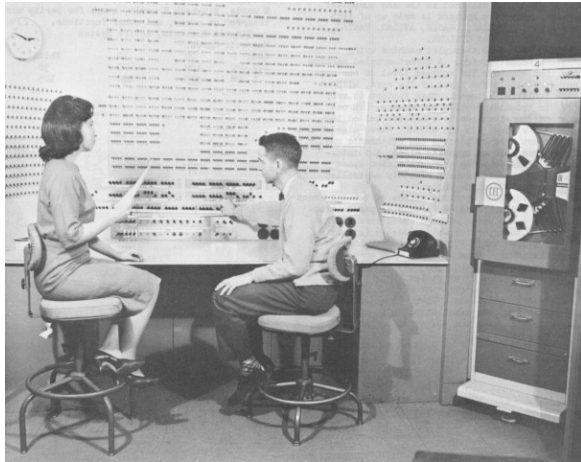
Fuel Mass per Energy of Hydrocarbons

Economies of scale favor fuels suited to higher power density and thus decarbonization



Like computers that comprise the Internet, power plants become more powerful AND SMALLER

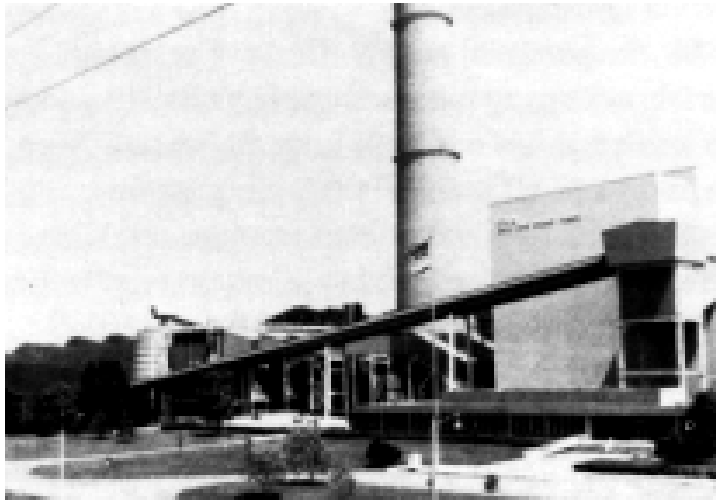
J. Ausubel & T. Barrett, 2004



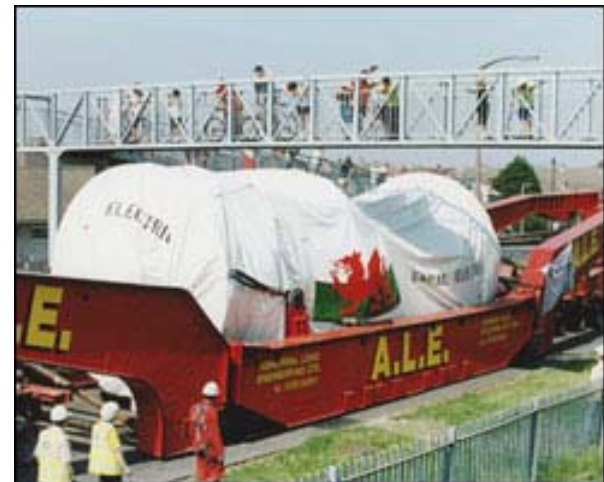
US Ballistic Research Lab computer, mid 1950s



Dell laptop, 2004



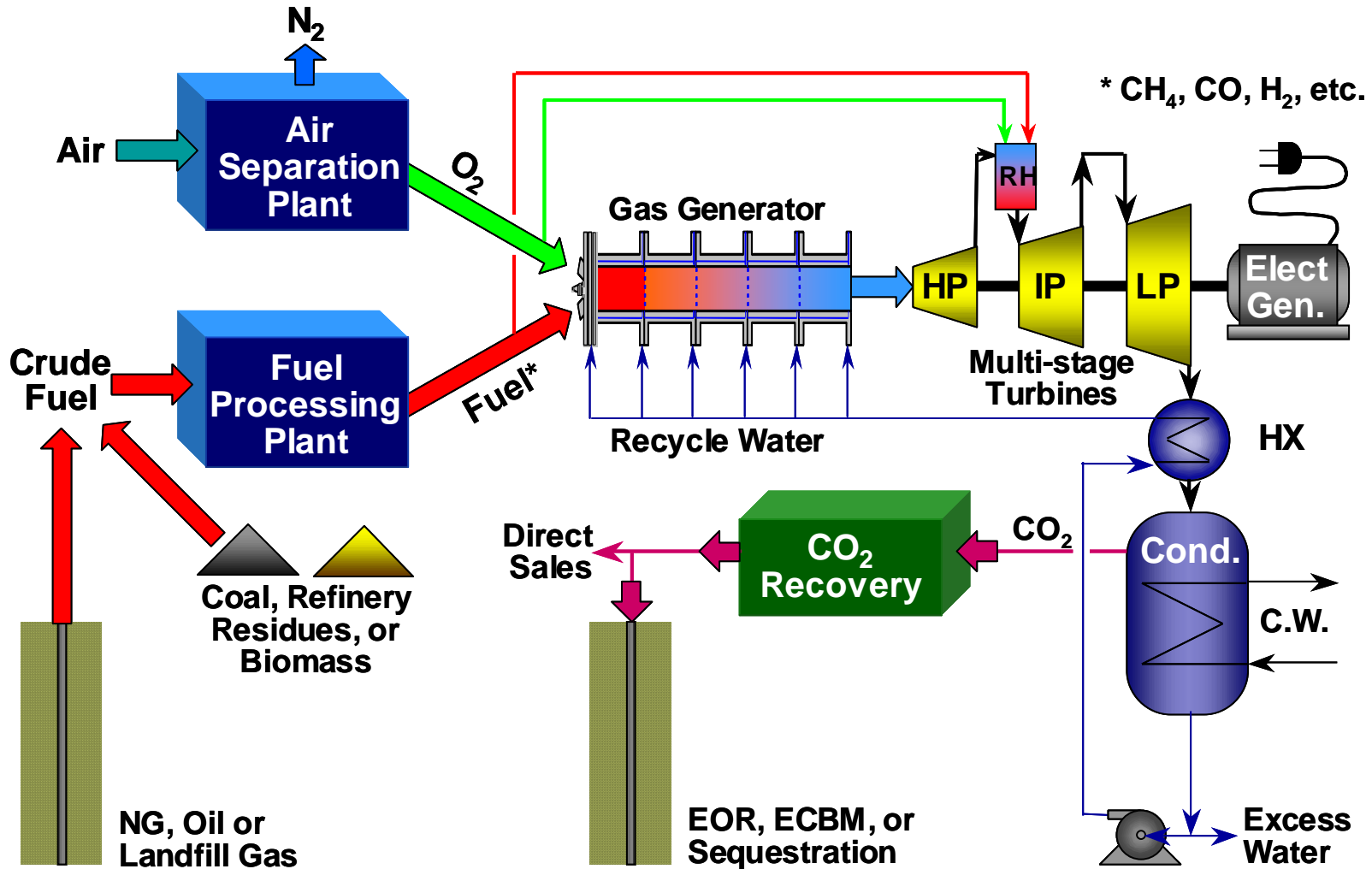
Tennessee Valley Authority coal plant
(date unknown)



Delivery of General Electric
480 MW natural gas turbine, 2000

Zero Emission Power Plant design

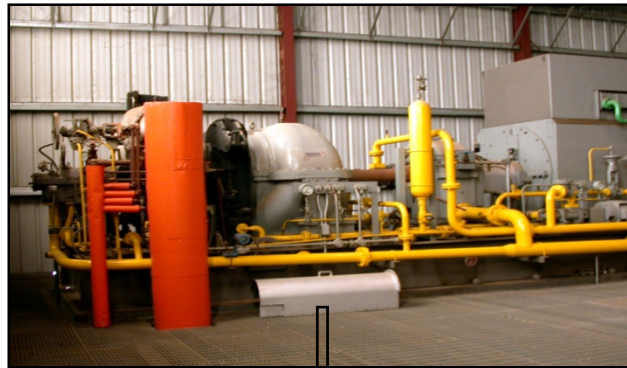
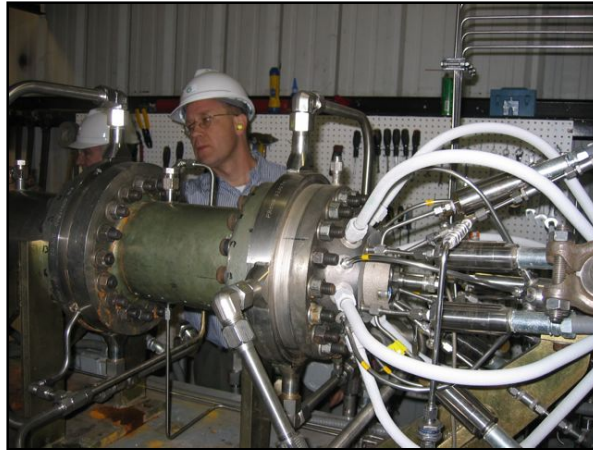
Clean Energy Systems, Inc.



Kimberlina Test Facility – 20 MW_t

Bakersfield CA (in idled 5 MWe biomass plant)

- Online Feb 2005
- 2,000 hrs & 400 starts
- Nat Gas, simulated syngas & liquid fuels with sulfur
- Funding from California Energy Commission, US DOE, Air Liquide, & Air Products



Gas generator only 2 meters long

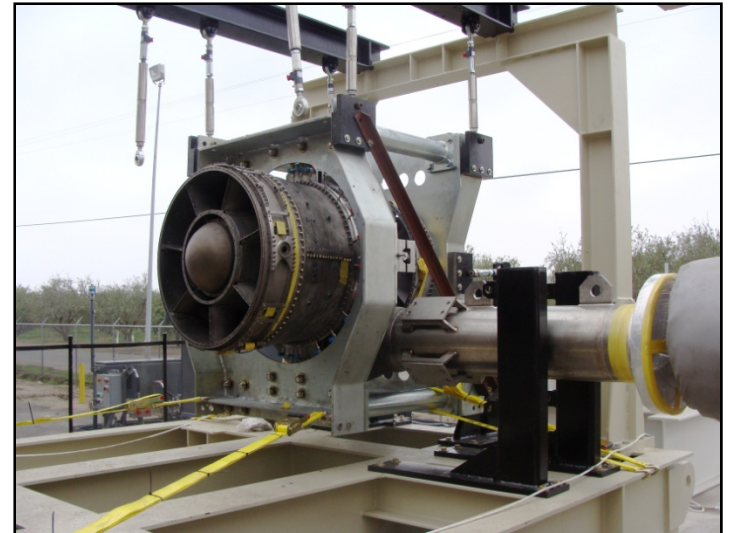
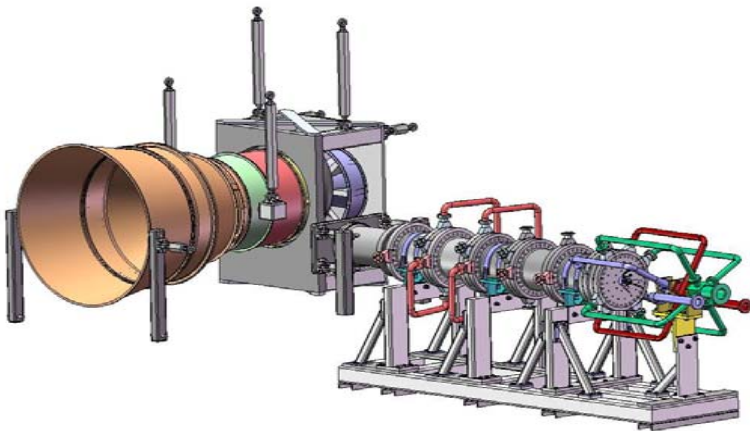


CES 200 MW_t Gas Generator



CES (J79-LM 1500)

First Generation Turbine – 920°C



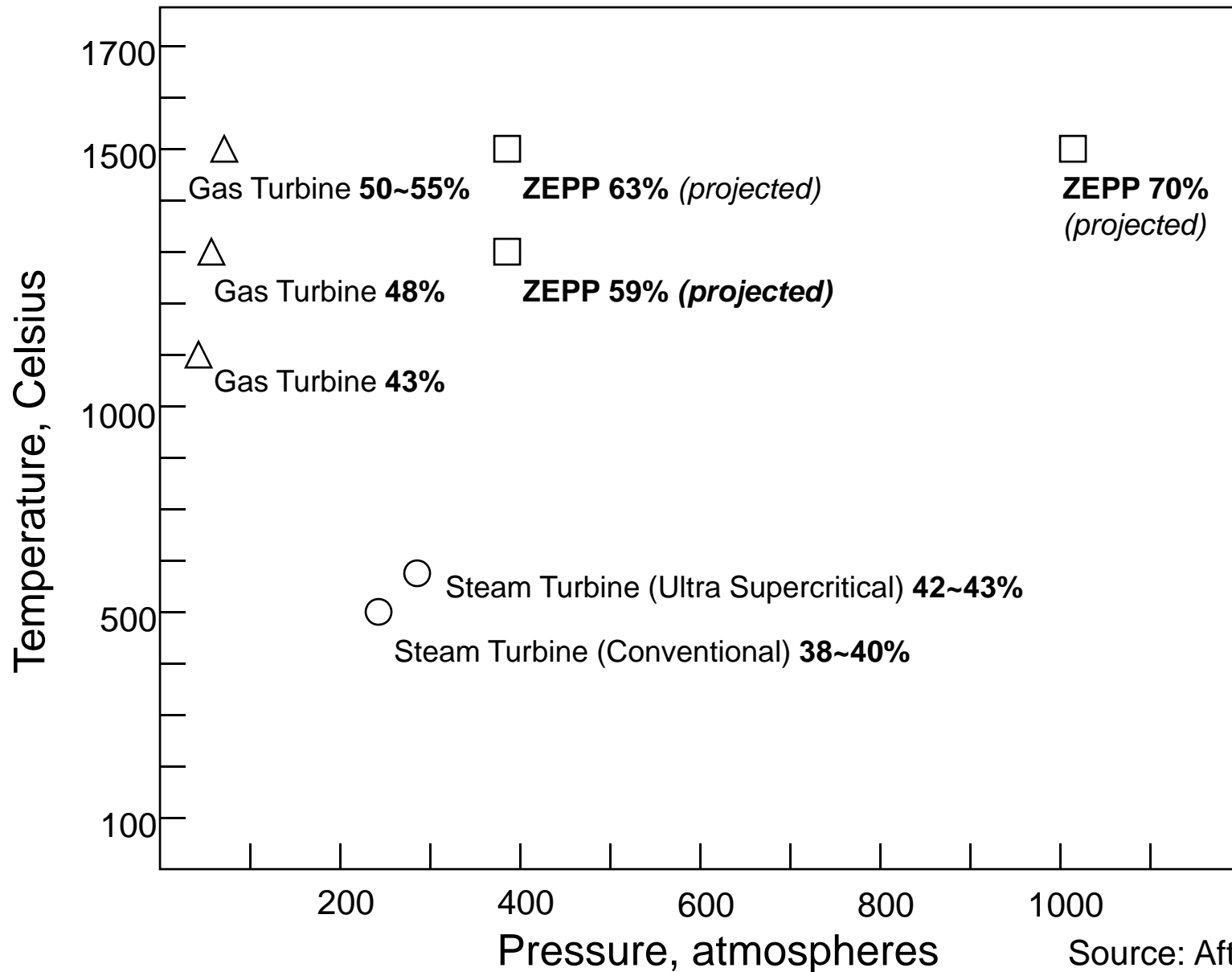
CES Test Facility (idled 55We biomass plant)

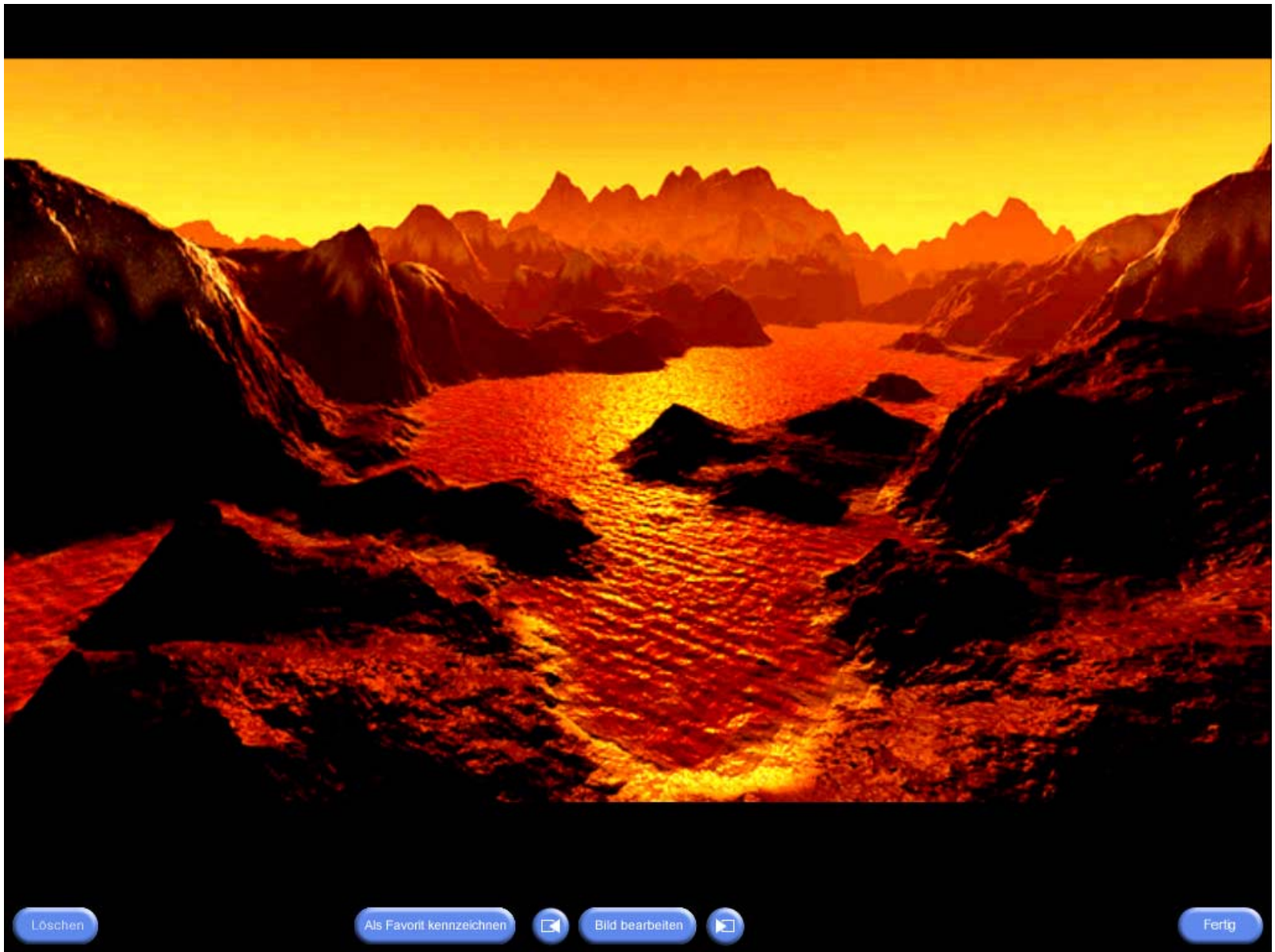
200 MW_t Gas Generator/J79 Turbine



Zero Emission Power Plants achieve efficiency at very high pressure & temperature

Power Generation Efficiencies for Power Plants





“Natural gas” abounds elsewhere in the solar system: A lake of liquid methane surrounded by mountains of solid ice on Saturn’s moon Titan

17

Source: Huygens probe, ESA

Natural gas on Mars

Simple explanation: outgassing abiotic methane, not captured fossil sunlight

Plumes of methane identified on Mars

ITHACA, NEW YORK

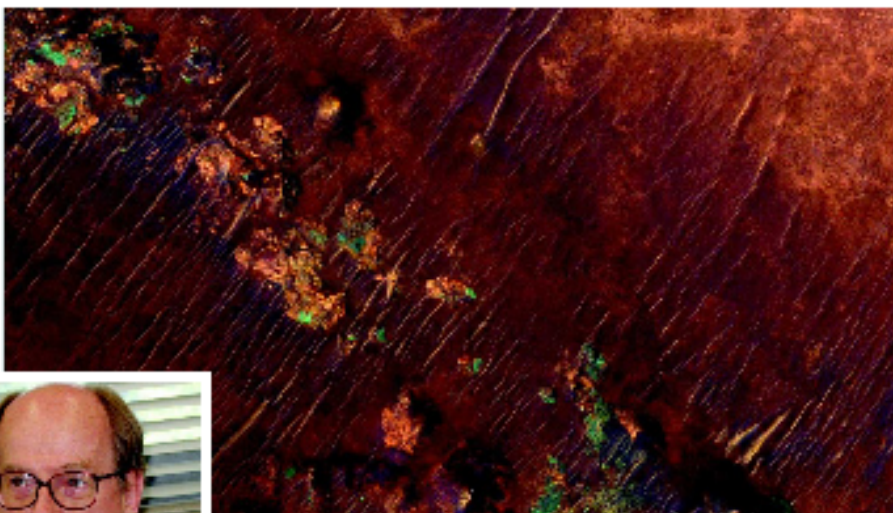
More than four years after researchers first said they had found methane gas on Mars, a scientist claims that he has "nailed" the controversial detection and identified key sources of the gas.

On Earth, methane is mostly biological in origin; on Mars, it could signal microbes living deep underground. The latest work suggests that martian methane is concentrated in both space and time — at a handful of hotspots hundreds of kilometres across, plumes of methane bloom and dissipate in less than a year.

News of the detection is rippling through the Mars community just months before a destination is picked for the Mars Science Laboratory (MSL), the US\$2-billion rover that is due to launch in 2009. It will carry an instrument that could both detect trace amounts of methane and help discern whether it is of biological or geological origin. One of the proposed methane plumes blankets one of the seven possible landing sites: Nili Fossae, which was given a middling ranking by the science community after a September evaluation that did not consider the emerging methane results.

"Now we've got these little signposts saying: 'Look, here I am. Come here!'" says Michael Mumma, a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. He presented his team's work on 11 October at a meeting of the American Astronomical Society in Ithaca, New York.

Mumma has been arguing for methane on Mars since 2003, when other startling findings began to emerge. One source, with the Comets



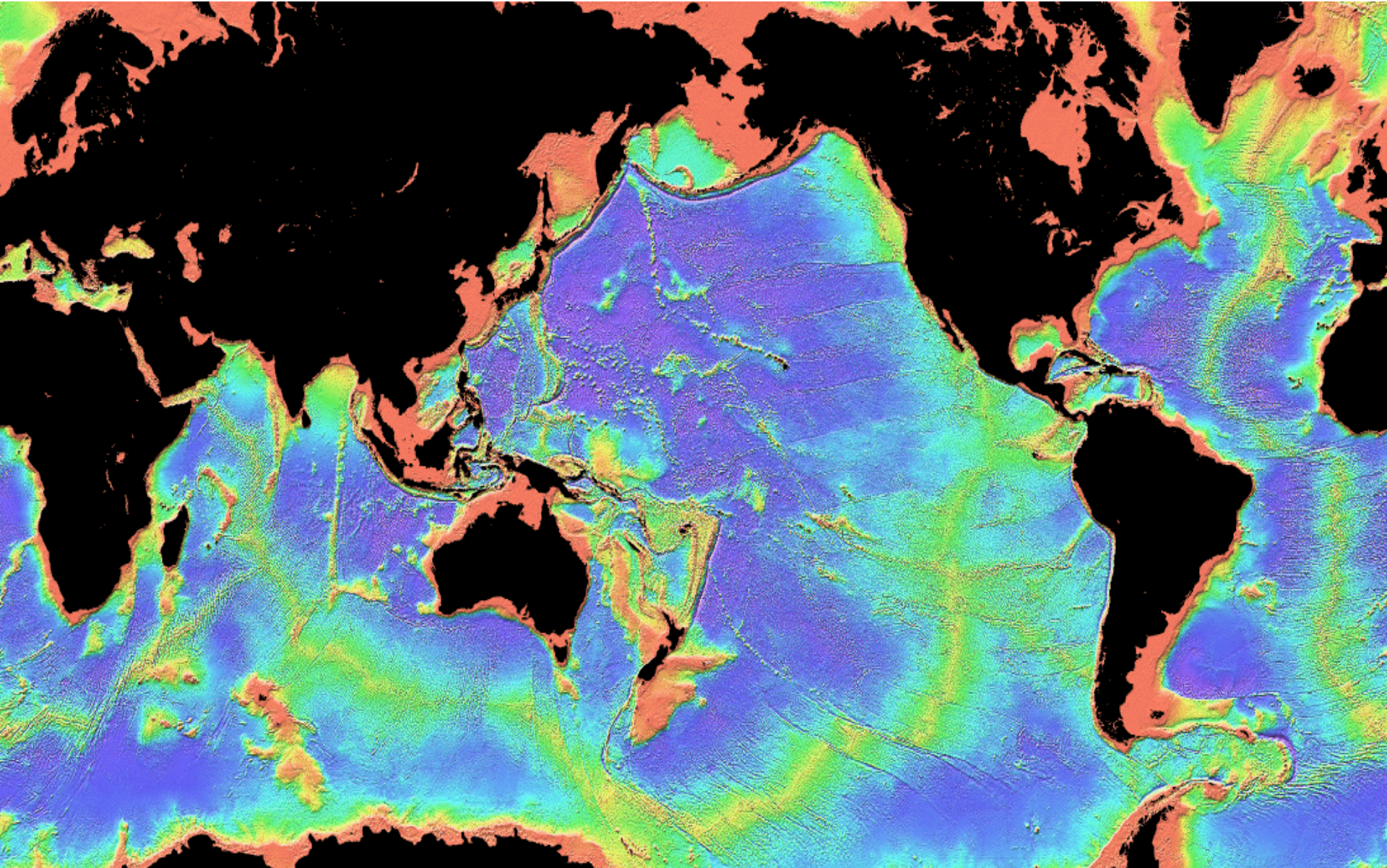
Nili Fossae is a hotspot for martian methane, says Michael Mumma (inset).

presence of methane by matching four lines in his infrared spectra of the planet's atmosphere to the characteristic signature of methane — a more definite determination than previous analyses — and found more evidence that the methane is localized in discrete hotspots, which peak at levels of 60 parts per billion. "His numbers have changed a lot over time. But Mike has made a pretty compelling case," says Steven Squyres, a planetary scientist at Cornell University in Ithaca, and principal investigator for the Mars Science Laboratory and Opportunity

at the moment, says Atreya. For example, microbes could be living in deep groundwater below a permafrost zone, and their waste methane could percolate up and leak out. The methane could also come from chemical reactions in which buried volcanic rocks rich in the mineral olivine interact with water. A third possibility is that the methane is escaping from buried clathrates, deposits of methane ice formed long ago by one of the other two mechanisms.

But NASA's next Mars rover will be able to analyse, at levels of parts per trillion, the fractional concentrations of the carbon isotopes in each methane molecule. Life on Earth prefers to use lighter carbon, 12 atoms. And so, as

Shelf break: Continental margins the methane frontier?



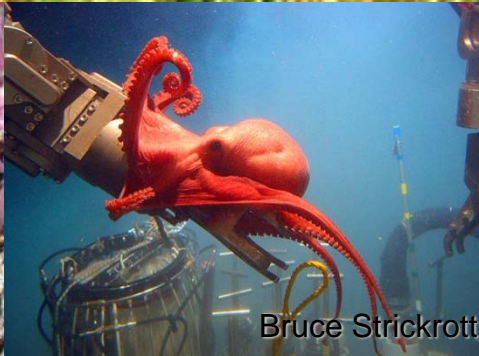
Life on methane: Census of Marine Life Expedition 2006 to Gulf of Mexico deep margin



First systematic exploration of hydrocarbon seep communities deeper than 1000m Source: ChEss



AquaPix; Bob Carney



Bruce Strickrott



Ian MacDonald



Ian MacDonald

Huge gas reserves discovered off Haifa

Jan. 18, 2009

JPost.com Staff , THE JERUSALEM POST

Three massive gas reservoirs have been discovered 80 kilometers off the Haifa coast, at the Tamar prospect, Noble Energy Inc. announced on Sunday.

The Tamar-1 well, located in approximately 5,500 feet of water, was drilled to a total depth of 16,076 feet.

Speaking on Army Radio Sunday morning, an exhilarated Yitzhak Tshuva, called the discovery "one of the biggest in the world," promising that the find would present a historic land mark in the economic independence of Israel. "We will no longer be dependent [on foreign sources] for our gas, and will even export. We are dealing with inconceivably huge quantities," Tshuva added.

An ecstatic Infrastructures Minister Binyamin Ben-Eliezer said before the weekly....

Average oil & gas well only 5,000 feet subsurface: DEEP CARBON ABOUNDS

**There are no ocean deserts!
Beautiful life abounds everywhere. Conserve it.**

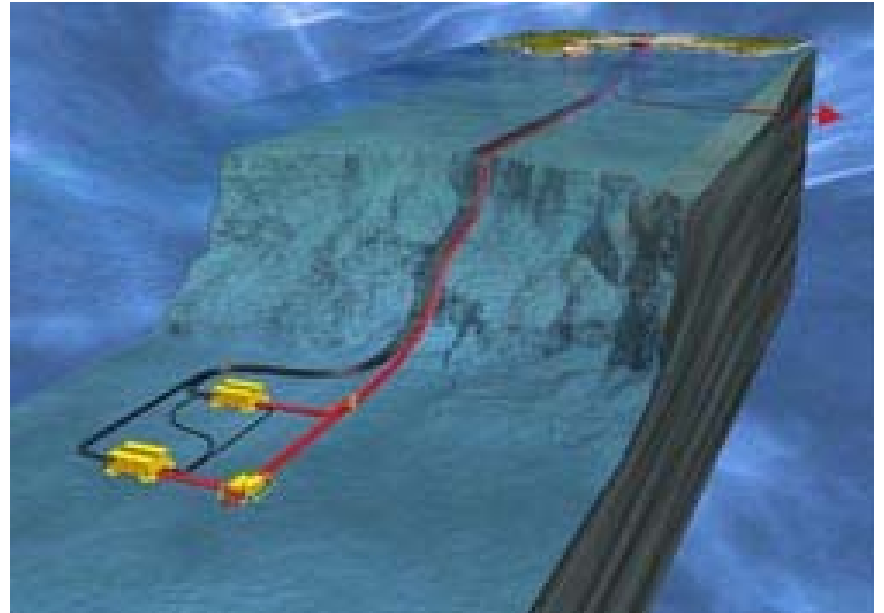


Extracting natural gas from the sea floor with no surface structures to harm vistas or annoy boaters

**Storegga, Norway
120 km offshore, 1000 m deep
Ormen Lange gas field**

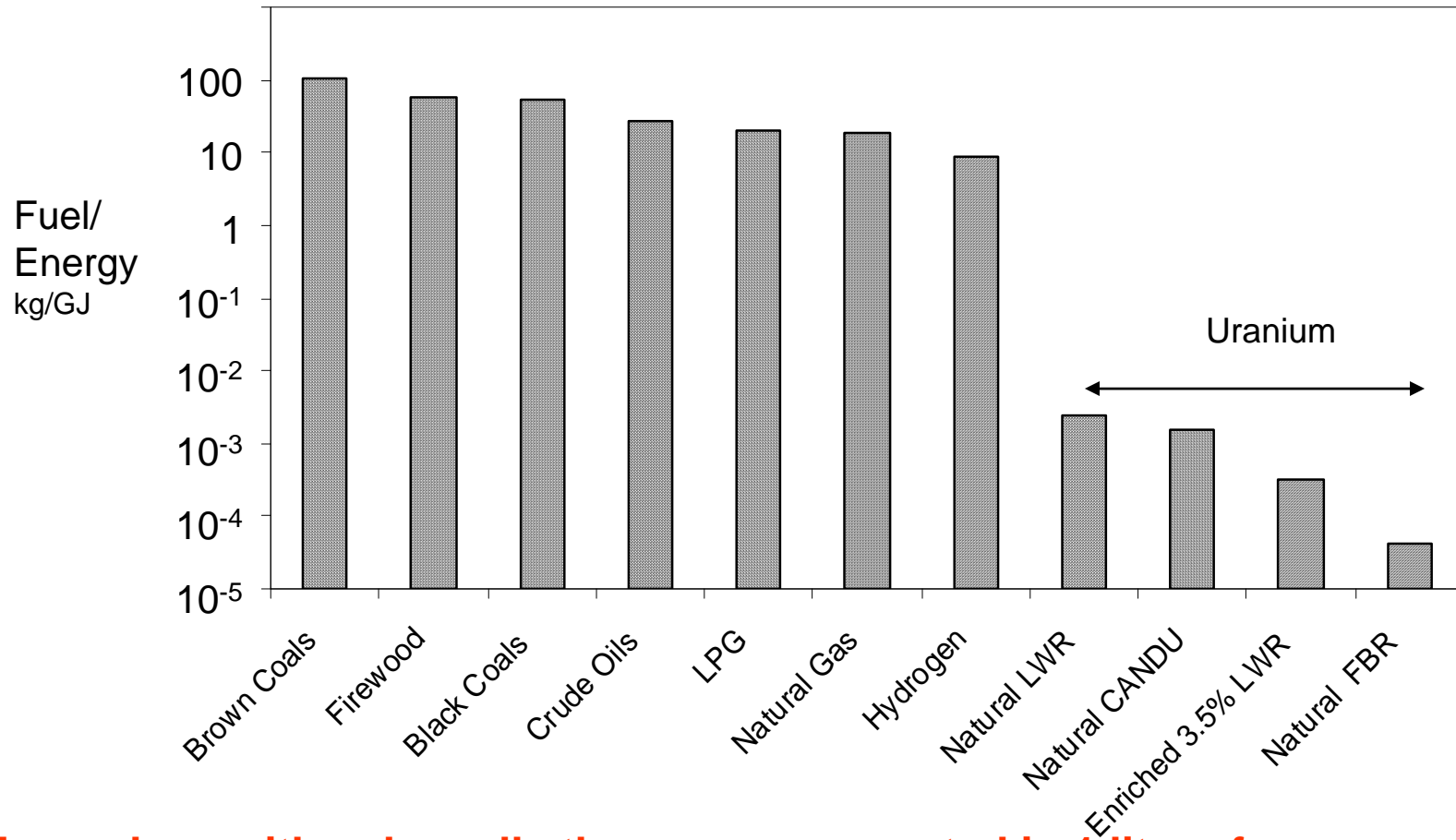
**without conventional offshore
platforms**

in production October 2007



fuel mass per energy including nuclear fuels

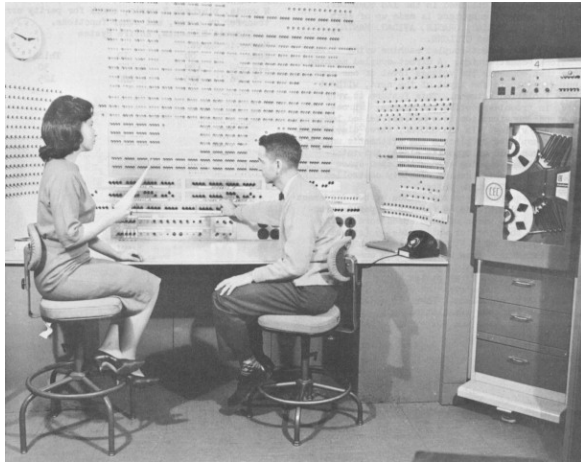
economies of scale favor fuels suited to higher power density, thus decarbonization
& thus finally nuclear sources 10,000 X more compact than hydrocarbons



To produce with solar cells the energy generated in 1 liter of core of a nuclear reactor, one needs ~ 1 hectare (10,000 square meters) of solar cells!

Like computers that comprise the Internet, power plants become more powerful AND SMALLER

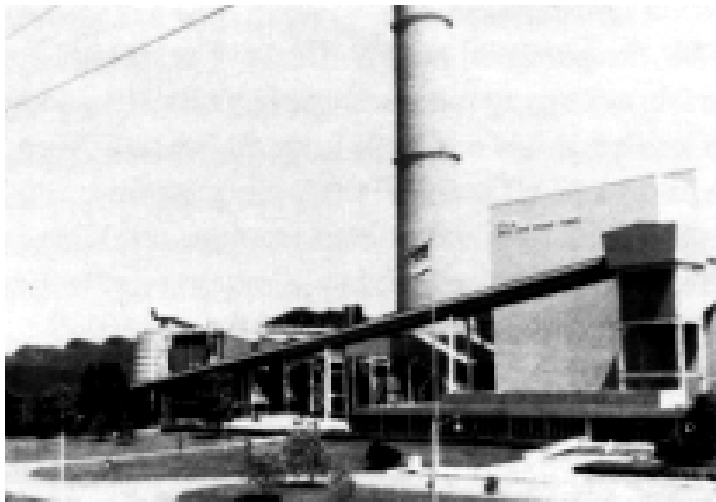
J. Ausubel & T. Barrett, 2004



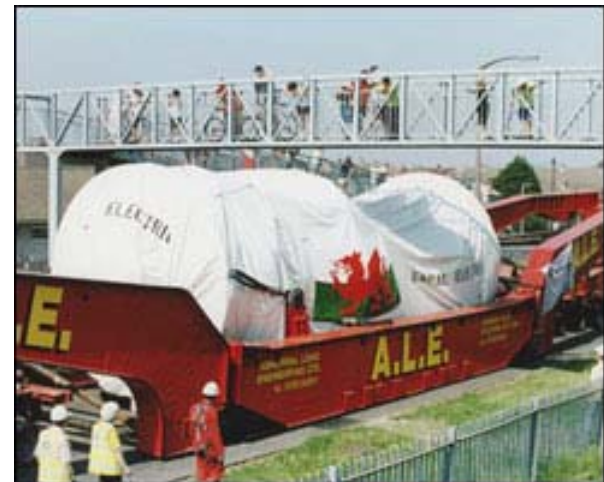
US Ballistic Research Lab computer, mid 1950s



Dell laptop, 2004



Tennessee Valley Authority coal plant
(date unknown)



Delivery of General Electric
480 MW natural gas turbine, 2000

Renewable Energy

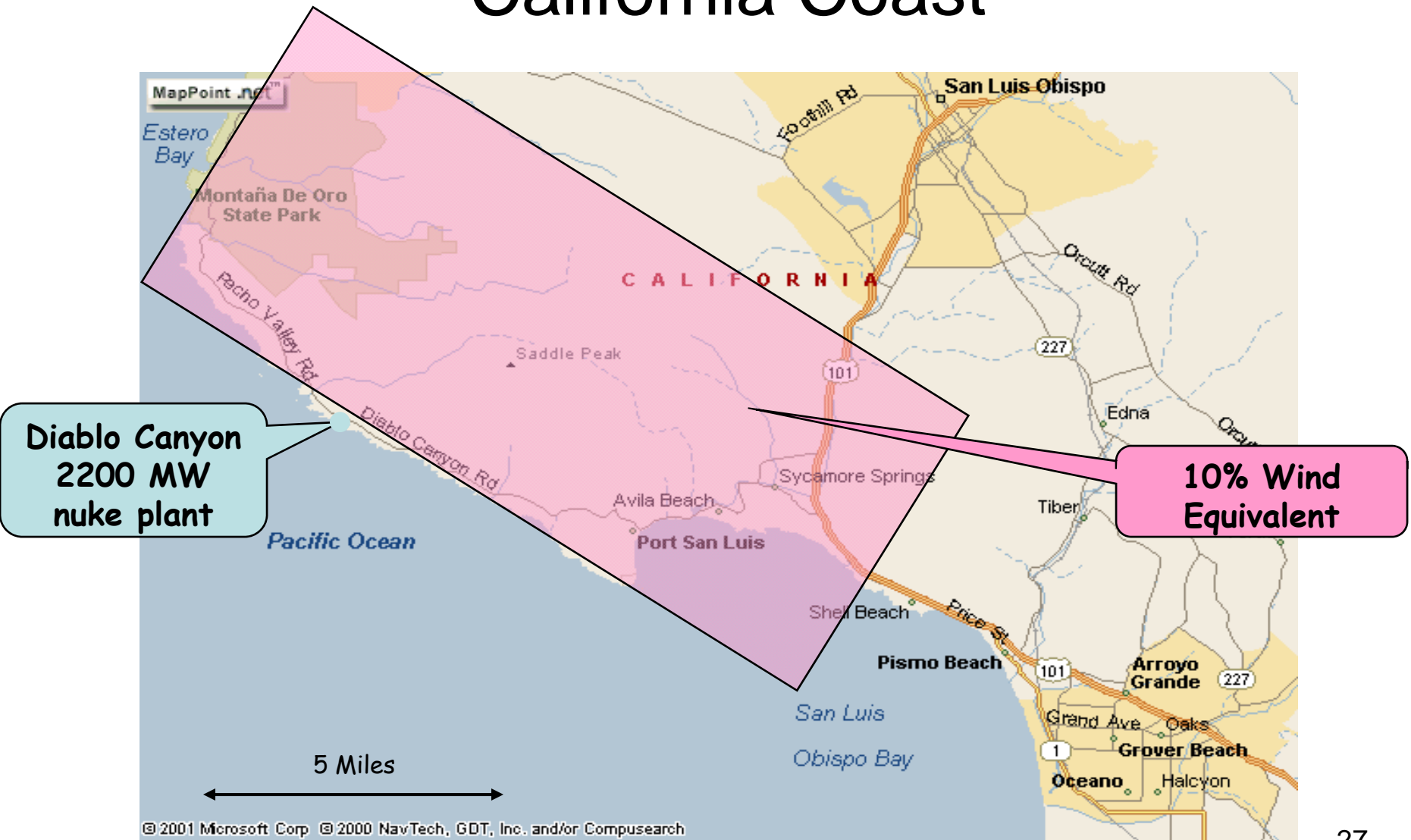
approximate production intensities & thus **VAST** land requirements

Hydro	watts/sq meter	sq km = 1000 MW nuke
– Average of all US dams	0.005	180,000
Biomass		
– ethanol from corn (net)	0.05	18,000
– New England forest	0.12	7,500
– Iowa crops	0.36	2,500
– Ocean biomass	0.6	1,500
– Corn (whole plant)	0.75	1,200
Wind	1.2	770
Solar thermal	3.2	280
Photovoltaics	~6	150

Covington County AL ~ 2,700 sq km

Sources: Ausubel, Hayden

Spatial scale: Nuclear and Wind California Coast



Source: P. Grant

Renewable Energy

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Covington County AL ~ 2,700 sq km

Sources: Ausubel, Hayden

Windmills in rural Pennsylvania

Transforming the
landscape by
vegetation removal,
access roads,
affecting flyways and
vistas

No economies of scale:
More watts demand
equally more mills

Dozen mills = 2 meter
CES ZEPP!



Wind Power – a heavy industry, not a soft path

July 3, 2008

First GE load from Port of Houston.

Finally got the show on the road.



David Waggoner
The Waggoners Trucking
9330 Jack Rabbit Road
Houston, TX



Blades



Blades



Oversize, indeed!

Windmill Towers

sections in Tulsa shipping yard



Photo Sent October 02, 2008 by
David Waggoner

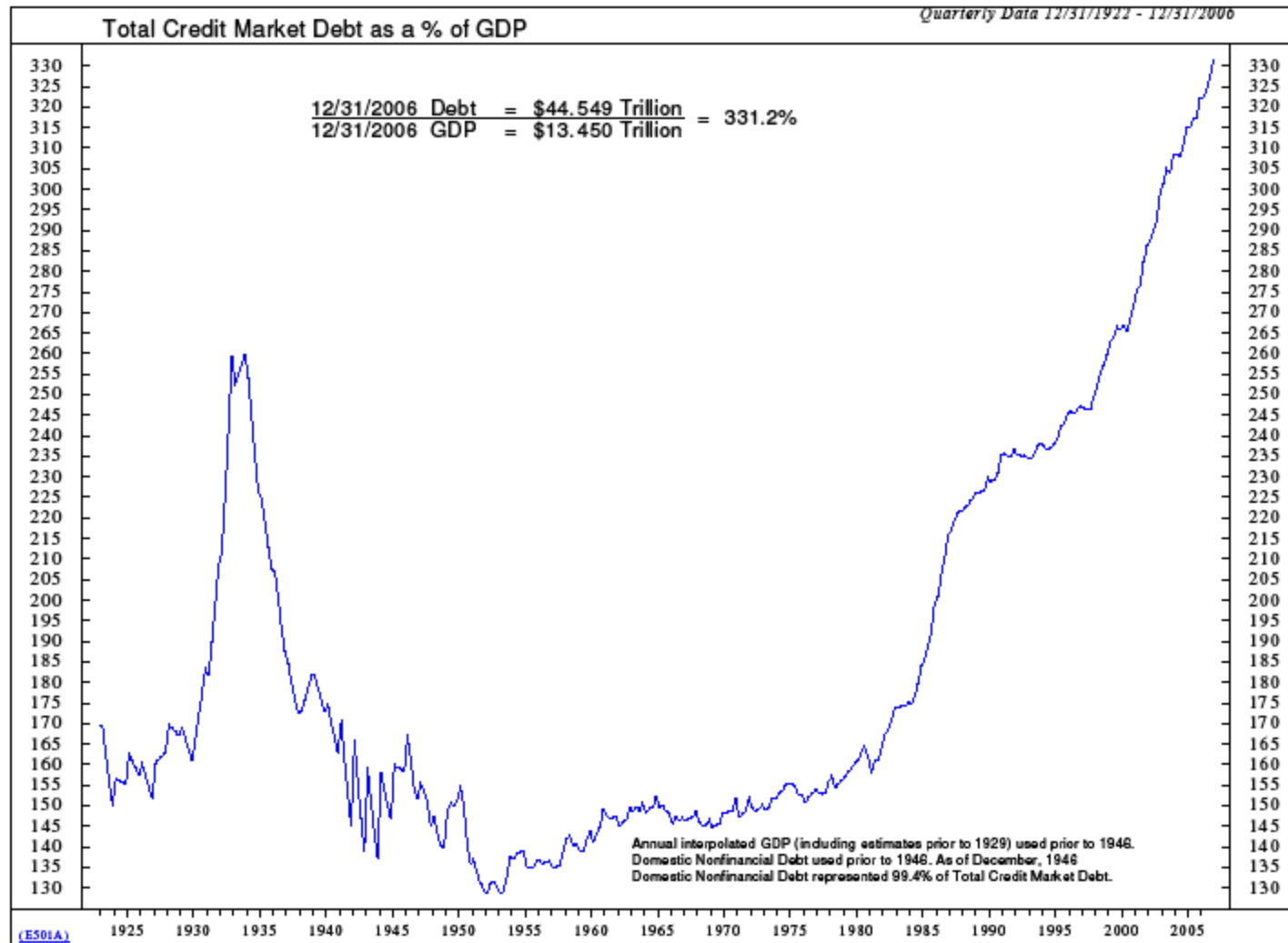
A German example
shows how the parts
fit together.



**Green, no,
Monsters, yes**

The Debt Culture

Causing slump & reminding us of virtues of thrift



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Bankside Power Station, London

Opened for power generation in 1953, became Tate Art Gallery in 2000

100m tall



“Footprint”
covers 3.5
hectares

Green is a
small footprint

Comparably powerful natural gas plant built today
could fit in 1/10th the space

Efficient use of abundant methane

The key to green evolution of energy systems for century 21



Endless sea of methane photographed from Titan's surface by probe Huygens, 14 January 2005 (ESA).