Beginnings

6/15/10 7:34 PM

Let me begin with four strong beliefs…

1. Along with 90% of the scientific community, I believe that global climate change driven by human activities is REAL and VERY, VERY serious. It deserves immediate action both for mitigation and adaptation.

2. Global oil resources are limited, and we are rapidly approaching Hubbert's peak. (In fact we've been pumping more oil out of the ground than discovering and developing new reserves for more than a decade. We may already have hit the peak!)

3. The nation faces increasingly serious risks–both economic and national security–because of the unsustainable nature of its energy infrastructure and its alarming dependence on petroleum imports (now approaching 70%), yet we remain held political hostage by Big Oil–much as we've been held hostage by the Tobacco and Insurance industries)

4. Today nuclear power currently provides 70% of the carbon-free electricity for the United States. We will be unable to achieve energy sustainability without nuclear power as a significant component of our energy infrastructure. President Obama agrees!!!

Introduction

6/15/10 7:34 PM

First, a few verses from the energy crisis hymnal to provide some context:

There are few contemporary challenges facing our state, the nation, and the world more threatening than the unsustainable nature of our current energy infrastructure.

- Every aspect of contemporary society is dependent upon the availability of clean, affordable, flexible, and sustainable energy resources. Yet our current energy infrastructure, heavily dependent upon fossil fuels, is unsustainable.
- Global oil production is expected to peak within the next several decades, with natural gas production peaking soon afterwards.
- While there are substantial reserves of coal and tar sands, the mining, processing, and burning of these fossil fuels poses increasingly unacceptable risk to both humankind and the environment, particularly within the context of global climate change.
- Furthermore, the security of our nation is threatened by our reliance on foreign energy imports from unstable regions of the world, particularly in the Middle East.

Of course, none of this is new…from the days of the OPEC oil embargo of the 1970s, it has been apparent that every aspect of contemporary society is dependent upon the availability of clean and affordable energy resources, these were at considerable risk.

Both Presidents Ford and Carter conveyed a sense of extreme urgency for the energy challenge ("we must deal with energy on a war footing") and proposed major new programs to develop new energy sources.

So where do we stand 30 years later?

1) The urgency of the 1970s soon disappeared as OPEC open its pipelines and oil began to flow once again…and the efforts to develop new technologies faded away.

- In fact, over the past 30 years, the federal government has actually reduced energy R&D by 85%, the electrical utility industry down by 50% (EPRI), and shareholder pressure for short term earnings has eroded the capacity of great industrial research laboratories such as the Ford Scientific Laboratory and General Motors Research Laboratories.

- As one of my colleagues put it, when the OPEC crisis receded, the leaders of industry and government put their concerns and plans in their drawers, forgot about the crisis, and went out and started playing golf again.

2) Just as M. King Hubbert predicted, domestic U.S. petroleum production peaked in the mid 1970s, while demand continued to rise by 40% over the next two decades.

- As a consequence, today over 60% of our petroleum is now imported, with over 90% of it controlled by governments in politically unstable regions such as the Middle East.

- Rapid increases in gasoline prices have brought the American automobile industry to its knees, as a combination of burdensome labor costs and corporate myopia have inhibited their capacity to compete with the high fuel efficiency products of foreign companies.

3) Nuclear power has also been in a state of suspended animation, with no new plant orders after the late 1970s, even though the 103 plants currently in operation not only provide 20% of the nation's electricity but do so at costs considerably below those of any other energy source including coal. (And Michigan today has only four nuclear plants, all approaching the end of their initial 40 year operating licenses.)

Why? Part of it was due to Three Mile Island.

But mostly it was due to the double-digit inflation of the late 1970s and early 1980s, which priced nuclear plant construction out of competitiveness (since

most of the cost of nuclear power is the financing of the capital cost of the plants)

- EXAMPLE: Nuclear Power and You
  - In 1970s predictions were 1,000 nuclear plants by 2000.
  - Three-Mile Island

- EXAMPLE: JJD Textbook
  - 30 years ago I wrote a popular textbook on the subject of nuclear reactors.
  - This summer I got a recall from the publisher that since the book was still selling well, and nuclear power was about to take off again, would I be interested in doing a new edition!
  - I continue to get inquiries about the problems in the text from places like Japan, India, Korea, and…Teheran!

4) And despite what Big Oil tells you, global warming is real and it is likely here to stay. To quote the recent Intergovernmental Panel on Climate Change report:

- "Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change."

- As John Holdren, president of the AAAS puts it, "We are not talking any more about what climate models say might happen in the future. We are experiencing dangerous human disruption of the global climate, and we are going to experience more. Yet we are not starting to address climate change with the technology we have in hand, and we are not accelerating our investment in energy technology R&D."

5) And, throughout it all, our political and corporate leaders continue to back into the future, blind to the degree to our American addiction to increasingly

expensive foreign petroleum is not only obliterating our national competitiveness in key industries such as automobile and airlines but driving us into international conflict (Iraq), while our dependence upon fossil fuels is putting future generations at great risk of global climate change.

Some Energy Characteristics

6/15/10 7:34 PM

Characteristics of energy itself:

- Magnitude of investment
    - While it takes a watt to run a cellphone and a kilowatt to power a home, it takes a gigawatt (a billion watts) to power a small city–one nuclear power plant's worth–and 1,500 gigawatts to meet the growing needs of our nation for electricity.
    - Perhaps in more understandable terms, a typical power plant–coal or nuclear–requires an investment of about $2 billion in capital costs. The projected energy needs of the U.S. will require roughly 1,500 new plants over the next several decades–an investment of $3 to $4 trillion.
    - More broadly, the world economy will require over $16 trillion in capital investments over the next two decades just to expand energy supply to meet growing global energy demands–compared to global domestic product of $44 trillion and U.S. GDP of $12 trillion (and the total worth of the U.S. at $47 trillion).
    - Put another way, to track the project growth in electrical demand, we will need a new $2 billion gigawatt power plant every other day!

- Timescales (generations)
    - Energy transformations take time. It took centuries to switch from wood to coal; then another century to petroleum. Nuclear energy was a bit more rapid, evolving in about a generation from Fermi's "pile" to the nuclear power plants that now dot the landscape and the world–over 440 in number, contributing 20% of the U.S. and 16% of the world's electricity
    - But this is glacial speed, compared to more recent technologies such as computers and networks that double in power every year or so.

    - And it is glacial as well compared to the election timescales of politics or the quarterly earnings demanded by Wall Street.
    - Which naturally raises the question of how do we develop and implement and sustain an energy strategy over a time scale many times that of politicians and shareholders, not to mention the career of the scientists and engineers who develop and implement the technology.

- Complexity

    - It is hard to imagine a technology more complex than energy, interwoven with every aspect of our society.
    - Involving not simply technology and economics, but complex issues of social priorities, international relations, and politics, politics, and more politics.

Little wonder then that one commonly hears the complaint that "The energy crisis is like the weather…everybody complains about it, but nobody is able to do much about it!"

History

6/15/10 7:34 PM

The Early Years

- During the early years the AEC built and tested a number of designs (LWRs, heavy water reactors, HTGRs, LMFBRs, and many others) to carefully select a technology for commercial nuclear power plants.

- Although in 1946 work began at Oak Ridge on the development of a civilian nuclear plant, the program was abandoned in 1948 and most of the personnel were transferred to the naval reactors program under Rickover. This resulted in the use of the pressurized-water reactor as the standard for the nuclear Navy.

- Over the next decade, the AEC would sponsor a series of reactor development projects, including Detroit Edison's Fermi I LMFBR at Monroe (100 Mwe) and Consumers Power's Big Rock Point BWR (50 Mwe) at Charlevoix.

The 1960s

- The next big breakthrough occurred in 1963 when General Electric signed a fixed cost or "turnkey" contract to build a 515 MWe plant at Oyster Creek for $68 million, about $132 per kw, about the same price as a coal plant. When all costs were taken into account, this would generate electricity at less cost than the 0.45 cents per kwhr from coal.

- Oyster Creek – "turnkey contracts"
- General Electric vs. Westinghouse
- 48 plants in 66-67, then 65 in 68-69
- 200 plants operating, under construction, or on order by 1974

The 1970s

- OPEC oil embargo (crude oil > $40/bbl)
- Great concern about future energy sources
- Projections: 1,000 nuclear plants in U.S. by 2000

- Major investment in nuclear power

Three Mile Island

- In 1979 Three Mile Island focused public concern on the safety of nuclear power plants.
- Double-digit interest rates pushed capital-intensive nuclear plant costs through the ceiling (x 10!).
- Increasing regulatory challenges and delaying tactics brought licensing to a halt.
- The Arab oil embargo and increased energy prices stimulated energy conservation leading to over capacity.
- All 103 plants operating today were ordered before 1975.

The 1980s

- High costs of nuclear plants were effectively subsidized by regulatory environment.
- Deregulation allowed for recovery of "stranded costs".
- Once capital costs were written down, nuclear plants could compete with fossil fuels on basis of operating costs.

The 1990s

- Recovery of stranded costs
- Improvement in capacity factors (60% to 90%)
- Consolidation of nuclear plant operators (Excelon – 19 plants)
- By 1999, nuclear plant operating costs had dropped below those of coal-fired plants (2 cents per kwh)

Today

- The current performance of U.S. nuclear plants is excellent! Capacity factors are above 90%, safety has been superb, and nuclear generated electricity costs are now less than coal.

- BUT, no nuclear plants have been ordered in the U.S. for 25 years, due to the capital intensive nature of plants, the long-term commitment required for construction, the financial risks, and most recently, the deregulation of the electricity marketplace.

Current Status of Nuclear Power

6/15/10 7:34 PM

United States

- 104 Operating Reactors – 102 GWe
- 34 Plants with 2 reactors, 2 Plants with 3 reactors
- 32 Companies licensed to operate nuclear plants
- 20% of U.S. Electrical Power Generation (although 12% of GWe)
- 70% of carbon-free electrical power generation
- Average 92% capacity factor
- Average cost: $16.80 per MWh (compared to $25 for coal and $40 or more for gas)

The current performance of U.S. nuclear plants is excellent! Capacity factors are above 90%, safety has been superb, and nuclear generated electricity costs are now less than coal.

Simpler designs cut maintenance and repair costs and provide more efficient operation. Current US plants run at 92% capacity factor and next stage will have passive safety features.

The squeeze on fossil fuels has also improved nuclear economics. Nuclear power plants are hugely expensive to build but very cheap to run. Gas-fired plants are just the opposite, and since gas provides power peaking needs, this sets the price and makes existing plants tremendously profitable.

- But most plants are now having their operating licenses extended another 20 years (as they reach end of 40 year license) (63 thus far, 20 more…"life after 60"?

BUT, no nuclear plants have been ordered in the U.S. for 25 years, due to the capital intensive nature of plants, the long-term commitment required for construction, the financial risks, and most recently, the deregulation of the electricity marketplace.

- Currently 36 applications for COLs fo, with 4 – 8 new plants expected in 2016

- Obama administration proposes 54 B of loan guarantees to get the first plants underway (probably the first two will be in Georgia)

- Note: Many of these are with foreign partners (France Areva, Japan Hitachi and Mitsubishi, Canada)

- U.S. NRG Energy will reportedly pay up to $8.8 billion for Toshiba/Westinghouse equipment used in two new Texas nuclear power plants. The equipment sale is the first time Toshiba has sold nuclear power equipment outside Japan and could put it in a better position to broker additional foreign deals.
- Viewed as a forerunner in the budding nuclear energy industry in India, GE-Hitachi Nuclear Energy hopes to build six to eight boiling water reactors capable of generating a total of 9,000 megawatts

Economics: While the capital costs of nuclear plants are very high (perhaps $4 B/GWe for FOAKE plants, declining to $1.25 B/GWe for n-th plants), their very low fuel costs give them a decided advantage over all but unusually low cost gas plants (assuming there is no carbon tax).

Credible estimates of overnight capital costs range from $2.4 B/GWe to $4.5 B/GWe. However of more concern is the cost of electricity compared to alternative sources of electricity and to the market. Even at costs in the $4 B/GWe to $6 B/GWe range, the electricity generated from nuclear power can be competitive with other new sources of baseload power, including coal and natural gas. (Here the technologies are pulverized coal and coal gasification, carbon capture or carbon abatement, and current gas prices).

Key additional factors:

Do rates include construction work in progress (CWIP)? (Avoids rate shock) (This reduces costs of plant by 20% to 30% because of carrying costs.) What about federal loan guarantees (thus far for only the first few plants). Will then nation regulate (or tax) carbon emissions.

Note: In 2006 28 GWe of new coal plants were announced, but thus far 22 GWe have been postponed or cancelled (because of carbon concerns).

The World

- 443 nuclear plants in 31 countries
- 16% of Global Electrical Power Generation
- 120 new nuclear plants under construction in 12 countries
- Over 200 additional plants are in the planning stage.

Europe

One-third of Europe's electricity is nuclear, "saving greenhouse emissions equivalent to those of all of Europe's cars".

- Nuclear produces 78% of France's electricity.
- Belgium, Sweden 50% nuclear
- Italy has reversed its earlier decision to abandon nuclear power and is now considering building new nuclear plants (strongly supported by younger generation). Germany is under pressure to do the same.

Goal is to move from nuclear at 30% to nuclear plus renewables at 75% of electrical generation by 2030, reducing carbon emissions to 80% of 1990 levels.
(Also concerned because of projections that energy imports may reach 65% in 2030 with oil at over $110 per barrel.)

Asia

- Japan with 55 nuclear plants
- Korea with 18 nuclear plants
- India at 16 plants, but intend to triple number by 2030.
- China at 6, but plan to add 30 new nuclear plants by 2020 to 40 GW (already orders for 4 from U.S.)
- Russia: Will double nuclear capacity to 45 GW.

IAEA predicts a 60% increase in demand for energy over next 25 years.

Consensus: "Only by building more nuclear power stations can the world meet its soaring energy needs while averting environmental disaster."

The Kyoto accord will force plant operators to pay for their pollution, making nuclear power facilities more competitive.

So the debate about whether nuclear plants can compete with coal and gas-fueled plants is over. The answer is clearly yes.

But simply being competitive today will not meet our needs for tomorrow. To meet that demand, new plants must be built.
Will these be competitive?

Key Challenges

6/15/10 7:34 PM

Challenges

- Sustainability
- Economics
- Safety and reliability
- Environmental Impact (radwaste)
- Proliferation resistance
- Physical protection

Sustainability

The ability to meet the needs of the present generation while enhancing the ability of future generations to meet society's needs indefinitely into the future.

Uranium Reserves

Known economically recoverable reserves

- 3.3 Mt of uranium
- 4 to 6 Mt of thorium

This represents 5,000 EJ for LWRs (limited)

Or 500,000 EJ for breeders (1,500 times the total worldwide annual consumption)

Uranium extraction from sea water similarly represents reserves of thousands of years

Economics

- Achieving economic life-cycle and energy production costs through a number of innovative advances in plant and fuel cycle efficiency, design simplifications, and plant sizes.
- Reducing economic risk to nuclear projects through innovative advances that may be possible with the development of plants

using innovative fabrication construction techniques and modular plants.

- Nuclear plant "time to market" is a key factor affecting economic competitiveness in the deregulated marketplace. Long lead times prior to construction and long construction periods reduce economic competitiveness and increase project risks.
- Resolution of licensing issues before project commitment is essential to ensuring acceptably short lead-times.
- Japan provides an example of 40 month (3 years) for construction.

University of Chicago Study

- Levelized cost of electricity (LCOE)
  - Coal: 3.3 to 4.1 cents/kWhr
  - Gas: 3.5 to 4.5 cents/kWhr
  - FOAKE Nuclear: 4.7 to 7.1 cents/kWhr
  - Later Nuclear: 3.1 to 4.5 cents/kWhr
- For new Gen III nuclear plants (e.g., ALWR)

- If carbon tax is implemented:
  - Coal: 9.1 cents/kWhr
  - Gas: 6.8 cents/kWhr

Safety

Increasing the use of inherent safety features, robust designs, and transparent safety features that can be understood by nonexperts. Enhancing public confidence in the safety of nuclear energy.

Environmental Impact

- No carbon…no release of emissions
- Decommissioning to clean site

Radioactive waste disposal?

Until recently U.S. policy is an once-through cycle in which spent fuel will be deposited in Yucca Mountain

However this year the Obama administration has announced it will suspend construction of Yucca Mountain and instead launch a major research program on alternatives.

But Yucca Mountain was envisioned at a time when the country did not have plans for significant nuclear expansion. At that time used reactor fuel was considered "waste"; thus direct disposal was chosen as the approach. In the long term, given the envisioned expanded use of nuclear energy, it is both appropriate and timely to reconsider the sustainability of the fuel cycle, and to recognize that even with recycling, a geologic repository will eventually be required.

As nuclear energy expands, "closing" the fuel cycle will ultimately be necessary. Simultaneously addressing such issues as the full utilization of the fuel's stored energy content, waste minimization, and strengthening of the nonproliferation regime is essential.

Many believe the industry could make do for the next few decades with an above-ground "interim storage" site in a remove desert facility. This would also allow us to reclaim the unused fissile material in spent fuel for reuse.

Allow geologic waste repositories to accept the waste of many more plant-years of nuclear plant operation through substantial reduction in the amount of wastes and their decay heat.

Greatly simply the scientific analysis and demonstration of safe repository performance for very long time periods (beyond 1,000 years), by a large reduction in the lifetime and toxicity of the residual radioactive wastes sent to repository.

Nuclear Weapons Proliferation

Providing continued effective proliferation resistance of nuclear energy systems through the increased use of intrinsic barriers and extrinsic safeguards.

Global Nuclear Energy Partnership

- Objectives
  - To recycle nuclear fuel using new proliferation-resistant technologies to recover more energy and reduce waste.
  - To provide proliferation resistant technologies and fuel services to developing nations,
  - To utilize "advanced burner reactors" to consume or destroy radioactive transuranic elements and fission products, reducing need for disposal by factors of 50 to 100 times.

- Elements
  - The U.S. would shift from one-through to UREX recycling that separates out uranium for re-enrichment without separating out plutonium.
  - The waste stream could then be partitioned further into short-lived fission products and transuranic elements.
  - The latter would be fabricated into fuel elements and loaded into advanced burner (fast) reactors to burn or transmute long-lived transuranic elements (including plutonium) while producing electricity.

- GNEP Participants
  - A consortium of nations with advanced nuclear technologies would provide fuel and reactors that are appropriately sized for the grids and industry needs of other countries that agree to refrain from fuel cycle activities (e.g., enrichment, reprocessing).
  - The GNEP is a comprehensive strategy to increase U.S. and global energy security, reduce the risk of nuclear proliferation, while reducing carbon and other emissions into the environment.

Federal Subsidies?

These take several forms:

- Federal R&D
- Subsidies for power generation
- External costs (e.g., environmental impact)

But over the last 50 years, the big winner has been oil!

Oil: $335 B (46%)
Gas: $100 B (14%)
Coal: $94 B (13%)
Hydro: 80 B (11%)
Nuclear: $65 B (9%)
Renewables: $45 B (6%)

Clearly the most massive subsidies have been for oil through tax benefits such as depletion allowances and off-shore drilling. This amounts to half of all federal energy subsidies over the past 50 years.

Most of nuclear support has been for R&D that peaked in the 1970s and has eroded to less than $100 M/y since 2001 (far less than renewables and even coal today). In fact, the actual federal R&D investment in the development of LWR technology, now producing 20% of our electricity, totals only $5 B. Since 1988 spending on nuclear R&D has been less than for coal, and since 1994 it has been less than for renewables

Of particular note is the implicit subsidy represented by the waste products of energy use that are allowed to be dumped into the biosphere. These completely dwarf the public funding of energy R&D and direct subsidies. The largest such subsidies are given to fossil fuel producers, now amounting to over 4 cents/KWh (almost as large as the electricity cost itself).

Nuclear power is quite unique in actually being required to pay for its environmental impact (waste storage and reprocessing), which so far exceeds disbursements by $14 billion!

A Nuclear Renaissance?

6/15/10 7:34 PM

Obama Administration

State of the Union Address: "But to create more of these clean energy jobs, we need more production, more efficiency, more incentives. And that means building a new generation of safe, clean nuclear power plants in this country." (Remember, Excelon is the largest operator of nuclear plants.)

Secretary Chu: "President Obama and I are committed to restarting the nuclear industry in the United States."

The US Stance

Today nuclear energy provides 16% of the world's electricity and offers unique benefits. It is the ONLY existing technology with capability for major expansion that can simultaneously provide stability for base-load electricity, security through reliable fuel supply, and environmental stewardship by avoiding emissions of greenhouse gases and other pollutants. Furthermore it has proven reliability (greater than 90% capacity factory), exemplary safety, and operational economy through improved performance.

We believe that nuclear energy must play a significant role in our nation's– and the world's–electricity portfolio for the next century and beyond. Nuclear energy has great potential for contributing more to our broader energy needs however. For example, nuclear energy could supplement or even supplant fossil fuels by providing the electricity for electric-powered vehicles, or it could be used to generate hydrogen for vehicles that utilize hydrogen fuel cells. Nuclear energy could also help to generate high-temperature process heat, provide a valuable input for feed stock to chemical production and aid in the production of freshwater from seawater.

The Economist:

"Nuclear power offers the possibility of large quantities of baseload electricity that is cleaner than coal, more secure than gas, and more reliable than wind. Furthermore, if cars switch from oil to electricity, the demand for power generated from carbon-free sources will increase still further.

Yet the economics of nuclear still look uncertain since its green virtues do not show up in its costs, since fossil-fuel power generation does not pay for the environmental damage it does. Nuclear and other clean energy sources to indeed deserve a hand from governments, but through a carbon tax which reflects the benefits of clean energy, not through subsidies to cover political risk. "

The New York Times (2/17/10)

"President Obama's decision to commit $8.3 billion in loan guarantees to help build two nuclear reactors in Georgia and restart the American nuclear power industry makes good sense.

Nuclear power, which generates far fewer greenhouse gases than ordinary fossil fuels, should be part of the energy mix as this country and others move toward a less carbon-intensive world.

While the U.S. has sat on the sidelines, other governments are enthusiastically embracing nuclear power as a way to lessen their greenhouse emissions and their dependence on imported oil.

The biggest remaining obstacle has been financing. Nuclear reactors are very expensive, with costs as high as $7 to $8 billion. There is a long lead time before a plant starts selling power and paying returns. For these and other reasons, banks have not been willing to lend.

It would be nice to think that the private sector could address this problem on its own. But the private sector does not underwrite the nuclear industry in other countries–governments do. And nothing is going to happen without loan guarantees.

From where we sit, the risks are worth taking to get the United States back into the game, for the sake of the climate, this country's energy future and the jobs a vibrant nuclear technology industry could create."

What To Do: Some Lessons Learned

6/15/10 7:34 PM

Lesson One: To make any progress at all, you have to get serious about things. Simply ranting about it or making token investments will simply bounce off without a dent–although they might make things work.

- Key are actions that are both significant and sustained.

- Not like the past two decades, energy research has been sharply curtailed by the federal government (85% decrease), the electrical utility industry (50% decrease), and the domestic automobile industry (50% decrease).

- So where does one get the billions of dollars necessary for energy R&D? I could remind you that last month Exxon-Mobil announced the largest profits last year in American history, roughly $36 billion. However the suggestion of windfall taxes on oil profits, even if intended to support R&D, would be akin to suggesting exploring nuclear options in the Middle East .

- Hence, instead, the key is to take action to deal simultaneously with the need to control carbon emissions, stimulate conservation, and establish a more realistic marketplace for energy alternatives by implementing a carbon tax–or possibly a cap and trade policy. There have long been suggestions of adding a $1 per gallon tax on gasoline to generate funds for R&D. Tom Friedman suggests an alternative of using taxes to set a floor of $3.50 for gasoline, thereby providing pricing predictability and generating R&D funds. Whatever… The funding is clearly available if the need is urgent. And most today feel it is!

Lesson Two: Today we need a much greater sense of urgency. Here I would only note two very large clouds on the horizon:

- Hubbert's Peak: Recent analyses of world petroleum production and known reserves suggest that global oil production could peak as early as the next decade (with gas production peaking roughly a decade later).

- The consequence of passing over the global production peak is not the disappearance of oil; roughly half of the reserves would remain.
- Rather it would be a permanent imbalance between supply and demand that would drive oil prices dramatically higher than today's levels–$100/bbl, $200/bbl, and beyond–with corresponding increases at the pump.
- The rapidly increasing oil and gas demands from developing economies such as China, India, and Latin America make this imbalance even more serious, particularly when it is noted that the United States currently consumes 25% of world production.
- A recent assessment by the U. S. Department of Energy in the spring of 2005 warned, "The world has never faced a problem like this. Without massive mitigation more than a decade before the fact, the problem will be pervasive and will not be temporary.
- Previous energy transitions (wood to coal and coal to oil) were gradual and evolutionary; oil peaking will be abrupt and revolutionary." (Hirsch, 2005)

- Global Climate Change: To this should be added the increasing consensus that utilization of fossil fuels in energy production is already causing significant global climate change.
  - Evidence of global warming is now incontrovertible–increasing global surface and air temperatures, receding glaciers and polar ice caps, rising sea levels, and increasingly powerful weather disruptions, all confirm that unless the utilization of fossil fuels is sharply curtailed, humankind could be seriously threatened.
  - Although there continues to be disagreement over particular strategies to slow global climate change–whether through regulation that restricts the use of fossil fuels or through market pressures (e.g., "cap and trade" strategies)–there is little doubt that energy utilization simply must shift away from fossil fuels toward non-hydrocarbon energy sources.

Lesson Three: We simply must think and act far more boldly.

- Let's stop being penny wise and pound foolish and begin to make investments commensurate with the challenges before us.
- If we can waste a $100 billion on the International Space Station or a trillion dollars in Iraq, we can certainly invest considerably more to deal with the staggering crisis of a building a sustainable energy future!
- More specifically, developing a sustainable energy future for the nation and the world requires a commitment comparable to the Manhattan Project, the Apollo Program, and the Cold War.
- It requires a total commitment on the part of the federal government, the states, industry, and higher education, as well as a much deeper understanding on the part of the American public.

Finally, beyond dollars and technology, it will require a new generation of scientists and engineers–something that both the federal government and industry generally put last on their priority list!