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Energy Options for the Future*

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This paper summarizes the presentations and discussion at the Energy Options for the Future meeting held at the Naval Research Laboratory in March of 2004. The presentations covered the present status and future potential for coal, oil, natural gas, nuclear, wind, solar, geothermal, and biomass energy sources and the effect of measures for energy conservation. The longevity of current major energy sources, means for resolving or mitigating environmental issues, and the role to be played by yet to be deployed sources, like fusion, were major topics of presentation and discussion.

KEY WORDS: Energy; fuels; nuclear; fusion; efficiency; renewables.

OPENING REMARKS: STEVE OBENSCHAIN (NRL)

Market driven development of energy has been successful so far. But, major depletion of the more readily accessible (inexpensive) resources will occur, in many areas of the world, during this century. It is also expected that environmental concerns will increase. Therefore, it is prudent to continue to have a broad portfolio of energy options. Presumably, this will require research, invention, and development **in time** to exploit new sources when they are needed. Among the questions to be discussed are:

- What are the progress and prospects in the various energy areas, including energy efficiency?
- How much time do we have? and,
- How should relatively long development times efforts like fusion energy fit?

Agenda

March 11, 2004
Energy projections, John Sheffield, Senior Fellow, JIEE at the University of Tennessee.

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* Summary of the Meeting held at the U.S. Naval Research Laboratory, March 11–12, 2004

CCTP, David Conover, Director, Climate Change Technology Program, DOE.
Coal & Gas, Rita Bajura, Director, National Energy Technology Laboratory.
Oil, David Greene, Corporate Fellow, ORNL.
Energy Efficiency, Marilyn Brown, Director, EE & RE Program, ORNL.
Renewable Energies, Eldon Boes, Director, Energy Analysis Office, NREL.
Nuclear Energy, Kathryn McCarthy, Director, Nuclear Science & Engineering, INEEL.
Power Industry Perspective, David Christian, Senior VP, Dominion Resources, Inc.
Paths to Fusion Power, Stephen Dean, President, Fusion Power Associates.
Energy Options Discussion, John Sheffield and John Soures (LLE).
Tour of Nike and Electra facilities.

March 12, 2004
How do nuclear and renewable power plants emit greenhouse gases, Gerald Kulcinski, Associate Dean, College of Engineering, University of Wisconsin.
Wrap-up discussions, Gerald Kulcinski and John Sheffield.

SUMMARY

There were many common themes in the presentations that are summarized below, including one that is well presented by the diagram:

Social Security (Stability)
→ **Economic Security**
→ **Energy Security**
→ **Diversity of Supply, including all sources.**

A second major theme was the impact expected on the energy sector by the need to consider climate change, as discussed in a review of the U.S. Climate Change Technology Program (CCTP), and as reflected in every presentation.

The technological carbon management options to achieve the two goals of a diverse energy supply and dealing with green house gas problems are:

- *Reduce carbon intensity* using renewable energies, nuclear, and fuel switching.
- *Improve efficiency* on both the demand side and supply side.
- *Sequester carbon* by capturing and storing it or through enhancing natural processes.

Today the CO_2 emissions per unit electrical energy output vary widely between the different energy sources, even when allowance is made for emissions during construction. [There are no zero-emission sources! See Kulcinski, section "How Do Nuclear Power Plants Emit Greenhouse Gases?"] But future systems are being developed which will narrow the gap between the options and allow all of them to play a role.

Details of these options are given in the presentation summaries below. Interestingly, many of the options involve major international collaborative efforts e.g.,

- FutureGen a one billion dollar 10-year demonstration project to create the world's first coal-based, zero-emission, electricity and hydrogen plant. Coupled with CO_2 sequestration R&D.
- Solar and Wind Energy Resource Assessment (SWERA) a program of the Global Environment Fund to accelerate and broaden investment in these areas—involving Bangladesh, Brazil, China, Cuba, El Salvador, Ethiopia, Ghana, Guatemala, Honduras, Kenya, Nepal, Nicaragua, and Sri Lanka.
- Generation IV International Forum (GIF) for advanced fission reactors involving Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, Switzerland, United Kingdom, and the United States.
- International Thermonuclear International Experimental Reactor (ITER) in the fusion energy area involving the European Union, China, Japan, Korea, Russia and the United States.

These collaborations are an example of the growing concerns about being able to meet the projected large increase in energy demand over this century, in an environmentally acceptable way. The involvement of the developing and transitional countries highlights the point that they will be responsible for much of the increased demand.

Major concerns are not that there is a lack of energy resources worldwide but that resources are unevenly distributed and as used today cause too much pollution. The uneven distribution is a major national issue for countries that do not have the indigenous resources to meet their needs. There is a significant issue over the next few decades as to whether the trillions of dollars of investment will be made available in all of the areas that need them.

Fortunately, as discussed in the presentations, very good progress is being made in all areas of RD&D, e.g.,

- In the fossil area, more efficient power generation with less pollution has been demonstrated, and demonstrations of CO_2 sequestration are encouraging.
- Increasing economic production of unconventional oil offers a way to sustain and increase its supply over the next 50+ years, if that route is chosen.
- Energy efficiency improvements are possible in nearly every area of energy use and numerous new technologies are ready to enter the market. Many other advances are foreseen, including a move to better integrated systems to optimize energy use, such as combined heat and power and solar powered buildings.
- Wind power is now competitive with other sources in regions of good wind and costs are dropping. Solar power is already economic for non-grid-connected applications and prices of solar PV modules continue to drop as production increases.
- The performance of nuclear reactors is steadily getting better. Options exist for substantial further improvements, leading to a system of reactors and fuel cycle that would minimize wastes and, increase safety and reduce proliferation possibilities.
- The ITER and National Ignition Facility will move fusion energy research into the burning plasma era and those efforts, coupled with a broad program to advance all the important areas for a fusion plant, will pave the way for demonstration power plants in the middle of this century.

On the second day there was a general discussion of factors that might affect the deployment of fusion energy. The conclusions briefly were that:

- Cost of electricity is important and it is necessary to be in the ballpark of other options. But environmental considerations, waste disposal, public perception, the balance between capital and operating costs, reliability and variability of cost of fuel supply, and regulation and politics also play a role.
- For a utility there must be a clear route for handling wastes. In this regard, fusion has the potential for shallow burial of radioactive wastes and possibly retaining them on site.
- There are many reasons why distributed generation will probably grow in importance, however it is unlikely to displace the need for a large grid connected system.
- Co-production of hydrogen from fission and fusion is an attractive option. Fusion plants because of their energetic neutrons and geometry may be able to have regions of higher temperature for H_2 production than a fission plant.
- There are pros and cons in international collaborations like ITER, but the pros of cost sharing R&D, increased brainpower, and preparing for deployment in a global market outweigh the cons.

ENERGY PROJECTIONS: JOHN SHEFFIELD (JIEE—U. TENNESSEE)

[Based upon the report of a workshop held at IPP-Garching, Germany, December 10–12, 2003. IPP-Garching report 16-1, 2004].

Summary

Energy demand, due to population increase and the need to raise the standards of living in developing and transitional countries, will require new energy technologies on a massive scale. Climate change considerations make this need more acute.

The extensive deployment of new energy technologies in the transitional and developing countries will require global development in each case. The International Thermonuclear Reactor (ITER) activity is an interesting model for how such activities might be undertaken in other areas—see Dean presentation, section "Paths to Fusion Power."

All energy sources will be required to meet the varying needs of the different countries and to enhance the security of each one against the kind of energy crises that have occurred in the past. New facilities will be required both to meet the increased demand and also to replace outdated equipment (notably electricity).

Important considerations include:

- The global energy situation and demand.
- Emphasis given to handling global warming.
- The availability of coal, gas, and oil.
- The extent of energy efficiency improvements.
- The availability of renewable energies.
- Opportunities for nuclear (fission and fusion) power
- Energy and geopolitics in Asia in the 21st century.

World Population and Energy Demand

During the last two centuries the population increased 6 times, life expectancy 2 times, and energy use (mainly carbon based) 35 times. Carbon use (grams per Mega Joule) decreased by about 2 times, because of the transition from wood to coal to oil to gas. Also, the energy intensity (MJ/$) decreased substantially in the developed world.

Over the 21st century the world's population is expected to rise from 6 billion to around 11 (8–14) billion people, see Figure 1. An increase in per capita energy use will be needed to raise the standard of living in the countries of the developing and transitional parts of the world.

In 2000, the IPCC issued a special report on "Emission Scenarios." Modeling groups, using different tools worked out 40 different scenarios of the possible future development (SRES, 2000). These studies cover a wide range of assumptions about driving forces and key relationships, encompassing an **economic emphasis (category A)** to an **environmental emphasis (category B)**. The range of projections for world energy demand in this century are shown in Figure 2 coupled with curves of atmospheric CO_2 stabilization.

The driving forces for changes in energy demand are population, economy, technology, energy, and agriculture (land-use). An important conclusion is that the bulk of the increase in energy demand will be in the non-OECD countries [OECD stands for Organisation for Economic Co-operation and Development. Member states are all EU states, the US, Canada, New Zealand, Turkey, Mexico, South Korea, Japan, Australia, Czech Republic, Hungary, Poland and Slovakia]. In the period from 2003 to 2030, IEA studies suggest that 70% of demand growth will be in non-OECD countries, including 20% in China alone. This change has started with the shift of Middle East oil delivery from being predominantly to Europe and the USA to being 60% to Asia.

New and carbon-free energy sources, respectively, will be important for both extremes of a very

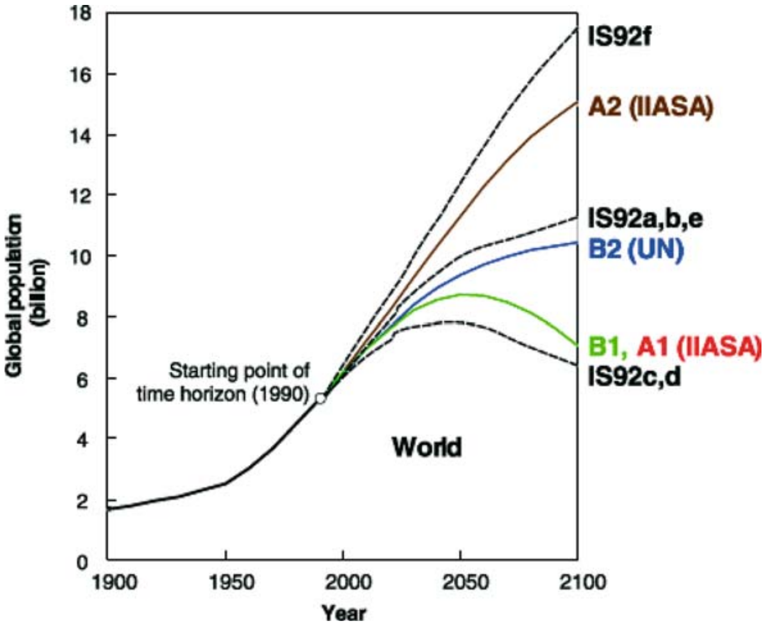


Fig. 1. Global population projections. Nakicenovic (TU-Wien and IIASA) 2003.

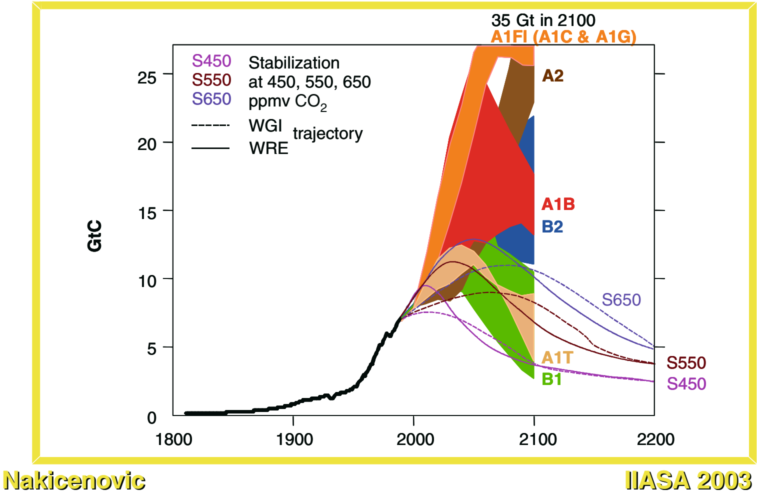


Fig. 2.

high increase in energy demand and a lower increase in demand but with carbon emission restrictions. This is significant for a new "carbon-free" energy source such as fusion.

A second important fact is that in most (all?) scenarios a substantial increase in electricity demand is expected.

Energy Sources

Fossil Fuels

The global resources of fossil fuels are immense and will not run out during the 21st century, even with a significant increase in use. There are sample resources of liquid fuels, from conventional and unconventional oil, gas, coal, and biomass Table 1.

Technologies exist for removal of carbon dioxide from fossil fuels or conversion. It is too early to define the extent of the role of sequestration over the next century (Bajura presentation, section "A Global perspective of Coal & Natural Gas").

Financial Investments—IEA

The IEA estimate of needed energy investment for the period **2001–2030** is **16 trillion dollars**. Credit ratings are a concern. In China and India more than **85%** of the investment will be in the **electricity area**.

Energy Efficiency

It is commonly assumed, consistent with past experience and including estimates of potential improvements, that energy intensity (E/GDP) will decline at around 1% per year over the next century. As an example of past achievements, the annual energy use for a 20 cu. ft. refrigerator unit was 1800 kW h/y in 1975 and the latest standard is the 2001 standard at 467 kW h/y. It uses CFC free

Table 1. Global Hydrocarbon Reserves and Resources in GtC (10^9 tonnes of carbon)

	Consumption					
	1860–1998	1998	Reserves	Resources	Resource Base	Additional Occurrences
Oil conventional	97	2.7	120	120	240	
Unconventional	6	0.2	120	320	440	1200
Gas conventional	36	1.2	90	170	260	
Unconventional	1	–	140	530	670	12,200
Coal	155	2.4	530	4620	5150	3600
Total	295	6.5	1000	5760	6760	17,000

Source: Nakicenovic, Grubler, and McDonald (1998), WEC (1998), Masters et al. (1994), Rogner et al. (2000).

insulation and the refrigerant is CFC free (Brown presentation, section "The Potential for Energy Efficiency in the Long Run").

Renewable Energies

Renewable energies have always played a major role—today about 15% of global energy use. A lot of this energy is in poorly used biomass. The renewable energy resource base is very large Table 2.

Improving technologies across the board and decreasing unit costs will increase their ability to contribute e.g., more efficient use of biomass residuals and crops; solar and wind power (Boes presentation).

Fission Energy

Studies by the Global Energy Technology Strategy Project (GTSP) found that stabilizing CO_2 will require revolutionary technology in all areas e.g., advanced reactor systems and fuel cycles and fusion. The **deployment of the massive amounts of fission energy**, that would meet a significant portion of the needs of the 21st century, is **not possible with current technology**. Specifically, a global integrated system encompassing the complete fuel cycle, waste management, and fissile fuel breeding is necessary (McCarthy, section "Nuclear Energy", and Christian, section "Nuclear Industry Perspective" presentations).

Climate Change Driven Scenarios

The requirement to reduce carbon emissions to prevent undesirable changes in the global climate will have a major impact on the deployment of energy sources and technologies.

Table 2. Renewable Energy Resource Base in EJ (10^{18} J) per year

Resource	Current Use[b]	Technical Potential	Theoretical Potential
Hydropower	9	50	147
Biomass energy	50	> 276	2900
Solar energy	0.1	> 1575	3,900,000
Wind energy	0.12	640	6000
Geothermal energy	0.6	[5000][a]	[140,000,000][a]
Ocean energy	n.e.	n.e.	7400
Total	56	> 2500	> 3,900,000

Source: WEA 2000.

[a] Resources and accessible resource base in EJ—not per year! n.e.: not estimated.

[b] The electricity part of current use is converted to primary energy with an average loss factor of 0.385.

To achieve a limit on atmospheric carbon dioxide concentration in the range 550–650 ppm requires that emission's must start decreasing in the period between 2030 and 2080. The exact pattern of the emission curve does not matter, only the cumulative emissions matter. It is important to remember that there are other significant greenhouse gases such as methane, to contend with.

The alternatives for energy supply include: fossil fuels with carbon sequestration; nuclear energy, and renewable energies. Hopefully, fusion will provide a part of the nuclear resource. In the IIASA studies, high-technology plays a most important role in reducing carbon emissions. One possibility is a shift to a hydrogen economy adding non-fossil sources (nuclear and renewables) opportunities for fusion energy would be similar to those for fission.

On the one hand, the issue of investments makes it clear that the projected large increases in the use of fossil fuel (or energy in general) are uncertain. On the other hand, Chinese and Indian energy scenarios foresee a massive increase in the use of coal.

Geo-political Considerations

The dependence on energy imports has been a major concern for many countries since the so-called oil crises in the early and late 1970s. After these oil crises countries looked intensively for new energy sources and intensified energy R&D efforts. One result was the development of the North Sea oil, which is still today one of the major oil sources for Europe.

Especially in the case of conventional oil the diversification of oil sources, which reduced the fraction of OPEC oil considerable, will find an end in the next 10–20 years and lead again to a strong dependence of the world conventional oil market on OPEC oil.

In the case of Europe the growing concern about energy imports has lead to a political initiative of the European Commission. While a country like South Korea imports 97% of its primary energy, it is questionable whether countries as big as the US, Europe as a whole, China, or India would accept such a policy.

Dynamics of the Introduction of Technology

Two other important factors that bear on the introduction of technologies are the limited knowledge of their feasibility and the cost and the improvements that normally occur as a function of accumulated experience (learning curve).

The advantage of a collaborative world approach to RD&D includes not just the obvious one of cost-sharing but also that it would bring capabilities for sharing in the manufacturing to the collaborators.

It would be hard to conceive of a country deploying hundreds of gigawatts of power plants that were not produced mainly in that country.

Previous energy disruptions were caused by a lack of short-term elasticity in the market and perceptions of problems. Prevention will require diversity of energy supply, the thoughtful deployment of all energy sources, and for each energy-importing country to have a wide choice of suppliers.

Energy in China

China's population is projected to rise to 1.6–2.0 billion people by 2050, with expected substantial economic growth and rise in standard of living. Per capita annual energy consumption will approach found in the developed countries; roughly, 2–3 STCE (standard tonnes of coal equivalent) per person per annum. Annual energy use in China would rise to 4–5 billion STCE.

Much of this energy could come from coal; up to 3 billion STCE/a. This choice would be made because there are the large coal resources in China, and limited oil, gas, and capability to increase hydro. An oil use of 500 Mtoe/a is foreseen, mainly for transportation.

It is projected that electricity capacity will have to increase from today's 300 GWe, to 600 GWe in 2020 and to at least 900 GWe in 2050 and 1300 GWe in 2100 depending on the population growth. It would be desirable to have about 1 kWe per person. Such a large increase means that a technology capable of not more than 100 GWe does not solve the problem. On the other hand, providing 100s of GWe by any one source will be a challenge.

To put this in perspective, imagine that the fission capacity in China were raised to 400 GWe. This would equal total world nuclear power today! To meet a sustainable nuclear production of 100s of MWe, China will have to deploy Gen-1V power plants in an integrated nuclear system. It can be expected that such power plants would be built in China (see Korean example).

Nuclear energy development, like fusion, needs a world collaborative effort so that countries like China can install systems that are sustainable. This is a particularly acute issue if the low emissions scenarios are to be realized. It appears that the Chinese believe that it will be important to have a broad portfolio of non-fossil energy sources to meet the needs of their country. In this context, fusion energy is viewed as having an important role in the latter half of this century. Initially, their fusion research emphasized fusion–fission hybrid and use of indigenous uranium resources. Good collaboration between their fission and fusion programs continues. During this work they came to realize that it would be very difficult for them to develop fusion energy independently. Hence, the interest in expanding international collaboration and ITER.

Energy in India

There has been a steady growth in energy use in India for decades. Fossil fuels, particularly coal are a major part of commercial energy, because of large coal resources in India. Substantial biomass energy is used, but only a part is viewed as commercial.

Future energy demand has been modeled using the full range of energy sources, production and end-use, technologies, and energy and emissions databases, considering environment, climate change, human health impacts and policy interventions.

For the **A2** case, the population of India is projected to rise to 1650 million by 2100, GDP will rise by 62 times, and primary energy will increase from 20 EJ in 2000 to 110 EJ (**3750 Gtce**) in 2100. The electricity generating capacity will rise from around 100 GWe to over 900 GWe by 2100. Carbon emissions will increase 5 times by 2100, but 1 ton/a/year less than many developed countries.

The seriousness of their need for new energy sources is highlighted by the discussions that have taken place about running gas pipelines from the Middle East and neighboring areas that would require pipelines through Afghanistan and Pakistan.

For CO_2 stabilization, there would be a decrease in the use of fossil fuels for electricity production and an increase in the use of renewable energies and nuclear energy, **including fusion**.

Nuclear Energy Development in Korea

Owing to a lack of domestic energy resources, Korea imports 97% of its energy. The cost of energy imports, $37B in 2000 (24% of total imports) was larger than the export value of both memory chips and automobiles. Eighty percent of energy imports are oil from the Middle East.

The growth rate of electricity averaged 10.3% annually from 1980 to 1999. The anticipated annual growth rate through 2015 is 4.9%. Such an increase takes place in a situation in which Korea's total CO_2 emissions rank 10th in the world and are the highest per unit area.

If it becomes necessary to impose a CO_2 tax it is feared that exports will become uncompetitive. In these circumstances, the increasing use of nuclear energy is attractive.

Fission is the approach today and for the many decades, and fusion is seen as an important complementary source when it is developed. There is close collaboration on R&D within the nuclear community. This collaboration has been enhanced by the involvement of Korea in the ITER project.

Korea's success in deploying nuclear plants is a very interesting model for other transitional and developing countries on how a country can become capable in a high technology area. Korea has gone from no nuclear power, to importing technologies, to having in-house capability for modern PWR's, and to be working at the forefront of research within 30-years. One area in which there remains reliance on foreign capabilities is the provision of fuel.

In Korea, the first commercial nuclear power plant, Kori Unit 1, started operation in 1978. Currently there are 14 PWR's and 4 CANDU's operating; with 6 of the PWR's being Korean Standard Nuclear Plants. These power plants amount to 28.5% of installed capacity and provide 38.9% of electricity. It is planned that there will be 28 plants by 2015. Today, Korea is involved in many of the aspects of nuclear power development, including the international Gen-IV collaborations Table 3.

U.S. CLIMATE CHANGE TECHNOLOGY PROGRAM: DAVID CONOVER, DIRECTOR, CLIMATE CHANGE TECHNOLOGY PROGRAM (DOE)

President's Position on Climate Change

- "While scientific uncertainties remain, we can begin now to address the factors that contribute to climate change." (June 11, 2001)
- "Our approach must be consistent with the long-term goal of stabilizing greenhouse gas concentrations in the atmosphere."
- "We should pursue market-based incentives and spur technological innovation."
- My administration is committed to cutting our nation's greenhouse gas intensity—by 18% percent over the next 10 years." (February 14, 2002)

To achieve the Presidents goals, the Administration has launched a number of initiatives:

- Organized a senior management team.
- Initiated large-scale technological programs.
- Streamlined and focused the supporting science program.
- Launched voluntary programs.
- Expanded global outreach and partnerships.

Climate Science and Technology Management Structure

This activity is led from the Office of the President and involves senior management of all the major agencies with an interest in the area—CEQ, DOD, DOE, DOI, DOS, DOT, EPA, HHS, NASA,

Table 3. Units

	kJ	kW h	kGoe	kGce	m^3 NG
kJ	1	2.78×10^{-4}	0.24×10^{-4}	0.34×10^{-4}	0.32×10^{-4}
kW h	3600	1	0.086	0.123	0.113
kGoe	41.868	11.63	1	1428	1.319
kGce	29.308	8.14	0.7	1	0.923
m^3 NG	31.736	8.816	0.758	1.083	1

1 barrel (bbl) = 159 l oil.
7.3 bbl = 1 t oil.

NEC, NSF, OMB, OSTP, Smithsonian, USAID, and USDA.

Policy Actions for Near-Term Progress

- Voluntary Programs:
- Climate Vision (www.climatevision.gov).
- Climate Leadrers (www.epa.gov/climate leaders).
- SmartWat Transport Partnership (www.epa.gov/smartway) 1605(b)
- *Tax Incentives/Deployment Partnerships.*
- *Fuel Economy Increase for Light Trucks.*
- *USDA Incentives for Sequestration.*
- *USAID and GEF Funding.*
- *Initiative Against Illegal Logging.*
- *Tropical Forest Conservation.*

Stabilization Requires a Diverse Portfolio of Options

End-use

- Supply technology.
- Energy use reduction.
- Renewable energies.
- Nuclear.
- Biomass.
- Sequestered fossil and unsequestered fossil.

Research

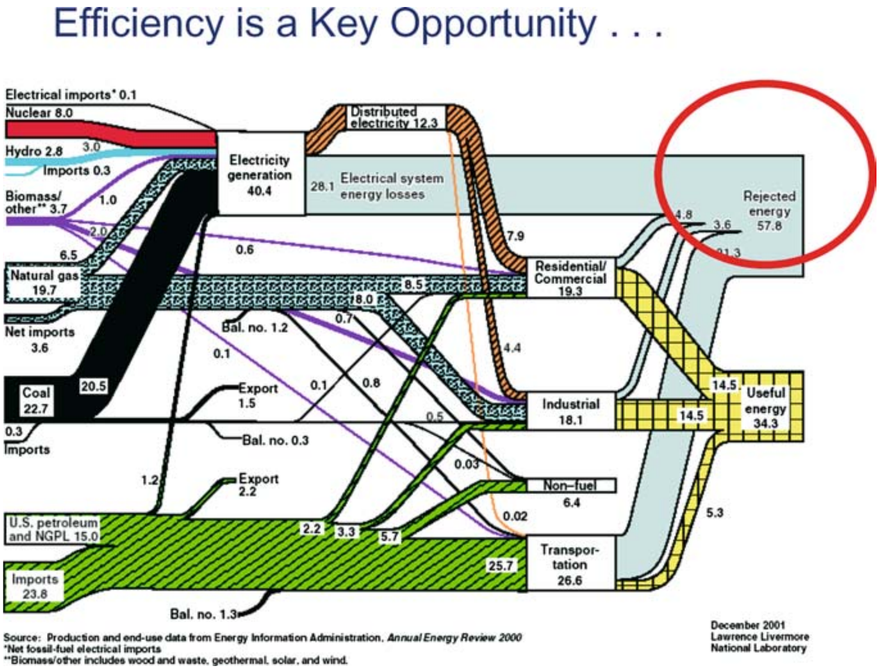
The U.S. Climate Change Technology Program document "Research and Current Activities" discusses the $3 billion RDD program supported by the government in all the areas relevant to the climate change program—energy efficiency 34%, deployment 17%, hydrogen 11%, fission 10%, fusion 9%, renewables 8%, future generation 8% and sequestration 3%.

Energy Efficiency

Improved efficiency of energy use is a key opportunity to make a difference, as illustrated in Figure 3. The government believes that efficiency improvements should be market driven to maintain the historic 1% annual improvement across all sectors. This should be achieved even with today's low energy prices of typically 7 c/kW h and $1.65 for a gallon of gasoline—see also the Brown presentation, section "The Potential for Energy Efficiency in the Long Run."

Transportation

Transportation today is inefficient as shown in Figure 3—only 5.3 out of 26.6 quads are useful energy. The Freedom CAR, using hydrogen fuel, is an initiative to provide a transportation system powered by hydrogen derived from a variety of domestic resources.



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2000*
*Net fossil-fuel electrical imports
**Biomass/other includes wood and waste, geothermal, solar, and wind.

December 2001
Lawrence Livermore
National Laboratory

Fig. 3.

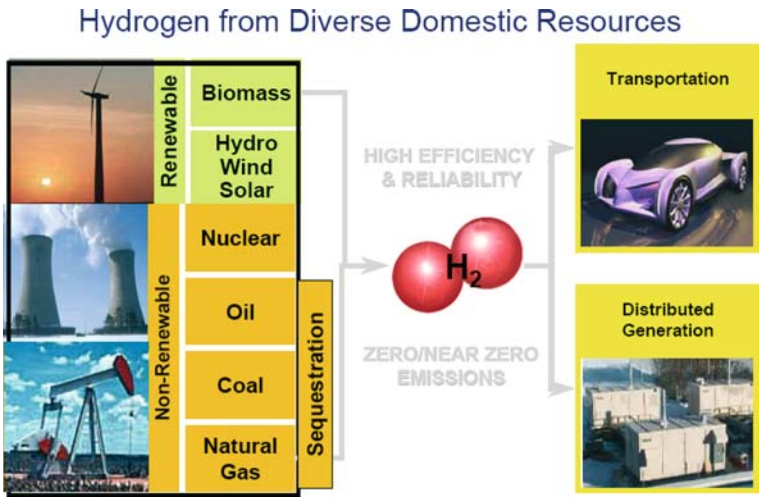


Fig. 4.

Figure 4 shows that hydrogen may be produced using all of the energy sources. The strategic approach is to develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and the hydrogen infrastructure to support them. [It was pointed out that hydrogen may also be used in ICE vehicles so that the use of hydrogen is of interest even if fuel cell turn out to be too expensive for some anticipated applications.] At the same time continue support for other technologies to reduce oil consumption and environmental impacts...

- CAFÉ,
- Hybrid Electric,
- Clean Diesel/Advanced ICE,
- Biofuels.

Electricity

Power production today is dominated by fossil fuels—51% coal, 16% natural gas and 3% petroleum. The resulting CO_2 emissions come from coal 81%, gas 15%, and from petroleum 4%. There are a number of options being pursued for reducing these emissions.

- There are \$263 million of annual direct Federal investments, including production tax credits, to spur development of renewable energy through RD&D—see Boes presentation, section ‘‘Renewables.’’
- In the coal area, development of a plant with very low emissions, including removal of CO_2 for sequestration is underway—see Bajura presentation, section ‘‘A Global perspective of Coal & Natural Gas.’’

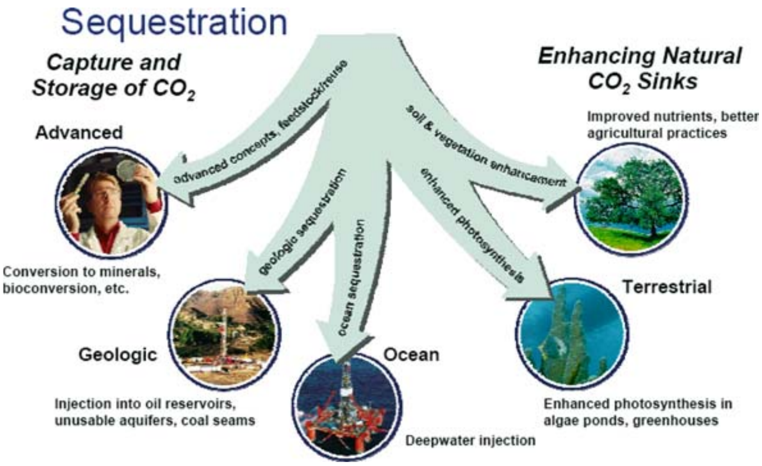
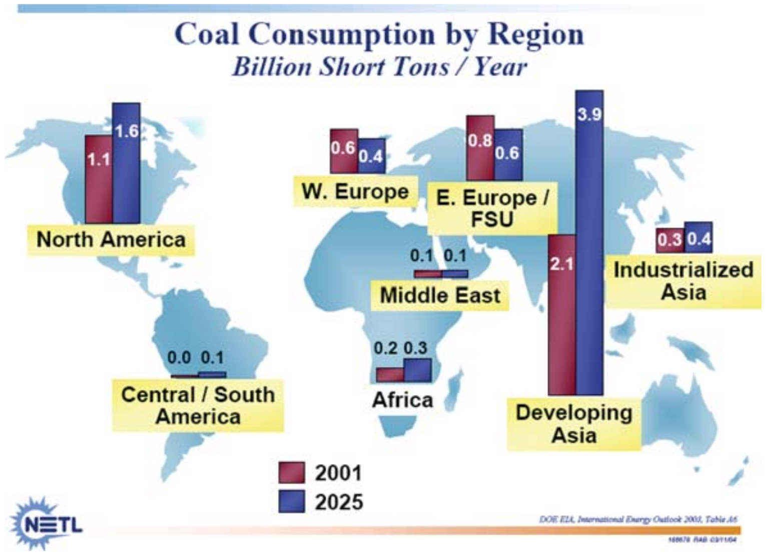


Fig. 5.



Coal Consumption by Region

Billion Short Tons / Year

DOE EIA, International Energy Outlook 2003, Table A6

188678 RAB 03/11/04

Fig. 6.

- In the nuclear area there are a number of programs to enhance the performance of existing plants and to develop improved fuel cycles and advanced reactors see talks by McCarthy, section "Nuclear Energy" and Christian, section "Nuclear Industry Perspective."
- In the fusion energy area, the U.S. has rejoined the International Thermonuclear Experimental Reactor activity—see Dean talk, section "Paths to Fusion Power."

Sequestration of CO_2

There is a large potential for the sequestration of CO_2 in a variety of storage options—gas and oil reservoirs, coal seams, saline aquifers, the deep ocean, and through conversion to minerals and by bioconversion, see Figure 5.

CCTP Process

The CCTP process is involved in Federal R&D portfolio review and budget input. It has a strategic plan and a working group structure in the areas of

- Energy production,
- Energy efficiency,
- Sequestration,
- Other gases,
- Monitoring and measurement, and
- Supporting basic research.

It has issued a competitive solicitation/RFI seeking new ideas.

The keys to meeting the President's goals are:

- leadership in climate science,
- leadership in climate-related technology,
- better understanding of the potential risks of climate change and costs of action, Robust set of viable technology options that address energy supply and efficiency/productivity,
- integrated understanding of both science and technology to chart future courses and actions,
- global approach… all nations must participate.

A GLOBAL PERSPECTIVE OF COAL & NATURAL GAS: RITA BAJURA (NETL)

Coal

Reserves and Use

The world's recoverable reserves of coal are 1083 billion tons, a 210 year supply at the current annual consumption. The United States has the largest amount of these reserves—25%. Russia has 16%, China 12%, and India and Australia about 9%.

Increasingly, coal is used for electricity production, 92% of 1.1 billion tons in the U.S. in 2002 and a projected 94% of 1.6 billion tons in 2025.

The bulk of the coal-fired electrical capacity of 330 MWe in the U.S. was built between 1966 and 1988. Similarly in the world, usage in electricity production was 66% of 5.3 billion tons in 2001, and a projected 74% of 5.9 billion tons in 2025, as illustrated in Figure 6.

While the DOE-EIA predicts that oil and natural gas prices will rise over the next 20 years, it predicts that coal prices will remain constant. A major factor affecting coal prices has been the steady improvements in coal productivity across the globe, with a doubling of output per miner per year from 1990 to 1999. Australia, the U.S. and Canada lead with a productivity of 11,000 to 12,000 tons per miner per year. Productivity in developing and transitional countries lags that in developed countries.

Coal mining safety has been improved a lot in the U.S. In 1907 there were 3200 mine deaths, in 2003 there were 30. However, this is still an issue in developing and transitional countries e.g., in China there were 7000–10,000 deaths per year in coal mines.

Environmental Concerns

There are numerous environmental impacts in the mining and use of coal, as illustrated in Figure 7. Regulators and industry are working to reduce these impacts through: improved permitting, reclamation, groundwater management, and utilization of coal mine methane.

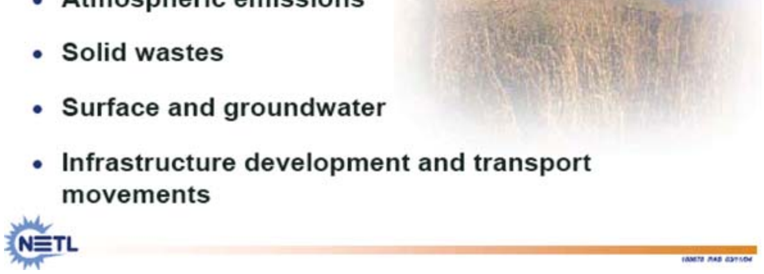
Contaminant emissions from fossil fired U.S. power plants, relative to fossil use, are down sharply as shown in Figure 8.

Coal plants operate under a complex system of environmental regulations that relate to the emissions of particulate matter, SO_x, and NO_x. The cost of removal of various percentages of these materials is shown in Table 4.

Mercury emissions are also a concern and the use of coal is the largest U.S emitter, contributing about 2% of world emissions. Today, there is no commercially available technology for limiting mercury emissions from coal plants. There is an active DOE-funded research effort. There are a number of field sites where mercury control is being tested. Co-control may be able to remove 40–80% Hg with bituminous coal but control will be much more difficult with low-rank coals. U.S. regulations are likely to be promulgated in the period from 2008 to 2018.

Climate Change. CO_2 from energy use is a major contributor—83%, to green house gas warming potential. The coal contribution is 30%. Stabilizing CO_2 concentrations (for any concentration between 350 and 750 ppm) means that global net CO_2 emissions must peak in this century and begin a long-term decline ultimately approaching zero. The pre-industrial level was 280 ppm. The technological carbon management options are:

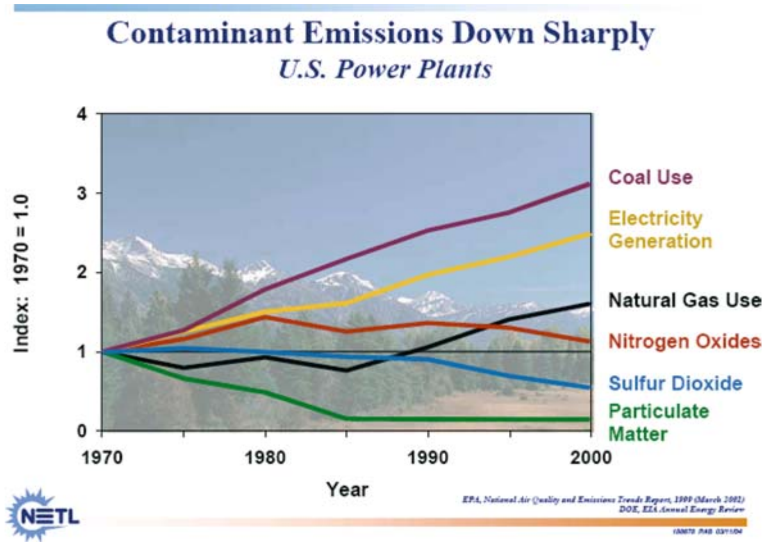
- *Reduce carbon intensity* using renewable energies, nuclear, and fuel switching.



Environmental Impacts of Mining

- Land disturbance
- Habitat loss
- Dust and noise pollution
- Atmospheric emissions
- Solid wastes
- Surface and groundwater
- Infrastructure development and transport movements

Fig. 7.


Contaminant Emissions Down Sharply

U.S. Power Plants

EPA, National Air Quality and Emissions Trends Report, 1999 (March 2002)
DOE, EIA Annual Energy Review

Fig. 8.

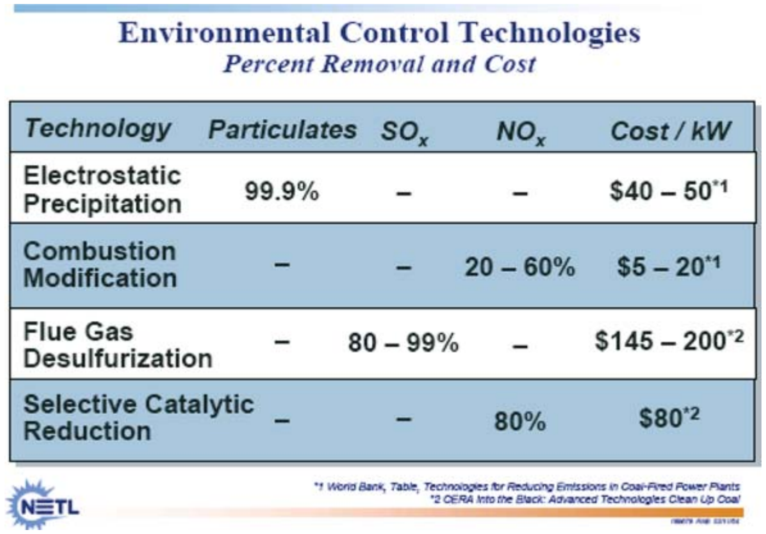
- *Improve efficiency* on both the demand side and supply side.
- *Sequester carbon* by capturing and storing it or through enhancing natural processes.

All of the options need to supply the energy demand and address environmental objectives.

Considerable improvements in efficiency are possible for coal plants, as shown in Figure 9.

The DOE's 2020 goal is 60%. The integrated gasification combined cycle (IGCC) plant is a promising pathway to "zero-emission" plants. It has fuel and product flexibility, high efficiency, is sequestration ready and environmentally superior. It can produce a concentrated stream of CO_2 at high pressure, reducing capital cost and efficiency penalties. It is being demonstrated at the Wabash River plant, which achieved 96% availability and won the 1996 powerplant of the year award, and at the Tampa electric, which won the 1997 award. The issues for the IGCC are that a 300 MWe plant costs 5–20% more than pulverized coal units however, economics for a 600 MWe plant appear more favorable. They take a longer shakedown time to achieve high availability and they suffer from the image of looking like a chemical plant. Worldwide there are 130 operating

Table 4.


Environmental Control Technologies

Percent Removal and Cost

Technology	Particulates	SO_x	NO_x	Cost / kW
Electrostatic Precipitation	99.9%	–	–	\$40 – 50^{*1}
Combustion Modification	–	–	20 – 60%	\$5 – 20^{*1}
Flue Gas Desulfurization	–	80 – 99%	–	\$145 – 200^{*2}
Selective Catalytic Reduction	–	–	80%	\$80^{*2}

**1 World Bank, Table, Technologies for Reducing Emissions in Coal-Fired Power Plants*
**2 CERA Into the Black: Advanced Technologies Clean Up Coal*

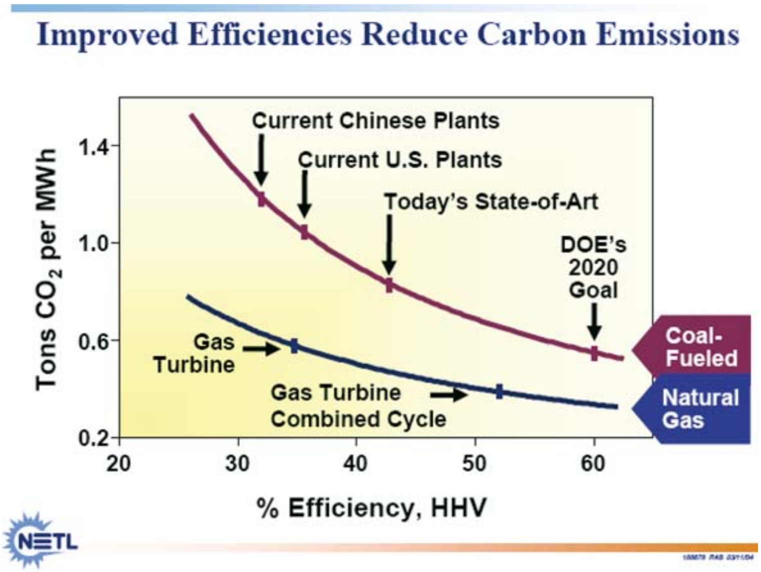


Fig. 9.

gasification plants with 24 GWe IGCC-equivalent, with more underway.

Sequestration. There are numerous options for separation and storage of CO_2 including unmineable coal seams, depleted oil and gas wells, saline aquifers, and deep-ocean injection. Sequestration can also be achieved through enhancing natural processes such as forestation, use of wood in buildings, enhanced photosynthesis and iron or nitrogen fertilization of the ocean. The potential capacity for storage is very large compared to annual world emissions. There remain concerns about the possibility of leaks from some forms of sequestration, but it has been demonstrated e.g., in the Weyburn CO_2 project, in which CO_2, produced in the U.S., is piped to Canada to support enhanced oil recovery; and in the Sleipner North Sea project, in which a million tonnes a year of CO_2 are removed from natural gas and sequestered in a saline aquifer under the sea. The costs, including separation, compression, transport, and sequestration, appear reasonable. The incremental average impact on a new IGCC is expected to be a 25% increase in cost of electricity (COE) relative to a non-scrubbed counterpart. DOE's goal is to reduce this increment to $<10\%$. Note that retrofitting CO_2 controls, unless a plant was designed for it would be expensive. There is a diverse research portfolio with >60 projects and a \$140 M portfolio. There is strong industry support with a 36% cost share. From AEP, Alstom, BP, Chevron Texaco, Consol, EPRI, McDermott, Shell, TVA, and TXU. The sequestration option could remove enough carbon from the atmosphere to stabilize CO_2 concentrations, be compatible with the existing energy structure, and be the lowest cost carbon management option.

FutureGen: A Global Partnership Effort

This effort is a "one billion dollar, 10-year demonstration project to create the world's first coal-based, zero-emission electricity and hydrogen plant" President Bush, February 27, 2003. It has broad U.S. participation and DOE contemplates implementation by a consortium. There is international collaboration including a Carbon Sequestration Leadership Forum. An industry group has announced the formation of a FutureGen Consortium. The charter members represent about 1/3 of the coal-fired utilities and about 1/2 of the U.S. coal industry—Americxan Electric Power, CINEnergy, PacificCorp, TXU (Texas Utilities), and CONSOL, Kennecot Energy, North American Coal, Peabody Energy, RAG American Coal Holding.

FutureGen opens the door to "reuse" of coal in the transportation sector through producing clean diesel fuel with Fischer-Tropsch synthesis. Also, hydrogen may be produced, by a shift process and separation with sequestration of the CO_2 for use in fuel cells and IC engines.

Why Coal is Important

Coal remains the largest energy source for power generation. It is a potential source for transportation. There are abundant reserves—particularly in the U.S. It contributes to our energy security. It had relatively low and stable prices. It has environmental impacts but, increasingly, the technology is becoming available to address them.

Natural Gas

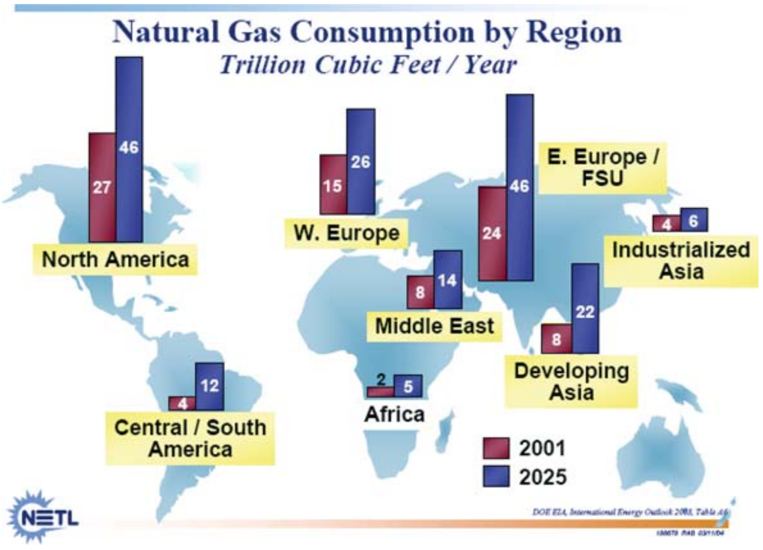
Resources and Use

The world's proven gas reserves of 5.500 Tcf could supply the current annual usage for 62 years. The largest reserves are in Iran, Qatar and Russia. However, there is more gas than the proven reserves including unconventional sources such as coalbed methane, tight gas, shale gas and methane hydrates for which the production is more difficult and will be impacted by technology.

In the U.S., 22.8 Tcf was used in 2002, 32% in industry and 24% for electricity production. The DOE-EIA predicts a usage of 31.4 Tcf in 2025 with 33% in industry and 27% for electricity. Worldwide usage in 2001 was 90.3 Tcf with 23% in industry and 36% for electricity increasing to 175.9 Tcf in 2025 with 46% for electricity. The usage is illustrated in Figure 10.

The EIA predicts that gas prices are likely to stay at the 2003 average of $5.50 per Mcf through at least 2025. In fact, U.S. gas prices are quite volatile with ±3% moves on 32 days of the year. Nevertheless, there has been construction of 200 GWe of new gas-fired capacity since 1998 in the U.S., despite a significant decrease in U.S. production since the peak in the 1970s. In fact while wells are being drilled more quickly there has been a decline in production from the lower-48 states. This decline is reflected in the lowering projections of the EIA. The shortfall has been made up from imports from Canada, Mexico and from shipments of LNG, but reduced imports from Canada are now forecast.

An 18-month comprehensive assessment of North American supply and demand has been made with broad industrial involvement—"Balancing Natural Gas Policy: Fueling the demands of a growing economy," National Petroleum Council, September 2003. The higher prices reflect a fundamental shift in the supply/demand balance. The traditional North American gas producing areas can only supply 75% of the projected demand and at best sustain a flat production. New larger-scale resources (LNG, Arctic) could meet 20–25% of demand. But they have higher cost, long lead-times and developmental barriers. The technical resources are impacted by access restrictions to the Pacific offshore (21 Tcf), the Rockies (69 Tcf), The Eastern Gulf Shelf and Slope (25 Tcf) and the Atlantic offshore Shelf and Slope (33 Tcf)—6 to 7 years of U.S. usage. Projections for future U.S. use are shown in Figure 11.



DOE EIA, International Energy Outlook 2003, Table A6

Fig. 10.

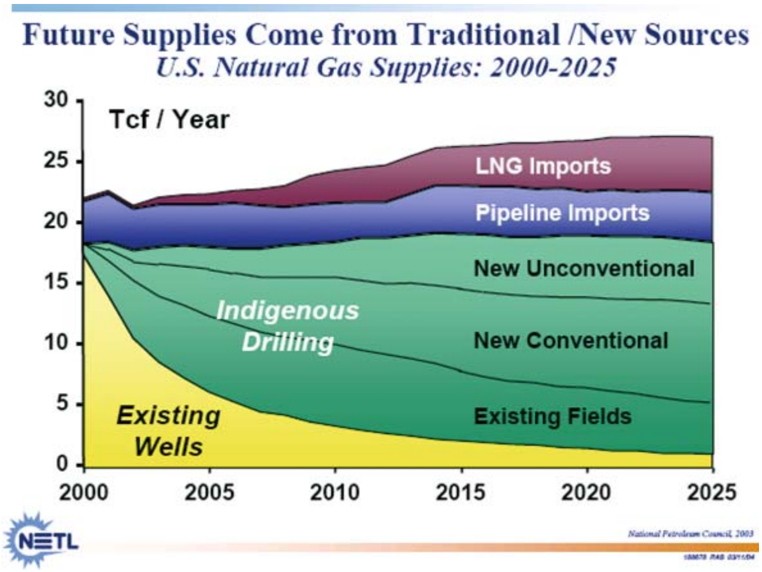


Fig. 11.

Liquid Natural Gas (LNG)

LNG will supply an estimated 15% of U.S. demand by 2025. Worldwide it is expected that LNG capacity will increase from 6 Tcf per year in 2003 to 35 Tcf in 2030. In 2003, there were 17 liquefaction terminals, 40 regasification terminals, 151 tankers with 55 under construction, and 12 exporting and 12 importing countries. Japan alone imports 1/2 of the world's production. In the U.S., there are 4 terminals, 32 active proposals amounting to 15 Tcf if built, but none are under construction and there is a 7-year construction period. Numerous global LNG liquefaction projects are competing to meet the growing demand. Qatar has massive reserves of 900 Tcf—more than the entire U.S. The higher gas prices are leading to the development of this very large, low-cost reserve with large-scale LNG and gas-to liquids facilities. As the LNG plant size has increased, improved technology has led to falling costs. Safety remains a concern as there have been serious accidents at facilities. Nevertheless, in its 40-year history, with 33,000 tanker voyages, there have been no major accidents. There is a dramatically changed perspective on infrastructure security in regard to the facilities since some of the facilities are close to major population centers such as Boston. Solutions to this concern include citing the facilities off-shore.

Environment

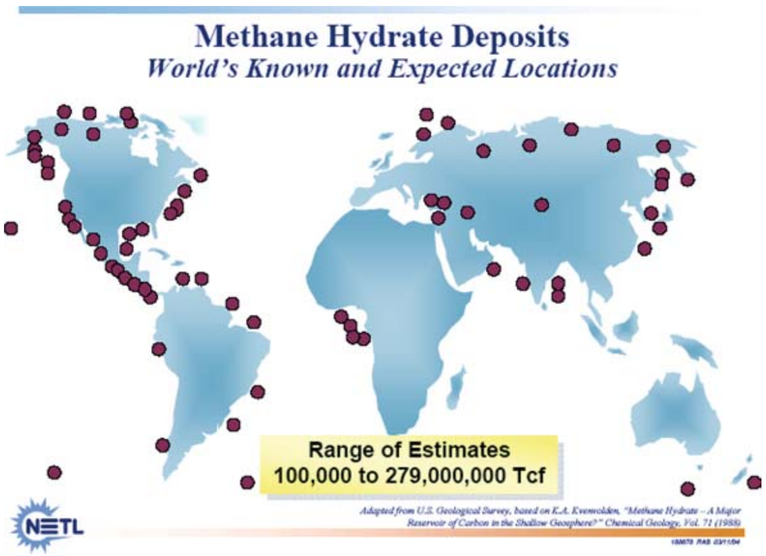
Technology is reducing the environmental impact of natural gas and oil supply. Fewer wells with a smaller footprint are needed to add the same level of reserves. There are lower drilling waste volumes, lower produced water volumes, and reduced air pollutants and greenhouse gas emissions. There is a greater protection of unique and sensitive environments.

Methane Hydrates

Methane hydrates consist of methane trapped in ice in which the methane density is comparable to liquid methane. They form when the temperature is cold enough at the given pressure e.g., in the tundra of the north or in the seabed at sufficient depth. For the longer term they may be a promising source of methane. The international Mallik Gas Hydrate project in the Mackenzie Delta of Canada has the first dedicated hydrates test wells. And depressurization has proved more effective than heating in extracting the methane. The estimated amount of such hydrates is huge and they are widely dispersed as shown in Figure 12.

Stranded Gas

A large amount of gas exists as so-called "stranded gas" i.e., isolate or small. Options for this gas are to reinject it, flare it, expand local uses in petrochemicals and basic industries such as aluminum. If economic build a pipeline. Alternatively, convert it to liquids, LNG or electricity.



Adapted from U.S. Geological Survey, based on K.A. Kvenvolden, "Methane Hydrate – A Major Reservoir of Carbon in the Shallow Geosphere?" Chemical Geology, Vol. 71 (1988)

Fig. 12.

Gas-fired Distributed Generation

The advent of fuel cells and efficient engines including reciprocating engines, small turbines, micro-turbines has enhanced the attractiveness of distributed generation that can defer new capacity, relieve transmission congestion, enhance reliability, improve efficiency, and promote the green image.

Future

In the natural gas-coal competition it is expected that coal will win for short-term dispatch and gas for long-term capacity share, because of an increasing desire for energy security. It is forecast that there will be a surge in coal capacity starting in 2010 in the U.S. There are proposals for 94 new plants with a capacity of 64 GWe. Worldwide there are proposals for thousands of GWe of new capacity, including 1400 GWe of coal technologies as shown in Figure 13. The estimated global investment required is 16.2 trillion dollars over the next three decades (IEA).

Therefore it is expected that coal and natural gas will continue to be a major part of the U.S. and global energy mix for at least 50 years. Maintaining fuel diversity and flexibility is important for price stability and continued economic growth. LNG use will increase; meeting a 5 Tcf demand will be challenging. Carbon sequestration at the scale envisioned is still a young technology. Near-zero emission technologies (SO_x, NO_x, CO_2, mercury) will be necessary to secure a long-term future for coal.

RUNNING OUT OF AND INTO OIL: ANALYZING GLOBAL OIL DEPLETION AND TRANSITION THROUGH 2050: DAVID GREENE (ORNL) WITH JANET HOPSON AND JIA LI (U. TENNESSEE), HTTP://WWW-CTA.ORNL.GOV/CTA/PUBLICATIONS/PUBLICATIONS_2003.HTML

Introduction

In regard to the question ''are we running out of oil,'' the pessimists aka ''geologists'' argue that geology rules, note that discovery lags production and that peaking not running out matters, and expect a peak by 2010 (conventional oil).

The optimists aka ''economists'' argue that economics rules, expect that the rate of technological progress will exceed the rate of depletion and that the market system will provide incentives to expand, and redefine resources.

The questions to answer if one took the optimists' viewpoint, but quantified it, are:

- How much oil remains to be discovered?
- How fast might technology increase recovery rates?
- How much will reserves grow?
- How fast will technology reduce the cost of unconventional sources?
- How much unconventional oil is there and where is it?

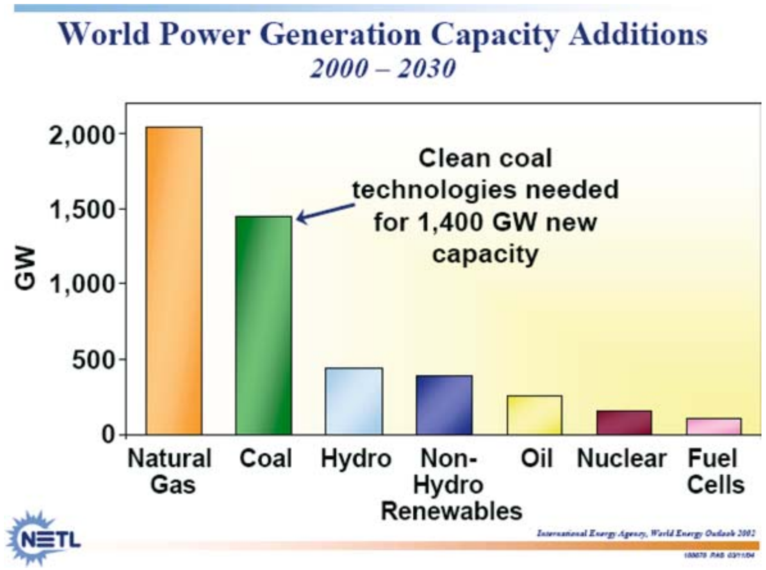


Fig. 13.

In this approach, there are no Hubbert's bell-shaped curves for production, and no geological constraints on production rates. **However, costs do rise with depletion**!

The Resource/Production ratio limits expansion of production. It is analogous to a limit based on the life of capital, but there is no explicit calculation of capital investment.

There are no environmental/social/political constraints on production—ANWAR, etc. are fair game.

What is Oil?

- *Conventional oil* is defined here as liquid hydrocarbons of light and medium gravity and viscosity, in porous and permeable reservoirs, plus enhanced recovery and natural gas liquids (NGLs).
- *Unconventional oil* is defined as deposits of density > water (heavy oil), viscosities > 10,000 cP (oil sands) and tight formations (shale oil).
- Liquid fuels can be made from coal or natural gas (**not considered here)**.

Many estimates have been made of the amount of oil as illustrated in Figure 14. *Conventional oil:* The USGS (2000) estimates a mean ultimate recovery of conventional oil of 3345 billion barrels (bbls) with a low of 2454 bbls (95% probability) and high of 4443 bbls (5% probability), with cumulative production to date of 717 bbls.

If there were no growth beyond the 2000 production level, production could continue for a 50 years at the mean level. With a 2% growth rate, peaking might occur around 2025.

Unconventional oil: A comparable amount to remaining conventional oil is estimated to exist. A large part of it is shale oil in the U.S. and oil sands in Canada and Venezuela.

In contrast, the pessimists estimate 2390 bbls of conventional oil and 300 bbls of unconventional oil.

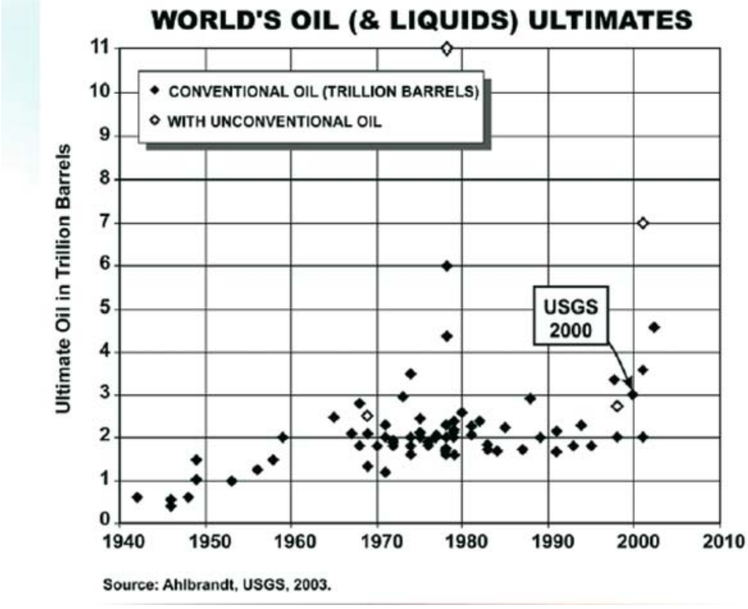
Modeling of Future Demand and Supply

A computer model has been constructed to explore how oil production might evolve up to 2050 under the projections for oil demand in the energy scenarios of the IIASA/WEC (2002).

The reference scenario A1 represents ‘‘business-as-usual". Oil consumption rises from about 3.9 Gtoe/a to about 8.8 Gtoe/a (1 tonne of oil equivalent (toe) = 7.3 bbls), much of the future growth is predicted to be in the developing world, see Figure 15.

An ‘‘ecologically driven scenario" C1 was also considered. In this scenario, oil consumption peaks at about 5.3 Gtoe/a around 2020 and then declines towards today's usage.

Both optimistic and pessimistic assumptions about oil resources were used. A risk analysis was



Source: Ahlbrandt, USGS, 2003.

Fig. 14.

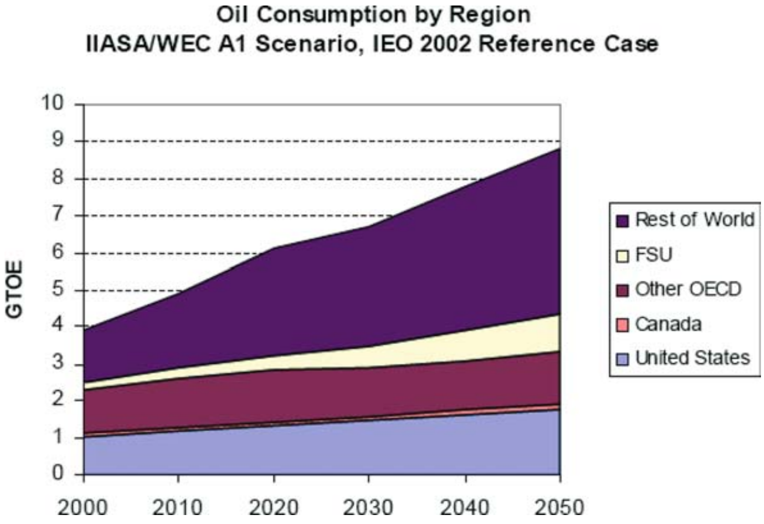


Fig. 15. The average growth of oil use in the world is 1.9%/yr.

carried out by defining the key parameters below as random variables: Prices for the different types of oil were taken to be—conventional oil $20/bbl, heavy oil and bitumen $15/bbl or $25/bbl, and for shale oil $40/bbl or $90/bbl.

Various assumptions were made about the growth rate of Middle East production, technological change, recovery/reserve expansion, speculative resources parameters, target R/P ratio, and supply and demand parameters such as short run demand elasticity, short run supply elasticity and the adjustment rate.

Depending on the assumptions the trade-off between the production of conventional and unconventional oil varied. So, if lower cost oil from Middle East production continued at a high level the demand for higher cost unconventional oil would be low—conventional oil production peaked earlier. If Middle East production was lower then oil prices were higher making unconventional oil more competitive—conventional oil production peaked later.

In the reference case, with the mean USGS data, the Rest of the World (ROW) conventional oil production peaks before 2030, with a mean year of 2023. In the pessimistic case, the mean year for peaking of ROW conventional oil is 2006. The total world conventional oil peaks between 2040 to after 2050. The year of peaking depends strongly on the rate of expansion of Middle East production and the resulting production of unconventional oil. Under the median assumptions, unconventional oil must expand rapidly after 2020, see Figure 16.

The depletion of all kinds of oil resources from the model is shown in Figure 17.

Rapid expansion of heavy oil and oil sands is needed to allow world oil use to continue to grow. Large amounts of shale oil might also be produced, mainly in the U.S., but the ability to achieve estimated production levels is more uncertain.

US petroleum production and imports continue to increase during this period, but the fraction from U.S. production increases owing to the U.S. production of unconventional oil.

The Middle East could maintain a dominant position in its share of total production through 2050.

Even in the low growth scenario, the ROW conventional oil would peak around 2017.

Conclusions

Present trends imply that ROW conventional oil will peak between 2010 and 2030. The rate of production is likely to decrease after 2020 in any case. The transition to unconventional oil may be rapid: 7–9%/year growth. First supplies will be from Venezuela, Canada, and Russia. Vast quantities of shale oil (or liquids from coal and NG) may be needed before 2050.

Caveats on the model are that it does not include geologic constraints on production rates; relies on target resource-to-production ratios; does not include environmental or political constraints; does not include coal- or gas-to liquids; the resource estimates of unconventional oil are weak; and scenario were used, not market equilibrium-based modeling of oil demand.

THE POTENTIAL FOR ENERGY EFFICIENCY IN THE LONG RUN: MARILYN BROWN (ORNL)

Introduction

The key points are that:

- A large economic potential for energy efficiency exists from deploying current technologies.
- Technology advance will further expand this potential.
- Energy efficiency can moderate the need for new energy supplies and:

– reduce greenhouse gas emissions,
– improve air quality,
– strengthen electric reliability and energy security.

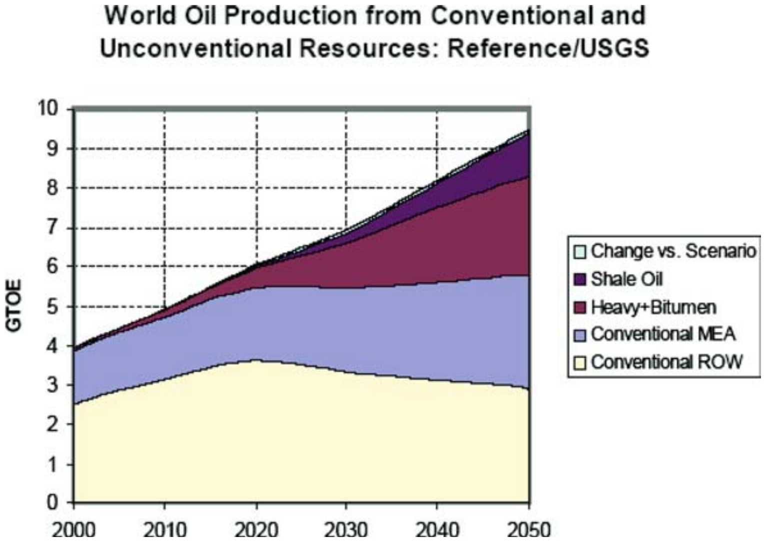


Fig. 16. Under median assumptions, unconventional oil production must expand rapidly after 2020.

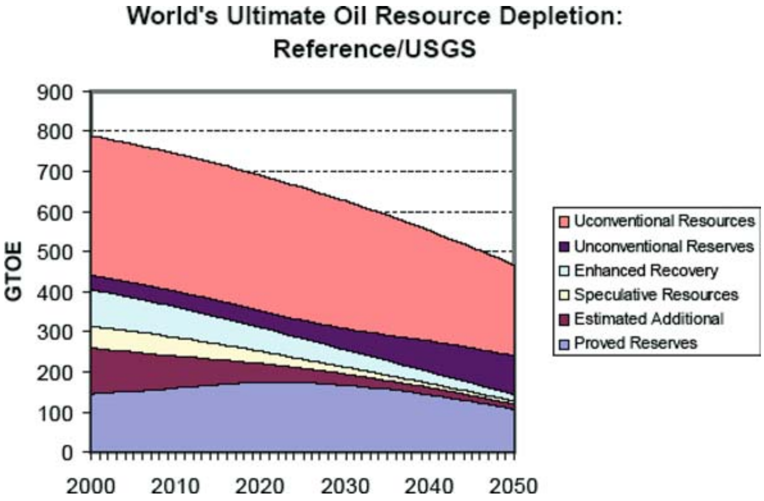


Fig. 17. The model predicts that production may peak before proved reserves (caveat).

Energy efficiency concepts include:

- *Conservation:* behavioral changes that reduce energy use.
- *Energy efficiency:* permanent changes in equipment that result in increased energy services per unit of energy consumed.
- *Economic potential for energy efficiency:* the technically feasible energy efficiency measures that are cost-effective. This potential may not be exploited because of market failures and barriers.

During the past century world energy consumption has grown at a 2% annual rate. If this rate were to continue, there would be a need for 7 times more energy per year in 2100. In the U.S. the energy consumption is growing at a 1–1.5% annual rate. At the 1% level this would lead to a 28% increase by 2025 and 2.7 times increase by 2100. If the energy mix remains the same, this will lead to a growing shortfall and increasing imports.

In the U.S. 39% of energy consumption is in residential and commercial buildings, 33% in industry, and 28% in transportation. Numerous studies have been made by groups of DOE's laboratories of the potential for improved energy efficiency [Scenarios of U.S. Carbon Reduction (1997) (www.ornl.gov/Energy_Eff), Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions (1998) (www.ornl.gov/climate_change/climate.htm), Scenarios for a Clean Energy Future (2000) (www.ornl.gov/ORNL/Energy_Eff/CEF.htm and Energy Policy, Vol. 29, No 14, Nov. 2001)].

Implementing Current Technologies

In "California's Secret Energy Surplus: The Potential for Energy Efficiency" by Rufo and Coito (2002: www.Hewlett.org) it is estimated that California has an economic energy savings potential of 13% of base electricity usage in 2011 and 15% of total base demand in 2011.

Similarly, in "Natural Gas Price Effects of Energy Efficiency and Renewable Energy practices and Policies" by Elliott et al., Am, Council for an Energy Efficient economy (2003: http://acee.org) it is estimated that the U.S. could reduce electricity consumption by 3.2% and natural gas consumption by 4.1%.

Inventing and Implementing New Technology

Estimates have been made of the upper limits on the attainable energy efficiency for non-electric uses, by 2100, of 232% for residential energy consumption and 119% for industry—"Technology Options" for the Near and Long Term (2003) (www.climate.technology.gov), and "Energy Intensity Decline Implications for Stabilization of Atmospheric CO_2 content by H," by Lightfoot and Green (2002) (www.mcgill.ca/ccgcr/). The goal of the study "Scenarios for a Clean Energy Future" was "to identify and analyze policies that promote efficient and clean energy technologies to reduce CO_2 emissions and improve energy security and air quality."

The following U.S. energy policies were considered in the "advanced scenario":

- *Buildings:* Efficiency standards for equipment and voluntary labeling and deployment programs.
- *Industry:* Voluntary programs to increase energy efficiency and agreements with aindividual industries.
- *Transportation:* Voluntary fuel economy agreements with auto manufacturers and “pay-at-the-pump” auto insurance.
- *Electric Utilities:* Renewable energy portfolio standards and production tax credits for renewable energy.
- *Cross-Sector Policies:* Doubled federal R&D and domestic carbon trading system.

The advanced scenario would reduce energy use by about 20% from the business-as-usual case, by 2020, see Figure 18. It would also reduce carbon emissions by about 30%—notably 41% in the pulp and paper industry.

More detailed conclusions of this and other studies are given below.

Buildings Sector

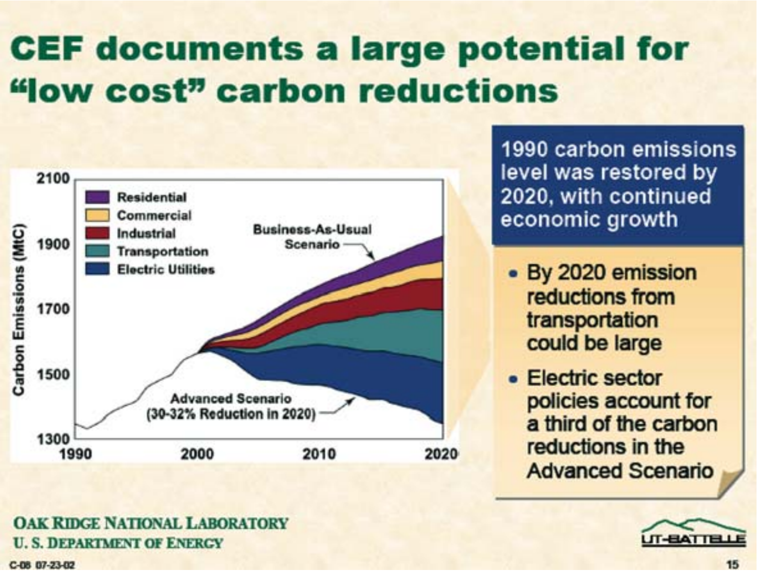
Residential buildings: Efficiency standards and voluntary programs are the key policy mechanisms. The end-uses with the greatest potential for energy savings are space cooling, space heating, water heating, and lighting. Primary energy consumption in 2001 is shown in Figure 19.

A good example of continuing progress over the past 30 years is the reduction in energy use of a “standard” U.S. refrigerator, from around 1800 kW h/year in 1972 to around 400 kW h/year in 2000, see Figure 20. At the same time CFC use was eliminated. It is estimated that DOE research from 1977 to 1982, translated into commercial sales saved consumers $9B in the 1980s. Projected energy saving by owing to research in the 1990s is estimated to be 0.7 quad/year by 2010.

A “Zero Energy” house i.e., using only solar energy, has been built as part of The Habitat for Humanity program. It is up to 90% more efficient than a typical Habitat home.

Commercial buildings: Voluntary programs and equipment standards key policy mechanisms. Among the opportunities to improve building energy use are (Figure 21):

- Solid-state lighting integrated into a hybrid solar lighting system.
- Smart windows.
- Photovoltaic roof shingles, walls and awnings.
- Solar heating and superinsulation.
- Combined heat and power-gas turbines and fuel cells.
- Intelligent building systems.



CEF documents a large potential for “low cost” carbon reductions

1990 carbon emissions level was restored by 2020, with continued economic growth

- By 2020 emission reductions from transportation could be large
- Electric sector policies account for a third of the carbon reductions in the Advanced Scenario

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY
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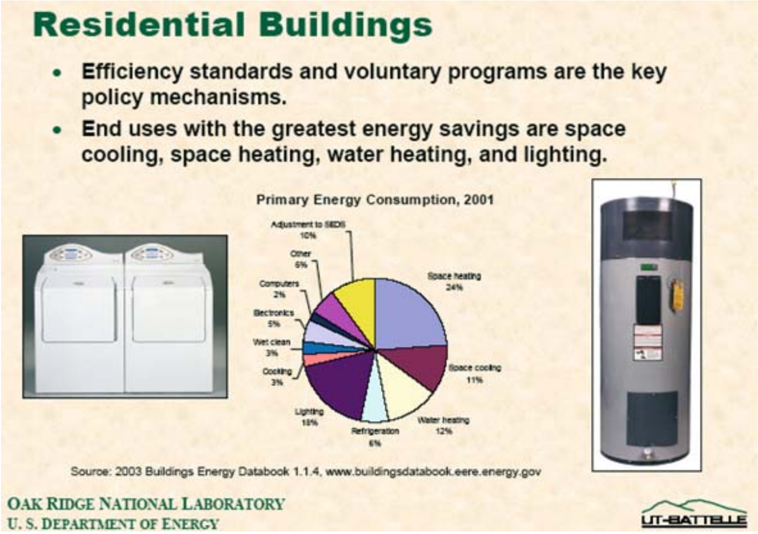
Fig. 18.



Residential Buildings

- Efficiency standards and voluntary programs are the key policy mechanisms.
- End uses with the greatest energy savings are space cooling, space heating, water heating, and lighting.

Source: 2003 Buildings Energy Databook 1.1.4, www.buildingsdatabook.eere.energy.gov

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Fig. 19.

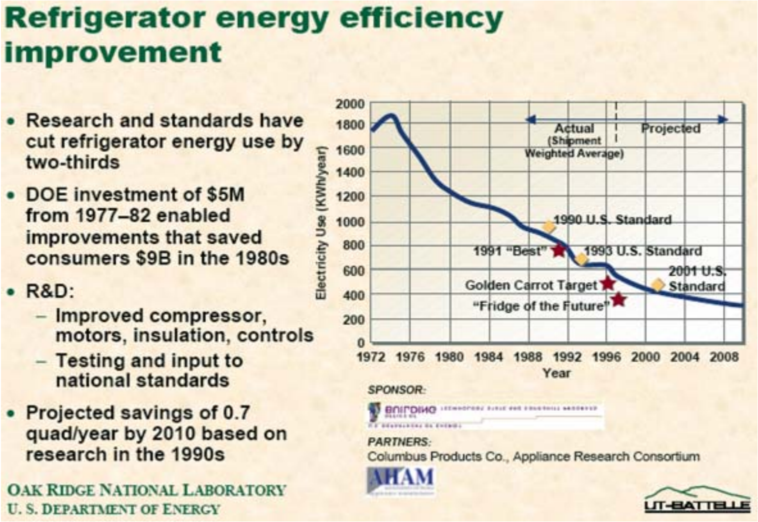
Industry Sector

Key policies for improvement are, voluntary programs (technology demonstrations, energy audits, financial incentives), voluntary agreements between government and industry, and doubling cost-shared federal R&D.

Key cross-cutting technologies include, combined heat and power, preventive maintenance, pollution prevention, waste recycling, process control, stream distribution, and motor and drive system improvements. Numerous sub-sector specific technologies play a role. Advanced materials, that operate at higher temperature and are more corrosion resistant, can cut energy use in energy intensive industries e.g., giving a 5–10% improvement in the efficiency of Kraft recovery boiler operations and 10–15% improvement in the steel and heat treating areas.

A systems approach to plant design is illustrated in Figure 22.

Opportunities exist to convert biomass feedstock—trees, grasses, crops, agricultural residues, animal wastes and municipal solid wastes—into fuels, power, and a wide range of chemicals. The conversion processes being investigated and improved are enzymatic fermentation, gas/liquid fermentation, acid



Refrigerator energy efficiency improvement

- Research and standards have cut refrigerator energy use by two-thirds
- DOE investment of $5M from 1977–82 enabled improvements that saved consumers $9B in the 1980s
- R&D:
  - Improved compressor, motors, insulation, controls
  - Testing and input to national standards
- Projected savings of 0.7 quad/year by 2010 based on research in the 1990s

SPONSOR:

PARTNERS:
Columbus Products Co., Appliance Research Consortium

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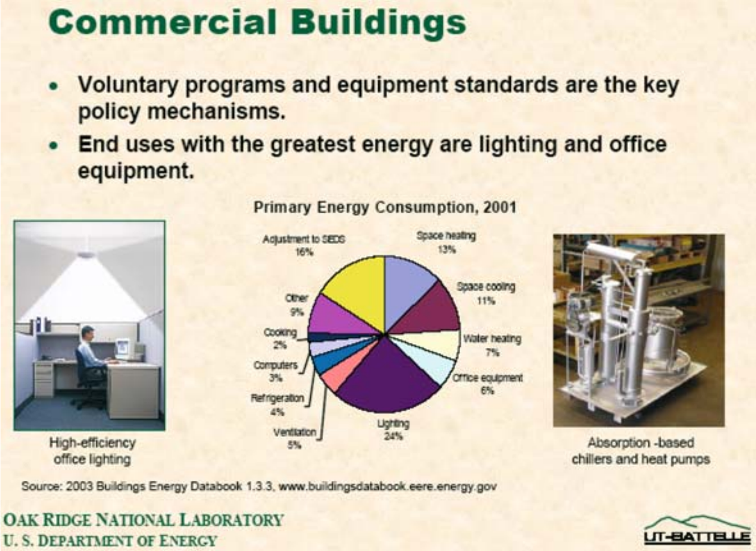
Fig. 20.



Commercial Buildings

- Voluntary programs and equipment standards are the key policy mechanisms.
- End uses with the greatest energy are lighting and office equipment.

Primary Energy Consumption, 2001

Source: 2003 Buildings Energy Databook 1.3.3, www.buildingsdatabook.eere.energy.gov

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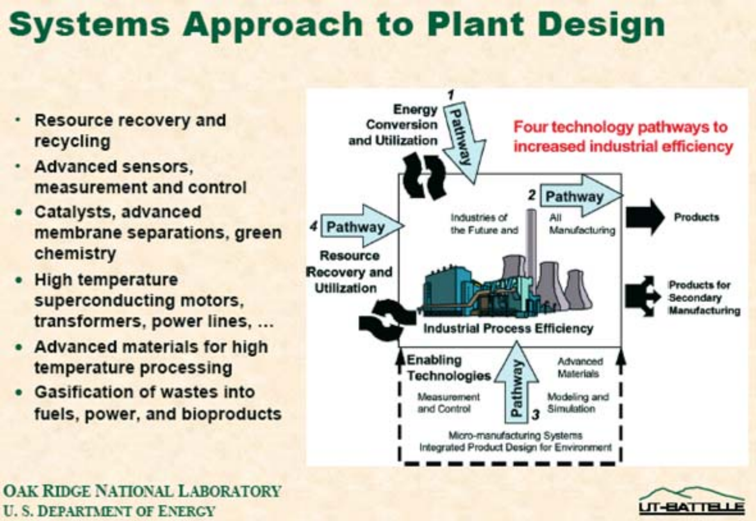
Fig. 21. The end-use energy distribution in commercial buildings.

hydrolysis/fermentation, gasification, combustion and co-firing.

Transportation Sector

In the advanced scenario passenger car mpg improves from 28 to 44 mpg owing to, materials substitution (9.7%), aerodynamics (5.4%), rolling resistance (3%), engine improvements (23.9%), transmissions (2.9%), accessories (0.4%), gasoline-hybrid (12.6%), while size and design (−2.9%) and safety and emissions (−1.1%).

Improvements in engine efficiency are being developed to allow a transition to a hydrogen economy. It is anticipated that efficiency will improve from 35 to 40% in today's engines to 50–60% in advanced combustion engines, owing to advances in emission controls, exhaust, thermodynamic combustion, heat transfer, mechanical pumping, and friction. This progress will facilitate the transition from gasoline diesel fuels, through hydrogenated fuels to hydrogen as a fuel. On-board storage of hydrogen is an area requiring improvement. If these improvements are



Systems Approach to Plant Design

- Resource recovery and recycling
- Advanced sensors, measurement and control
- Catalysts, advanced membrane separations, green chemistry
- High temperature superconducting motors, transformers, power lines, ...
- Advanced materials for high temperature processing
- Gasification of wastes into fuels, power, and bioproducts

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Fig. 22.

realized, sales of gasoline powered vehicles might be cut in half by 2020.

Power Sector

The use of distributed energy may increase because of improvements in industrial gas turbines and micro-turbines that allow greater efficiency at lower unit cost, the ability to have combined heat and power and lower emissions e.g., it is projected that by 2020 micro-turbine performance will go from the 2000 levels of 17–30% efficiency, 0.35 pounds/MW h of NO_x and \$900–1200/kW to 40% efficiency (> 80% combined with chillers and desiccant systems), 0.15 pounds/MW h of NO_x and \$500/kW. In the advanced scenario 29 GW will be added by 2010, and 76 GW by 2020. This would save 2.4 quads of energy and 40 MtC of emissions.

High temperature superconducting materials offer opportunities to improve the efficiency of transmission lines, transformers, motors and generators. Progress has been made in all of these areas.

RENEWABLES: ELDON BOES (NREL)

Resources

Renewable energy resources include:

- Biomass
- Geothermal
- Hydropower
- Solar
- Wind

They may be used for electricity, fuel, heat, hydrogen and light. The interest in them is because they can have a low environmental impact. They reduce dependence on imported fuel and increase the diversity of energy supply. They can have low or zero fuel cost with no risk of escalation. They offer a job creation potential, especially in rural areas and there is strong public support for them.

A map showing the widespread distribution of renewable resources in the U.S. is shown in Figure 23.

For solar energy, large areas of the world receive an average radiation of 5 or more kW h/sq. m. per day e.g., western China averages 6–8 kW h/m^2 per day during the summer, and 2–5 kW h/m^2 per day during the winter.

Solar and Wind Energy Resource Assessment (SWERA)

This is a \$3.6M program of the Global Environmental Fund (GEF) designed to:

- Accelerate and broaden the investment in solar and wind technologies through better quality and higher resolution resource assessment.
- Demonstrate the benefits of assessments through 13 pilot countries in 3 major regions.

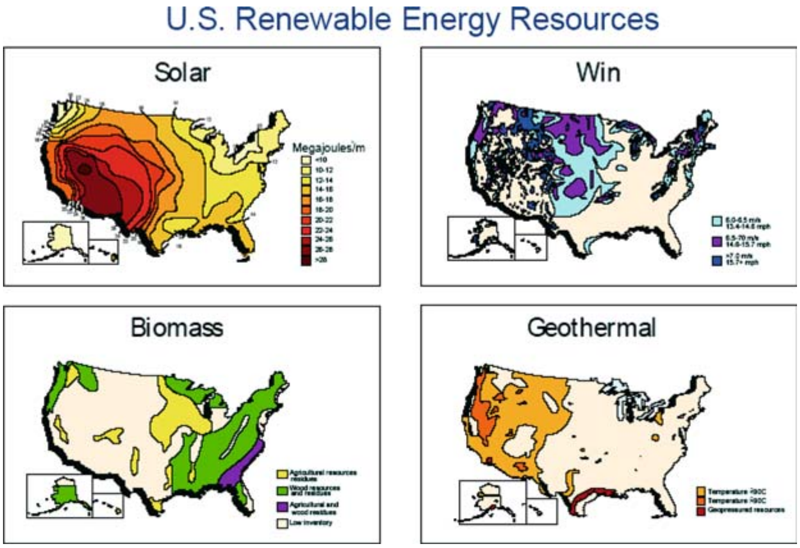


Fig. 23.

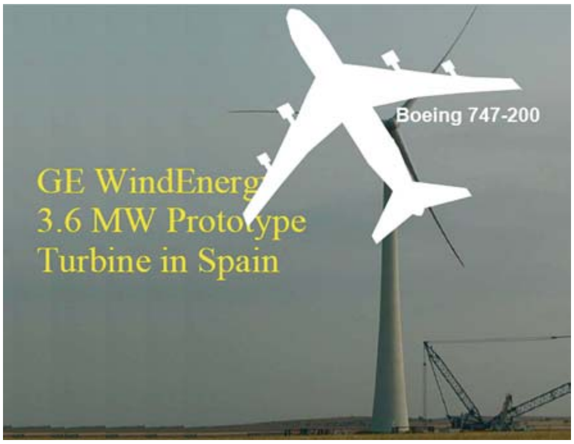


Fig. 24.

- Engage country partners in all aspects of the project.

The countries are Bangladesh, Brazil, China, Cuba, El Salvador, Ethiopia, Ghana, Guatemala, Honduras, Kenya, Nepal, Nicaragua, and Sri Lanka.

A medium resolution mapping of potential solar energy in Sri Lanka shows a resource of typically 5–6 kW h/m^2 per day during December to February, and 4.5–5.5 kW h/m^2 per day during May to September. Similar maps have been made for wind speed showing some regions with a moderate (6.4–7.0 m/s at 50 m) to excellent (7.5–8 m/s at 50 m) classification.

Wind Power

An example of a modern large turbine of 3.6 MWe is shown in Figure 24. For perspective note that the blade diameter is comparable to the span of a 747.

In the U.S. as wind power capacity has increased the cost of electricity (COE) has come down, see Figure 25. California with 2011 MWe and Texas with 1293 MWe lead in capacity. The total installed capacity on the world is 37,220 MWe (on average about 12,500 MWe) with:

14,000 MWe in Germany,
6374 MWe in the U.S.,
5780 MWe in Spain,
3094 MWe in Denmark, and
1900 MWe in India.

Achievements and Status

- Cost of energy reduced to 3.5–5.5 cents/kW h.
- Wind resources are vast, but also vary considerably on both regional and micro-levels.
- Global capacity increasing at 20% per year.
- Green power markets in U.S. are stimulating 100s of MWs.

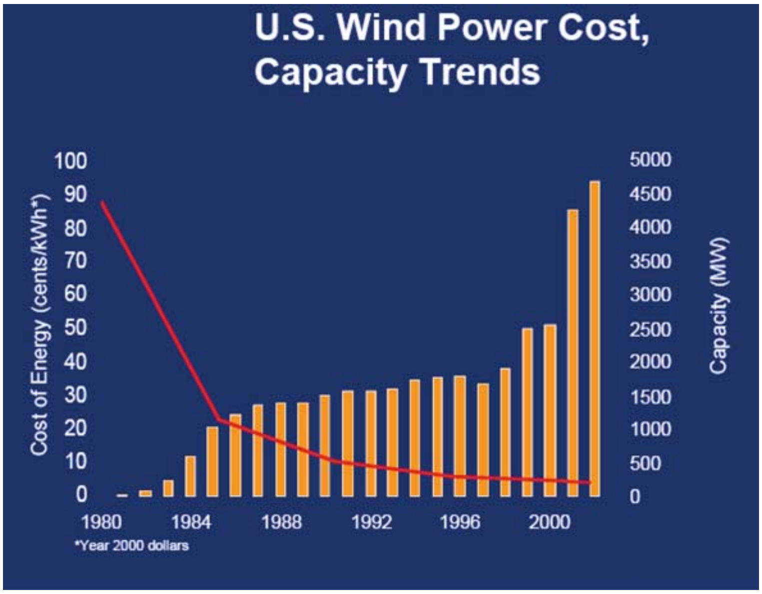


Fig. 25.

- Recent energy costs are also accelerating interest in wind power systems.
- Bird kill issue appears to be manageable.
- Not in my backyard remains an issue for some proposed sites.

Likely Advances

- Larger turbines: 3+ MW.
- Expanding field experience will support both technology and business development.
- Low wind speed turbines.
- Advanced power electronics.
- Win resource forecasting will enhance systems value.
- Major transmission systems to tap Great Plains resources.
- Offshore wind power plants in shallow and deep water.

Geothermal Power

Achievements and Status

- The technology has been used at the Geyser's site in northern CA since the 1960s.
- Quite a few additional systems have been built in the past 20 years.
- Advances in resource mapping and access.
- Advances in conversion technologies—binary systems and heat exchangers.
- High quality resources in the U.S. are limited.

Likely Advances

- Broad utilization of high-quality resources around the globe.
- Major challenges are resource characterization and extraction.

– Where is it?
– How large and durable?
– Cheaper drilling.

- Benefits will come from seismic mapping and extraction technologies used in the oil & gas industries.
- Hot dry rock technology has long term prospects.

Solar Thermal Electric

Achievements and Status

- 350 MW of parabolic trough plants built around 1990 still operate well.
- Several power tower demonstration plants have established technology viability.
- Several dish systems have also operated successfully.
- The challenges are system size and cost.

Potential Advances

- There are major opportunities for technology advances in:

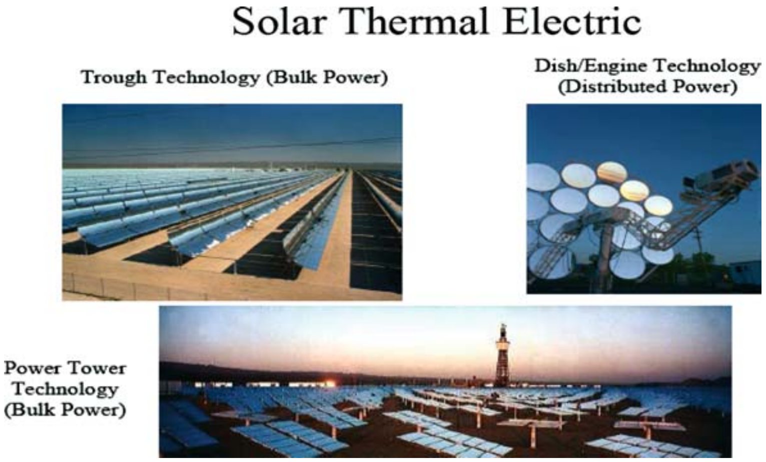


Fig. 26.

  - Collectors.
  - Power conversion.
  - Thermal storage.

- New systems are planned in Spain and Nevada.
- Success with new systems will catalyze manufacturing advances.

Solar Buildings

Worldwide there are 4.5 million water heating systems installed. The typical cost of 8 c/kW h is projected to drop to 4 c/kW h.

Several hundred transpired collectors for air heating have been installed worldwide. Their current cost is around 2 c/kW h.

Zero net energy buildings, in which annual production equals use, have been demonstrated.

Solar Photovoltaics

Photovoltaics already provide cost-effective electricity in small power units where there is no electricity grid e.g., for pumping water, providing lighting, and operating remote equipment. Larger systems have been installed on a number of buildings as illustrated in Figure 27.

The world PV market continues to grow steadily as shown in Figure 28. While U.S. production is increasing it lags the worldwide rates of increase. Japan is the major producer with nearly 50% of the production in 2002.

Photocell efficiency for all types of cell has improved markedly over the past 27 years as shown in Figure 29. At the same time, as the cumulative production has increased the price of a PV module has decreased steadily, see Figure 30.

Achievements and Status

- Steady progress in increasing cell efficiencies for 20 years.
- Sales increasing 25%/year.
- Major expansions of manufacturing capacities underway.
- Value of building-integrated systems gaining recognition.
- U.S. owned manufacturing is losing ground.
- Very substantial subsidies in Japan and Europe.

Likely Advances

- Large potential for technology and manufacturing advances.
- Significant increases in conversion efficiency likely.
- Organic and polymeric cells being researched.
- Standardized power controls and interconnection equipment.
- Better understanding of PV's distributed resource and peaking load values.

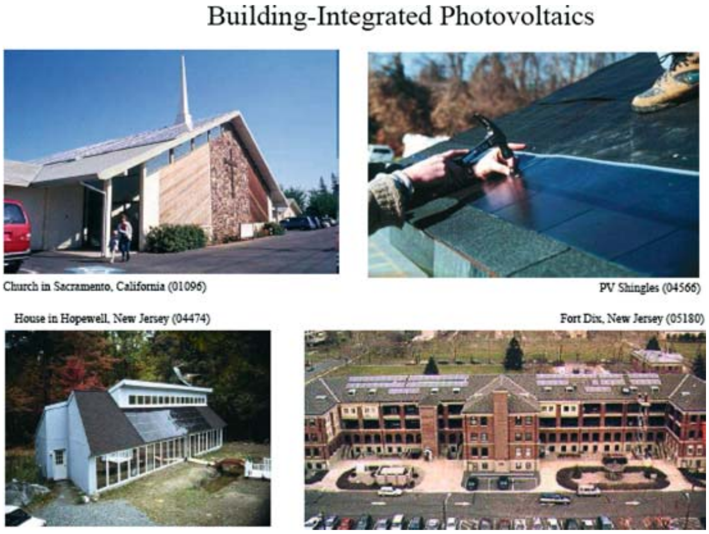
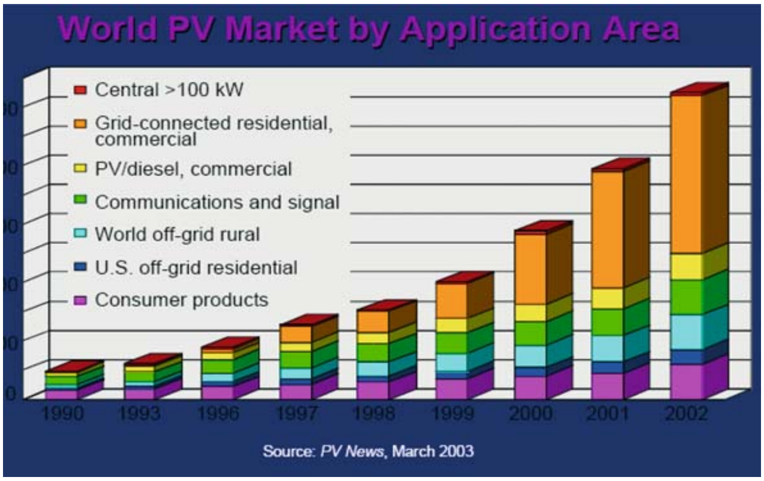

Building-Integrated Photovoltaics
Church in Sacramento, California (01096)
PV Shingles (04566)
House in Hopewell, New Jersey (04474)
Fort Dix, New Jersey (05180)

Fig. 27.



Source: *PV News*, March 2003

Fig. 28.

Biomass

Resources

The resources of biomass are large and widespread: trees and various crops, switchgrass, agriculture and forestry residues—such as wood chips, sugar cane residue, and manure—and municipal solid wastes.

Biomass Electricity

In the U.S. there is 9700 MWe of capacity from direct combustion of biomass and a further 400 MWe from co-firing with coal. Biomass gasification is being tried in small 3–5 kW systems in field verification tests. Larger systems have been demonstrated.

Ethanol and Bioethanol

Ethanol is made from the starch in corn kernels. It is available blended in motor fuels at a cost of about $1.22/gal.

Bioethanol is made from cellulosic materials such as corn stalks and rice. The technology is under development and the cost is about $2.73/gal and projected to drop to #1.32/gal. In the near-term it is used as a fuel blend. In the longer-term as a bulk fuel it will require energy crops.

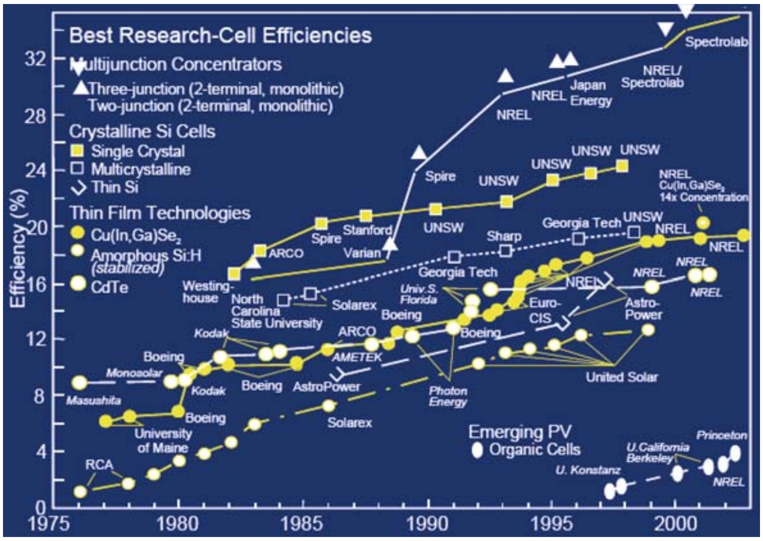


Fig. 29.

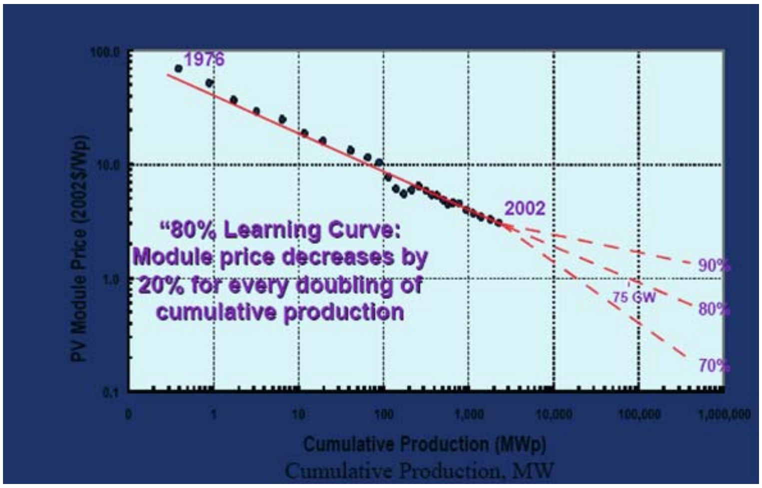


Fig. 30. PV module production experience (or "Learning") Curve.

The New Bio-Industry

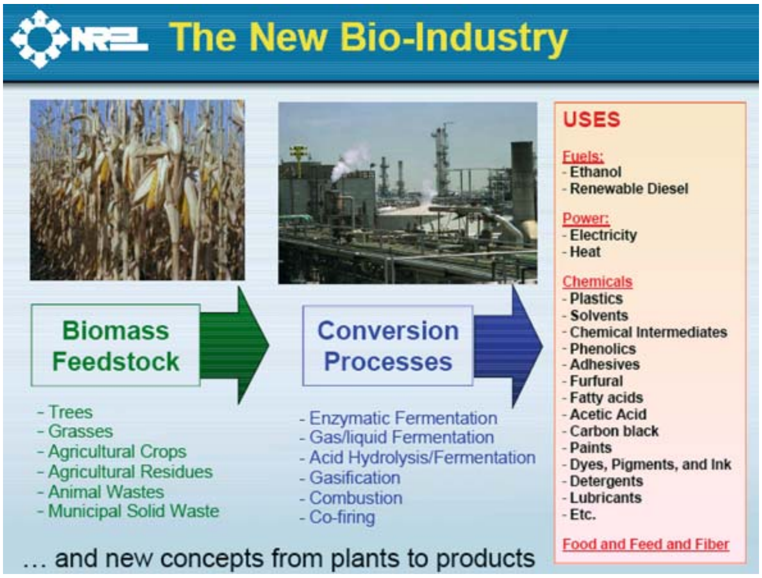
There are numerous uses for biomass as illustrated in Figure 31 and research is ongoing to improve the conversion processes. One vision is to develop a biorefinery in which feedstock is converted by various processes to produce electricity, fuel ethanol, and other bioproducts.

Hydrogen

Hydrogen is one of the many potential products of biomass, but it can also be produced from other renewable energies by electrolysis, photochemical water splitting and through solar assisted production.

A Transition to Renewables Scenario

A transition to renewable energies will require "getting serious" about adopting significant amounts. An analysis was made of using renewable energies for some of the expected added capacity and replacements of capacity from 2006 to by 2020. DOE/EPRI costs for renewables and DOE-EIA costs for conventional power sources were used. Costs for transmission of wind, geothermal and solar thermal were added. It was assumed that the energy mix would be



NREL The New Bio-Industry

Biomass Feedstock

- Trees
- Grasses
- Agricultural Crops
- Agricultural Residues
- Animal Wastes
- Municipal Solid Waste

Conversion Processes

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Combustion
- Co-firing

USES

Fuels:
- Ethanol
- Renewable Diesel

Power:
- Electricity
- Heat

Chemicals
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty acids
- Acetic Acid
- Carbon black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Lubricants
- Etc.

Food and Feed and Fiber

… and new concepts from plants to products

Fig. 31.

wind 55%, biopower 25%, geothermal 10%, PV 5%, and solar thermal 5%.

The result was the addition of 150 GWe of non-hydro renewables by 2020—15% of total capacity in 2020. In 2012, the highest cost year, the annual increase was about $1B for the nation, including a residential share of about 25 cents per month per household. In 2020, the annual cost savings are about $1.5B or 37 cents per month per household.

An EIA analysis modeled 10% and 20% renewable portfolios in 2020. Their results were that electricity process were 4.3% higher in 2020. Their renewables mix was biopower 58%, wind 31%, and geothermal 10%. Natural gas prices decreased by 9% and the total energy expenditures go down slightly.

Summary

"Renewable energy development is at a crossroads... The momentum for renewables has never been greater, despite the fact that energy prices are low and there are few immediate energy concerns." IEA 1999: The Evolving Renewable World.

National Renewable Energy Laboratory: www.nrel.gov.

U.S. DOE, Office of Energy Efficiency and Renewable Energy: www.eere.energy.gov.

U.S Climate Change Technology Program: www.climatechangetechnology.gov.

International Energy Agency: www.iea.org.

NUCLEAR ENERGY: KATHRYN MCCARTHY (INEEL)

Role of and Need for Nuclear Energy

It is estimated in the EIA's "2003 Annual Energy Outlook" that U.S. energy consumption will grow by about 1.5% per year to 2025. Much of the projected growth is in natural gas and coal, and imports will increase from 27% of energy to 35%. In the transportation area imports could rise from 66% to 79%. In this situation, nuclear energy could be an important contributor, provided nuclear wastes can be handled satisfactorily. In addition, if hydrogen becomes an important transportation fuel, production of hydrogen from nuclear plants could play a useful role.

It is important to note that nuclear energy is 8% of today's energy production in the U.S. and it provides 19% of the electricity. Emission-free generating sources supply almost 30% of U.S. electricity and nuclear is the major part of this supply. During the past 20 years there has been a substantial improvement in the performance of nuclear plants, and a growing public acceptance of this "Zero-emissions" source of energy—plant availability has increased steadily, electricity production has increased, production costs have decreased, and unplanned automatic scrams have decreased. Nevertheless, there are no new plants under construction or on order in the U.S.

Worldwide, 31 countries are operating 438 nuclear plants, with a total installed capacity of 353 GWe. In 12 countries, 30 new nuclear power plants are under construction. The EIA predicts that nuclear energy consumption will continue to increase up to 2020 in all areas of the world.

There are a number of challenges to the long-term viability of nuclear energy:

- *Economics:* It is important to reduce costs—particularly capital costs—and reduce the financial risk, particularly owing to licensing/construction times.
- *Safety and Reliability:* Continued improvement is important in operations safety, protection from core damage—reduced likelihood and severity—and in eliminating the potential for offsite release of radioactivity.
- *Sustainability:* through efficient fuel utilization, waste minimization and management, and achieving non-proliferation.

Major DOE Programs

The "National Energy Policy" (May 2000) endorses nuclear energy as a major component of future U.S. energy supplies and considers the following factors:

- *Existing nuclear plants:* Update and relicensing of nuclear plants. Geologic depository for nuclear waste. Price–Anderson Act renewal. Nuclear energy's role in improved air quality.
- *New Nuclear Plants:* Advanced fuel cycle/pyroprocessing. Next-generation advanced reactors. Expedition of NRC licensing of advanced reactors.

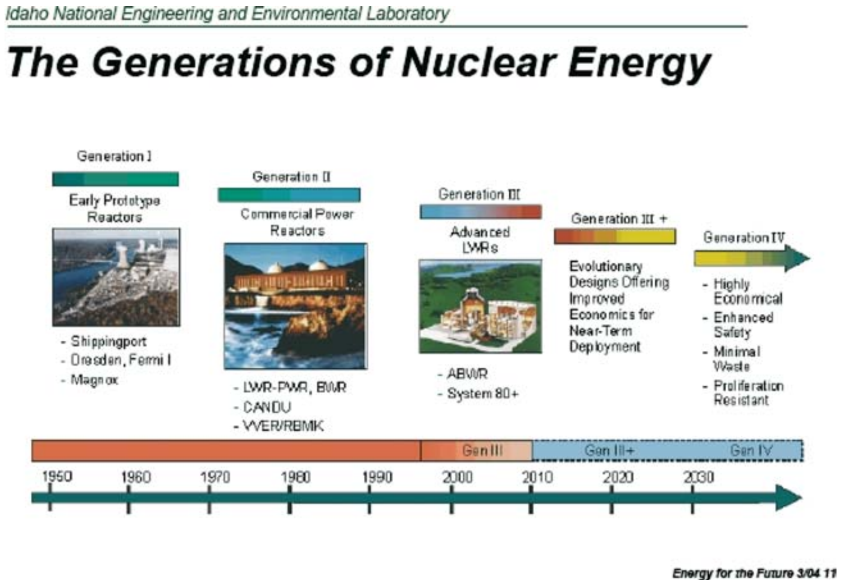


Fig. 32.

- *Reprocessing:* International collaboration. Cleaner, more efficient, less waste, more proliferation resistant systems.

US-DOE “Nuclear Power 2010” and “Generation IV" programs are addressing near-term regulatory and long-term viability issues.

NP-2010Program is designed to eliminate regulatory uncertainties and demonstrate the 10CFR52 process (early site permitting and a combined operating license). It also plans to complete the design and engineering and construct one gas-cooled reactor by 2010.

[A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010, Volume 1, Summary Report, October 31, 2001].

Generation IV Nuclear Energy Systems Program involves a “Generation IV International Forum” with concept screening and a technology roadmap for a broad spectrum of advanced system concepts.

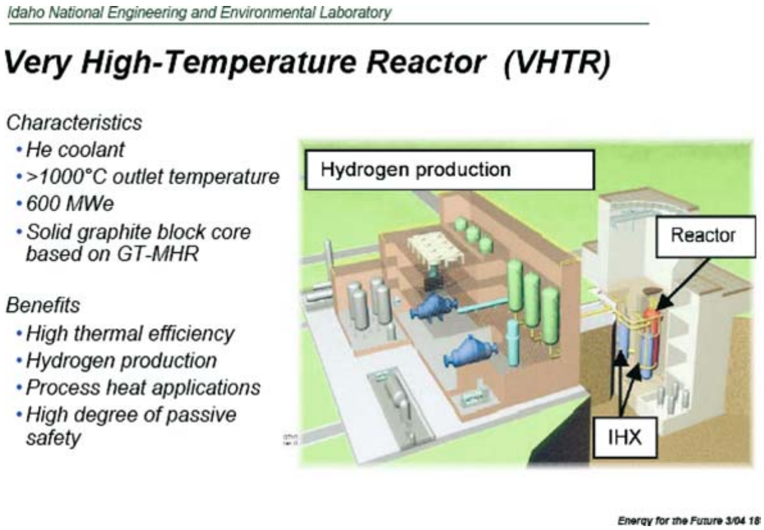
The successive generations of nuclear power plants are shown in Figure 32.

Generation IV Nuclear Systems

The report “A Technology Roadmap for Generation IV Nuclear Energy Systems", December 2002, [http://gif.inel.gov/roadmap] identifies systems that are deployable by 2030 or earlier and summarizes the R&D activities and priorities, laying the foundation for their program plans. The six most promising concepts were selected from over 100 submissions. They promise advances towards:

- Sustainability through closed-cycle fast-spectrum systems with reduced waste heat and radiotoxicity, optimal use of repository capacity, and resource extension via regeneration of fissile material.
- Economics through water- and gas-cooled concepts having higher thermal efficiency, simplified balance of plant and both large and small plant size.
- Hydrogen production and high-temperature applications using very high temperature gas- and lead alloy-cooled reactors.
- Safety and reliability with many concepts making good advances.
- Improved proliferation resistance and physical protection.

Generation IV International Forum (GIF) involves Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, Switzerland, United Kingdom, and the U.S.A. It also involves observers from the IAEA, OECD/Nuclear Energy Agency, European Commission, and the U.S. Nuclear Regulatory Commission and the Department of State. It identifies areas of multilateral collaborations and establishes guidelines for collaborations.



Idaho National Engineering and Environmental Laboratory

Very High-Temperature Reactor (VHTR)

Characteristics
- He coolant
- >1000°C outlet temperature
- 600 MWe
- Solid graphite block core based on GT-MHR

Benefits
- High thermal efficiency
- Hydrogen production
- Process heat applications
- High degree of passive safety

Energy for the Future 3/04 18

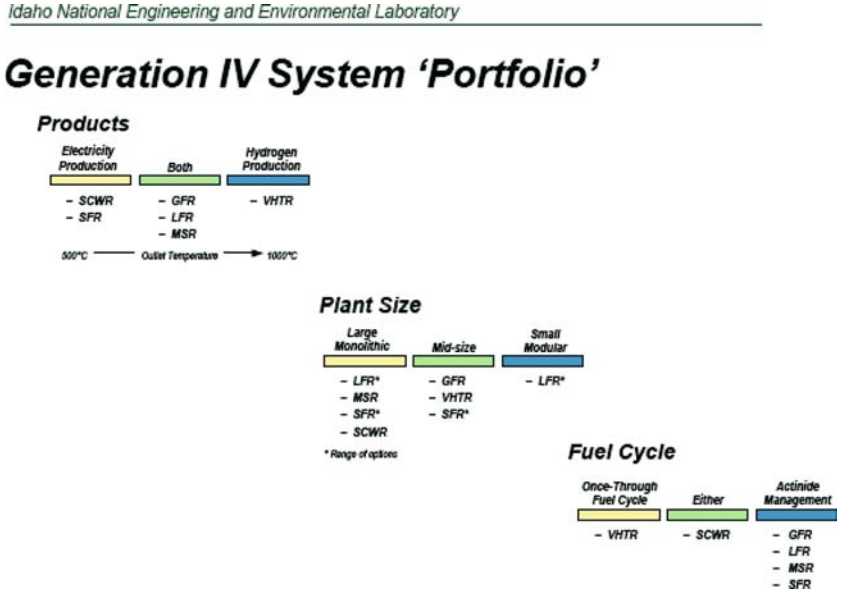
Fig. 33.

The 6 Generation IV Systems

- *Very-High-Temperature Reactor System* uses a helium coolant at > 1000 °C outlet temperature, has a solid graphite block core based on the GT-MHR and generates 600 MWe. The benefits are high thermal efficiency, capability for hydrogen production and process heat applications and it has a high degree of passive safety. Figure 33.
- Lead-Cooled Fast Reactor System (Sustainability and safety).
- Gas-Cooled Fast Reactor System (sustainability and economics).
- Supercritical-Water-Cooled Reactor System (economics).
- Molten Salt Reactor System (Sustainability).
- Sodium-Cooled Fast Reactor System (sustainability).

The roles of this portfolio of options are illustrated in Figure 34.

Each system has R&D challenges and none are certain of success.



Idaho National Engineering and Environmental Laboratory

Generation IV System 'Portfolio'

Products

Electricity Production	Both	Hydrogen Production
– SCWR – SFR	– GFR – LFR – MSR	– VHTR

500°C —— Outlet Temperature ——→ 1000°C

Plant Size

Large Monolithic	Mid-size	Small Modular
– LFR* – MSR – SFR* – SCWR	– GFR – VHTR – SFR*	– LFR*

* Range of options

Fuel Cycle

Once-Through Fuel Cycle	Either	Actinide Management
– VHTR	– SCWR	– GFR – LFR – MSR – SFR

Fig. 34.

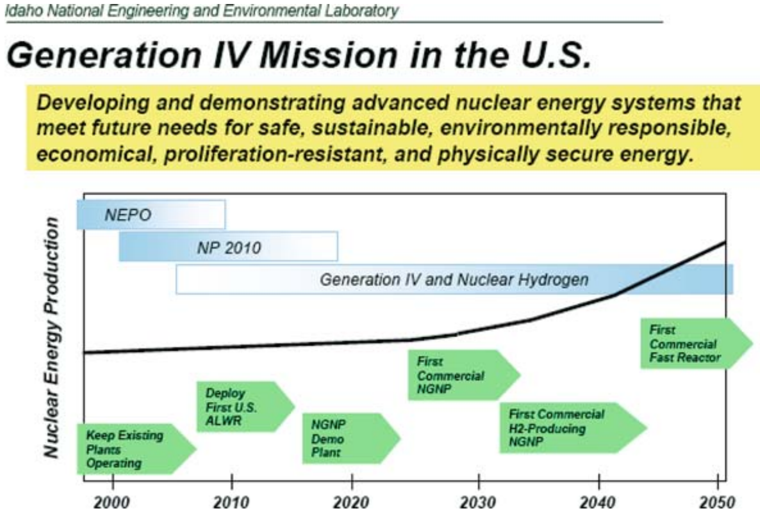


Fig. 35.

NGNP Mission Objectives

- Demonstrate a full-scale prototype NGNP by about 2015–2017.
- Demonstrate nuclear-assisted production of hydrogen with about 105% of the heat.
- Demonstrate by test the exceptional safety capabilities of the advanced gas cooled reactors.
- Obtain an NRC license to construct and operate the NGNP, to provide a basis for future performance-based, risk-informed licensing.
- Support the development, testing, and prototyping of hydrogen infrastructures.

Generation IV Mission in the U.S.

This is illustrated in Figure 35.

Advanced Fuel Cycle Initiative (AFCI)

The goal is to implement fuel cycle technology that:

- Enables recovery of the nuclear energy value from commercial spent nuclear fuel.
- Reduces the inventories of civilian plutonium in the U.S.
- Reduces the toxicity of high-level nuclear waste bound for geologic disposal.

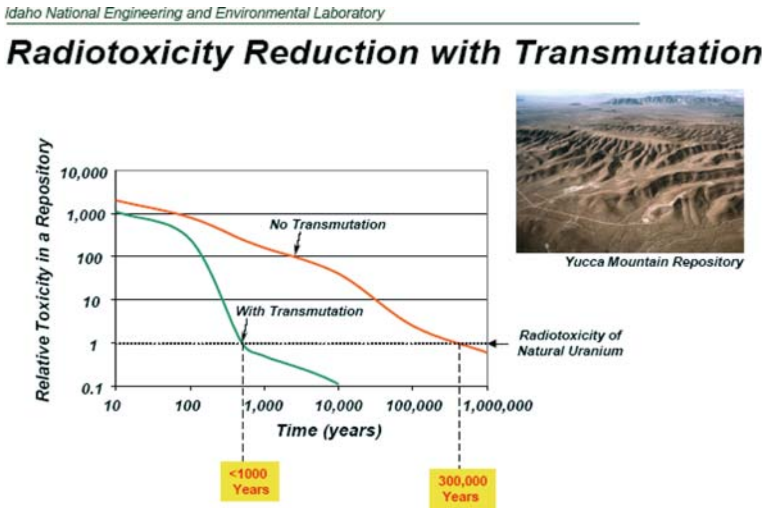


Fig. 36.

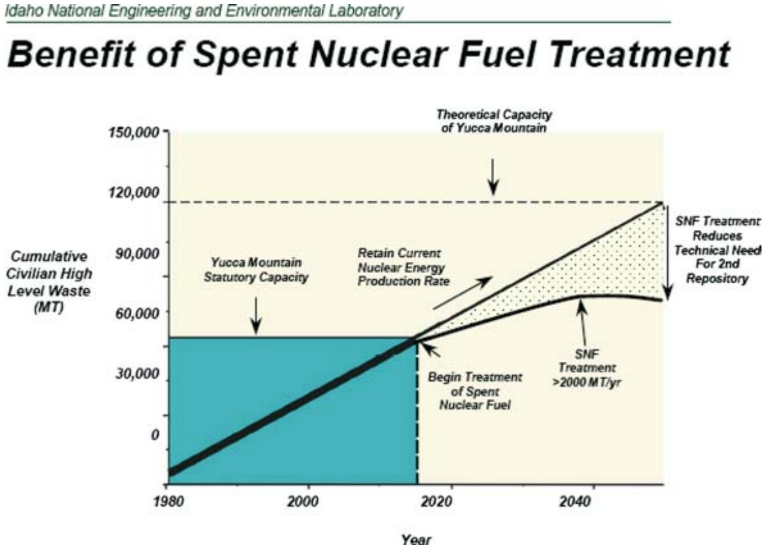


Fig. 37.

- Enables the more effective use of the currently proposed geologic repository and reduces the cost of geologic disposal.

The potential for the reduction of radiotoxicity with transmutation is illustrated in Figure 35. The more effective use of repository space is illustrated in Figure 36.

The possibility for expansion of the nuclear energy supply in the U.S. following success in the DOE programs is shown in Figure 37.

The development of the spectrum of reactor options is important for effective utilization of uranium resources. If only once-through LWRs were used, assuming a moderate increase in world nuclear capacity, the uranium resources would be depleted some time between 2030 and 2050.

Summary

The economics, operating performance and safety of U.S. nuclear power plants are excellent.

Nuclear power is a substantial contributor to reducing CO_2 emissions.

Nuclear power can grow in the future if it can respond to the following challenges:

- remain economically competitive,
- retain public confidence in safety, and
- manage nuclear wastes and spent fuel.

Nuclear power's impact on U.S. energy security and CO_2 emissions reduction can increase substantially with increased electricity production and new missions (hydrogen production for transportation fuel).

The DOE's Generation IV program and Advanced Fuel Cycle Initiative are addressing next generation nuclear energy systems for hydrogen, waste management, and electricity.

NUCLEAR INDUSTRY PERSPECTIVE: DAVID CHRISTIAN (DOMINION RESOURCES INC)

Dominion's Energy Portfolio and Market Area

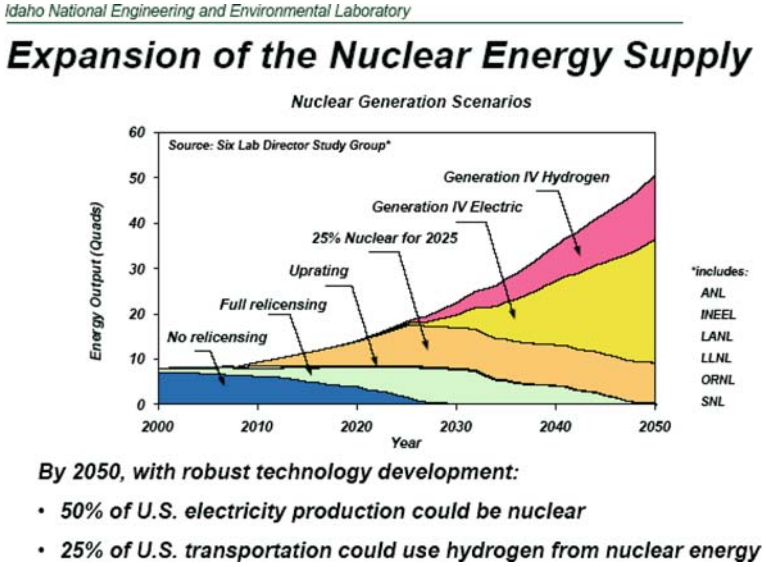
Dominion's energy portfolio includes about 24 GWe of generating capacity, gas reserves of 6.1 Tcfe, gas storage of 960 Bcf, a LNG facility, 6000 miles of electricity transmission lines (bulk delivery), and 7900 miles of gas pipelines.

The gas franchise covers 3 states and 1.7 million customers. The electricity franchise covers 2 states and 2.2 million customers. In addition, there are 1.1 million unregulated retail customers in 8 states.

Energy plays a crucial role in the stability, and security of every country as illustrated in the diagram:

Social Security (Stability)
  → **Economic Security**
    → **Energy Security**
      → **Diversity of Supply, including Nuclear.**

In the U.S. in 2001 net primary energy consumption was 97 quadrillion BTUs (quads). Of this



Idaho National Engineering and Environmental Laboratory

Expansion of the Nuclear Energy Supply

Nuclear Generation Scenarios

Source: Six Lab Director Study Group*

*includes:
ANL
INEEL
LANL
LLNL
ORNL
SNL

By 2050, with robust technology development:

- 50% of U.S. electricity production could be nuclear
- 25% of U.S. transportation could use hydrogen from nuclear energy

Fig. 38.

amount it is estimated that 55.9 quads was lost energy, highlighting the opportunities to improve efficiency. In the electricity sector, 37.5 quads of primary energy was converted to 11.6 quads of electricity.

In the natural gas area, there is a concern that the rapid growth of demand may be constrained by the ability to increase the supply leading to a unit price increase. This is of concern to utilities who were encouraged earlier to increase their generating capacity from gas.

There is also concern about the future of the nuclear generation capacity. Absent relicensing of existing plants, the present 100 GWe of capacity would decrease rapidly starting in 2010, see Figure 39. An extension of 20 years would give time to bring on line new plants. Since 1990, with no new plants, nuclear plant output has increased from 577 to 780 BkW h in 2002. This represents the equivalent of 25 1-GWe plants and 30% of the growth in U.S. electricity demand.

If natural gas were used to replace nuclear energy it would require an additional supply of 5460 Bcf/year, comparable to that consumed in present electricity generation and about a quarter of current gas usage.

If coal were used to replace nuclear energy, it would require an additional supply of 288 MT/year, which is about a quarter of current coal use. It would add about 196 Mt carbon equivalent per year of CO_2, increasing emissions by about 12%. This latter point illustrates how the use of nuclear energy helps hold down greenhouse gas emissions—see the presentation by Kulcinski for more detail

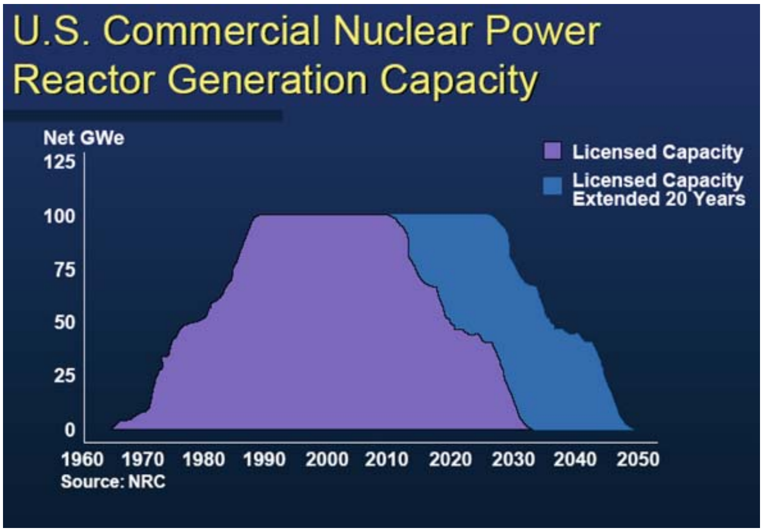
There are valuable opportunities to increase the contributions of nuclear energy to minimizing emissions in the U.S through enhancing existing nuclear capability and through construction of new plants with many attractive features—see presentation by McCarthy, section “Nuclear Energy.” These improvements will be enabled by the new NRC licensing process—part 52—which involved design certification, early site permitting and a combined license, see Figure 40. The advantages of the new process are that:

- Licensing decisions will be made BEFORE large capital investments are made:

– safety and environmental issues will be resolved before construction starts,
– NCSS and BOP design will be well developed before COL application is submitted, and
– plants will be almost fully designed before construction starts.

The result will be a high confidence in construction schedule and control.

Design certification addresses design issues early in the process. Plants are designed to be constructed in less than 48 months., and each manufacturer’s plants will be a standard certified design. To date, 3


U.S. Commercial Nuclear Power Reactor Generation Capacity

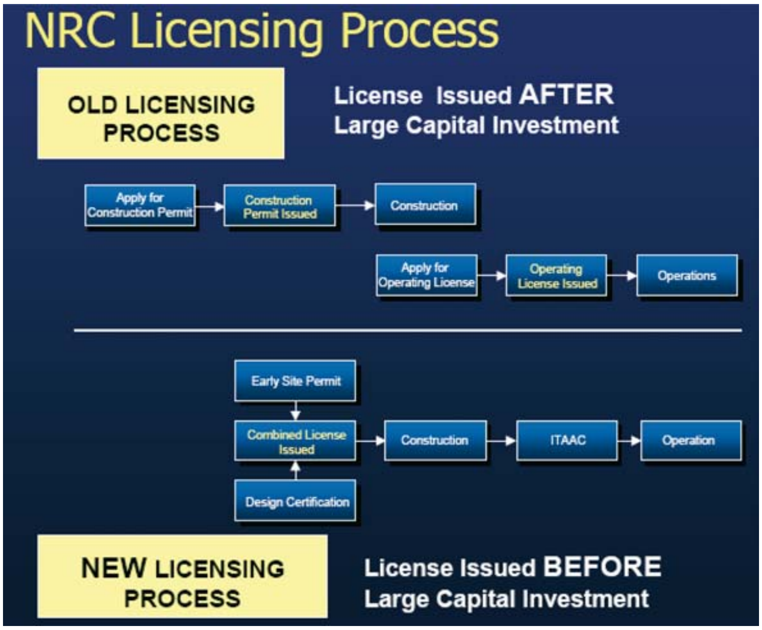
Source: NRC

Fig. 39.

design certificates have been issues, and 1 active application is in review.

Early Site Permit (ESP) Obtaining and ESP allows a company like Dominion to "bank" a site for 20 years, with an option to renew. If and when market conditions warrant, nuclear may then be considered among a variety of generation options. Dominion's ESP was submitted on 9/25/2003, however, Dominion has no plans to build another nuclear plant at this time. Exelon submitted on 9/25/2003 and Entergy on 10.21.2003.

Combined License combines the ESP and the design certificate into a site and technology specific document. When approved, it provides authorization to build and operate. It resolves operational and construction issues before construction begins. The process has yet to be tested.


NRC Licensing Process

OLD LICENSING PROCESS

License Issued AFTER Large Capital Investment

Apply for Construction Permit → Construction Permit Issued → Construction

Apply for Operating License → Operating License Issued → Operations

Early Site Permit ↓ Combined License Issued ↑ Design Certification

Combined License Issued → Construction → ITAAC → Operation

NEW LICENSING PROCESS

License Issued BEFORE Large Capital Investment

Fig. 40.

Despite these system improvements, barriers remain to the decision to build:

- Licensing uncertainties with untested processes.
- High initial unit costs.
- Financing risks.
- Earnings dilution during construction.
- High-level waste disposal.
- Price–Anderson renewal.

However, as Peter Drucker said, "the best way to predict the future is to create it."

PATHS TO FUSION POWER: STEPHEN DEAN (FPA)

Introduction

Fusion is the process that generates light and heat in the sun and other stars. It is most easily achieved on earth by combining the heavy isotopes of hydrogen—deuterium and tritium. This reaction has the lowest temperature for fusion of 50–100 million degrees (about 5–10 keV. The product of a deuteron-triton fusion reaction is a helium nucleus and a neutron. They weigh less than the fusing hydrogen and the mass lost is converted to energy according to Einstein's formula.

Deuterium is present as about 1 part in 6000 in water and hence is essentially inexhaustible Tritium may be produced by bombardment with the fusion neutrons of a blanket of lithium surrounding the fusing fuel. Lithium is an abundant element, both in land sources and in sea water. Fuel costs are not expected to be a significant element in the projected cost of fusion electricity. This fusion reaction itself does not result in a radioactive waste product; however, neutrons will induce radioactivity in the structure surrounding the fusing material. With careful choice of the surrounding materials, it is believed that the radioactivity can have a relatively short half life (decades) and a relatively low biological hazard potential.

In a fusion system, the deuterium–tritium mixture is heated to a high temperature and must be confined long enough to fuse and burn to release net energy. The hot mixture, in which the electrons are separated from the ions is known as a "plasma." The criteria for a burning plasma are:

- Ion temperature >5 keV (50,000,000 degrees).
- Density × confinement of energy $> 5 \times 10^{13}$ cm^{-3} s.

At low density, 0.00001 of atmospheric, about 1 s confinement time is needed.

At high density, ten thousand times atmospheric, the confinement time must be about 1 billionth of a second.

Once the plasma is burning the energetic helium nucleus created by the fusion can sustain the temperature.

Technical Approaches

The good news is that there are many promising technical approaches to achieve useful fusion energy. The bad news is that we do not have the funding to pursue them all vigorously. The two main approaches are:

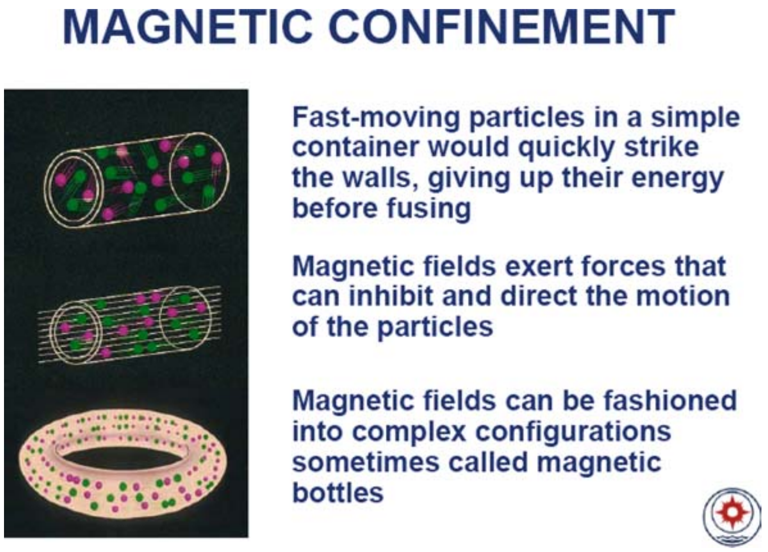
- Magnetic confinement at low density,
- Inertial confinement at high density, and
- Each approach has many variations.

Magnetic Confinement

The fast moving plasma particles in a simple container would quickly strike the walls, giving up their energy before fusing. Magnetic fields exert forces that can direct the motion of particles and magnetic fields can be fashioned in complex configurations—sometimes called magnetic bottles—to inhibit the transport of plasma to the material walls of the container, see Figure 41.

There are many magnetic configurations going by many names. The most successful have been toroidal arrangements of the magnetic field. The greatest performance has been achieved in the tokamak configuration, which uses a toroidal array of coils containing a plasma with a large current flowing in it. The combination of fields from the coils and from the plasma current creates a most effective bottle. Progress in reaching burning plasma conditions is illustrated in Figure 42.

The International Thermonuclear Experimental Reactor (ITER) a tokamak engineering test reactor, is aimed at achieving burning plasma conditions near or at ignition in the latter half of the next decade. It is a joint venture of the European Union, Japan, Russia, United States, China, and Korea. Selection



MAGNETIC CONFINEMENT

Fast-moving particles in a simple container would quickly strike the walls, giving up their energy before fusing

Magnetic fields exert forces that can inhibit and direct the motion of the particles

Magnetic fields can be fashioned into complex configurations sometimes called magnetic bottles

Fig. 41.

of a site, to be in either France or Japan, is underway. It is hoped to initiate construction in 2006 and begin operation ion 2014.

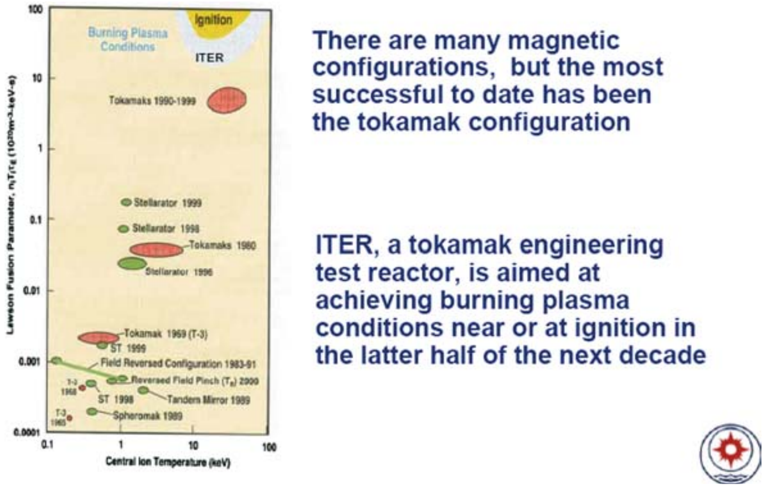
The design parameters of ITER are:

- Fusion Power: 500–700 MW (thermal).
- Burn time: 300 s (upgradeable to steady state).
- Plasma volume: 837 m^3.
- Machine major radius: 6.2 m.
- Plasma radius: 2 m.
- Magnetic field: 5.3 T.

A cutaway drawing is in Figure 43.

The primary efforts in this area are in Europe, Japan, and the United States. Major U.S. sites are at the Princeton Plasma Physics Laboratory, General Atomics, MIT and the Oak Ridge National Laboratory.

The JET tokamak in England and the TFTR at Princeton produced around 10 MW of fusion power for a few seconds during the 1990s. The JT-60 in Japan, which does not use tritium produced equivalent conditions in deuterium. The DIII-D, at General Atomics, and the Alcator C-Mod, at MIT, are currently the largest tokamaks operating in the U.S. TFTR and DIII-D are shown in Figure 44.



There are many magnetic configurations, but the most successful to date has been the tokamak configuration

ITER, a tokamak engineering test reactor, is aimed at achieving burning plasma conditions near or at ignition in the latter half of the next decade

Fig. 42.

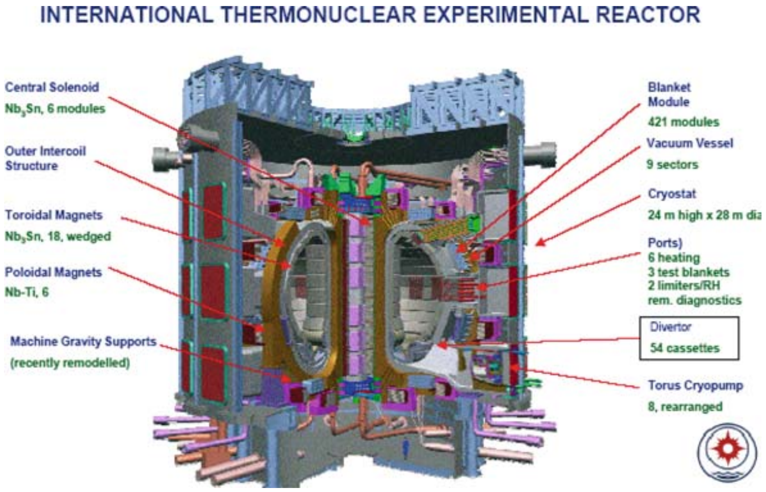


Fig. 43. ITER

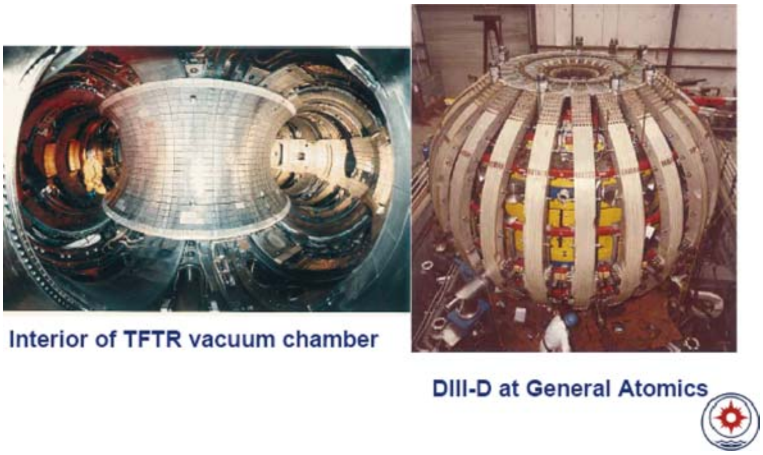


Fig. 44. Magnetic fusion facilities.

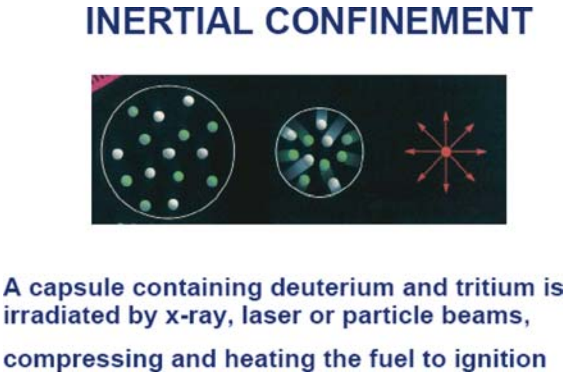


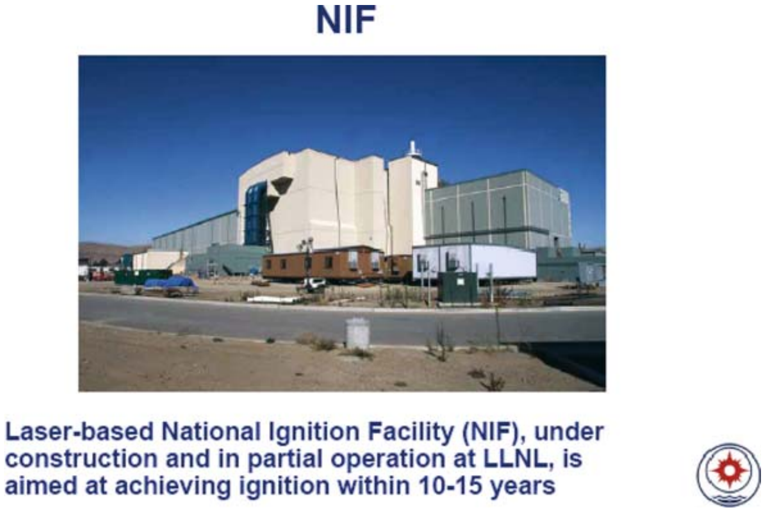
Fig. 45.

Inertial Confinement

In this area, a small capsule, containing deuterium and tritium, is irradiated by X-rays, or laser radiation, or particle beams. The rocket action of the material ablating from the capsule shell compresses and heats the fuel to ignition, see Figure 45. The capsules may be "driven" by various energy sources and four drivers are currently under development:

- Krypton Fluoride Lasers.
- Diode-pumped solid-state lasers.
- Heavy-ion accelerators.
- Z-pinch X-rays.

The laser-based National Ignition Facility (NIF), under construction and in partial operation



NIF

Laser-based National Ignition Facility (NIF), under construction and in partial operation at LLNL, is aimed at achieving ignition within 10-15 years

Fig. 46. National Ignition Facility.

at the Lawrence Livermore National Laboratory (LLNL), is aimed at achieving ignition within 10–15 years, see Figure 46.

''Fast ignition'' is an option that may allow the driver energy to be reduced by separately compressing then rapidly heating the target locally. Using a petaWatt driver.

The primary efforts in this area are in the U.S., France and Japan.. The major U.S. sites are at the Lawrence Berkeley National Laboratory (heavy ions), LLNL (solid-state lasers), Naval Research Laboratory (KrF lasers), Sandia National Laboratories (Z-pinch X-rays), University of Rochester (capsule irradiation), and General Atomics (capsule fabrication). Example drivers are shown in Figure 47.

Progress

Progress has been systematic in both magnetic and inertial fusion in experiment, technology and theory. However, the pace of progress has been slowed by inadequate funding for timely commitments to the construction of new facilities, some important technology areas, and radiation resistant materials. Advances in computers and scientific computation are allowing more rapid progress in the understanding of plasmas and system components and the ability to make projections. An example of computation in IFE is in Figure 48.

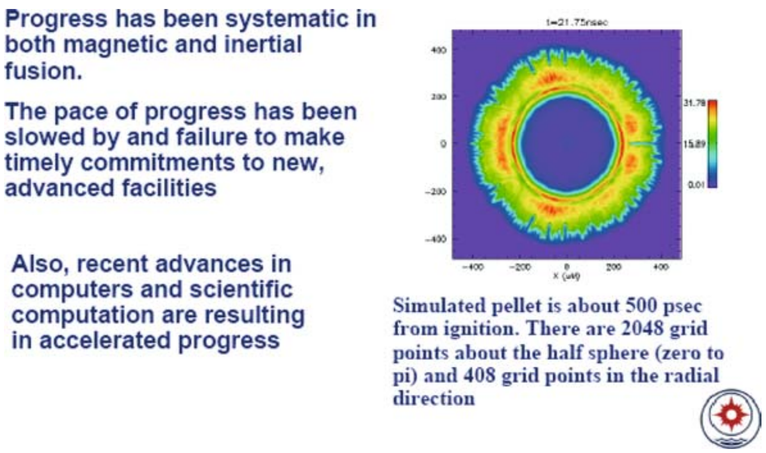
Issues

For magnetic fusion, the primary issue is optimizing the configuration for effective confinement of the fuel. For inertial fusion, the primary issue is optimizing the techniques for compressing the fuel in a stable manner. For both approaches, an important additional issue is identifying materials that provide long life and low induced radioactivity in the harsh neutron-rich environment.

Heavy-ion 4-beam accelerator at LBNL

Electra KrF laser at NRL

Fig. 47. Inertial fusion facilities.



Progress has been systematic in both magnetic and inertial fusion.

The pace of progress has been slowed by and failure to make timely commitments to new, advanced facilities

Also, recent advances in computers and scientific computation are resulting in accelerated progress

Simulated pellet is about 500 psec from ignition. There are 2048 grid points about the half sphere (zero to pi) and 408 grid points in the radial direction

Fig. 48. Good progress has been made.

Overall a major issue is optimizing the total capital cost of a system with high availability.

Projections

A number of projections of the time to power plant operation have been made, though there is no official government timetable for fusion There are large uncertainties in these projections due to technical unknowns and to a lack of firm funding commitments. The projections range from 15 to 50 years, with a mean around 30–35 years. Example projections, assuming the required funding are shown in Figures 49 and 50.

HOW DO NUCLEAR POWER PLANTS EMIT GREENHOUSE GASES? P.L. DENHOLM AND G. KULCINSKI (U. WISCONSIN)

There have been numerous inaccurate statements that have been published about how nuclear power and renewable energies are carbon-free. In reality, in the present energy system, fossil fuels will have been used in building the plant—electricity coming typically 56% from coal plants, transportation using oil products, etc. even if there are no such emissions from producing electricity e.g., as for wind power. The study discussed in this presentation considers all stages of the "fuel cycle" in construction of the power plant as shown in Figure 51.

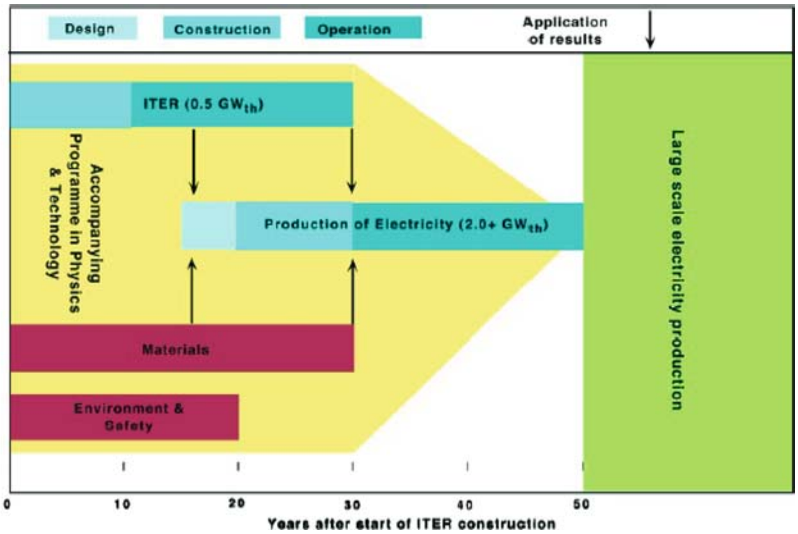


Fig. 49. ITER project office magnetic fusion roadmap, December 2003.

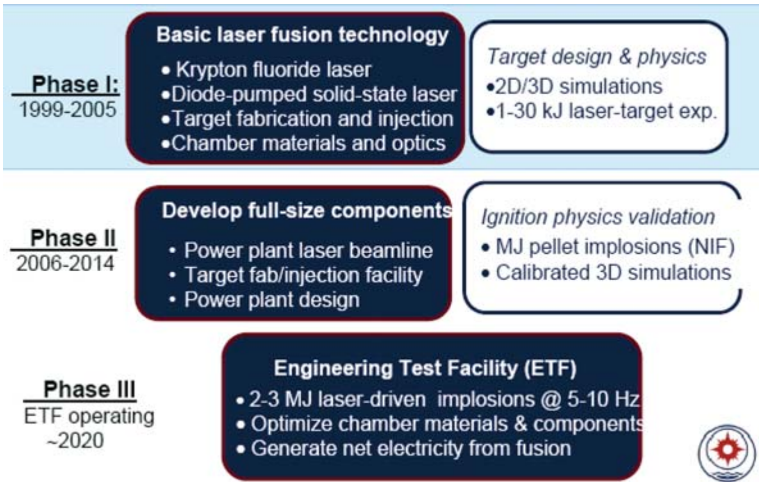


Fig. 50. The path to develop laser fusion energy UNNRL-2003.

The energy input to six power plants was analyzed:

- *Coal*—El-Bassioni, NUREG/CR-1539, 1980.
- *Natural Gas*—2 × 1 combined cycle, Cass County, MO.
- *Fission*—Brian, ORNL TM-4515, 1974.
- *Fusion*—2 tokamaks (Aries -RS and UWMAK-1).
- *Wind*—Buffalo Ridge Wind Farm, Southwestern MN.
- *Photovoltaic*—Big Horn Center, Silverthorne, CO; a roof unit.

An example of a process chain analysis for material components of a gas plant is given in Table 5. It uses information on the typical amount of energy used to produce a tonne of each material, coupled with the amount of material used in the plant. An alternative approach, uses an analysis for major components based on information on energy investment per dollar of cost.

The CO_2 emissions are calculated from both electrical and thermal inputs as shown in Figure 52.

Relative to the CO_2 emissions of coal and natural gas, those from nuclear and renewable energies are low but not zero, see Figure 53. Note that, given

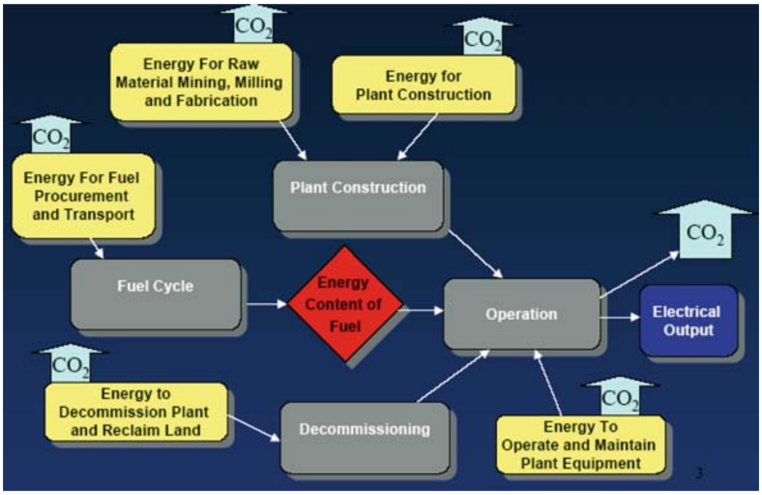
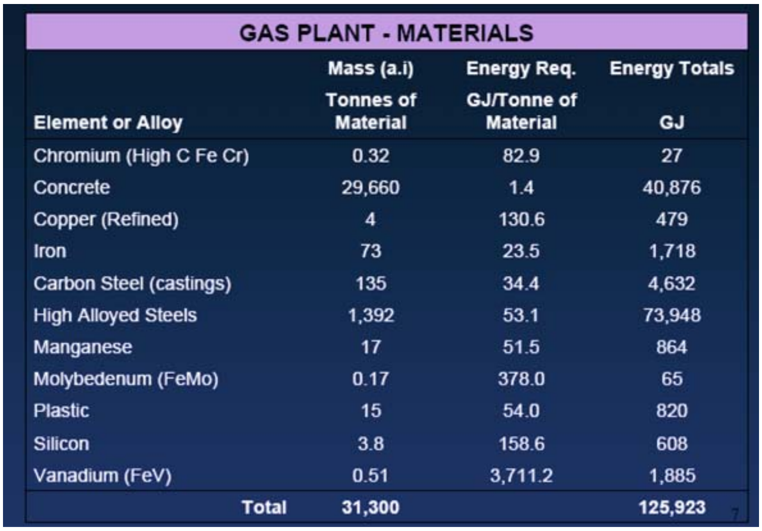


Fig. 51. Life-cycle analysis considers all stages of the "Fuel cycle".

Table 5. Example of process chain analysis.



GAS PLANT - MATERIALS

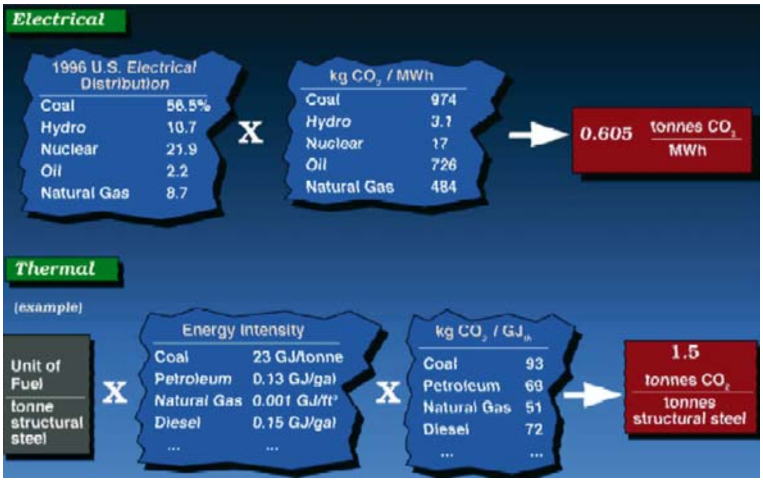
Element or Alloy	Mass (a.i) Tonnes of Material	Energy Req. GJ/Tonne of Material	Energy Totals GJ
Chromium (High C Fe Cr)	0.32	82.9	27
Concrete	29,660	1.4	40,876
Copper (Refined)	4	130.6	479
Iron	73	23.5	1,718
Carbon Steel (castings)	135	34.4	4,632
High Alloyed Steels	1,392	53.1	73,948
Manganese	17	51.5	864
Molybedenum (FeMo)	0.17	378.0	65
Plastic	15	54.0	820
Silicon	3.8	158.6	608
Vanadium (FeV)	0.51	3,711.2	1,885
Total	31,300		125,923

uncertainties in the calculations, no weight should be given to small differences in the numbers!

In the case of intermittent energies it may be necessary to use energy storage. [It was pointed out that in a strong grid system typically 20% of the electricity can be from intermittents, particularly when it is known when they will be producing].

In this study the following storage technologies were analyzed:

- *Pumped storage*, which is >99% of utility storage world-wide with about 100 GWe. The U.S. capacity is 18GWe from 36 facilities with sizes ranging from about 200 MWe to 2100 MWe.
- *Compressed Air Energy Storage (CAES)*, which is usually a hybrid storage/generation technology and consumes natural gas. There are 2 facilities world-wide with 400 MWe total capacity. There are plans for 3 facilities in the U.S. including a 2700 MWe plant in Ohio (the model for this study). The system requires a large storage cavern in hard rock or a salt dome.
- *Battery Energy Storage Systems (BESS)*—lead acid, flow batteries, vanadium, Regenesys. Partially through the USABC program a number of new technologies, with longer life and greater efficiency, have become competitive.



1996 U.S. Electrical Distribution	
Coal	56.5%
Hydro	10.7
Nuclear	21.9
Oil	2.2
Natural Gas	8.7

kg CO_2 / MWh	
Coal	974
Hydro	3.1
Nuclear	17
Oil	726
Natural Gas	484

0.605 tonnes CO_2 / MWh

Energy Intensity	
Coal	23 GJ/tonne
Petroleum	0.13 GJ/gal
Natural Gas	0.001 GJ/ft³
Diesel	0.15 GJ/gal
...	...

kg CO_2 / GJ_{th}	
Coal	93
Petroleum	69
Natural Gas	51
Diesel	72
...	...

1.5 tonnes CO_2 / tonnes structural steel

Fig. 52.

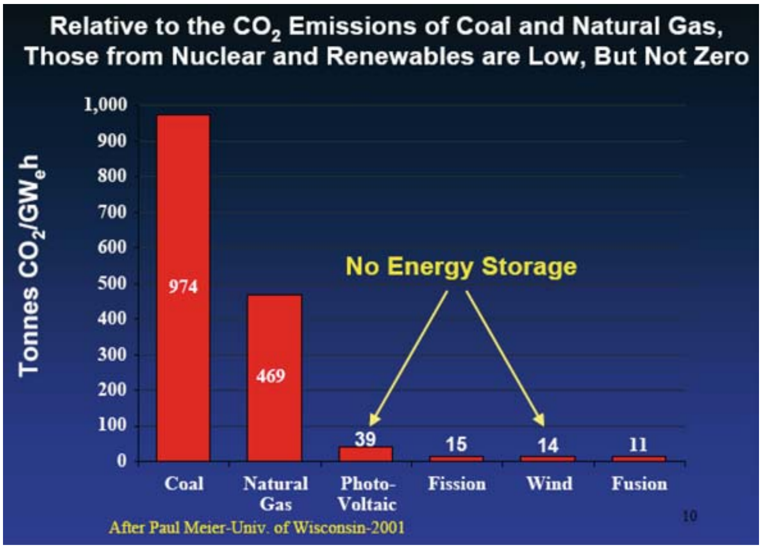


Fig. 53. CO_2 are calculated from both electrical and thermal inputs.

Likely renewable energy + storage scenarios which were analyzed are:

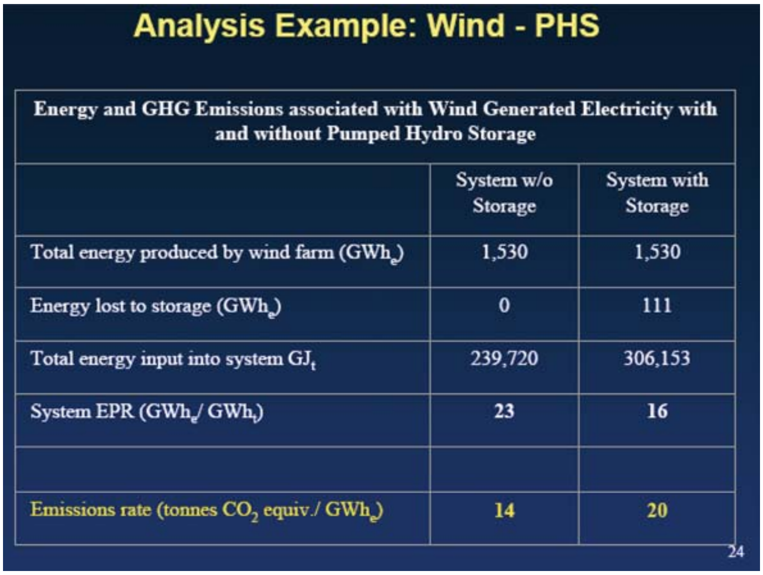
- Wind + PHS, shown in Table 6.
- Wind + CAES.
- Solar PV + Battery.

In the example shown, the emissions rate increased from 14 to 20 tonnes of CO_2 equivalent/GW he. For the case where a CAES system was used the increase was to 109 tonnes of CO_2 equivalent/GW he, because of the use of gas. For the case of batteries there are significant construction related energy requirements and emissions, and in the PV + batteries case the emission rate rises from 39 to more than 136–152 tonnes of CO_2 equivalent/GW he.

In the discussions it was pointed out that with CO_2 sequestration the emissions rate from coal and gas would be very much reduced e.g., with 97% sequestration to 88 and 47 tonnes of CO_2 equivalent/GW he respectively.

An interesting approach to displaying what it would take to achieve policy goals such as those of Kyoto, is to use a "triangle plot," see Figure 54.

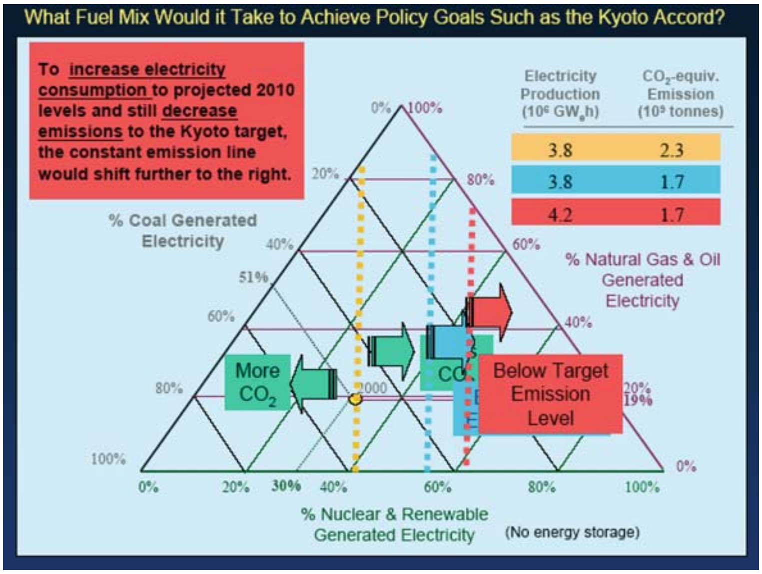
Table 6.



Analysis Example: Wind - PHS

Energy and GHG Emissions associated with Wind Generated Electricity with and without Pumped Hydro Storage		
	System w/o Storage	System with Storage
Total energy produced by wind farm (GWh_e)	1,530	1,530
Energy lost to storage (GWh_e)	0	111
Total energy input into system GJ_t	239,720	306,153
System EPR (GWh_e/GWh_t)	23	16
Emissions rate (tonnes CO_2 equiv./ GWh_e)	14	20

24



What Fuel Mix Would it Take to Achieve Policy Goals Such as the Kyoto Accord?

To increase electricity consumption to projected 2010 levels and still decrease emissions to the Kyoto target, the constant emission line would shift further to the right.

Electricity Production (10^6 GW_eh)	CO_2-equiv. Emission (10^9 tonnes)
3.8	2.3
3.8	1.7
4.2	1.7

Fig. 54.

[Note that if sequestration were used then the curves would shift allowing the goals to be met with a lower percentage of nuclear and renewables].

GENERAL DISCUSSION

Cost of Electricity: Numerous studies have been made of potential fusion power plants. In these studies, it is the normal practice to calculate a cost of electricity (COE). The main purpose of these calculations is to help in understanding the relative importance of achieving a certain performance in the various components of the power plant. In addition, it is important to understand what would be necessary in order to achieve a COE that is in the ballpark of other sources of electricity. This aspect leads to the question of "what is the ballpark?"

In the discussion of this topic, a number of points were made:

- COE is not the only factor that determines choice of a new power plant. Environmental considerations, including waste disposal, public perception, balance between capital cost and operating cost, reliability and variability of cost of fuel supply, regulation, and politics also play important roles. This is seen very clearly for the case of fission plants.
- In the U.S., the COE varies widely from region to region. The COE can vary owing to changes in demand and its production costs can depend strongly on fuel costs—as seen, recently in the cases of both coal and gas.

In summary, it will be necessary for fusion energy to be competitive but the other factors may be as important in determining its deployment when it is developed. Competitive does not mean that if another source has a COE of around 5 c/kW.h., fusion would have to come in at most 4.9 c/kW.h

Waste disposal: One advantage cited for fusion is its relative safety and environmental advantages over fission energy. A discussion was held on what this meant. It was noted that, while the fuel rods require special storage and disposal—ultimately a depository such as Yucca Mountain, the other material activated in a fission reactor can be disposed of much more readily. Further, in activated structural materials the radioactivity is bound up in the material and could not be dispersed easily. Fusion power plants do not contain the uranium, plutonium, actinides and other products of fission. By careful choice of materials the radioactivity can have a lifetime much shorter than fission products and most of it will be bound up in solid structures. In fact, it is conceivable that these waste materials could be disposed of by shallow burial and possibly be retained on site until they had decayed to an acceptable level to be reused. This is important because the bottom line for a utility will be that there must be a clear route to handling the wastes.

Distributed generation: There are some who believe that distributed generation i.e., not grid connected, will become a larger part of electricity supply in the future. Reasons for this trend include:

- The need for high quality, guaranteed power for sensitive equipment.
- Making it more difficult for terrorists to disrupt supply.
- Taking advantage of combined heat and power-co-generation.
- Such a trend would probably favor smaller unit size power plants and be less favorable to fusion systems. In the discussion a number of points were made:
- There are numerous, successful co-generation systems that are grid connected.
- Distributed does not have to mean small. Sizes up to 600 MWe exist. Co-generation can also be large and in Russia some nuclear plants are used to also provide district heating.
- It would be hard to implement a completely distributed system in a big city. Switching to natural gas does not alter that conclusion. Unless the gas were delivered in bottles it would simply change from an electric grid to a gas grid.
- Future improvements to the grid can make it more attractive.

In summary, it was concluded that distributed power may well play a valuable role but probably, on average, only at the 10s% level. There will continue to be a major role for grid-connected large power plants.

Hydrogen: The attractiveness of large fission and fusion plants can be enhanced by using them to co-produce hydrogen. This would also allow them to do some load-following. A possible plus for fusion, for high temperature hydrogen production, could be the ability to allow a part of the neutron capture region to run at higher temperatures than the walls e.g., 1800–2500 °C.

The issue of the safety of hydrogen pipelines was raised. At high enough pressures a small leak can lead to spontaneous combustion of the leaking hydrogen. It was noted that pipelines many 10s of kilometers in length have been operating for decades—presumably at lower pressures.

International collaboration: There is a growing trend towards undertaking the development of the big new power systems with widespread international collaboration—advanced, clean coal plants, Gen-IV fission reactors and, in fusion, the International Thermonuclear Experimental Reactor. A discussion was held on the pros and cons of such an approach. The following comments were made:

- It is politically good even though, in total across the participants, it may cost more.
- It can benefit from the combined technical strengths of the participants. Even the United States does not retain all industrial capabilities and many major industrial companies have a multi-national base.
- In the case of the moon program, the U.S. went it alone, why can't we do it for energy areas? The total cost to the U.S. of developing advanced fossil, fission and fusion plants could be less than a major defense acquisition.
- It makes great sense sharing costs for R&D. As the system nears demonstration and commercialization is it necessary to reduce the collaboration for our industries to gain manufacturing advantages?
- One view is that we are living in a globalized society and having the ability to be competitive in the world market means we will benefit from doing things internationally all along.