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ENERGY TECHNOLOGY PROGRESS FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

Energy security is a fundamental part of a country's national security. Access to affordable, environmentally sustainable energy is a stabilizing force and is in the world community's best interest. The current global energy situation however is not sustainable and has many complicating factors. The primary goal for government energy policy should be to provide stability and predictability to the market. This paper differentiates between short-term and long-term issues and argues that although the options for addressing the short-term issues are limited, there is an opportunity to alter the course of long-term energy stability and predictability through research and technology development. While reliance on foreign oil in the short term can be consistent with short-term energy security goals, there are sufficient long-term issues associated with fossil fuel use, in particular, as to require a long-term role for the federal government in funding research. The longer term issues fall into three categories. First, oil resources are finite and there is increasing world dependence on a limited number of suppliers. Second, the world demographics are changing dramatically and the emerging industrialized nations will have greater supply needs. Third, increasing attention to the environmental impacts of energy production and use will limit supply options. In addition to this global view, some of the changes occurring in the U.S. domestic energy picture have implications that will encourage energy efficiency and new technology development. The paper concludes that technological innovation has provided great benefit in the past and can continue to do so in the future if it is both channeled toward a sustainable energy future and if it is committed to, and invested in, as a deliberate long-term policy option.

INTRODUCTION

Energy security is a vital component of U.S. national security policy. Achieving energy security requires clear differentiation between short- and long-term issues and the definition of appropriate roles for government involvement in each type of issue. For shorter term issues, assuring energy security requires proactive policies that allow the market to work. In the longer term, it requires government investment in basic R&D aimed at diversifying supply options and increasing conversion, delivery, and end-use efficiency to minimize disruptions and price volatility associated with future long-term shortages.

DISCLAIMER

This paper summarizes key issues affecting U.S. energy security, suggests appropriate government responses to both short- and long-term issues, and discusses the role technology can play in making an inevitable transition from non-renewable energy sources such as oil to alternatives. As an example of how energy R&D could lead to an energy secure future, consider the following scenario. Worldwide oil production doubles over the next 20 years due largely to increased demands of industrializing countries such as China and other non-OECD[1] Asia countries. After 20 years, worldwide oil production peaks and prices increase as supplies tighten. Meanwhile, in the utility sector, deregulation initially leads to reduced private sector funding of technology R&D as utilities slash costs to remain competitive. In subsequent years, however, deregulation leads to increased efficiency in the overall system and leads to widespread adoption of distributed power options, small generating and storage units located at strategic points along the transmission and distribution systems. Federal government and private investments in renewable energy technologies, fuel cells, and storage systems result in significant efficiency improvements that lower the overall cost and usefulness of these technologies. Transition technologies, such as fuel cells operating originally on natural gas or other hydrocarbons, achieve widespread acceptance as distributed power options. Likewise, in the transportation sector, concerns about the long-term availability of oil and environmental awareness lead to the widespread adoption of ultra low, or zero emission vehicles standards and the subsequent mass production of hybrid electric vehicles that utilize flywheels, advanced batteries, and fuel cells powered directly with hydrogen from nuclear or renewable energy sources.

This hypothetical scenario paints a future in which active involvement by the federal government in funding technology R&D reduces overall vulnerability to supply disruptions and enhances energy security. It is easy to imagine an alternative scenario as well, a scenario lacking the federal commitment to R&D. In this scenario, deregulation proceeds as above, but without federal funding for R&D, the price of alternative systems remains high. As price shocks associated with depleting reserves begin, the federal government scrambles in the face of public outcry to "do something." However, years of neglect and decay of the research infrastructure mean any response by the government will take years to have an effect. The uncertainty about supplies sends energy prices soaring in the commodity markets, leading to recession and severe economic losses for not just the U.S., but for the whole world.

Although this paper focuses largely on U.S. energy security interests, its message has clear implications for other countries as well. In terms of sustainability, it lays out a realistic plan for making the transition from a fossil-fuel based economy to more permanent, diversified energy supply portfolio for the future.

JUSTIFICATION FOR GOVERNMENTAL FUNDING FOR TECHNOLOGY RESEARCH & DEVELOPMENT

Defining Energy Security

A 1992 Department of Energy panel (DOE, 1992) on national security concluded that the U.S. will have achieved national security when:

> *"...we are able to anticipate the economic, military, political, and sociocultural challenges of a diverse, interactive, changing, and unstable world order and to develop effective and appropriate initiatives and responses that benefit current and future US interests and the interests of our alliances."*

Energy security is not specifically mentioned in this definition of national security; however, there is sufficient evidence that energy supply or price disruptions can have sufficient economic, military, and political implications to be considered a vital part of our national security. Clearly, there is a role for government involvement in assuring U.S. energy security.

[1] OECD is the Organisation for Economic Co-operation and Development and includes: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, New Zealand, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

Critics challenge this view, noting that the federal government has spent in excess of 100 billion dollars since 1973 in order to increase our energy security and that these outlays "cannot be said to have measurably altered the energy security of the nation," (Stagliano, 1995). However, this view confuses energy security with energy independence. In a world where fuels are traded in the commodity markets, reliance on foreign suppliers may be justified. As former Congressman and chair of the Subcommittee on Energy and Power of the House Energy and Commerce Committee, Phil Sharp (1995) points out, by relying on the basic market forces, "we have cheaper energy, we have greater supply, and we therefore have more energy security than if we had relied upon central control decisions to allocate energy resources."

Determining the appropriate government role in enhancing energy security requires that we differentiate between the short- and long-term and recognize that the role of government is very different in these horizons. Further, evaluating success at achieving energy security requires focusing on a broader set of criteria that includes economics, energy independence, international obligations, and the relationship of the choice to sustainability (Hartley, 1995).

Differentiation Between Short- and Long-Term Issues

Reliance on fossil fuels will continue for the foreseeable future. Although world oil prices have increased over the past few months, worldwide production capacity is adequate to meet needs for at least the short term. Despite adequate supply, short-term crises, similar to those of the past two decades, can be expected to occur. Typically, short-term crises are either politically motivated or are due to temporary market disequilibrium. Politically driven crises result from one (or a few) country's decision to reduce oil exports to achieve a foreign policy objective or as a result of wars begun as political decisions. The oil-price surges of Spring 1996 are an example of market disequilibrium type crisis. They were brought about by a series of miscalculations, including winter supply requirements, the weather, and incorrect market expectations about the timing of lifting the oil sanctions against Iraq, which led to unacceptably low inventory levels for major producers and eventually led to panic buying and sharp price increases.

Short-term crises are extremely difficult to predict. The goal of any governmental action during short-term crises should be to help provide stability and predictability in the market. Above all, the primary role for the government during short-term crises should be to allow the market to work. Oil has become a commodity bought and sold on the futures markets. Unhindered, these markets provide transparency of prices and allow buyers and sellers to hedge risks associated with price volatility. Unclear governmental policies can adversely affect this process by sending false signals to the market. This does not necessitate a hands-off policy, but rather the creation of clear policies before such crises occur. One example of an appropriate government role is prior formulation of Strategic Petroleum Reserve (SPR) drawdown plans for various short-term supply interruption scenarios.

While short-term crises are either politically driven or due to temporary market disequilibrium, there are several longer term issues on the horizon that may lead to longer term crises. These issues include diminishing oil reserves and increasing concentration of remaining reserves among a few countries in a potentially politically unstable region; fundamental changes in worldwide demographics that will mean increased demand from other world regions, such as Asia; and increased global awareness resulting in increased obligations to various international environmental agreements. Each issue is discussed in detail below, although it is often difficult to isolate the impacts associated with any one factor. For example, fundamental demographic and economic changes in developing countries complicate the task of achieving meaningful international agreements to limit carbon dioxide emissions. The long-term nature of these issues and their potential impact on overall energy security justify government involvement, because these are issues not adequately dealt with in the market place.

Oil Reserves

Many analysts incorrectly assumed that the energy crisis of the 1970s heralded the onset of declining worldwide oil production and compelled an immediate transition to alternative sources. During the 1980s, many predicted oil prices could reach $100/barrel by 2000. These forecasters failed to consider that higher prices would result in increased exploration, the discovery of vast new reserves, and the more efficient extraction, production, and use of energy.

Although past estimates of oil prices have often been wrong, fossil fuels are indeed finite, non-renewable resources. And even though estimation of ultimately recoverable reserves is an inexact science, several studies suggest that oil production will peak in the next 20-40 years. In the U.S., proven reserves have declined from 28.4 billion barrels (bbbls) in 1984 to 22.4 bbbls in 1994, Figure 1. At current production rates of 8.5 million barrels (mbbls)/day, remaining domestic reserves would only last 7.2 years.[2] Without the discovery of major new oil reserves in the U.S. or a shift away from an oil-based economy, the U.S. will have to rely more and more on imports from a select group of countries. By contrast, estimates of worldwide reserves have increased over the past decade. DOE estimates total remaining reserves of approximately 1,000-1,100 billion barrels, Table 1 (DOE, 1995a), equivalent to 43-48 years at current production rates. A review of various reserve estimates by MacKenzie (1996) suggests a slightly higher range, 1,035-1,435 billion barrels.

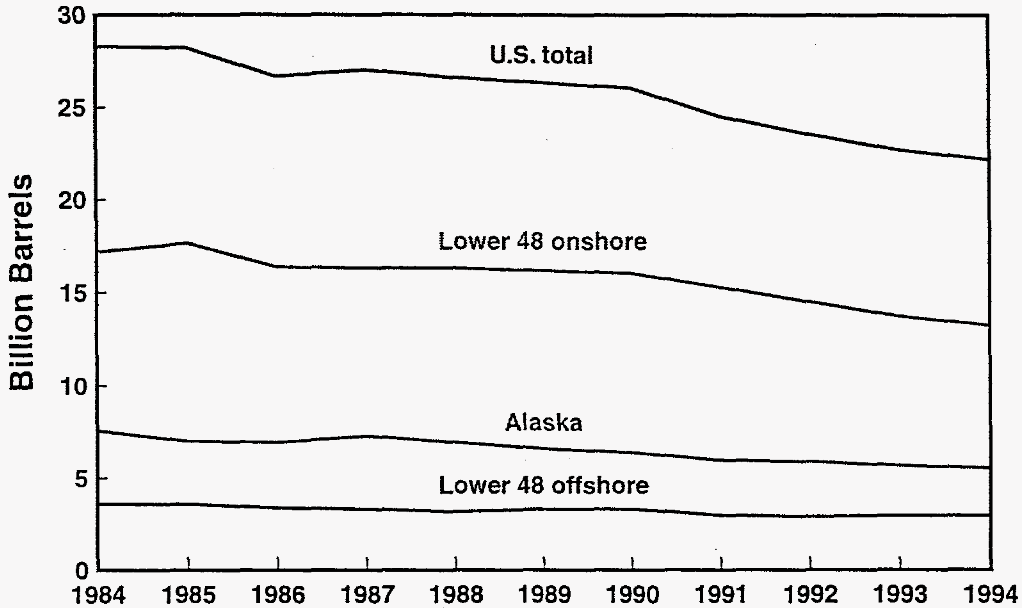

Figure 1. U.S. Crude Reserves, 1984-1994 (Source: DOE, 1995a).

Oil prices have not increased over time as forecasted in the early 1970s due to these increased reserve estimates, competition amongst suppliers, and reduced production costs. However, as is the case in the U.S., worldwide reserves will eventually peak, production efficiencies will reach a point of diminishing returns, and prices will increase. MacKenzie (1996) estimates that global production is likely to peak between 2007-2014. Even under the most optimistic assumptions about remaining reserves, MacKenzie demonstrates that production will begin to decline by approximately 2020.

[2] The problem with using this static measure of reserve size [referred to as the reserves/production (R/P) ratio], is that it doesn't take account of new reserves, technological change, or increased demand, thereby making it difficult to predict long-term availability.

Table 1. International Oil Reserves, Production, and Reserve/Production (R/P) Ratio

Rank	Country	Oil Reserves 1994 (mbbls)	Production 1995 (mbbls)	Max. R/P (years)
1	Saudi Arabia	161,203-262,475	3,004	87.4
2	Former Soviet Union	57,000-191,144	2,391	79.9
3	Iraq	99,427-100,000	202	N/A
4	Kuwait	96,500 - 97,675	751	130
5	Abu Dhabi	62,000 - 92,200	N/A	N/A
6	Iran	58,650 - 89,250	1,330	67.1
7	Venezuela	64,477 - 64,878	1,004	64.6
8	Mexico	49,775 - 50,776	956	53.1
9	Libya	22,800 - 36,570	507	72.1
10	China	24,000 - 30,204	1,100	27.5
11	United States	22,132 - 22,957	2,394	9.6
12	Nigeria	17,210 - 17,900	740	24.2
13	Norway	9,416 - 16,998	N/A	N/A
14	United Kingdom	4,517 - 15,492	908	17.1
15	Algeria	9,200 - 10,157	437	23.2
16	Indonesia	5,779 - 6,347	556	11.4
17	India	5,776 - 5,807	N/A	N/A
18	Canada	5,038 - 5,848	663	8.8
19	Oman	4,828 - 5,183	N/A	N/A
20	Malaysia	4,300 - 5,090	N/A	N/A
Top 20	**Total for Oil**	**947,917-1,063,063**		
World	**Total for Oil**	**999,761-1,111,598**	**22,714**	**48.9**

Sources: DOE, 1996b; DOE, 1996c.

If production peaks in the next 20-25 years, this is when the U.S. and other countries need to make the transition to alternative fuel sources. Of course, the change cannot occur overnight. Therefore, responsible government policy requires an appropriate R&D program to help smooth the transition. The government should take a portfolio type approach to prioritizing research needs, selecting a broad range of projects with varying degrees of risk and potential payout. Specifically, federal R&D should not just focus on renewable technologies, but should include such areas as improved oil exploration and recovery techniques, including for oil shale; increased efficiency in energy end use; advanced nuclear design options; and cost-effective fuels or fuel substitutes for the future. The next section discusses how fundamental changes in demographics further complicate future supply questions by significantly increasing worldwide demand and altering existing consumption patterns.

Fundamental Changes in Demographics

The global energy balance will shift dramatically in the near future as developing countries pursue wide-scale industrialization. Worldwide, the EIA predicts that total energy consumption will increase 55% by 2015, from 349 Quads in 1993 to 542 Quads (DOE 1996b), Figure 2. However, that statistic only tells part of the story. The EIA predicts that 69% of that increase will occur in non-OECD or former Soviet Union or Eastern European countries. The largest increases will occur in Asian countries, with energy consumption in these increasing 150%. Despite this increased demand in developing countries, serious inequities in per capita energy consumption will remain. For example, EIA estimates assume that average per capita energy consumption in non-OECD countries, excluding Eastern Europe and the former Soviet Union, would increase from one-tenth or less of OECD country averages now to just one-fifth of these averages by 2015 (DOE, 1996b).

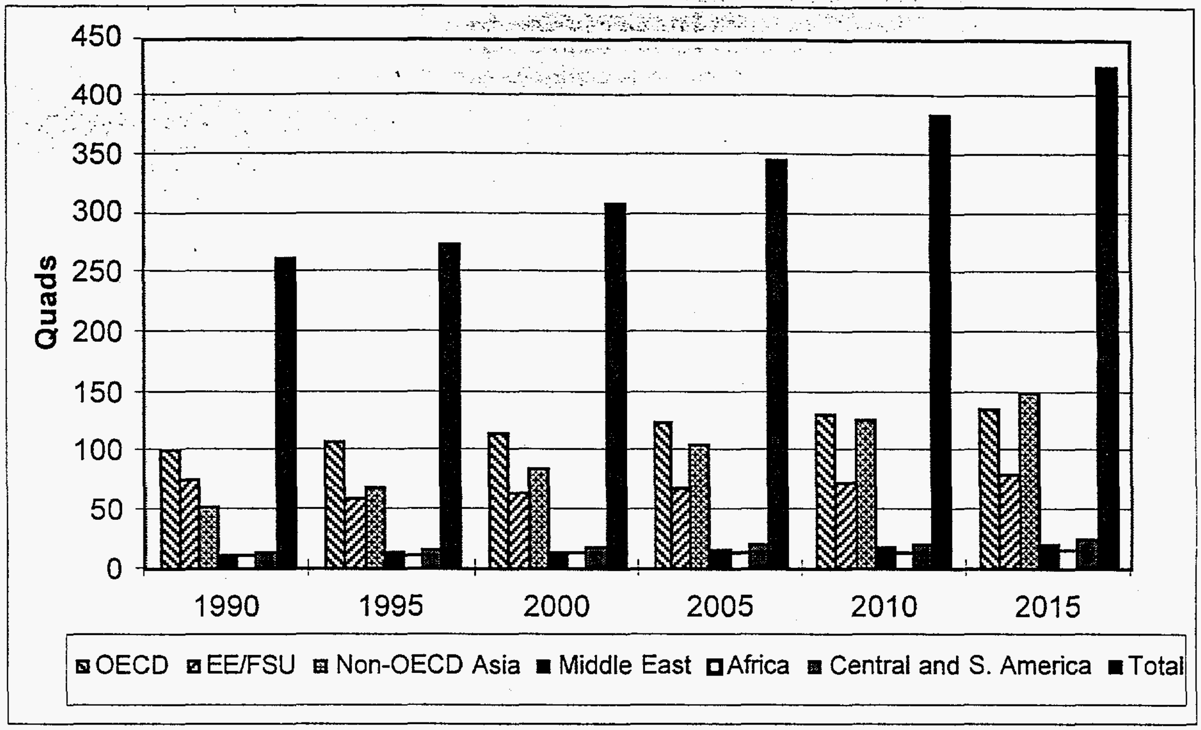

Figure 2. World Energy Consumption by Region, 1990-2015 (Source: DOE, 1996b).

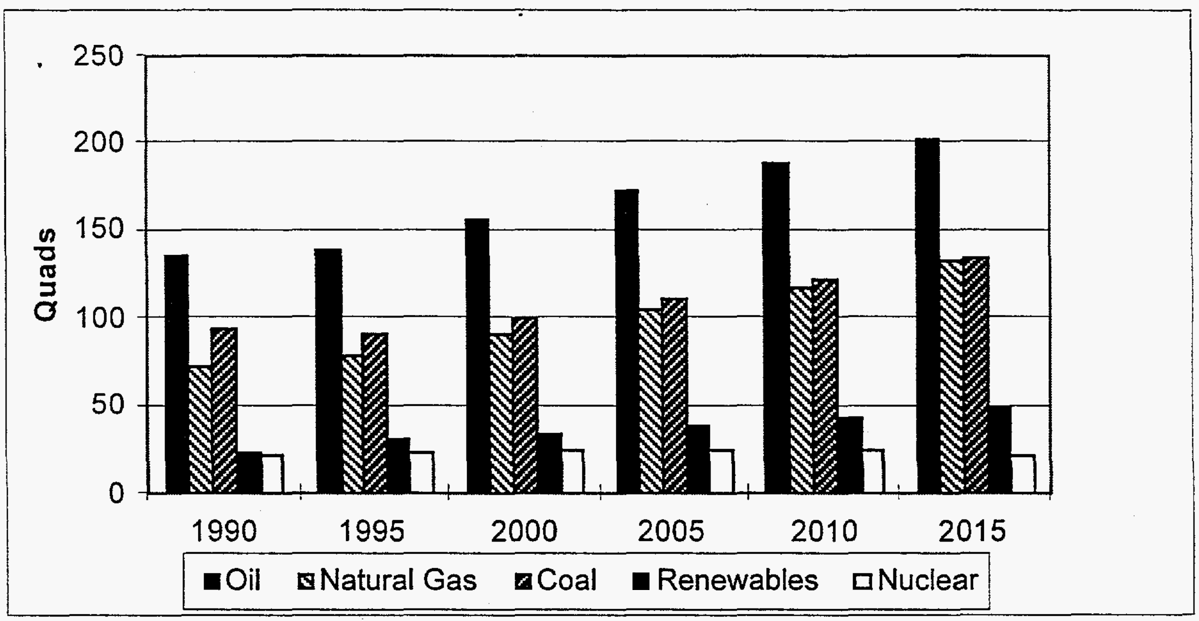

Figure 3. World Energy Consumption by Fuel Type, 1990-2015 (Source: DOE, 1996b).

Much of the increased energy demand will be for oil, Figure 3. For oil, the EIA projects that annual consumption will increase 49%, from 136 Quads in 1993 to 203 Quads in 2015. While reserves appear sufficient to meet this demand in the near term (as discussed in the previous section), increasing demand from other regions will add new stresses to the global oil supply. For example, Fesharaki (1995) estimates that oil consumption in the Asia Pacific region, which now is about 17.8 million barrels/day[3], will grow by 3.5 to 4.0 million barrels/day by the year 2000. As total demand increases, overall market share held by Middle-Eastern countries is forecasted to increase. Whereas OPEC supplied 40% of total

[3] World oil consumption totaled 69.4 million barrels/day in 1995 (DOE, 1997).

world oil in 1993, the EIA estimates OPEC's market share could increase to 56% in 2015 (DOE, 1996a).

A specific implication of the growing world-wide demand for world oil supplies relates to production capacity. The EIA estimates that the Persian Gulf countries are currently producing at 78-84% capacity, compared to just 55% in 1985 (DOE, 1996a). The projected increased demand in oil implies a need for increased investments in the global oil infrastructure. Otherwise, physical shortfalls due to war or other political issues could be exacerbated by this increased demand and decreased surplus production capacity, thereby possibly impacting consumers worldwide.

Compliance with International Agreements

There are many externalities associated with the production and consumption of energy. At the local level, energy production choices have a direct impact on local air quality levels. Many large cities in developing countries already familiar with deteriorating air quality conditions, will experience significant local impacts as energy production increases due to changing demographics and increasing incomes. On an international level, growing consumption of fossil fuels by all countries will increase emissions of key greenhouse gases, particularly carbon dioxide. Increased attention to international environmental problems such as climate change could, in the long term, lead countries to make the transition from fossil-based energy before actual production declines begin.

For example, at the recent second annual Conference of the Parties (COP2) to the Framework Convention on Climate Change (FCCC),[4] the U.S. announced its support for future negotiations aimed at "an agreement that sets a realistic, verifiable and binding medium-term emissions target," (Wirth, 1996). This decision to move beyond the voluntary commitments of the FCCC was motivated, according to Wirth, by the 1996 finding by the Intergovernmental Panel on Climate Change (IPCC) that for the first time "the balance of evidence suggests that there is a discernible human influence on the global climate," (IPCC, 1996).

Increasing fossil fuel consumption worldwide will make it difficult for countries to make significant progress toward reducing the threat of climate change. The atmospheric concentrations of several key greenhouse gases have increased significantly over pre-industrial (1860) levels: CO_2, 30%; methane (CH_4), 145%; and nitrous oxide (N_2O), 15% (IPCC, 1996). Achieving meaningful emission reductions will not be easy; stabilizing concentrations of CO_2 in the atmosphere at its existing level would require reducing emissions by 60% (IPCC, 1992). Based on the huge increases in fossil fuel consumption forecasted for developing countries (as discussed previously), unilateral action by industrialized nations would be largely ineffective at reducing global greenhouse gas emissions. Figure 4 illustrates the problem; despite low per capita consumption levels in developing countries, aggregate emissions from electricity production alone could grow significantly. In the next 20 years, the relative share of CO_2 emissions from the developing world, including China, could increase from 19% to 48%. Furthermore, if developing countries achieve the level of electrification expected by 2040, their relative share of CO_2 emissions would increase to over 70% of the global total from electricity production (Drennen, 1993).

The U.S., among others, has signed and ratified the FCCC. More recently, the U.S. voiced its commitment to negotiate actual binding commitments, perhaps in a manner similar to what was done for the phaseout of CFCs under the Montreal Protocol to the Vienna Convention. Although most counties still appear reluctant to commit to serious reductions in fossil fuel use, it would be difficult, if not impossible, for countries to achieve meaningful reductions in global greenhouse gas emissions without the adoption of policies that move the world away from its long-term dependence on carbon-based fuels. The eventual recognition of this issue may lead governments to enact policies that seek to persuade people, through taxes or other measures, to reduce fossil fuel consumption. Of course, increased taxes on fossil fuels in one region would decrease demand in that region, but could lead to lower oil prices worldwide, leading again to increased consumer demand, particularly in developing countries.

[4] Over 160 countries have signed and 120 ratified the FCCC since its negotiation in 1992. The overall goal of the FCCC is to stabilize emissions of greenhouse gases at a level that prevents "dangerous" interference with the climate system.

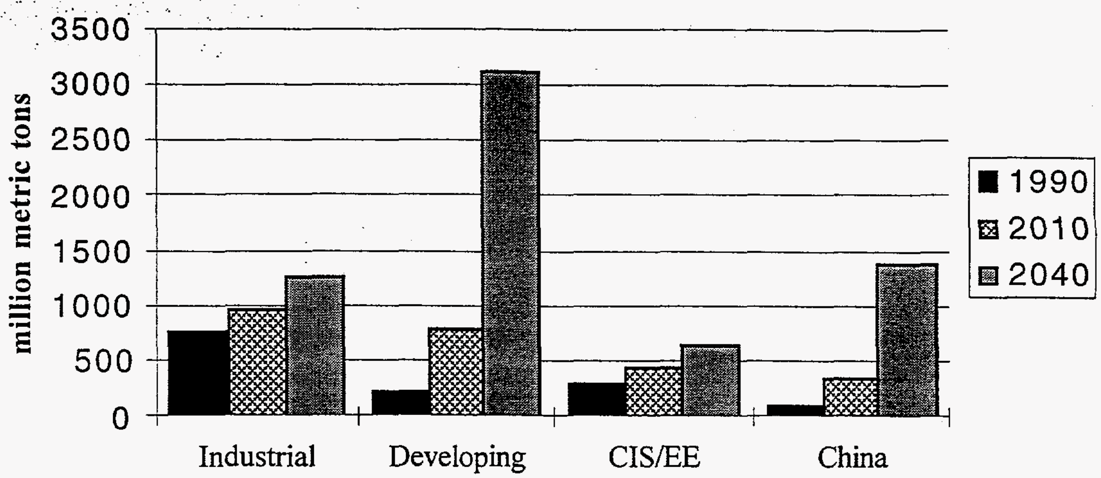

Figure 4. CO_2 Emissions from Electricity (Source: Drennen, 1993)

Summary of Role for Government in Long-Term Issues

The previous discussion summarizes the long term issues affecting global energy supply. There are no simple solutions to any of these issues. It is important to recognize the potential ramifications for U.S. energy security and to formulate a long-term policy for dealing with the fact that at some point in the not too distant future, countries will have to begin the transition away from fossil fuels and toward alternative sources. The primary goal of a country's energy policy should be to maintain price stability and predictability. As argued above, for short-term crises, this requires a clear up-front policy toward involvement in stabilizing the market, whether by use of the SPR or other measures. In the long term, achieving this goal requires, in economic terms, increasing the oil demand price elasticity so that as oil prices increase, oil demand decreases, lessening the upward pressure on prices. Accomplishing this goal would have minimal impact during short-term crises, as supply switching normally involves substantial capital costs, such as replacing furnaces, engines, or cars. However, it would have significant economic and social benefits during a sustained period of increasing prices, whether brought about by increasing scarcity, or by governmental policy (such as a commitment to reduce fossil fuel use to meet international obligations to the climate change treaty by increasing carbon taxes). Achieving this goal requires a long-term political and financial commitment to maintaining a diversified energy R&D portfolio. While past programs have attempted to do just that (alternative fuels program, etc.), success has often been linked to achieving energy independence or having a significant short-term impact. However, sound energy policy does not require that the U.S. achieve energy independence.

Energy independence should be but one of several criteria for selecting amongst competing energy sources and alternative research goals. The fact that the U.S. imports almost 50% of its oil does not necessarily imply a failed energy policy. Likewise, while reliance on domestic sources of energy could increase the overall surety of energy supply, because of the economic efficiency losses, such a policy could actually result in diminished energy security. As proposed by Hartley (1995), a more comprehensive evaluation of success at achieving energy security should include such factors as economics, energy independence, international obligations, and the relationship of the choice to sustainability.

ROLE OF TECHNOLOGY IN MAKING THE TRANSITION

The long-term issues discussed in the previous section define an approximate 20-25 year time frame for countries to begin the transition from oil to alternative sources. The existing state of affairs is not sustainable. A recent report by Shell Oil (1996) concurs; under its

"Sustained Growth" scenario of 2% annual worldwide growth in energy consumption per year, the contribution of fossil fuels (oil, natural gas, and coal) continues to increase until 2030. However, by 2065, Shell estimates that renewable energy's share could be as high as 65%. Included in Shell's estimate is a significant contribution from "surprise sources," meaning sources that are, as of now, not yet demonstrated or even yet envisioned.

Making the transition to a more sustainable future requires long-term commitments to basic and applied energy R&D. While past research has led to significant cost reductions for several technologies, Figure 5, much work remains. Our contention is that the government must play an instrumental role in spurring innovation and creativity in facilitating energy technologies aimed at this transition. Preferably, this can be done in partnership with the evolving industry where market forces drive the technology choices.

Future demands on technology innovation are great. However, the good news is that the boundaries on future advances and discoveries in energy technology are unlimited. As an example, we make the observation that to date, researchers have exploited advances in the understanding of the photoelectric effect to develop photovoltaics, the electrochemical effect to develop batteries and fuel cells, the thermionic effect to develop space nuclear power, and the basic laws governing kinetic energy to develop flywheels. In the future, we envision coupling advances in semiconductor technology to harnessing these various effects for the development of small, smart, efficient power units which could have a dramatic effect on overall end use efficiency. The point is that sufficient inefficiencies in the overall energy supply, conversion, and end use remain and technologies, both imagined and as yet undiscovered, can vastly change the future use of energy.

The next section summarizes the current status and potential of several key technologies that promise to be a part of transitional strategies in the near term.

Renewables. Research over the past 20 years has resulted in significantly improved efficiencies for renewable energy technologies. The economics (Figure 5) have improved to the point that renewables are now feasible in a broad range of niche markets, particularly remote site applications. The economics are expected to continue improving as research continues. Several of these technologies show particular promise in the developing world, where billions of people currently lack access to electricity.

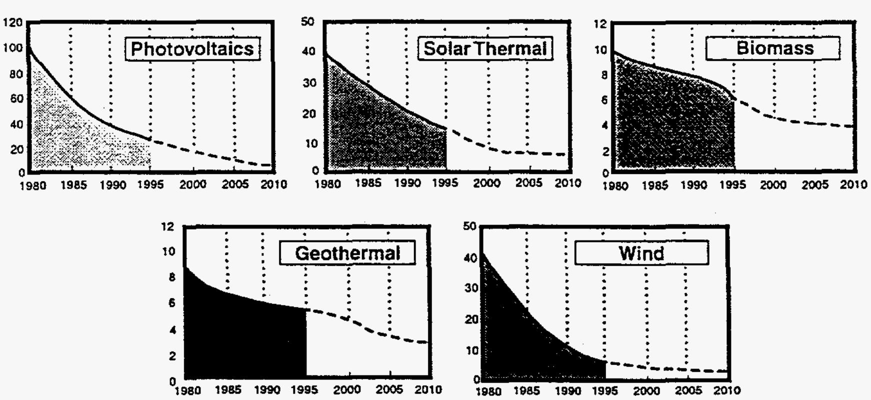

Figure 5. Estimated Costs of Renewable Energy Options in ¢/kwh (Source: DOE, 1995b)

Ongoing utility restructuring in the U.S. complicates any discussion of the future for renewable technologies here. To prepare for deregulation, utilities are cutting costs in order to lower overall production costs. In the short run, restructuring may actually increase reliance on fossil fuels as natural gas gains market share. However, in the longer term, reliance on market forces will encourage efficiency of energy supply and end use, resulting in better asset utilization. Likewise, an energy services market will emerge to better meet customer needs. This may actually accelerate the acceptance of new technologies. For example, in the long run, increased attention to improved asset utilization may lead to increased use of distributed utility options.

Distributed utilities refer to the concept of strategically locating small generating units or storage devices at points of high utilization in the transmission and distribution grid. This is important for many of the newer technologies, including renewables and fuel cells, as it creates a niche market for these new technologies that otherwise might appear uneconomical with traditional generating techniques.

While renewable energy use in the U.S. may increase as the concept of distributed utilities increases, many obstacles to its widespread deployment remain, see Table 2. Specific necessary technological improvements include advanced manufacturing techniques, integrated system designs, increased reliability, and decreased maintenance requirements. It will take a concerted and long-term commitment on the part of the government and the private sector to overcome some of these hurdles. Complicating the picture for U.S. interests is that compared to other countries, fuel costs in the U.S. are relatively low. Without a commitment in the U.S. to increased fuel taxes, or possibly externality taxes (like the proposed carbon tax), the economics of renewables may be better in other countries.

Table 2. Research/Funding Priorities for Renewable Energy Technologies

Photovoltaics	• Advanced manufacturing processes • Development of thin-film PV cells • Multibandgap, multijunction monolithic devices • Module and system reliability • International market initiatives
Solar Thermal	• High-temperature working fluids • High-temperature materials/interfaces • Thermodynamic cycles • Thermal storage materials • High-efficiency concentrators • Decreased manufacturing costs
Wind	• Wind characterization studies • Improved understanding of aerodynamics • Structural dynamics and fatigue • Improved component performance • Hybrid system design and testing • Avian risk reduction
Geothermal	• Advanced exploration methods • Improved drilling techniques • Reducing capital and operating costs • Accelerating acceptance of heat pump technology
Biomass	• Improved combustion techniques • Advanced gasification, combined-cycle technologies • High-temperature gas cleanup technologies • Short rotation intensive cropping

Storage, Peaking, and Increased Power Quality

As discussed above, utility restructuring will give rise both to markets for better asset utilization and custom power. Central to these market needs are storage/peaking/power quality systems. At present, among the most interesting options are batteries, superconducting magnetic energy storage devices (SMES), and flywheels. While most of the attention in the past has focused on batteries, SMES and flywheels may also hold great promise for the longer term. For example, existing batteries are limited to storage of about 1.5 kwh/sq. foot. It is expected that the storage capabilities of advanced batteries may be in the range of 5-10 kwh/sq. ft. Flywheels, which would store energy in the form of kinetic, rather than chemical energy, have a projected range of 10-14 kwh/sq. foot. As with the renewable technologies, significant research obstacles remain. Table 3 summarizes the current status, potential, and research needs for the storage technologies.

Table 3. Status of Storage Technologies

Technology	Status	System Size	Application Status	Technology Need	Energy Density
Batteries	Turnkey systems commercially available	kw - MW	Utility-scale applications in US: China & Puerto Rico	Improved cycle life and energy density Lower-cost "modular" systems	Existing Batteries: 1.5 kwh/s.f. Advanced Batteries: 5-10 kwh/s.f.
SMES	Turnkey systems commercially available in Micro-SMES	1-6 MW-sec	5 Micro-SMES units are in use today	Improved high temperature superconductors Less expensive manufacturing techniques High-powered switching device development	SMES systems are generally power systems
Flywheels	Privately funded research on components	Less than 40 kw	Complete utility-scale system demo is at least 5 years away	High-strength, lower-cost rotor materials Long-life, low-loss bearings System integration & interconnection capability	Projected: 10-14 kwh/s.f.

Fuel Cells. Fuel cells, perhaps more than other technology, could well be a technology that assists in the eventual transition away from fossil fuels. Fuel cells directly generate electricity through an electrochemical reaction between a fuel, such as hydrogen, and an oxidant. The reason that fuel cells may be a true transition technology is that in the near term, they can run on reformed natural gas (with potential to run on other petrofuels) until such time as it becomes practical to rely on clean, non-carbon based sustainable technologies, such as nuclear or renewables, to provide inexpensive hydrogen. In a fuel cell operated by natural gas the gas is first processed to create a hydrogen-rich gas that is then electrochemically reacted with an oxidant to provide power.

In addition to assisting the transition from natural gas to alternative energy sources, such as renewables, there are other benefits that make fuel cells attractive to utilities, independent power producers, and automakers. Fuel cells fit in well with the distributed utility concept: their modular design allows their placement in some applications in the transmission grid. Present-day fuel cells operate at elevated temperatures of 200-600°C and thereby provide a good technology match when there is a cogeneration application needing electricity and heat. Finally, fuel cells also provide environmental benefits, typically, emitting just 1% of the NOx emissions associated with internal combustion engines and 10% of those associated with gas turbines.

Widespread commercialization of fuel cells requires advances in several areas, including improved manufacturing techniques to reduce system costs, new catalysts to replace expensive precious metal catalysts, improved membranes, and technologies for producing low-cost hydrogen from non-fossil fuel sources.

Other technologies. In addition to renewables and fuel cells, there are many other technologies that may be important for managing the transition from today's fossil fuel dominated economy to a more sustainable economy. Some of those technologies, such as nuclear, already play a significant role in meeting our energy needs. For example, while nuclear faces many obstacles to continued growth in the U.S., nuclear's market share continues to increase worldwide. A total of 437 nuclear reactors generated over 22% of the world's electricity in 1995; an additional 85 plants are under construction, including 32 in the Far East (DOE, 1996d).

Finally, on even a longer scale, continued support of energy R&D could lead to surprises in energy technology. For example, fusion remains an attractive option for the next century and beyond. Remaining obstacles are significant but may be overcome through ongoing international collaborations such as the International Thermonuclear Experimental Reactor (ITER) program.

CONCLUSIONS

Energy security is a vital part of national security. Assuring energy security requires clear differentiation between short- and long-term issues and a definition of the appropriate role for government involvement in each time horizon. In the short term, reliance on fossil fuels will continue. Despite adequate supply, short-term crises, similar to those of the last two decades, are likely. Short-term crises are extremely difficult to predict and provide limited opportunity for government involvement. However, in the long run, reliance on fossil fuels is not sustainable. Long-term issues leading to this conclusion include diminishing oil reserves and increasing concentration of remaining reserves among a few countries in a politically unstable region, fundamental changes in worldwide demographics shifting oil demand toward the Asian countries, and increased global awareness resulting in increased obligations to various international agreements.

These long-term issues define a 20-25 year time frame for countries to begin the transition to alternative sources of energy. Making this transition to a more sustainable future requires long-term commitments to basic and applied energy R&D. Past research efforts have led to significant improvements in existing technologies, as evidenced by the large efficiency gains and improved economics of renewable energy technologies. In the future, the government must play an instrumental role in spurring innovation and creativity in energy technologies aimed at this transition. Achieving a stable long-term energy supply will place heavy demands on technology innovation. Fortunately, as evidenced by some of the technologies highlighted in this paper, the boundaries on future advances and discoveries in energy technologies is unlimited.

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