L20
The G20 at the Leader's Level

ENERGY SECURITY AND THE L20

October 13-14, 2005

CESP STANFORD
PROGRAM ON ENERGY AND SUSTAINABLE DEVELOPMENT

The G20 at the Leader's Level

Energy Security and the L20

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Oksenberg Room, Encina Hall, 3rd Floor Central
Stanford University, Palo Alto, California

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PRELIMINARY PROGRAM

Oksenberg Room, Encina Hall, 3rd Floor Central
Stanford University, Palo Alto, California

Thursday, October 13th

13:00 **Introduction & overview of L20 concept** (Gordon Smith)

13:15 **Objectives for the meeting; Energy security as a possible topic for the L20** (David Victor)
- discussion (based on background paper)

13:45 **Major topics and their policy dimensions**
During this period we will address five major aspects of energy markets and examine, in each, areas where coordinated policy actions may be required and, in particular, where the L20 could play a role.
- Pricing, supply and demand: the world oil market today and prospects (background paper by Anthony Cordesman)
- International institutions for managing price shocks and the "rules of the road" (background paper by Klaus Jacoby)
- Managing oil supplies in volatile regions (background paper by Richard Cooper)

15:15 **Break**

15:30 **Continued Discussion of major topics: energy security for fuels other than oil**
- The shift to gas and implications for gas security in a globalizing world gas market (background paper by David Victor)
- Energy security for the next nuclear fuel cycle (background paper by Burton Richter)

16:30 **Discussion**
- Lead Discussant **-** Peter Schwartz
- Remarks from provocateurs/sceptics - Edgard Habib, Hoesung Lee, Ron Lehman
- Initial synthesis of areas where L20 may have leverage – Hans-Holger Rogner, PR Shukla, Jim Sweeney

17:30 **Adjourn**

18:30 **Cocktails**

19:00 **Dinner** *(Three Seasons, 518 Bryant Street off University Avenue, Palo Alto 650-838-0353)*

Friday, October 14th

08:00 **Breakfast**

08:30 **Introduction to Day two** (chair David Victor)
Remarks: Some ideas on what should be done
- Barry Carin
- Jane Long (LLNL)
- Critique by the group - Lead Discussants: George Anderson and Tom Heller

10:30 **Break**

10:45 **Toward an agenda for the L20**
- proposal for main elements for leaders' level attention to energy security

13:00 **Lunch**

L20 The G20 at the Leader's Level

Energy Security and the L20

- Participant List -

Abbott	Clint	Research Associate	Centre for Global Studies
Anderson	George	President	Forum of Federations
Carin	Barry	Associate Director	Centre for Global Studies
Clapp	Jennifer	Fellow	Centre for International Governance Innovation
Cooper	Richard	Maurits C. Boas Professor of International Economics	Weatherhead Centre for International Affairs
Cordesman	Anthony H.	Arleigh A. Burke Chair in Strategy	Centre for Strategic & International Studies
Habib	Edgard	Chief Economist	Chevron-Texaco Corporation
Heller	Tom	Lewis Talbot and Nadine Hearn Shelton Professor of International Legal Studies	Stanford University Law School
Huntington	Hill	Executive Director	Stanford University Energy Modeling Forum
Isnor	Richard	Director, Innovation, Policy and Science	International Development Research Council (IDRC)
Jacoby	Klaus	Head of Emergency Planning and Preparations Division	International Energy Association
Lee	Hoesung	President	Council on Energy and Environment, Korea
Lehman	Ron	Director	Lawrence Livermore National Laboratory, Center for Global Security Research
Long	Jane	Associate Director	Energy and Environment Directorate, Lawrence Livermore National Laboratory
Murray	Glen	Chair	National Roundtable on Environment and the Economy
Richter	Burton	Paul Piggott Professor emeritus	Stanford University
Rogner	Hans-Holger	Head	International Atomic Energy Agency, Planning and Economic Studies Section
Schwartz	Peter	President	Global Business Network
Shukla	P.R.	Professor	Indian Institute of Management
Smith	Gordon	Executive Director	Centre for Global Studies
Song	Allan	Programme Officer	Smith Richardson Foundation
Sweeney	James	Senior Fellow	Stanford University, Institute for Economic Policy Research and Hoover Institution on War, Revolution and Peace
Victor	David	Director	Stanford University, Program on Energy and Sustainable Development
Weyant	John	Professor	Stanford University, Energy Modeling Forum
CIDA Representative			

Energy Security at the L20?
Overview of the Issues

Background discussion paper for L20 Energy Security Workshop
Stanford University, October 13-14, 2005

David Victor, Barry Carin, and Clint Abbott

This meeting is one of several in a project that is exploring the possible creation of the "L20"—a regular forum at which the leaders of approximately 20 industrialized and developing countries would convene on a regular basis. The founding logic of the L20, advanced especially by Canadian Prime Minister Paul Martin, is to provide a means for managing global challenges that have proved difficult or impossible to settle efficiently through other mechanisms such as the G8. Through a series of workshops and background papers the L20 team has refined the central concepts that could guide an L20. Notably, issues are ripe for L20 if they truly require attention of heads of government—for example, issues that require the brokering of complex package deals that cut across line ministries, and issues that require sustained high level attention because that is the one way to ensure proper follow-through. Moreover, the L20 offers the prospect of success in managing issues that require cooperation between industrialized and developing countries. Indeed, the closest analogy—the G20 group of finance ministers—was created in the wake of the Asian financial crisis and played an important role in easing adjustment to that crisis.

Our task is to see whether the L20, if it were convened, should focus on matters surrounding energy. Thus we must be severely practical. We must explore the issues to see where, if at all, leaders must be engaged and there are possibilities for meaningful agreement. Should "energy security" be on the L20's agenda? If so, our meeting should conclude with some concrete ideas for possible elements of an L20 meeting on the topic and thus possible elements of communiqué on energy security. In effect, our goal is to anticipate how leaders from approximately 20 of the most important industrialized and developing countries could approach the issues in a collective fashion. In addition to exploring the issues of energy security we also intend to foster some discussions on the composition of the L20, the impact on existing fora, the best means to engage the major powers, and opportunities for civil society to participate in any future solutions to these global problems.

In this overview paper we introduce some key concepts and outline areas where countries may want to explore possible gains from cooperation. We also introduce the five specific topics that are addressed in more detail in other background papers.

What is Energy Security?

"Security" has at least two meanings. First, in its narrow and traditional meaning it refers to territorial autonomy. A nation's security is a measure of its ability to survive without territorial interference by others. Ever since Churchill moved the British navy from coal to oil there has been particularly acute attention to ensuring adequate fuel supplies. For oil is not nearly so widely distributed as coal; moreover, the assets needed to deliver useful fuels from crude oil—such as refineries and storage tanks—are themselves soft targets. Thus the ability of the nation to ensure its territorial integrity has depended partly on its skill in securing energy supplies.

Second, a broader meaning has arisen where "energy security" is the ability of a nation to muster the energy resources needed to ensure its welfare. This definition has come into common usage alongside a general expansion (many say deflation) of the concept of "security." Some of this expansion in security matters reflects the growing importance of economic integration in the welfare of most countries. Insofar as all policies are aimed at promoting welfare, the expansionists simply maintain that attention at the highest levels of government must focus on a wide range of matters.

This diversity in definition—from the narrowest and traditional territorial focus to the wooliest notions of welfare—means that efforts to identify ways that the L20 could engage the issue require special attention to goals and definitions. While it may be useful, in some sense, to allow a proliferation of definitions and to foster broad agreements that allow every party to apply their own concept of "energy security," useful efforts that command the sustained attention of leaders probably require more attention to goals.

THE PROSPECTS FOR COOPERATION: GOALS, STRATEGIES AND INSTRUMENTS

Before turning to particular issues that might be on the L20's agenda we set the scene by starting with underlying goals that countries might pursue, along with the strategies they might prefer and the instruments they could deploy. Our purpose is to suggest that some goals, strategies and instruments are amenable to action by leaders working in concert on a sustained basis—and thus prime for the L20's agenda—while others suggest that concerted action is unlikely to bear fruit. Indeed, we will suggest that looking beyond goals to particular instruments there is much in the sphere of "energy security" that is not amenable to the L20's agenda. Crafting a viable agenda will require care to ensure that the broad rhetoric of energy security does not become a liability by focusing attention on topics where the L20 is unable to make headway while eclipsing areas where the L20 could play an important role. In the subsequent section we look at those particulars.

We begin with goals. Table 1 lists a series of goals for "energy security" often articulated by governments and analysts. In general, attention to energy security within a given country has started at the top (i.e., the narrowest military and territorial concepts), only to expand and shift down the list with time. Some of this progress may simply reflect that the narrowest concepts of energy security are easiest satisfy. For example, many navies and air forces have established special reserves for marine and jet fuel; governments often have provisions in place that allow them to divert commercial and strategic stockpiles to military uses in time of emergency. Thus once these concepts are satisfied the others remain. In general, all of the most highly industrialized countries have adopted a strategy that includes elements from the middle to the bottom of the list. Less developed countries, where they have been able, have tended to concentrate near the top. While there is much attention to China and India trying to attain energy independence (more on that below), it is easily forgotten that the U.S. did the same until the early 1970s. It framed "energy security" (and the health of the American oil industry) in terms of American production; it set quotas when lower-priced imported oil began to displace the market share of dwindling (and thus more expensive) domestic production. Those quotas, in turn, made it harder for the U.S. economy to respond to the shock of the Arab oil embargo.

In addition to examining goals we must also look at strategies & policy instruments. Even if nations agreed on goals (e.g., secure lines of supply) there may be strong divergences in the preferred means of achieving those goals. To the extent that it is not possible to devise meaningful accommodations of those differences, even broad agreement on goals will not yield much leverage for collective action through the L20. On Table 1 we array (left to right) the types of strategies and instruments that are often cited in plans for attaining energy security. With "Xs" we indicate the types of strategies and instruments that are usually associated with particular goals.

This table matters because it forces careful thinking about what, if anything, the L20 could achieve if it were focused on the matters of energy security. In particular, at least three specific implications follow. First, the matrix will help our meeting focus on what is possible. We do not plan an extensive debate on the proper placing of the "Xs" in the matrix. However, the array of "Xs" on table 1 suggests that for visions of energy security in the northwest corner that the L20 may have not have an instrumental role to play. The goals, strategies and instruments that populate the northwest are mainly autarkic in nature. And where the rules of self-help dominate there is usually little space for international collaboration. Insofar as elements of the energy security agenda include locales in the southeast, then the L20, perhaps, can play an important role. Nonetheless, the L20's utility will depend on how it amplifies or supplants other international efforts—a topic to which we will return later when we consider the international "rules of the road" and the IEA's stockpiling program in particular.

Table 1: Two Dimensions of Energy Security: Goals (rows) and Strategies & Instruments (columns)

	Self-production (e.g., closed fuel cycle, coal to liquids)	**Energy mercantilism** (e.g., flag ownership of oil fields)	**Control over Sea Lanes** (e.g., strong blue water navy)	**Domestic Stockpile** (e.g., SPR)	**Promotion of alternative energy technology**	**Coordination of domestic policies** (e.g., fuel taxes, efficiency incentives)	**International regimes to coordinate stockpiles** (e.g., IEA stockpile stewardship)	**International regimes to coordinate fuel cycle** (e.g., collective security for SLOCs, international nuclear fuel cycle)
Fuel autonomy (e.g., independence in oil, gas, fissile material)	X							
Assured fuel quantities for military operations	X		X	X				
Assured min. Supply for the economy	X	X	X	X	X			
Fuel Diversity					X	X		
Secure lines of fuel supply (e.g., nuclear fuel cycles and oil & gas lines hardened against terrorist intrusion)			X	X		X	X	X
Stable prices (or not excessive volatility) for key fuels (notably oil, which drives prices for other fuels)			X				X	X
Preventing Nuclear Proliferation								X
Efficient markets (i.e., allow price level and volatility to signal scarcity)							X	X

The need to examine underlying interests will arise most strikingly, perhaps, in our deliberations about China and India. Both countries are becoming major consumers of oil (and other natural resources), and their domestic markets are increasingly interlinked with world markets. Both are substantial oil importers. Yet both, at the same time, are pursuing mercantilist approaches to energy that are apparently intended to assure particular energy supplies flow into the country rather than to rely on the whims of a global marketplace. Do we think that this approach is merely a costly transient that will recede as these countries accept that oil is a fungible commodity whose particular national origin matters little? Or will resource nationalism reign—especially as deals are made with national oil companies in regions in such as Sudan, Venezuela, Nigeria and Russia, that lock in an alternative means of organizing the world oil market? If the former is correct then the L20 could play an essential role in framing a transition to global engagement and cooperation for India and China along with other important nascent oil importers. If the latter is true then cooperation will be hard to forge.

Second, the prospects for convergence (or not) of underlying interests will have a strong effect on the L20's membership. The L20 must certainly include the world's largest economies and populations—it must embrace the United States, EU, China, Japan and India. Thus regardless of other members, even these core five have illustrated severe divergence in interests. Beyond those five parties, however, the criteria for membership becomes harder to devise. Should Canada, as a good global citizen and architect of the L20 (and one of the world's largest producers of natural resources), be a member? Should the EU speak with a single voice (and can it), or will the EU have multiple seats as it does in the G8 (where fully half the seats are EU members)? Russia, with its large population, nuclear weapons, and vast energy resources, also ranks for membership. If energy is to be a major issue for the L20 then probably Saudi Arabia must participate. Similarly, on matters energetic and most else that could be on the L20's agenda the institution should include key regional countries—Brazil, South Africa, Indonesia and perhaps Turkey among them. One place to start is the membership of the G20 finance ministers.[1] Or perhaps the L20 should not begin with 20 but, rather, a smaller and less unwieldy group in which it is easier to negotiate and form the camaraderie that is essential to a nimble and effective institution.

A third reason why table 1 matters is that the divergence in interests suggests the need for care in devising an agenda that can allow progress in some areas where common interests can be identified while tolerating divergence in others. This could lead to cooperation of the "big tent" variety—a broad umbrella agenda under which variable geometries of cooperation could emerge. The European Union, perhaps the most effective example of international cooperation ever observed, emerged because its structure allowed such multiple configurations that facilitated deeper cooperation in some areas (and with some subsets of countries) even as collective action proved difficult or impossible in other areas. Even in the areas where instrumental agreement is not immediately possible, the L20 could play an important role in promoting common

[1] The G20 Finance Ministers, an institution that still exists, includes the G8, Argentina, Australia, Brazil, China, India, Indonesia, Korea, Mexico, Russia, Saudi Arabia, South Africa and Turkey. To avoid confusion, the "L20" has referred to a potential grouping of the Leaders from these 20 countries.

understanding that, with time and effort, could lead to further collective action. The G20 appears to have played such a role with finance ministers in the aftermath of the Asian financial crisis, and in many other international institutions the preferences of key countries have changed (with concomitant increases in the prospects for deeper cooperation) as the institution has focused a process of learning and adjustment.

PARTICULARS: MARKETS, FUELS AND INVESTORS

The meeting will begin with a discussion of the broad picture and our goals for evaluating the L20's prospects and design. Quickly, however, we will shift to particulars. We will focus on the oil markets, which we consider first, and then we will look at ways that energy security considerations could affect two other primary fuels: gas and nuclear. Here we introduce these three fuels—oil, gas and nuclear—and some particular issues that could arise for the L20. The discussion is not exhaustive, and in our deliberations we will allow time to explore what may be missing; our purpose is to outline some elements that could help to set an agenda for the L20 should it be convened to address the questions of energy security.

Oil: Market Fundamentals, Rules of the Road, and Diversity in Supply

Energy security is a prime candidate for the L20, first and foremost, because the price of oil is headed to the stratosphere and the forward markets suggest that high prices are here to stay for some time. At its root, the problems do not appear to be related to the geological exhaustion of oil resources—so-called "peak oil"—but rather to a host of troubles above ground, such as continued rise in demand and especially the difficulty and wariness of investors in opening new supplies. Figures 1 and 2 summarize the situation with demand and supply.

Figure 1: World Oil Demand

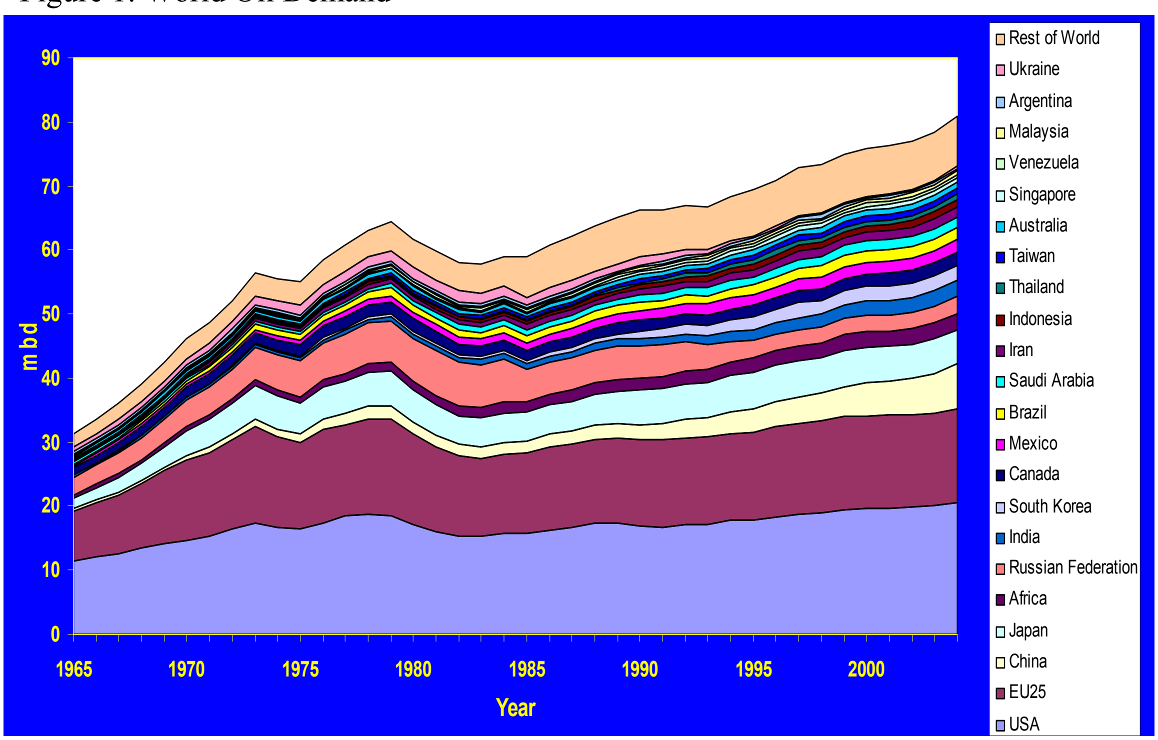
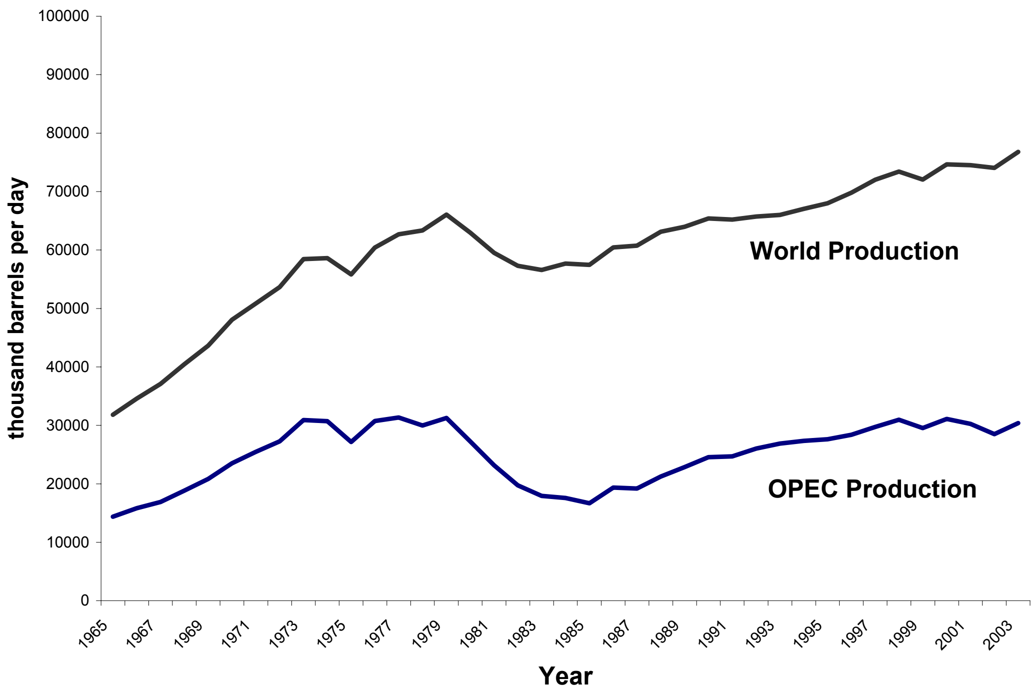


Figure 2: World Oil Supply



We look at the issues from three perspectives—each covered by a commissioned paper. The first issue is the overall balance of supply and demand, as introduced by Cordesman. The market is extremely tight, and insofar as the L20 would be animated by the desire to improve the oil market's ability to absorb shocks it should consider whether and where it might have leverage on issues such as:

- Improving the stability (and attractiveness to investors) of oil exporting nations;
- Creating an effective coalition to break OPEC's influence;
- Improving the quality of underlying data on the oil market;
- Encouraging investment in new spare production capacity;
- Hardening key oil export infrastructures against terrorist attack and Nature;
- Improving the modeling of oil prices and their macroeconomic effects.

Cordesman's paper covers a much fuller array of options than the five we summarize above. However, just the above five reveal the quite diverse roles that the L20 could play and the distinct difficulties that will arise in convening the L20. We have arrayed them in order of increasing possible leverage by the L20 (and roughly decreasing importance). Fundamentally, many of the problems in the oil market are rooted in the difficulty of attracting and sustaining investment in the states that have the most geologically attractive resources. Fixing that problem, however, is no easier than solving the problem of national governance altogether, and in oil states it may be additionally difficult because of the scramble for oil money that tends to distort all but the strongest systems of government—the so-called "resource curse." The L20 may not have much leverage on that problem, but perhaps it could help to array some solutions, such as fuller use of anti-corruption measures (e.g., "publish what you pay") and restricted funding mechanisms (e.g., the systems in Norway, Azerbaijan and Chad—in rough order of decreasing effectiveness). The final options on this list of five are the easiest for governments to alter—for example, special programs to harden infrastructure and fuller investments in energy modeling—yet may have the least leverage on the underlying problem.

A second major issue, addressed in Klaus Jacoby's paper, is the "rules of the road" for the international oil market. Ever since the first oil crisis of the 1970s major oil importing countries have organized themselves through the International Energy Agency (IEA) to coordinate their management of strategic oil stocks and responses to supply interruptions. Jacoby's paper looks at the ways that volatility in oil-producing nations can be countered by collective action on the part of consumers. The IEA arrangements, which cover 60% of the world's demand, include obligations to maintain strategic stocks (90 days worth of net oil imports), to have mechanisms in place that could restrain demand up to 7-10% of total consumption, to share oil in an emergency, and other provisions. These arrangements were triggered in the wake of Katrina, and the present moment offers an opportunity to evaluate whether such arrangements need updating. Jacoby notes that the world oil market has changed dramatically in structure since the IEA arrangements were created but that the system has evolved efficiently. At the meeting, we should consider whether there are special roles that the L20 could play in improving the system. At least two areas of possible improvement might be considered. First, the IEA arrangements notably exclude China and India (and most other developing countries); while the U.S. and E.U. are the largest consumers of oil (see figure 1), the rate of increase in China and India is staggering. (Some of the Chinese increase reflects vagaries in the electric power market that will probably settle when the building of central power stations catches up with the rate of economic growth; even then, the expected increase in oil consumption is very high.) Second, we should take a fresh look at the rules themselves since they are likely to come under increasing pressure. Some observers worry that the IEA doesn't have enough muscle to ensure adequate collective action in the face of real crisis, although Jacoby's paper argues that the IEA arrangements are in good shape. Moreover, the IEA (and most other energy analysts) are projecting that OPEC's share of world production (41% today) is likely to rise again in the near future as OPEC members generally hold the geologically most attractive reserves. Does this suggest a rising dependence on a cartel that has already proved its muscle, and if so what can be done to adjust the rules of the road so possible harms are minimized?

Third, the paper by Cooper reassembles these issues by framing what could be a "world agreement on oil"—and, by implication, a role for the L20 as broker of that agreement. Cooper argues that major oil-exporting governments, notably in the Gulf, are marked by stability and are unlikely to deliberately disrupt oil exports. However, internal conflicts might spill over to affect world oil markets—a possibility that is abundantly evident in recent years. Cooper suggests two radically different strategies for addressing the problem. One is to create a forum in which existing low-cost producers (notably Saudi Arabia) would be aided in their efforts to expand production capacity as well as supply additional data needed to calm markets. The other would focus on limiting demand for petroleum through aggressive energy efficiency programs and investment in substitute energy sources. At our meeting we should debate other possible integrated packages, the role of the L20 in each and the implications for L20's strategy and membership. As Cooper points out, for example, a production strategy for the L20 will require the central involvement of Saudi Arabia (and perhaps other candidate producers, such as Iran, Russia and Nigeria); a conservation and substitution strategy requires the concerted efforts of major users, with the danger that oil suppliers would have a strong incentive to frustrate effective action.

Gas: Different from Oil?

We give extensive attention to oil because it is the single largest source of primary energy (accounting for about two-fifths of the world total), as a liquid dense with energy it is the most flexible fuel, and thus oil prices tend to signal the price for all energy sources. However, we have commissioned papers on topics surrounding two other fuels, which allow the opportunity for focused discussion on additional topics that, in addition to their importance, will help us focus on a wider package of measures that could comprise the L20's energy security agenda.

A paper by Victor looks at the emerging global market for natural gas and explores whether this market will pose similar threats of security as have arisen in the oil markets. He suggests that the answer is "no"—that supplies of natural gas have proved remarkably stable for two reasons. First, gas (unlike oil) has many competitors for supplying its service, notably electric power, and thus strategic interruptions quickly become self-defeating for the exporter. Second, gas projects are generally much more capital intensive than most oil projects and thus the incentives strongly favor running a facility—such as a large production field or a LNG export train—at maximum capacity once the facility is operational, rather than adjusting output according to the price-fixing aspirations of a cartel. (By contrast, one of the chief enforcement mechanisms of OPEC has been the availability of spare capacity, notably in Saudi Arabia, that was built with low capital cost and is relatively easy to operate when needed.) Victor also notes that the experience in most gas markets is that prices follow oil—either by fiat (e.g., oil-indexed contracts) or de facto (e.g., due to substitution between gas and oil products such as residual fuel oil). Thus insofar as the goal with "gas security" is to dampen price swings then success with oil security will, in turn, have positive effects for gas.

The important issues for gas, argues Victor, concern investor confidence. Gas can help to promote diversity in fuels, and it has a special role to play in supplanting carbon-intensive coal for the generation of electric power. Yet the most important frontiers where investment in new electric power generating capacity is intense and coal is the incumbent—China, India and the United States—are all countries where gas resources that are readily at hand appear to be dwindling. For these and similarly situated nations, there has been a special wariness about dependence on imported gas. The issues are most striking in the market that is least well developed (China) and thus perhaps most vulnerable to supply interruptions. In China's case, the most interesting and attractive gas supply options are Russia—notably the huge Kovykta field near lake Baikal. Yet Russia's Gazprom wants to send that gas to the main Russian market in the West, and so far Gazprom has blocked the Kovykta project; China fears that if such a western export infrastructure were built that Kovykta supplies would not be secure for China. Similar issues arise in India, with pipelines from Iran, Bangladesh and Myanmar all technically feasible yet encountering substantial political obstacles (e.g., crossing Pakistan). For the U.S. the issues are different and relate to perceived insecurities in LNG supplies. For all these items, perhaps the L20 could play a role. With China and Russia, or with India and her potential suppliers and transit countries, perhaps the L20 could help to provide an umbrella for these countries to reach agreements on security of supply. For all countries, perhaps the L20 could call for (and ensure the success of) efforts to ensure that LNG remains a safe and viable option. In the former, the L20's role would be as a political guarantor; in the latter it would use its convening power to ensure that a vital technology is nurtured.

Nuclear: Taming Proliferation and Encouraging the Next Wave

Finally, Burt Richter looks at nuclear power. Richter notes that for large quantities of electric power generation—notably in the developing countries, which are likely to account for nearly all the incremental demand—the most abundant and least costly fuel is coal. The large-scale pollution consequences of a massive coal program have forced a rethinking and new embrace of nuclear as a largely pollution-free option for generating electricity. About three-quarters of the 440 existing reactors are in the OECD; many of the new reactors being built are in developing countries, most in Asia. Net growth in nuclear generation could be modest (e.g., 16%) or robust (60%), a range suggested by the IAEA that reflects uncertainties in cost, safety, political acceptability, waste handling, and other issues.

Richter suggests that there are enormous uncertainties surrounding the fuel cycle. Some of these are technical and relate to the relative merits of a "once-through" system (which generates much waste but has been a favorite of the U.S. because of its resistance to proliferation) and systems that involve varying types and degrees of fuel reprocessing. A robust future for nuclear power would seem to imply significant amounts of reprocessing, not least because a simple once-through cycle would generate unmanageable quantities of waste. Richter favors the French system for reprocessing, although there are other alternatives, and he notes that any scheme would involve working at scale with technologies that remain immature. Richter also notes that the dangers of proliferation arise not only with the "back end" of the fuel cycle (i.e, reprocessing and treatment of spent fuel) but also the "front end" (i.e., enrichment of raw uranium). Thus a system for supplying nuclear fuel implies intervention in the full fuel cycle. Richter notes that recent reports have found that once-through and many variants of reprocessing fuel cycles have similar scores in their vulnerability to proliferation, which suggests that regardless of the fuel cycle chosen a reinvigorated effort to manage proliferation is needed.

The L20 could play several roles here; Richter's analysis suggests three that our meeting should discuss. First, there may be a need for collective efforts to study and demonstrate key technologies needed for a proliferation-resistant fuel cycle. Indeed, there is a long history of cooperation on big technology programs—not only in nuclear power but also the Human Genome project, the space station, geophysical research, and other areas. Second, particular facilities may merit collective operation either because they are too expensive for one government to run on its own or because it would be unacceptable to some nations that just one (or a few) have full control over the critical equipment. Third, Richter gives particular attention to the growing interest in a truly international fuel cycle that would put key facilities into some form of international control. Such a system, if designed well, could help to reduce proliferation by hardening the fuel cycle against breaches and also increasing the odds that countries would rely on a superior international system rather than their own (probably proliferation-prone) national systems. On all three of these fronts the L20's role could include the creation of a political framework needed for success as well as the establishment of funding mechanisms and oversight. Mindful of that potential, however, many countries are also pursuing their own fuel cycles, and in a few cases the existing IAEA safeguards against proliferation from those fuel systems have already proved inadequate, and thus any effort by L20 to become involved in such issues must contend with both their political difficulty and the already existing array of international arrangements, including bilateral technology sharing programs and notably the IAEA's multilateral program.

WHAT IS MISSING?

These five papers and our agenda are far from a comprehensive treatment of the issues. We have focused on oil because of its central importance and considered other elements that are critically important and also allow for a more diverse analysis of possible roles for the L20. Nonetheless, we have left many stones unturned. Among them are possibly aggressive programs to improve investment in energy conservation and collective efforts to boost renewable energy sources. Nor have we considered the many intriguing options for advanced coal combustion.

In an effort to draw attention to elements that may be missing from our deliberation, we offer a simple listing of some possible actions that the L20 could take in relation to energy security—beyond the items discussed in more detail above and in the five other background papers:

- Expand the Bio-energy and the Renewable Energy and Energy Efficiency Partnerships and encourage the World Bank and the financial industry to devise ways to reduce the cost of financing renewable energy investments
- Instruct Trade Ministers to work together within the Doha trade round to replace food production subsidies with incentives for farmers to grow environmentally beneficial bio fuel crops;
- Ask the World Bank, WTO and the OECD to develop incentives, policies and programs to give priority to overcoming barriers to clean energy. Make Gleneagles' call for voluntary energy savings assessments mandatory;
- Evaluate the feasibility of quantitative bio fuel standards and targets for transportation;
- Instruct Finance Ministers, with the assistance of the IMF, to introduce, as appropriate, fiscally neutral GHG taxes, to be harmonized with the design of an internationally agreed tradable permit framework. Countries could retain the option of a "safety-valve system", that is, national tradable permit systems with government promise to sales of additional permits at a stated price (and thereby cost) ceiling. Taxes can have a powerful effect on emissions;
- Pursuant to Gleneagles' encouragement of co-ordination of international policies on labelling, standard setting and testing procedures for energy efficiency appliances, phase in global efficiency standards; apply the same approach to automobiles;
- Coordinate the provision of tax credit schemes and other incentives for technologies that exceed standards (including automobile manufacturing industry);
- Implore member nations to fund incentives by redirecting fossil fuel subsidies;

- Coordinate the creation of greater economies of scale through mass support for marketable or near market technologies such as hybrid or hydrogen vehicles.

We include this list not as an endorsement of its elements but as a reminder of the wider array of items that could be included in a package that the L20 could craft. By the end of our meeting we aim to have identified some of the main elements of such a package, along with an agenda for the L20 session itself.

QUESTIONS TO CONSIDER

We close with two broad questions that will help to focus our deliberations over the two days of the meeting.

First, if there is an L20 meeting with energy security on the agenda, what would be a pragmatic substantive outcome? What decisions at the leaders' level will yield benefits for large, important developing and industrialized countries—such that leaders will be willing to back them at L20 and beyond? What elements relate to short-term aspects of energy security and which require a longer term perspective?

Second, how would advocates for the L20 get there from here? In particular:

- What are the specific decisions and actions implied in each of the background papers, and which packages of actions are likely to be most attractive?
- What message or series of events would entice key countries—notably the United States, the EU and China—to embrace energy security as a subject for L20 attention?
- How do we catalyze support from civil society, including business?

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The Changing Risks in Global Oil Supply and Demand:

Crisis or Evolving Solutions?

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Executive Summary

The future of energy is of enormous importance. The global energy market is intricate and the analysis of it is uncertain. The ability of policy planners and strategists in petroleum-consuming nations is limited at best. Most of the known world reserves exist in regions and countries that are not stable. Consumers cannot control where oil reserves exist and the geostrategic risks are not likely to change in the near future.

The dynamics of the current oil market rely on four major interdependent areas of uncertainty: geostrategic risks, macroeconomic fluctuations, nature of resources risks, and the uncertainty in current and future oil production capacity.

At this point, about all that is certain is that the global energy market is unpredictable and that recent oil prices have been high and volatile. In four years, the price per barrel of oil has increased by roughly 108%. The price of crude oil averaged $25.9/barrel in 2001 and for the first eight months of 2005, the average price crude oil increased to approximately $54.1/barrel.[i]

Rigorous, transparent, and credible analysis, however, can improve our understanding of the forces at play and provide policy makers and analysts the tools necessary to forge sound energy policy based on real-world realities and risks.

Key Geopolitical Uncertainties

The six major petroleum-producing areas (Middle East, Africa, Asia-Pacific, Europe-Eurasia, North America, and Latin America) face major production and resource uncertainties. It is clear the geostrategic risks facing these regions have tangible implications on their energy sector and on the global petroleum market. The geopolitical and military implications are hard to quantify. The risk premium of these uncertainties, however, will be affected by the following key geostrategic challenges, all of which could have direct and indirect affect on the global energy market:

- **Stability of oil exporting nations:** The stability of oil producing nations is of paramount importance to the world oil market. The strikes in Venezuela, the War in Iraq, and the ongoing disruptions of Angolan and Nigeria oil were examples of what could happened if this happened in other countries such as Saudi Arabia and Iran.

- **Terrorism in the Gulf and oil facilities securities**: While the threat from Iran's conventional military may be real, the more dangerous threat is that of extremists groups' asymmetric attacks on oil facilitates. The Gulf contains over 65% of the world's "proven" reserves. There is no attack-proof security system. It may take only one asymmetric or conventional attack on a Ghawar or tankers in the Strait of Hormuz to through the market into a spiral at least for the near future.

- **Proliferations of WMD**: The success in stopping the AQ Khan does not mean the end of a nuclear black market. It remains a real threat to the entire world, especially the Gulf, of a nuclear weapon falling in "the wrong hands" such as Al-Qaeda.

- **Embargos and sanctions:** Another OPEC oil embargo is very unlikely, however, if oil is ever used a weapon to combat US or Western foreign policy or if sanctions were imposed on Iran, for example, it will have devastating effects on the global economy.

- **Ethnic conflicts and strives:** Disagreements over the control of oil revenues by ethnic groups can destabilize countries and disrupt the flow of oil. Currently, the ongoing conflict in the Niger Delta and the War in Iraq provide two examples of how devastating such crises are.

- **Natural disasters:** Natural incidents in production, export, or refining areas can be damaging to the energy market. Hurricanes in the Gulf of Mexico have caused supply and distribution disruption in the US, and have added large premiums to the price of a barrel of oil. Hurricanes Katrina and Rita, which hit the US during August and September 2005, shut down most of the refineries in the US Gulf of Mexico and forced the US to release some of their strategic petroleum reserves.

- **Security problems and accidents:** The world can absorb the problems created by most forms of local conflict and internal security problems when there is significant surplus capacity and prices start from a relatively low base. Behavior changes drastically, however, when supply is very limited and prices are already high. Even potential threats to petroleum production, exports, and distribution can radically alter prices and market behavior. Actual attacks, or major industrial accidents, can have a much more serious impact. The loss of a major supplier, or a sustained major reduction in regional exports, potentially can have unpredictable price and supply impacts that impact on the entire global economy.

Stability in petroleum exporting regions is tenuous at best. Algeria, Iran, and Iraq all present immediate security problems, but recent experience has shown that exporting countries in Africa, the Caspian Sea, and South America are no more stable than the Gulf. There has been pipeline sabotage in Nigeria, labor strikes in Venezuela, alleged corruption in Russia, and civil unrest in Uzbekistan and other FSU states.

Experts believe that, in the near future, energy supply and transportation routes may be challenged by transnational terrorism and proliferation. It is equally possible that recent surges in the demand for oil, supply disruptions by hurricanes, the US refining capacity bottleneck, and the limited spare production capacity will continue to test the energy market in the mid to long-term.[ii] Natural disasters, such as hurricanes and tsunamis, may also prove to be troublesome to the instability of the energy markets by causing production, transportation, and refining disruptions.

Macroeconomic Fluctuations

Like all economic forecasts, predicting supply, demand, and prices of crude oil involves significant uncertainty. Predicting the oil market is notoriously difficult and constant updates and additions to the models are needed. The most recent EIA, IEA, and OPEC forecasts have not been adjusted to consider long-term oil prices in the $50 and above range, even in their high oil price case. Only the EIA analysis partially addresses high price cases for petroleum and it does not examine the influence these high prices would have on the demand, supply, and the long-term elasticity of global energy balances.

The following key factors influence the oil market, and each involves major uncertainties and unknowns:

- **Problems in import-dependent developing countries**: Countries with relatively free market economies that are highly developed are rich and flexible enough to adapt to high prices and supply problems far more flexible than poor countries, countries with serious foreign reserve and balance of payments problems, and importers with high levels of subsidies for oil and gas. By and large, the impact of high prices is not modeled in such terms.

- **The sustainable and spare capacity of oil producing countries:** There is a growing debate over spare capacity of OPEC nations, and their ability to “balance the market.” Perceptions are as important as realities. The market’s lack of confidence in the producers to meet the demand adds a risk premium to any estimates and pushes prices up.

- **The cost of sustaining and expanding petroleum production and exports, and of the necessary investments**: Most of today's estimates of the cost of future production are badly dated, and do not take into account the cost of the most advanced technology for exploration, development, and production, or the scale of the investment needed in distribution in areas like port facilities, new tankers, refineries, etc. Cost models need a major reevaluation.

- **Country capability and practice in sustaining and expanding petroleum production and exports:** There is little effort to assess country-by-country capability to use best practices, and adopt the most advanced technology and methods. Countries like Kuwait and Iran have failed to move forward in using such practices for very different reasons. Countries like Iraq face insurgency, the risk of civil war, and a long legacy of underfunding proper development.

- **The long-term elasticity of demand:** The development of alternative sources of energy, efficiency, and conservation have long-term effect on the market, but time lags, investment costs, and delivery prices are uncertain at best in the foreseeable future.

- **The Long-term elasticity of supply:** Major debates exist over the size of proven, possible, and potential resources' rates of discovery, development and production costs, fields' life, and the impact of advanced technology.

- **The refining capacity and inventory build up of the importing nations:** The lack of ability by importing states to refine crude oil and distribute it to the domestic market in a timely manner can build bottlenecks. These bottlenecks exert upward pressure on the price of crude oil and squeeze the average consumer at the gas bump.

- **The overall health of the global economy:** While it is clear that oil prices and economic growth in developed countries are negatively correlated, it works both ways. High oil prices have negative effect on economic growth in consuming states, but low economic growth in industrialized nations causes a decrease in demand for oil and lower oil prices.

- **The rise of new economic powers:** In recent years, the oil market has experienced an unexpected increase demand of oil from countries in Asia such as China and India. According to the IMF, this surge from emerging countries could account for 40% of the increase in oil demand in 2004.

- **Lack of investment:** These pressures and uncertainties add to the economic risk premium causing oil prices to rise further. Moreover, while higher oil prices may provide incentives for private and public investment in the oil industry, the lack of geopolitical stability, and ability to predict how long high oil prices will continue, prevents many from investing in these areas.

  Providing the kind of massive surges in the demand for oil projected in recent studies, requires massive investments to build new infrastructure and finance new technologies. In 2003, the IEA projected that the world oil demand would rise by 60% by 2030, and that the world energy market would need $16 trillion of cumulative investment between 2003 and 2030 or $568 billion a year. Even this estimate is based on unrealistically low estimates of investment cost and outdated assumptions about the sophisticated exploration, development, and production technology and equipment needed in modern oil fields. Yet it still requires vast transfers of capital.

It is too soon to draw any firm conclusions about the impact of high oil prices on global oil dependence, on US and other imports, and on increases in conservation and the supply of alternative fuels, but these factors indicate that high prices are not necessarily bad for the global economy and could trigger market forces that offset their short-term negative effects. The fact, however, is that no one really knows given the complex mix of elasticities involved because meaningful modeling and analysis is only beginning.

Nature of Resource Risks

Given the strategic risks faced by oil producing nations, claims about production goals and capacity and oil reserves have long been a political tool. Some producers have inflated their “proven” reserves to project strategic importance, which has added to the uncertainty and the lack of transparency.

The fall of the Shah in 1979 and the Iran-Iraq War, for examples, led to a competition in the Gulf to announce new levels of “proven” reserves to demonstrate the strategic importance of given countries, and major increases in the claims made by Iran, Iraq, Saudi Arabia, Kuwait, and other countries.

Limited hard data are available to validate many national claims and plans. Yet, credibility in this area is of enormous importance because as we will see key modelers depend on each country’s report for their demand-driven models to forecast the global supply and demand. In many cases, data are lacking, there is little validation and transparency, and current models and estimates simply assume levels of petroleum capacity that may never exist.

The global energy market faces key uncertainties in the determining the exact nature of reserves, which include:

- **True nature of reserves:** There are ongoing debates on the reliability of reserves. The USGS 2000 continues to be the benchmark estimate. However, as with any estimates, forecasting uncertain. Furthermore, analysts disagree about the definition of “known” vs. “undiscovered” vs. “proven” resources.

- **Impact of technological gain:** Some experts argue that aging oil fields have higher water cuts and that “vertical” wells cannot be used. Other energy estimates do not take into account new technological developments, which may change the estimate of “possible” & “probable” reserves.

- **Ability to substitute for current super-giant and giant fields:** Some experts have argued that new field discoveries do not support reserve estimates, and major producers such as Saudi Arabia, Iraq, Kuwait, and UAE rely on aging super-giant fields that were discovered in the 1950s and 1960s and are in decline, and that none of their kind has been found in recent years.

- **Rate of decline in fields:** The percentage of the oil reserves in the fields that have pumped out is a contentious and uncertain estimate. Analysts and investors have to rely on independent estimates and the announcements by oil companies.

- **Rate and size of new developments and discoveries:** Outside analysts have to rely on the discovering country’s announcement and statement for estimate of any new discoveries. Moreover, it remains uncertain whether certain countries are “over explored” or “under-explored.”

- **Inaccuracy of 3-D seismic modeling:** Some experts have argued that new technologies that use computer modeling are not enough. They provide a good estimate of possible reserves, but they do not replace old fashion drilling and physically measuring actual reserves.

In many cases, it is not clear that the Energy Information Administration (EIA), International Energy Agency (IEA), Organization of Petroleum Exporting Countries (OPEC), or United States Geological Survey (USGS) have applied sufficient rigor to a country-by-country reexamination of such estimates. (The USGS does use a different methodology because it looks at the basins on a geological potential basis, but the data available are uncertain and dated.)

Lack of Robust Modeling

Modeling urgently needs to examine supply-driven models, not just demand-driven models. Equally important, the key modelers of global energy supply and demand have not yet chosen to react to the recent rises in oil prices and examine cases that go above

$50 a barrel in detail. There have been some preliminary efforts by the IMF and the EIA in its *International Energy Outlook 2005.* Projections by OPEC, the IEA, and the latest EIA's forecasts need to be revised or expanded to examine such cases, and to examine the implications of a world with a "sustained" $60/barrel, $80/barrel, or even $100/barrel oil.

The modeling of sustained high price cases is just beginning, but previous modeling efforts do provide important warnings. If oil prices drop back to the level between $31 and $35 a barrel (in 2003 dollars), as assumed in the reference case of the *International Energy Outlook 2005*, the EIA estimates that world demand for oil will increase from 78 MMBD in 2002 to 119 barrels per day in 2025. This projected increase of world oil demand would require the global oil production to increase by 42.0 MMBD over the world's 2002 capacity levels--accounting for approximately 38% of the world's energy consumption through 2025.[iii] In addition, a 2004 EIA report estimates that the US and its major trading partners in developing Asia will account for 60% of the increase in world demand through this period.[iv]

More generally, many laymen do not understand the wide range of problems in foundations on which forecasting methodology is based. It is all too clear that the modeling the EIA, IEA, and OPEC used in the global petroleum supply and demand forecasting has been driven by estimating global demand at comparatively low oil prices.

Reports by the EIA, IEA, and OPEC could provide a better benchmark for the global energy market if they addressed certain areas of deficiencies. The key gaps and areas of uncertainty in the *International Energy Outlook 2005*, for example, include:

- **Parametric analysis:** They lack of any parametric analysis of its oil price forecast. Furthermore, models such as the IEO treat major shifts in energy cost and different levels of economic growth largely as independent assumptions and variables.

- **Economic growth rates:** They do not provide sufficient explanation as to how the rates of economic growth interact with the price of oil and how the price-elasticity of demand changes over time given an economic growth rate.

- **Countries' plans:** They do not take into account country-by-country plans in forecasting oil production capacity. If they do, there is little explanation of how such plans have changed since their last forecast and how realistic or unrealistic those plans are.

- **Indirect imports:** The reports do not make estimates of indirect imports of oil/petroleum from other regions in terms of the energy required to produce finished goods. The US, for example, indirectly imported very significant amounts of oil in the form of manufactured goods from Asian countries dependent on Middle Eastern oil imports.

- **Technological improvements:** They do not explicitly analyze technological improvements and the role technological breakthroughs in enhancing oil recovery and exploration for new oil reservoirs, development that have significant affects on future oil supply and the oil market.

- **Relation of oil prices to demand of alternatives and conservation:** No credible explanations are given of the interactions between different oil prices and the level of oil supply and demand, or changes in the supply and demand of gas, coal, nuclear power, renewables, electricity, and conservation.

- **Supply and demand elasticities:** No effort is made to determine the very different patterns of elasticity in supply and demand for gas, coal, nuclear power, renewables, electricity, and conservation that have to emerge over time if oil prices remain so much higher than in the past, or the major uncertainties that will inevitably result from such changes.

- **Discontinuity theory**: Models and forecasts use smooth curves and largely "static" assumptions. Growth in demand and supply tends to be at constant rates or in predictable curves. Reality never produces consistent trends or allows trees to grow to the sky. There is a clear near for an assessment of what kind of sudden events or discontinuities are critical and for some form of Baseian approach to risk analysis.

As a result of these gaps, the current forecasts of EIA, IEA, and OPEC now do little more than illustrate what might happen in a world where virtually everything goes right from the importer's view, where export capacities automatically respond to need, and political and military risk have no impact.

Oil Production Uncertainties

If high-sustained demand growth actually occurs, virtually all sources indicate that it will put a growing strain on both global petroleum supply and export capacity. The BP's *Statistical Review of World Energy 2005* reported that in 2004, the average total world production was 80.26 MMBD—higher than the 2003 average by 3.206 MMBD. In 2004, OPEC produced 32.927 MMBD, which is a 7.7% increase from their 2003 production levels of 2.241 MMBD, Russia increased its production by 0.741 MMBD (+8.9%), and China by 0.089 MMBD (+2.9%).[v]

Non-OPEC supply so far has been slow to respond to the high oil prices. In fact, it increased by only 0.046 MMBD in 2004 (31.8% of which came from the FSU). According to the US DOE, the expected increase in Non-OPEC oil production for 2005 is 0.92 MMBD.[vi] In the years of 2005 and 2006, more than half of this non-OPEC increase is estimated to come from the FSU and the Atlantic Basin, including Latin America and West Africa.[vii]

The EIA forecasts the total world production capacity in 2025 for the low, medium, and high price cases as follows: 135.2 MMBD for the low price case, 122.2 MMBD for the reference case, and 115.5 MMBD for the high price case. In both the 2004 and 2005 cases, the projected increase in total world production capacity is still significant. By 2010, it could increase from 14.6 MMBD to as high as 21.6 MMBD. The "high price" case, however, is far easier to achieve in the real world than the "reference" or "low price" cases.

As is clear from these numbers, as the price oil decreases, production capacity increases. One notable exception is that Non-OPEC countries' production capacities have the opposite reaction to a change in the price of oil. OPEC countries largely drive this relationship between price and production capacity. From an economics point of view, a decrease in the price of oil decreases the willingness of suppliers to produce and sell oil. The *IEO2005*, however, shows the opposite effect for OPEC countries. One possible explanation is that OPEC countries control the price of oil with their quotas.

The shift toward high oil prices could, however, sharply reduce the growth in future demand for oil, and lead to major new investment in all forms of energy supply, conservation, and efficiency. In the interim, however, the following points production and resource risks now affect oil-producing nations in their efforts to expand their spare capacity:

- **Little "sustainable" spare capacity:** With the exception of Saudi Arabia, in 2005, the rest of the world had no spare capacity. If there were sudden surges in demand (high economic growth) or distributions in supply of other exporters (the Iraq War in 2003, Venezuela strikes in 2004), will producers be able to meet such shortage?

- **Elasticity in importer conservation, efficiency, and alternative supply and time/uncertainty lags:** One of the flaws of the current forecasts by the EIA, IEA, and OPEC is that they do not take into account changes in the elasticity of supply and demand. Long-term and mid-term elasticities have an impact on the demand, supply, and price, which in turns changes investment incentives and production capacity.

- **Producablilty at given prices:** Some experts have argued that the "easy oil" era is over. Oil recovery is more costly, and the price of oil has to be high enough to cover variable, fixed, and sunk costs and investment, but not too high that it exerts downward pressure on demand.

- **Technological gain in the upstream & downstream sector:** Current production capacity forecasts do not and may not be able to anticipate technological gains in the upstream side of the industry, especially demand-driven models. Producers strive to improve efficiency by investing in R&D and new technological innovations, but it remains uncertain how much, how, and when these technological gains may bear fruits in terms of real-world change in the level of recovery.

- **The "sustainable" inflow of foreign investment:** Natural depletion of current oil fields is inevitable. Expansion programs, therefore, are needed to replenish this natural decline, but developing countries are in need of foreign investment in terms of both capital and technological sharing. The lacks of security and stability, rigid foreign investment and tax laws, and limited transparency have prevented the inflow of much needed foreign investment into developing countries.

Estimates of near term spare capacity are increasingly uncertain and inevitably differ. According to the IEA, in early 2005, OPEC had 1.92-2.42 MMBD spare capacity, but according to the EIA, it had 1.1-1.6 MMBD. In both cases, practically all of the spare capacity was from Saudi Arabia. HETCO forecasted that in 2005, OPEC would increase its production by 0.70 MMBD. Again, most of the increase will depend on Saudi Arabia's ability to increase its capacity. HETCO forecasted an increase in Saudi production capacity from 10.68 to 11.15 MMBD.[viii]

Solving Supply Issues Relating to Middle Eastern Oil

The potential impact of high oil prices in easy the strain on world oil supplies becomes clearer when one looks at the impact of oil prices on the need for Middle East and North Africa (MENA) conventional oil production capacity.

- The *IEO2004* called for major increases in MENA oil production capacity. It forecast that Saudi Arabia's production capacity in 2025 would be 31.5 MMBD for the low price case, 22.5 MMBD for the reference case, and 16.0 MMBD for the high price case.

- The *IEO2005* forecasts that conventional MENA production capacity in 2025 will be 51.1 MMBD for the low price case, 39.5 MMBD for the reference case, and only 28.1 MMBD for the high price case.

These contrasts are even more striking for Saudi Arabia. For many years, most of OPEC's projected increase in production capacity in both the EIA and IEA models has been driven by Saudi Arabia. In recent times, the Saudi production capacity has received a lot of attention. Some analysts have questioned the Kingdom's ability to meet sudden surges in demand because of its lack of spare production capacity, and others – like

Matthew Simmons – have estimated that Saudi production may be moving towards a period of sustained decline.

In 2002, Saudi Arabia had an oil production capacity of 9.2 MMBD. This capacity was roughly 9.0-10.5 MMBD in 2004, and has so far averaged 10.5-11 MMBD in 2005. Like most of its predecessors, the *IEO* analysis for 2004 called for truly massive increases in Saudi oil. It forecast that Saudi Arabia's production capacity in 2025 would be 31.5 MMBD for the low price case, 22.5 MMBD for the reference case, and 16.0 MMBD for the high price case.

Te *IEO2005* forecasts that Saudi Arabia's production capacity in 2025 will be 20.4 MMBD for the low price case, 16.3 MMBD for the reference case, *but only 11.0 MMBD for the high price case. Yet, Saudi Arabia already plans to increase its production capacity to 12.5 MMBD by 2009.*

Most analysts, including current and former Saudi Aramco officials, believe that the 20.0 MMBD is an unattainable production capacity. At this point, one can argue that the Kingdom could reach this production capacity only if two things happen: there are major technological breakthroughs that enhance recovery of existing oil fields or help find new reservoirs and there are major supply disruptions that forces Saudi Arabia to meet the shortages in supply.

General Patterns of Oil Dependence

The US and China are key "drivers" in the increasing demand for energy imports and production capacity in most models. However, current models project that African and Middle Eastern imports could double by 2025. India could emerge as a major new importer, as could other Asian states. Russia could increase domestic consumption sharply in ways that would reduce its exports. Western Europe and Japan are the only major importers not projected to make massive increases in potential demand. Once again, however, the failure to model the high prices or examine supply by supply by supplier nation in credible terms, leaves massive uncertainties.

US Import Dependence

The US has become progressively more dependent on both a growing volume of imports and steadily growing imports from troubled countries and regions. Direct US petroleum imports increased from an annual average of 6.3 MMBD in 1973, to 7.9 MMBD in 1992 to 11.3 MMBD in 2002, and 12.9 MMBD in 2004. Some 2.5 MMBD worth of US petroleum imports came directly from the Middle East in 2004.[ix] Additionally, the average US petroleum imports from the Persian Gulf alone equaled 2.3 MMBD in the first 6 months of 2005, 2.4 MMBD in 2004, 2.5 MMBD in 2003, 2.2 MMBD in 2002, 2.7 MMBD in 2001, and 2.4 MMBD in 2000.[x]

If one looks at OPEC exports as a percent of US imports, these ranged from 47.8% in 1973, and 51.9% MMBD in 1992, to 39.9% MMBD in 2002, and 43.6% MMBD in 2004. If one looks at Gulf exports as a percent of US imports, these ranged from 13.6% in 1973, and 22.5% MMBD in 1992, to 19.7% MMBD in 2002, and 19.3% MMBD in 2004.

Future US gross petroleum imports will vary sharply according to price. If prices are low ($20.99/barrel), imports rise to 47.86 MMBD in 2025. If prices are moderate ($30.31/barrel), US gross petroleum imports are still 43.43 MMBD. If prices rise to $39.87/barrel, however, US imports are only 38.87 MMBD, and they would be far lower at $50, $60, $70, or more per barrel. Even the "high price" case leaves the US with nearly 60% dependence on oil imports in 2025, but the impact of this dependence on world supply is far lower than if oil prices are low or moderate. The EIA estimates of future US imports indicate that moderate oil prices will lead to major increases in US imports from the Gulf (from 2.5 MMBD in 2000 to 6.0 MMBD in 2025), the Americas (from 3.1 MMBD in 2000 to 5.0 MMBD in 2025), and "other" including North Africa (from 2.7 MMBD in 2000 to 6.2 MMBD in 2025).

The size of direct US imports of petroleum is only a partial measure of US strategic dependence on imports. The U.S. economy is dependent on energy-intensive imports from Asia and other regions, and what comes around must literally go around. While the EIA and IEA do not make estimates of indirect imports of oil from the Gulf and other regions in terms of the energy required to produce the finished goods, the US imports them from countries that are dependent on Middle Eastern exports, analysts guess that they would add at least 1.0 MMBD to total US oil imports.

The failure of the DOE and the EIA to explicitly model such indirect imports, and their steady growth, is a long-standing and critical failure in US energy analysis and policy. It seems almost certain that the that the future increase in such indirect imports will, for example, vastly exceed any benefits in increased domestic energy supply that will result from the energy bill just passed by the US Congress in the summer of 2005.

Surge in Chinese and Indian Demand for Oil

According to China's state media reports, China imported 79.9 million tons of oil in first three quarter of 2004, which represented a 40% increase from the first eight months of 2003.[xi] In 2002, China consumed 5.0 MMBD. According to EIA 2005 high price estimates, this number *could* triple by 2025 (12.50 MMBD for the low price case, 14.50 MMBD reference case, and 16.1 MMBD for the high price case).[xii]

According the BP *Statistical Review of World Energy 2005*, Chinese imports totaled 3.40 MMBD in 2004. China imported 0.15 MMBD from the US, 0.038 MMBD from South and Central America, 0.052 MMBD from Europe, 0.365 MMBD from the FSU, 1.264 MMBD from the Middle East, 0.709 MMBD from Africa, 0.045 MMBD from Australasia, 0.044 MMBD from Japan, 0.824 from other Asia Pacific, and 0.010 MMBD from others.[xiii]

China's domestic production could reach 3.8 MMBD in 2020, but its demand is likely to be more than three times as high.[xiv] During 2004, China imported 40% of its oil consumption, despite the fact that it produced 174 million tons of oil during the whole year. Some experts believe that recent high oil prices can provide the right incentives for investment into new technologies to enhance recovery and exploration and increase China's domestic output, and reduce reliance on oil imports.[xv]

There is also the "India factor." Oil composes 30% of India's energy consumption, but the country has only 5.4 billion barrels of oil.[xvi] India in 2001 consumed 2.1 MMBD, 2.2

MMBD in 2003, and according to the EIA's reference case forecast Indian consumption will reach 2.67 MMBD in 2010 and double to as high as 4.9 MMBD in 2025.[xvii]

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[i] WTI Crude oil spot price, adapted from the EIA historical database, available at: http://www.eia.doe.gov/oil_gas/petroleum/info_glance/prices.html

[ii] John J. Fialka, "Search for Crude Comes With New Dangers," *Wall Street Journal,* April 11, 2005.

[iii] EIA, *International Energy Outlook 2005,* July 2005, Pages 2-3.

[iv] See http://www.eia.doe.gov/emeu/cabs/pgulf.html, DOE/EIA estimated in September 2004 that the Persian Gulf contains 715 billion barrels of proven oil reserves, representing over half (57%) of the world's oil reserves, and 2,462 Tcf of natural gas reserves (45% of the world total). In addition, at the end of 2003, Persian Gulf countries maintained about 22.9 MMBD of oil production capacity, or 32% of the world total. Perhaps even more significantly, the Persian Gulf countries normally maintain almost all of the world's excess oil production capacity. As of early September 2004, excess world oil production capacity was only about 0.5-1.0 MMBD, all of which was located in Saudi Arabia.

According to the Energy Information Administration's *International Energy Outlook 2005's* reference case forecast, Persian Gulf oil production increased from 18.7 MMBD in 1990 to 22.4 MMBD in 2001 to 20.7 MMBD. It is expected to reach about 28.3 MMBD by 2010, and 35.2 MMBD by 2020, and 39.3 MMBD in 2025.

The estimate, however, does change in the high oil price case: it is expected to reach about 24.4 MMBD by 2010, and 26.2 MMBD by 2020, and 27.8 MMBD in 2025.

[v] EIA, *Monthly Energy Review*, March 2005, Page 149

[vi] Edward Morse and Thomas Stenvoll, "The New Supplier(s) of Last Resort," *Weekly Market Review*, Hess Energy Trading Company, LLC, April 1, 2005.

[vii] EIA, *International Energy Outlook 2005*, July 2005, Page 26.

[viii] Edward Morse and Thomas Stenvoll, "The New Supplier(s) of Last Resort," *Weekly Market Review*, Hess Energy Trading Company, LLC, April 1, 2005.

[ix] BP, *Statistical Review of World Energy 2005,* June 2003, Page. 17.

[x] EIA, "Petroleum Imports from Qatar, Saudi Arabia, U.A.E. and Total Persian Gulf," *Monthly Energy Review,* August 2005, available at http://www.eia.doe.gov/emeu/mer/pdf/pages/sec3_9.pdf

[xi] "China reports soaring oil imports," *BBC News*, available at: http://news.bbc.co.uk/1/hi/business/3654060.stm

[xii] EIA, *International Energy Outlook 2005*, July 2005.

[xiii] BP, *Statistical Review of World Energy 2005*, June 2005, Page 18.

[xiv] Jin Liangziang, "Energy First: China and the Middle East," *Middle East Quarterly*, Spring 2005, available at: http://www.meforum.org/article/694

[xv] "China to control its reliance on oil imports," *Xinhua*, April 23, 2005, available at: http://www2.chinadaily.com.cn/english/doc/2005-04/23/content_436862.htm#

[xvi] EIA, Country Analysis Brief, "India," available at: http://www.eia.doe.gov/emeu/cabs/india.html

[xvii] EIA, *International Energy Outlook 2005*, July 2005.

Coordination of Oil stocks and Interventions in the Oil Markets

Klaus-Dietmar Jacoby*

1. Background

To give some background to the rationale behind the establishment of stocks of oil to be used strategically during emergencies, I will refer to historical precedents in the United Kingdom and France. The origin of the notion of the need for oil stocks to be used for national security goes probably back to World War I, when Lord Admiral Winston Churchill first became aware of the need to procure fuel (in this case, coal) for his military fleet. In 1917, France experienced a rupture in oil supplies when its army required more petrol than was available, as available supplies were diverted for use in the Russian Revolution and by American submarines. Consequently, in 1925, France imposed on its oil industry to reserve stock representing 25% of the declared amount of oil delivered for consumption during the last 12 months, or 91.25 days of domestic consumption.

In order to supply fuel for military operations during World War II, countries resorted to compulsory demand restraint programs such as fuel rationing. As Germany had no indigenous oil production, it succeeded in a type of ersatz fuel switching by converting coal into a type of petrol. But it was following Egypt's blockade of the Suez Canal in the 1950s that European politicians became increasingly aware of the necessity of maintaining oil reserves. Eventually, in 1968, the six members of the European Economic Community (Belgium, France, Germany, Italy, Luxembourg, and Netherlands) agreed to maintain a minimum level of crude oil stocks and oil products corresponding to 65 days of domestic consumption. In 1972, this obligation was raised to 90 days.

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The IEA's initial stockholding obligation as formulated in 1974 was "to maintain emergency reserves sufficient to sustain consumption for at least 60 days with no net oil imports" [Article 2.1 of the International Energy Program (IEP)]. In 1975-6, the Governing Board raised the minimum legal obligation from 60 to 90 days by stipulating incremental increases until the 90 days' level was achieved in 1980. Throughout the 1980s and 1990s, the overall emergency reserve stock level of IEA net importing countries has been well above 90 days, peaking at 193 days in 1986. The IEA used its stocks in 1991 during the Gulf War, when it made 2.5 million barrels per day available to the market.

By the latter half of the 1990s, many changes in the oil market resulted in a renewed focus on assuring supply of oil in case of a disruption for both oil-producing and –consuming countries. The market became more globalize with increased production from of non-OPEC producers, and output increased to keep pace with the booming U.S. and Asia Pacific economies. But OPEC's slow reaction in adjusting its production quotas to accommodate the Asian economic crisis of 1998 and U.S. economic downturn of 2000 made oil prices drop. Emergency plans and procedures of the International Energy Agency and its member countries were reviewed and reshaped in anticipation that possible computer problems related to Y2K could seriously impact energy security, Then, just as OPEC and non-OPEC producers had instituted lower production quotas to regain control of oil prices in 2001, the terrorist events of 9/11 raised fears that oil could again be used as a weapon.

Other geopolitical events, along with perceived diminution of the ability of oil producers to compensate for a supply loss by using spare capacity, have acted to create a climate of uncertainty about future supply. In 2002-3, problems in Venezuela led to a strike at PDVSA, causing Venezuelan production to plummet. Both social unrest in Nigeria, which affected that country's oil production, and the second war in Iraq in 2003 reinforced possible risks of a significant supply disruption. With spare capacity in oil-producing countries at historical lows and demand from fast-growing economies like China or India increasing, the market must find new balance. In this context, economies are more vulnerable, as increasingly high oil prices could negatively effect economic growth. Also, because of tighter management of stocks due to technological innovation, even historically smaller supply disruptions could have significant market ramifications. Reminding the world of the existence of the IEA's collective stockpile through well-timed news releases serves to assuage the insecurity.

A core activity of the International Energy Agency is to create a reliable emergency response policy. The IEA was established after the first oil price shock in 1974 with an overriding mandate to establish, maintain and improve systems enabling our member countries to mitigate the risk of oil supply disruptions. The Agency's 26 member countries span the globe. Broad membership is important as interdependency in the global oil market means that regional disruptions have the potential for global impact. The IEA includes major oil producers and consumers in its outreach activities and collaboration on energy security issues.

With globalisation and interdependency of energy markets, the IEA's energy security focus relates not only to oil security but also encompasses gas and electricity. Security of natural gas supply, in particular, is becoming more important with the growing share of gas in the global energy mix.

Furthermore, it is now widely understood that the attainment of energy security embraces other policy objectives too. Indeed, as far back as 10 years ago, IEA member governments stated their "Shared Goals," which included a commitment to "seek to create the conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and the well-being of their people and of the environment."

2. Response Measures and Procedures

By signing the IEA treaty - an "Agreement on an International Energy Program" (IEP), 16 OECD countries founded the IEA as an autonomous body of the OECD. The IEA now has 26 Member countries which represent some 60% of total world oil demand and include all EU countries as well as some of the new EU countries. Core commitments of the member countries under the IEP Agreement include:

- The maintenance of oil reserves equivalent to at least 90 days of net oil imports;
- To have ready a programme of demand restraint measures to reduce national oil consumption by 7 to 10%; and,
- To participate in an oil sharing system in a severe supply disruption using these tools.
- In addition, member countries cooperate with the oil industry for advice and operational assistance in emergencies.

The committee for discussion and development of security policies and procedures is the IEA Standing Group on Emergency Questions (SEQ), which is comprised of representatives from our member countries, together with a representative of the European Commission as an observer. The SEQ makes recommendations to the IEA Governing Board for consideration and adoption and it is assisted by an Industry Advisory Board, which includes senior representatives of oil companies headquartered in IEA member countries.

To reflect the evolution of energy markets since the IEA was established, its underlying IEP Agreement treaty obligations to share oil in an emergency have been reinforced by a system of co-ordinated emergency response measures that can be readily calibrated to the circumstances at hand. This concept, introduced in 1984, is known as “Co-ordinated Emergency Response Measures” (CERM). It established a flexible framework for international consultations on co-ordinated stockdraw and other response measures in the event of an actual or potentially significant oil supply disruption. The formal sharing system has not been deployed to-date and CERM-based collective responses reflect the belief that, under normal circumstances, the global oil market is fully capable of determining the most efficient initial physical re-allocation of supplies in any given crisis scenario. Collective action utilizing stocks and other measures provides a strategic safety net to reinforce the market.

3. Response Potential

On the supply side, stocks are by far the most rapid and effective response measure to meet physical supply shortfalls or the threat of an imminent shortfall. IEA stocks are for strategic use to avoid negative economic impacts of a severe supply disruption; they are not to be deployed as a means to manage the market.

As at 1st June 2005, total combined government-controlled and industry-held stocks in IEA countries were about 4 billion barrels. IEA net importing countries held an amount equivalent to 118 days of the previous year’s net imports, but when stocks held by net exporting members are taken into account, stock coverage actually rises to the equivalent of 152 days of net imports, well above the minimum requirement of 90 days. The ready availability of stocks is important when OPEC spare capacity is unsure and commercial stocks are low. In this context the IEA Secretariat sees, with some satisfaction, a trend in member countries to create or increase Government-controlled stocks in place of mandatory industry stocks. With the completion of U.S. effort to fill its Strategic Petroleum Reserve (SPR) to its 700 million barrel capacity, the government-controlled reserves held by IEA members are at an all-time high of nearly 1.5 billion barrels. To put this in perspective, IEA government-controlled reserves could compensate for a 2 mb/d supply loss for about 700 days, nearly two years. IEA members also hold over 2.5 billion barrels of commercial stocks.

Other response measures on the supply side, such as fuel switching or surge production, would not contribute as much now as in the past. An IEA survey (IEA, 2001) showed that only a few countries like the United States, Japan or Italy have significant potential to switch from gas to oil or vice versa, a result of the trend to replace oil with natural gas in electricity generation. Nevertheless, the IEA is updating this fuel switching survey and will discuss the outcome and implication on short and long term policies. The capacity for surge production as a potential response to a global supply disruption has also diminished.

On the demand side, policies and measures to save oil have a relevant importance, particularly for the transport sector. Member countries are obliged by the IEP to have ready demand restraint programmes which may include light-handed measures to increase public transit usage, car-pooling, eco-driving, telecommuting (working at home) and speed limit reductions as well as more compulsory measures like driving bans and fuel restrictions. The IEA 2005 study, "Saving Oil in a Hurry", evaluated the potential oil savings by various measures if implemented in all our member countries with the conclusion that, *inter alia*:

- Car pooling and driving bans could save more than one million barrels per day.
- Speed limits, free public transit, telecommuting, compressed work week (fewer but longer workdays), driving bans (1 in 10 days) and eco-driving can save more than 500 000 barrels per day.
- Other measures such as reduced speed limits, encouraging public transit, telecommuting, compressed work week, driving bans and eco-driving could save more than 500,000 b/d.

4. IEA Co-ordinated Action

There has been no need to draw on IEA's emergency stocks since 1991, but as widely reported in the press, this does not indicate inactivity. Indeed, as scenarios evolved in the wake of September 11th, the strike action in Venezuela, unrest in Nigeria and war in Iraq, the

IEA Secretariat was carefully assessing the situation on a daily basis and kept in close contact with our member countries, the oil industry and strategic non-member countries. The IEA and its member countries were ready to act in coordination with oil-producing countries, in particular, with OPEC countries, and the markets knew it. For these reasons, the possible risk of a supply disruption was minimized and price spikes and their duration were limited.

The IEA regularly carries out Emergency Response Exercises, which serve to train to staff in Administrations and industry in IEA emergency procedures as well as to give the opportunity for an in-depth exchange of views between experts from Administrations and the oil industry to review procedures and to introduce, if necessary, new measures to react to market changes. Since 2002, these exercises have included participants from major oil consuming countries outside the IEA, like China. In 2004, a special Emergency Response Exercise for non-member countries with the participation of delegates from China, India, ASEAN countries, Brazil and new EU member countries was held.

Most recently, IEA member countries were tasked with developing a response to a series of supply disruption scenarios. From this, we learned that an overwhelming majority would first use stockdraw (82%), followed by demand restraint (12%), and then fuel switching or other measures (6%) -- answers which closely corresponded to the actual IEA response during the first Iraq war in 1991-92.

5. Security of Gas and Electricity Supply

The IEA's work on energy security is not limited to oil. In particular, the concept of security of gas supply has broadened beyond country borders. The external dimension of security of supply requires increased attention given the growing import dependency of most IEA member countries. While import dependency is not, in itself, a threat, it requires governments and companies to pursue their efforts to diversify natural gas supply (supply sources and mode of imports: pipeline gas vs. LNG) and transmission routes.

With liberalisation of the natural gas industry, the market is becoming more fragmented due to both the unbundling of activities and the entrance of newcomers in the market. The responsibility for security of supply has therefore to be defined and shared between all players involved, including governments, producers, suppliers, traders, regulators and customers. Policy makers have the responsibility of creating a framework for security of supply and defining the objectives for security of supply and the responsibilities of each market participant. For some countries, gas storage will be the most economic choice for ensuring security; for others, supply flexibility and diversity is adequate to ensure security.

The IEA (IEA, 2004) published a comprehensive study on "Security of Gas Supply in Open Markets" and is involved in monitoring gas security in its member countries. It has also started a dialogue with member governments and the gas industry to review the changing concept of security of gas supply in open gas markets and the roles of the different stakeholders. However, it is our belief that when the framework has been defined and the role of the different players defined, governments should leave market players the choice of instruments/means to provide the required level of security of gas supply.

Electricity is also a concern of supply security, as several shortfalls in recent years in OECD countries all over the world have shown. Similar to gas, electricity shortfalls have mostly national and regional impacts but no global ones. Therefore, while there is no urgency to introduce global emergency response policies and measures, there is nevertheless the need to analyse the different types of emergencies and how best to avoid shortfalls or to remedy the situation. In this context, the IEA has recently published a study on "Saving Electricity in a Hurry" which deals with temporary shortfalls in electricity supplies. Key messages are how to develop a strategy to save electricity quickly and what measures might be appropriate to use.

6. Challenges

As the oil market continues to evolve, the IEA and its Members recognise the importance of keeping pace with market dynamics. One by-product of the increasingly sophisticated oil market is price volatility. This is an issue of common concern to producers and consumers. The IEA does not believe strategic oil stocks can be effectively used to address price fluctuations. This would distort market mechanisms and signals, and invites unnecessary confrontation with producers. The IEA believes emergency oil stocks should be reserved for emergency use. Issues of volatility and other market imperfections should be addressed, inter alia, through dialogue and data transparency.

The IEA's *World Energy Outlook* (forthcoming) projects that by 2030 the world will be consuming two-thirds more energy than it is today. Almost three-quarters of the increase in demand is expected to come from the transport sector and oil is expected to still dominate this sector. Meanwhile, consumption in developing countries and the transition economies is expected to grow much faster than in the OECD. Under one scenario, almost two-thirds of incremental demand for oil between now and 2030 is projected to come from outside the OECD, particularly from Asian economies.

If policies do not change and this scenario becomes a reality, it would have significant implications for security of supply which cannot be addressed adequately from an insular perspective. The success of IEA efforts today to reach out to these emerging consuming countries and to encourage the adoption by these countries of the principles embodied in the IEA's Shared Goals can, we believe, significantly improve global energy security in the coming decades.

The Agency is proactively involved in the wider producer/consumer dialogue at the Ministerial level in the International Energy Forum and at a technical level in the Energy Experts Meeting, as well as regional and topical workshops and seminars. Also, the Agency has Memoranda of Understanding in place with Russia, China and India and extends its global reach further through collaboration with regional organisations. The IEA is committed to forging a dialogue and cooperation with regional bodies, thus avoiding duplication of effort and ensuring that topics of specific regional concern are addressed and evaluated from a global perspective.

The span and scope of the Agency's outreach programme reflects the IEA's commitment to improved global energy security and a clear recognition of the increasingly global nature of security of supply issues. As advocates for the collective benefits to be derived from adherence to the IEA shared goals to which all EU countries subscribe, the IEA Secretariat is confident that with sustained and targeted effort, this wider collaborative effort will bear fruit and global energy security response policies will converge.

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Points to Discuss

- The IEA policy is that oil prices should not be used as a reason for an emergency stockdraw. (Only a severe supply disruption should serve as a trigger.) Do you think this economically reasonable?

- If oil prices increase further in the direction to $100/barrel, what do you think the IEA and its members should do?

    1. Implement voluntary and/or compulsory demand restraint programmes
    2. Change oil-related fiscal policy
    3. Declare a severe supply disruption and start drawing down stocks

- The IEA and its member countries released oil stocks only in response to the 1991 Gulf War. Do you think that the emergency stock potential has much more in common with deterrent systems like nuclear weapons, i.e. “show them but better not use them”?

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A World Agreement on Oil?

Richard N. Cooper

This paper addresses ways to cope with potential instability in the world oil market, with a view to whether action by the L20 can do anything about it. It is often said that the major geographical source of oil, the "Middle East," is a highly turbulent and politically unstable area. In fact, there has been remarkable political stability in the region, at least as measured by the longevity of its political leaders and key decision-makers. King Hussein of Jordan came to the throne in 1952, and Asad became president of Syria in 1972. Both have been replaced smoothly in the last few years by their sons. Rulers of Libya, Oman, and the UAE have been around for over 30 years. Saddam Hussein became president of Iraq in 1979 and was a key decision-maker before then; his rule was ended by the United States in 2003. Mubarak became president of Egypt after Sadat's assassination in 1981, and was just re-elected. Fahd became king of Saudi Arabia in 1982, but as Crown Prince he had been effective ruler for seven years before then; the pattern was repeated when Abdullah became king on Fahd's death in 2005, after about a decade as effective ruler as Crown Prince. Even the Iranian revolution and its firmly ensconced clerical regime are now 26 years years old. Only Lebanon and the Palestinians have experienced continual turbulence during the past three decades, and neither is directly concerned with production of oil.

It is true that oil supplies have been disrupted three times by political turbulence, in 1979-80 with the Iranian revolution and subsequent invasion of Iran by Iraq; in 1990 with Iraq's invasion of Kuwait; and in 2003 with the US invasion of Iraq, following a long UN embargo that limited Iraq's exports of oil. In all cases Saudi Arabia (and others) increased their production of oil to compensate for the shortfall, although not with perfect timing.

Interruptions in flows of oil can originate outside the Middle East as well, as we have learned in recent years with serious disturbances in Nigeria and in Venezuela in 2003, and with the extensive damage to both crude production and especially refinery production by hurricane Katrina on the US Gulf

Coast in 2005. Nonetheless, there are some reasons to be concerned about potential turbulence in the Middle East, for at least three reasons. First, the Israel-Palestinian conflict remains unresolved, and could flare up to a point at which Arab oil suppliers curtail their exports (or more likely limit increases in production) to show sympathy for the Palestinians and to put pressure on the United States to be less solicitous of Israel.

Second, some states have designs on their neighbors, although the removal of Saddam Hussein has probably limited the main threat under this heading. Only Jordan among countries in the region has settled borders; and Iran may desire to destabilize the regimes of neighboring countries if not literally coveting their territory (although it occupies several islands claimed by the UAE). Further afield, Kashmir (between India and Pakistan) and Cyprus (between Turkey and Greece) remain areas of contention, although each is over a thousand miles from Kuwait at the head of the Persian Gulf.

Third, several countries face acute problems of succession after today's long-lived leaders pass away (Libya and Egypt especially come to mind), although as noted recent successions in Jordan, Syria, and Saudi Arabia have been relatively smooth. Islam as a creed for political organization holds leaders accountable to the rule of law as well as to specifically religious injunctions on behavior. So rulers that deviate from acceptable behavior risk religious wrath, and authoritarian regimes provide no peaceful outlet for this dissatisfaction. The clerical regime in Iran faces the age-old tension between Islamic severity and Persian indulgence, as well as tensions with Iranians who wish to be part of the modernizing world.

Nonetheless, the governments of the oil-producing countries have a continuing interest in producing and selling oil, since it is the main source of public revenue in all the oil-producing Middle Eastern countries, and they are unlikely deliberately to disrupt the flow of oil. They may however resist increasing supplies in the interests of raising world oil prices.

The last qualification is highly relevant. The US Department of Energy projects world demand for oil (assuming 3.0 percent growth in the world economy and an oil price of around $27 a barrel) to grow from 77 mb/d in 2000 to 121 mb/d in 2025. More than half of this growth needs to come from

OPEC, concretely from Venezuela and the Middle East, the only areas of OPEC that can expect to produce substantially more oil than they are now providing. Thus if this 2004 projection comes to pass, world dependence on oil from the Persian Gulf will grow substantially, from 29 percent of the world total in the mid-1990s to nearly half in 2025. To provide this increment of over 25 mb/d, significant investment in exploration and development must occur in the countries of the Persian Gulf, and especially in Saudi Arabia, which allegedly has the largest proven reserves, at around 250 billion barrels, but with Iraq, Iran, Kuwait, and UAE all making significant contributions.

Vulnerability

For the reasons noted sitting governments are not likely deliberately to disrupt the flow of oil. Disruptions are therefore most likely to arise from internal conflicts between contending claimants to leadership. This could arise either as an inadvertent by-product of the conflict, or deliberately if one faction wanted to deny oil revenue to a competing faction. A succession struggle is likely to be confined to a single country, although factions may enlist tacit or overt support from neighboring countries.

But that still leaves the possibility of disruption by non-state actors – disaffected ethnic, religious, or other political groups – attacking the sitting government or even the system of government; or by a government that perceives it has nothing to lose. How much damage could be done?

There are two sources of exit for Persian Gulf oil: (1) through pipelines to loading terminals in the Gulf, thence into tankers that exit through the Strait of Hormuz to the Arabian Sea and the open ocean; (2) through pipelines to loading terminals on the Red Sea (Saudi Arabia) or the Mediterranean Sea (Iraq through Turkey), thence into tankers destined for distant refiners and distributors. Before reaching the loading terminals the oil must be gathered from disparate oil wells and the gas and other unwanted materials separated from it. Thus there are four potential bottlenecks: gas-oil separators, which are large, expensive pieces of equipment; pipelines to terminals; loading terminals, which are relatively few in number; and the Strait of Hormuz. For oil pumped to the Red Sea, the Suez Canal might seem to be a potential bottleneck. But it was closed for 15 years following 1967, giving great encouragement to supertankers, the largest of which are too large to use even the enlarged Canal, but offer cheap transportation despite that. In any case, the most rapidly growing markets for oil are in Asia, and tankers can exit the Red Sea to the south.

Pipelines are long and vulnerable, and can be cut without too much difficulty. But they are easy to repair. Gas-oil separators are highly specialized and expensive machines, with long procurement lead times. A loss could be significant, but can be avoided by installing spare capacity and ordering spare machines. Loading terminals are robust and relatively easy to protect physically against raids, except by a well-armed foreign power. Of course, effective protective, preventive, and remedial measures assume that a government is effectively in charge. Civil war or major and persistent guerrilla actions could be highly disruptive.

What about the Strait of Hormuz? Despite its constrictive appearance on a world map, this is not a small body of water. The Strait is about 35 miles wide at its narrowest point (about twice the width of the English Channel), and exceeds 45 meters in depth throughout most of its width, sloping gradually from the Iranian side to over 200 meters deep off the coast of Oman. The two ship channels (one for incoming vessels, one for out-going vessels, each two miles wide with two miles separation between them) lie wholly within the territorial waters of Oman at the Strait's narrowest point. In the mid-1990s traffic averaged about 60 ships a day, roughly one-quarter of which were tankers. This is heavy, but only one-third the traffic through the slightly narrower Strait of Malacca, and somewhat lighter than the traffic through the much narrower Bosporus.

The Strait of Hormuz is thus much too large and too deep to be blocked, as the Suez Canal was in 1967. Military forces could however attack shipping, and the Strait could be mined by a national power of some means. Iran could do either. It has acquired Kilo-class submarines from Russia and land-based silkworm missiles from China. Its air force has attack planes originally provided by the United States and France. It mined the Persian Gulf during the 1980-88 Iran-Iraq war, especially after Iraqi aircraft bombed its offshore oil-loading terminals, and presumably maintains a large inventory of mines. Of course such actions in the Strait, in the territorial waters of Oman, would be an act of war. Conceivably, Iran could deny responsibility for mine explosions that damaged one or several ships. It could even feign participation in search for mines. The presence of mines would inhibit commercial shipping, and insurance rates for Gulf-bound vessels would rise substantially, perhaps prohibitively. So some disruption could be caused, but short of war it would be temporary. Even with war, the Strait could be cleared relatively quickly (measured in weeks, not days) if US and allied forces were engaged to do so.

But as noted above, Iran has no interest in preventing oil from being shipped out of the Persian Gulf, or merchant goods from being shipped into the Gulf. Iran is highly dependent on both oil revenues and on imported goods. Thus an attempt by Iran to block the Strait would be an act of desperation, induced by what Iran considered extreme provocation, such as an attempt by its neighbors or the international community to embargo or blockade Iran.

Thus we have two questions: Will the Persian Gulf countries make investments to increase oil production on the required scale? Will the world find it acceptable to be drawing such a high proportion of such a critical product from a single region? These questions in turn suggest two quite different strategies, the first to do what can be done to assure the required investment, the second to diversity energy sources so significantly that the investment will not be required. Both require international collaboration, but of quite different kinds, and involving different parties.

First strategy: Assuring Saudi Investment

The first strategy is to persuade the Gulf governments, and especially the government of Saudi Arabia, the key player, to commit to making the extensive investments required, over time, to increase oil production and export by the required amounts to assure a price, say, in the range $20-25 a barrel (in dollars of 2005). Government commitments are required because all these countries have national oil companies that control the flow of oil, although how Iraq rebuilds its productive capacity remains to be seen, and could involve private companies to an extent not seen in the Gulf since the early 1970s. This assumes, of course, that the Gulf countries can increase their oil production by a factor of roughly two over the next two decades. Matthew Simmons (2005) has recently argued, based on an examination of hundreds of technical papers by petroleum engineers working in the country, that Saudi Arabia is currently at or even exceeds its optimal economic production, that except for two areas the country has been widely explored, that further large fields are unlikely to be discovered, that the current large fields are being over-exploited (from the perspective of ultimate recovery) and soon will experience declining production. Saudi Arabia will therefore have to struggle to maintain production in the vicinity of ten mb/d; doubling that production on a sustained basis, on this view, would be impossible. The Saudi government, in contrast, has recently suggested that it will increase productive capacity to 13 mb/d, although so far as I know there is no evidence, either in terms of committed funds or exploratory and developmental drilling, to suggest that the process has actually started.

The L20 might provide a forum in which Saudi Arabia could be cajoled to provide much more information than it has traditionally done on its capacity-building plans, and secondly to commit itself to make investments in new capacity against expected growth in world demand for oil (net of increased non-OPEC production), including the construction of spare capacity to help deal with occasional shortages arising elsewhere, as it has in fact done during the past 30 years; and to stock spares of expensive, long-lead time equipment such as gas-oil separators, as insurance against terrorist or other disruptive actions. Such investments would themselves (by agreement) be made more transparent, be monitored, and be the topic of occasional review by the L20 or their deputies. The commitment also might involve the construction of new or enlarged pipelines to the Red Sea, to reduce dependence on the Persian Gulf as a point of exit, although this might be less economic in view of the rapid growth of markets for oil east of Arabia.

Such a commitment by Saudi Arabia would no doubt also stimulate the other Gulf countries to increase their investments in additional production, so long as it could be done economically, so as not to lose market share to Saudi Arabia. The details of allocation of additional investment (including perhaps Venezuela, the other OPEC country with significant known possibilities for expanding production) could and would no doubt be worked out within OPEC.

The other major oil producers within the current list of L20 countries are Russia and Mexico, as well as Canada and the United States. Russia at least in principle allows private exploitation of its oil reserves, subject to government taxation and other government regulations, although that may change in the coming years. Mexico maintains a national monopoly on oil exploitation, and has (deliberately?) limited its increases in production more or less to incremental domestic needs during the past two decades, although that may be due in part to technical limitations on the ability of Pemex to exploit increasingly deep offshore oil. Both countries would no doubt demonstrate a strong interest in any L20 discussions of oil production, but neither is in a position to make the commitments (assuming Simmons is wrong) that Saudi Arabia is, and the policies of each would very likely be influenced by any prospective commitment by Saudi Arabia, and indeed could be made part of a broad L20 agreement.

This strategy of course implies increasing dependence for oil on OPEC, and on the Persian Gulf in particular, with the vulnerabilities noted above. Furthermore, it would re-enforce the position of Saudi Arabia in the world oil market, and in particular its ability to threaten to withhold oil (explicitly or implicitly) motivated by political or economic considerations. Such a strategy would place heavy weight on continued cooperation by Saudi Arabia over the coming years within an agreed L20 framework.

If these consequences are unacceptable, an alternative strategy is needed.

Second strategy: Vigorous Diversification of Energy

The starting point for the alternative strategy is that high and growing dependence on the Persian Gulf for a critical input to modern economies is unacceptable at a fundamental level, particularly when the critical resource is state controlled and sold at a price that is routinely managed through restriction of supply – the situation that has obtained since 1974. This alternative involves an aggressive pursuit of conservation and development of substitute products. To be viable, such a strategy requires agreement on an effective floor below which oil prices would not be allowed to drop, say $20 a barrel, to prevent Saudi Arabia from undermining alternative investments through occasional bouts of low pricing.

The elements of such a strategy have been outlined in many places: most explicitly by Shultz and Woolsey (2005), but also in Lovins and Datta (2004), and in Lackner and Sachs (2005). New technologies are not required for a serious start, although existing technologies would be improved and near-proven technologies would be developed more urgently if such a strategy were adopted. The key elements would be: 1) pushing motor fuel conservation hard, especially clean Diesel and hybrid vehicles; 2) high priority work on improved batteries to further (1); 3) pushing ethanol and bio-diesel hard, especially cellulosic biofuel that relies mainly on agricultural and forestry waste products; 4) faster development of Canada's (and perhaps Russia's) tar sands; 5) further development of coal liquefaction.

Hybrid cars – internal combustion combined with electric motor – can double the mileage of automobiles and light trucks. They could be strongly encouraged, either by raising CAFÉ standards or by imposing higher taxes on gasoline and perhaps non-hybrid cars. Of course, people cannot buy more such cars than are being produced, so the automobile firms need to be encouraged strongly to increase their production of improved hybrid vehicles. Clean diesel fuel also significantly increases mileage, so the environmental regulations tilting against diesel should be reviewed in view of improved diesel fuel, as has been done in Europe.

Mileage can be increased further with better, cheaper batteries, which could fuel automobiles on short trips, 10-20 miles, which would cover most household auto use. Batteries could be charged from house current, at rates equivalent to $1 a gallon. This technology is not yet at hand, but it seems to be close; further work should be accelerated and, if successful, rolled out with the hybrid cars.

Mileage in terms of <u>petroleum</u> can be increased further by mixing gasoline with ethanol or making biodiesel from agricultural products, including waste products. Here the promising new developments are the possibility for using waste agriculture and forestry products, mainly cellulose, to produce liquid fuel through bio-transformation. Even offal from chicken rendering plants, and old tires – indeed almost any organic material – can be used. Automobiles using electricity and biofuels could reach mileages of up to 500 miles per gallon of petroleum product – a huge reduction in oil demand from that at present.

In addition, unconventional oil could be developed more rapidly, including the infrastructure to move it. The Canadian tar sands are said to be economic at $22 a barrel, and already produce about 1 mb/d. They are abundant – second only to Saudi Arabia in proven reserves – and are being developed, but could be developed faster and more conspicuously. Venezuela and Russia also have abundant tar sands that could and no doubt under the right conditions would be developed.

Finally, coal liquefaction is a proven technology. Germany used it during the Second World War, and South Africa developed operating plants in response to the economic sanctions that were imposed against that country for many years, and allegedly can produce liquid fuel from coal economically at $45 a barrel. With a large rollout and larger scale plants, this cost could undoubtedly be reduced, perhaps by fifty percent as suggested by Lackner and Sachs (2005).

The problem with such concerted strategy for reducing demand for petroleum, partly through conservation, partly through substitutes, is that Saudi Arabia (and perhaps others, such as Iran) could undermine any private investment based on an oil price in excess of $x by selling oil for long enough below $x to undermine the investment, in effect predatory pricing by a quasi-monopolist. Such a possibility strongly inhibits new investment in both high-cost conventional oil and in alternatives. Thus this strategy would be greatly enhanced by agreement among major users of oil not to accept oil priced below some agreed level, say $20 a barrel. Such an agreement would be implemented by agreement to impose a variable levy on crude oil from Saudi Arabia or elsewhere priced below $20, to bring the tariff-inclusive price to the targeted minimum. Such a tariff could be on an MFN basis; but so long as Saudi Arabia is not a member of the WTO it could legally be applied to Saudi oil alone, since that country is the major potential challenger to the strategy.

The main purpose of the strategy would be to reduce dependence on Persian Gulf oil. It would have the effect of weakening the oligopoly power of OPEC, but that would not be its main purpose. This contrasts with the suggestion of Morse and Jaffe (2005), who have proposed that Saudi Arabian oil be discriminated against unless Saudi Arabia opens its territory to private exploration and development. But compliance by Saudi Arabia with the Morse/Jaffe proposal would increase, not reduce dependence on Persian Gulf oil, although it would reduce state influence in oil pricing.

Composition of the L20

Either of these two strategies requires international cooperation: the first mainly by Saudi Arabia, the second by the major exporters of manufactured products, including China, Brazil, and India, to assure a common cost of oil, a key industrial input. Here is the conundrum: it is difficult to discuss Strategy 1 without the presence of Saudi Arabia, since agreement by that country would be necessary; it is difficult to discuss Strategy 2 in the presence of Saudi Arabia. Thus the composition of the L20 will shape, or at least limit, its agenda. The composition of the group needs to be formulated with an eye on the prospective agenda, and on desired outcomes.

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Energy Security:
The Gas Dimension

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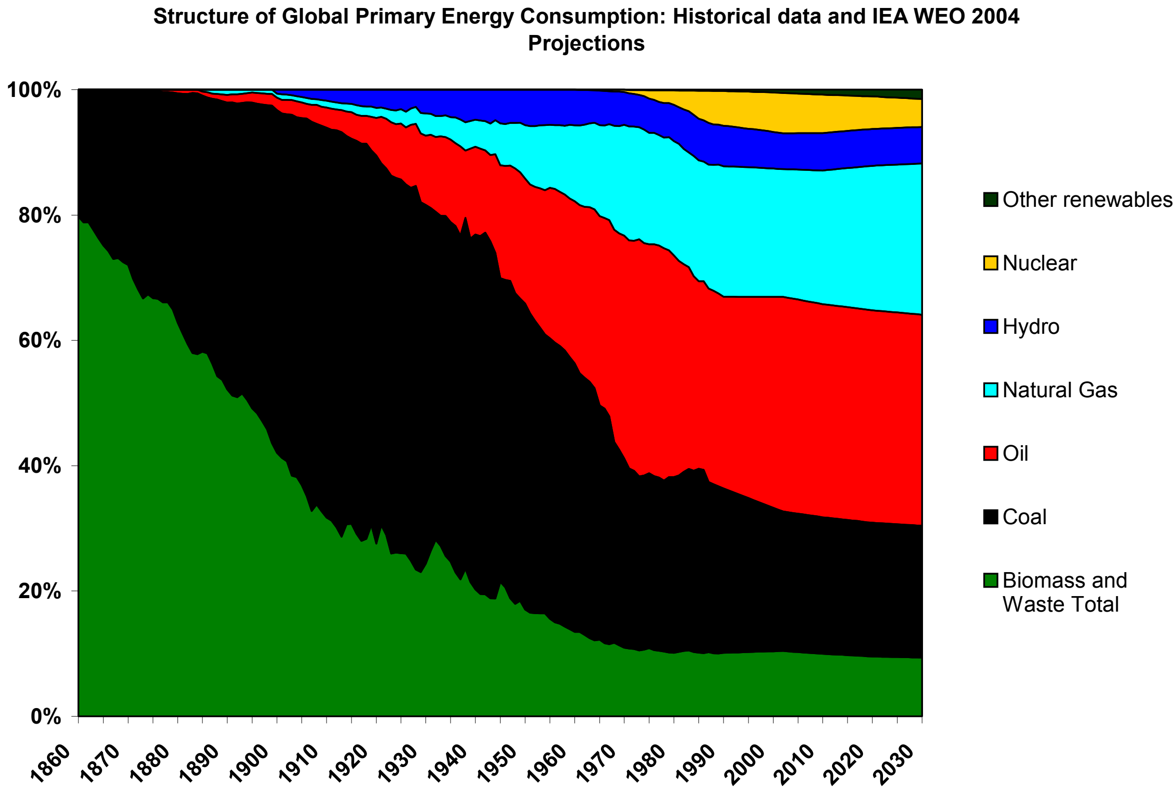
BEYOND OIL

For more than three decades Americans have examined their energy security through the lens of oil. Liquid in form and dense with energy, oil has been unbeatable in moving cars, trucks, and airplanes. Oil prices arise in a world market that is often buffeted by geopolitical gyrations, occasionally with severe effects on the world economy. Outside oil, however, questions of energy security have barely arisen. And while oil is the single largest source of primary energy for the world economy, nearly three fifths of the world's energy comes from sources that are close to home and available with confidence (figure 1).

This oil-centered concept of energy security is set to change rapidly. Prized for its high efficiency and clean burning, consumption of gas has grown sharply since the 1950. Natural gas has become an indispensable fuel, especially for the generation of electricity. Gas drillers, like all who hunt and gather, are exhausting the conventional gas sources close at hand and are now tapping more distant and exotic locales. Consequently, most of the world's largest gas markets face the prospect of importing large amounts of natural gas. In the United States, for example, onshore gas production is declining sharply; while deepwater production in the Gulf of Mexico and techniques for extracting the natural gas from coal seams in the West have filled the gap, total U.S. domestic gas production has been nearly flat since the early 1990s. Almost all the incremental U.S. demand in gas over that period has been supplied by imports from Canada; yet in recent years Canadian supplies have also begun to dwindle, leading North American gas users to look further afield.

Figure 1:



These issues are hardly unique to North America. In Europe, the gas market emerged in the 1950s around local supplies in areas such as in the Netherlands and in northern Italy. For the last three decades, however, most new supplies have come from outside western Europe—notably Russia and Algeria. About 30 percent of the gas in the west European market comes from Russia; the fraction approaches 100% in parts of central and eastern Europe where bottlenecks in the pipeline network and the absence of convenient alternative energy sources gives Russia (i.e., Gazprom) a secure monopoly. So far, Russia has proved to a highly reliable supplier. From the time that the first Russian export pipelines began operation around 1970, through even the darkest period of the cold war in the early 1980s, the record of Soviet gas deliveries was remarkably consistent. Only the 1990s—after the Cold War had ended—did the Russian supply hiccup for two brief periods. One, in 1995, arose in the wake of political turmoil in Ukraine, the main transit country for Russian gas exports. These troubles spurred Gazprom and a German importer to build a bypass line around Ukraine and through Belarus, which was seen at the time as more reliable. The second interruption, in February 2004, lasted only a day and involved relatively small amounts of gas in transit along that new pipeline across Belarus. Belarus had fallen out of Russian favor, and Gazprom was freezing its users to demand higher prices and control of the pipeline. These events are rare because Gazprom knows that they are a one-shot game. In the early 1980s Algeria—the second-largest exporter of gas to Europe, after the Soviet Union—left a costly pipeline that crossed the Mediterranean empty for nearly two years while it haggled over price. (At the same time, Algeria was the largest supplier of LNG to the United States and demanded higher prices. The U.S. government refused to let private importers pay the new price, Algeria's LNG supply faltered, and the U.S. actually shut one of its LNG terminals—only in 2004, more than two decades later, the facility on Elba Island was reopened.) The experience branded Algeria as an unreliable gas exporter and explains why Algeria, ever since, has fallen far short of its potential role of gas exporter. Algeria's catastrophic strategy—an effort to do for its gas exports what Algeria and other OPEC members had achieved in higher oil prices—is long remembered as a misstep. It is unlikely, but not impossible, that Russia could strategically or accidentally become a flaky supplier, and such a risk requires contingent planning.

In the coming decade the big news for gas-poor markets will be rising gas imports in the form of liquefied natural gas (LNG). There has been steady progress in the entire chain of LNG technologies—the compressors and coolers that turn it into a minus 260 degree Fahrenheit liquid, the stainless steel tanks and special ships for storage and conveyance, and the receiving terminals that regasify the liquid to useful form. The cost of moving a quantity of LNG today - through the whole chain of compressors, coolers, tanks, ships, and regasifiers - is just two-thirds that of the projects that began operation in the early 1990s.

LNG matters because it appears to be changing the structure of gas markets. In its natural state, gas is bulky and costly to move except by pipeline. Even as pipeline technologies have improved—in part under competition with LNG—it is impractical to build most pipelines longer than a couple thousand miles, and underwater pipelines are especially costly to install and operate. Thus most natural gas markets have been regional affairs—covering Western Europe, or bits of Latin America or North America, for example—often with large variations in price between markets because it was nearly impossible to move gas from glutted regions to those where prices were dear. As a compact liquid, natural gas can move in a global market.

LNG has allowed much longer distance gas transportation, but until very recently the LNG business did not yield an integrated world gas market. The reasons are technological, financial and political. The basic technologies for LNG have been known since the 1940s and were first used as convenient way to keep gas on hand for moments of peak demand. (The worst accident in LNG history occurred in 1944 at the very first of these early "peaker" LNG storage facilities—in Cleveland. A ruptured tank filled the sewers with gas, and the subsequent explosion killed 128 people and leveled one square mile.) As a scheme for bulk trading, LNG was really pioneered in the late 1960s by Japanese engineering companies; their government, aware that Japan's growth required energy resources and the country was poorly endowed with its own, led the effort. LNG trains are capital intensive, and justifying the expenditure required long-term contracts (typically 20 to 25 years). In this contracted market, there was no fungibility of supply, which is the hallmark of a global commodity. The banks that financed these projects liked point-to-point trading because revenues were easier to predict; the Japanese government also favored dedicated trading because it assured security. The business was extremely lucrative as the Japanese governments was willing to allow its gas and electric companies to pay high prices for LNG, which was seen as more secure than oil. While other countries—the United States, Korea, Taiwan, Italy, Spain and France—also imported LNG, Japan dominated the business and valued security over flexibility. Nearly everywhere, until the 1990s, LNG trading routes were more like long, dedicated pipelines than fungible cargoes that could sail to whatever port offered the best price.

These managed markets are now changing. The world's largest gas markets—the United States—is been open to competition since the late 1980s. The Western European gas market is now increasingly governed by rules and trading relationships that allow markets to determine prices and shipments. Elsewhere in the world—in South America and India, notably, but not yet in China—market forces are arriving, slowly, for gas. At the same time, the cost of LNG trading has declined—making it competitive with local gas sources in many markets, not just in security-minded Japan—and new suppliers and users of LNG are creating a liquid market. The significance of LNG is not its sheer volumes, but the prospect for arbitrage. The volumes are still small—in 2003, for example, just 6% of the world's gas consumption was moved as LNG. Even if the volumes of gas traded as LNG remain small, this arbitrage is already connecting disparate markets into something resembling a global market. As shown in figure 2, while the total production of gas today is about 2.5 times the level in 1970 international trade has risen sharply. LNG trade has increased more than sixty-fold during the period. Pipelines dominate international gas trade because bulk gas over relatively short distances is easier to move by pipe than as LNG (figure 3).

The emerging global gas market will force policy makers in the U.S. and other gas-using nations to adopt new thinking about energy security. LNG offers the potential for a more efficient and environmentally 'friendly' energy system, but the security challenges will be difficult to handle because they do not map easily onto any of the existing foreign policy apparatus. Key decisions about fuel choices will be made by regulators, especially in the electric sector, who are not accustomed to pursuing a global security strategy. Insofar as the LNG industry itself has worried about security, it has hardened its facilities against the already miniscule threat of terrorist attack; yet the much larger risks arise from market manipulation and interconnections in a global gas market that local regulators have barely contemplated. In addition to preparing the markets where gas is used, a successful gas security strategy will require engaging with the world's largest gas producers—notably Russia, which holds one-quarter of the world's gas reserves, is already the world's largest producer and exporter, and is best positioned to be a direct and indirect supplier to the U.S. market.

Figure 2:

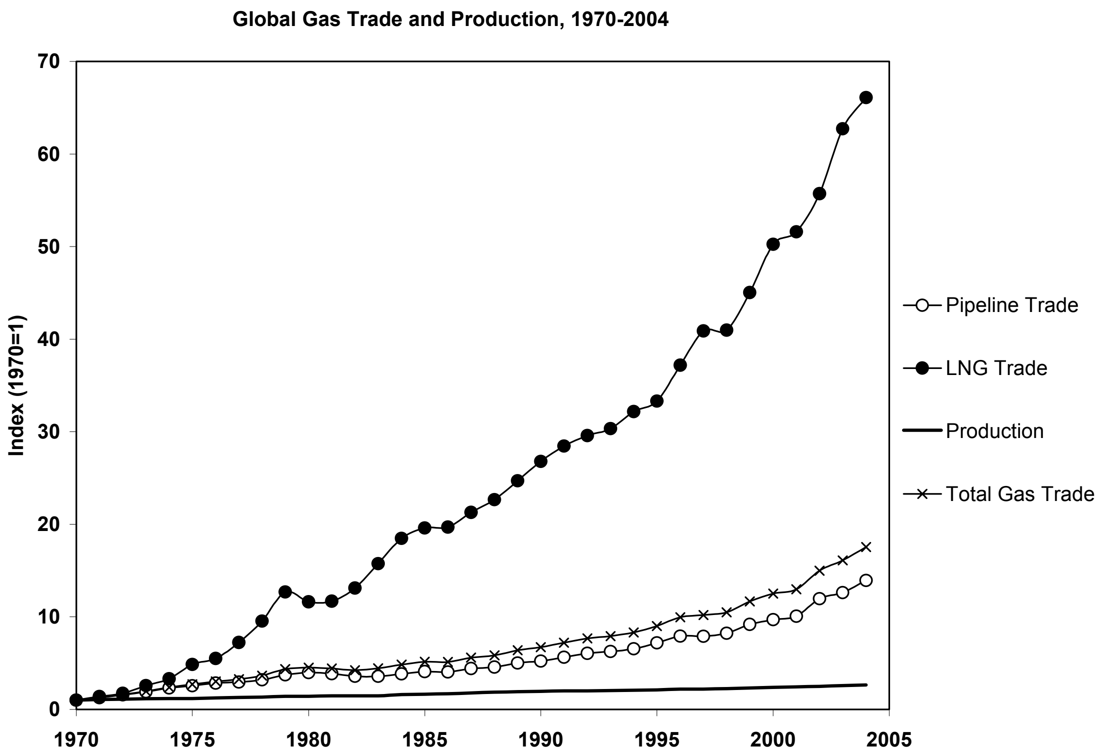
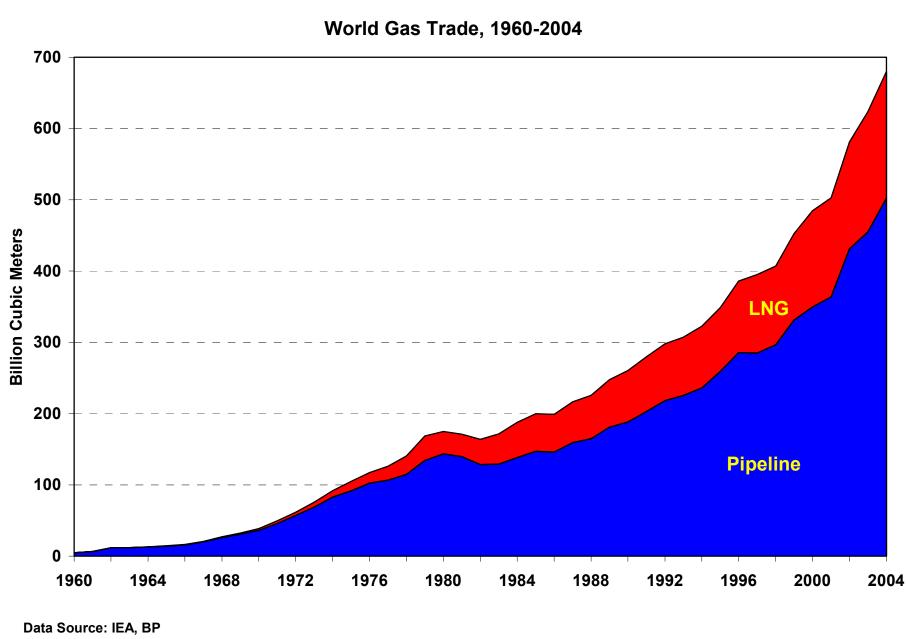


Figure 3:

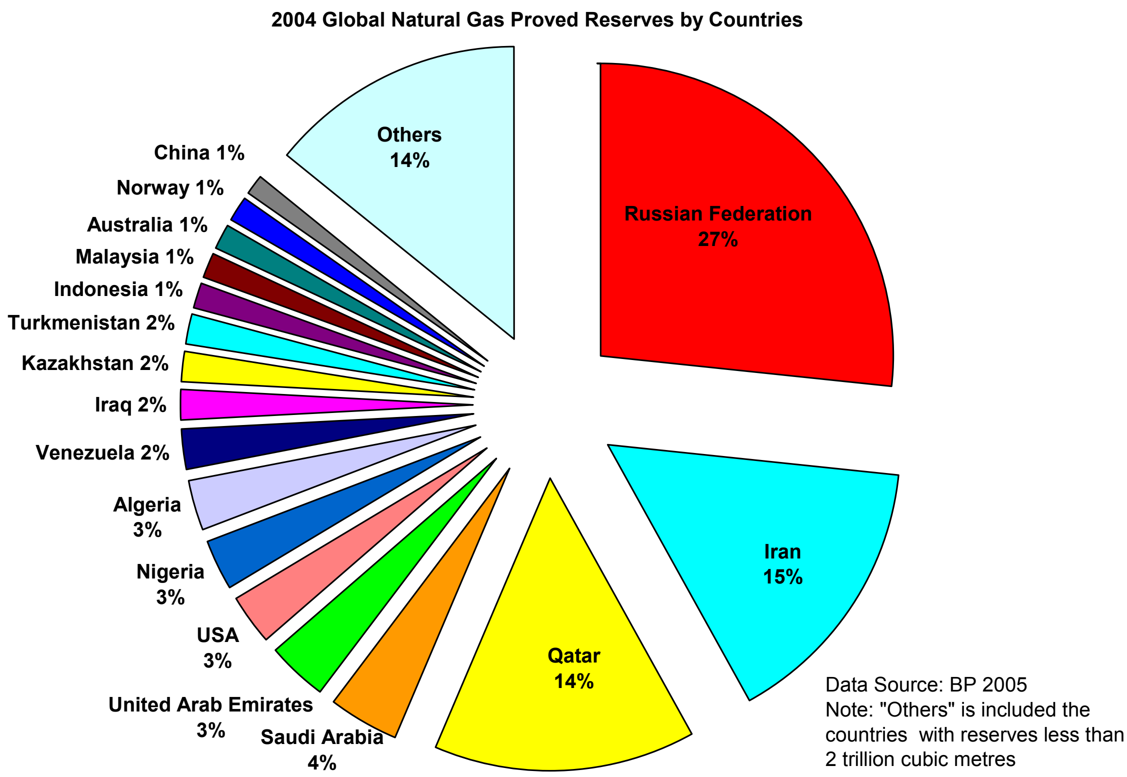


RUSSIA'S SPECIAL ROLE

A full tour of the world's gas producing and consuming regions is beyond the scope of this paper, but the most striking feature of this emerging gas market is the central position of Russia. Russia's proximity to the European market has already made it the world's largest gas exporter, accounting for 21% of all the international trade in gas. (The next largest exporter, Canada, is far behind.) Russia is poised to become even more dominant supplier in the global gas market. While world is generally rich in gas resources—proved reserves will last 70 years at current production level, and likely resources are many times that level—Russia unquestionably controls the largest cache (about 27 percent of the world total, see Figure 4). While most of Russia's richest resources are found in difficult terrain or distant from markets (or both)—in Northwest Siberia where permafrost makes it difficult to anchor equipment to the ground, in the icy seas off Sakhalin and in the Arctic where drilling is costly and dangerous, and off Lake Baikal where more than three thousand kilometers of pipelines are needed to reach the closest markets in China and Korea—technological change is making it feasible to tap those resources economically. The size of the resource is staggering. The giant Shtockman field in the Barents Sea, discovered only in 1988, has reserves double those of all Canadian gas fields combined. The Kovykta field near Lake Baikal holds roughly twice the reserves in all of China. Most of Russia's gas appears to be in the Far East where essentially none of the potential has been tapped; active drilling could find still more super-giant gas fields. With an attractive environment for investors to apply capital and new technology, Russia is the prize in the gas world.

Russia's biggest liability is the firm Gazprom, a state-dominated company that controls nearly all gas production, piping and distribution. Like most state energy companies, Gazprom is organized to yield political benefits rather than economic efficiency and sustainable profit. The firm is heavily indebted and would be bankrupt under western accounting standards. Its assets are not financial but political—Gazprom, unlike any other player in Russian gas, can mobilize the power of the Russian state and thus is assured of a lucrative role in any gas project. As incumbent owner of Russia's pipeline system it can control which firms are able to sell their gas, which explains why 93% of all the gas produced in Russia comes from Gazprom's own fields even though the ownership of gas resources is more evenly distributed and includes independent gas companies and oil companies. The neighboring gas-rich countries of Kazakhstan and Turkmenistan are also at the mercy of Russia and Gazprom when they attempt to move their gas across Russian territory to markets in Ukraine and especially the west. Landlocked Turkmenistan, is especially disadvantaged because it has huge gas production but no access to markets. Gazprom has forced Turkmenistan to accept prices that are about one-third the level at which Russia exports gas to the west and has appropriated the difference for itself. This predatory arrangement explains why Gazprom's production strategy for the near term relies on the fact that it is cheaper to buy gas from Turkmenistan than to invest in practically any new gas producing project.

Figure 4:



Gazprom's dysfunction is a looming problem for the West because Russia is already the largest fixture on the world gas market, and success in creating an attractive place for new production is important to the realization of a vision of globally available gas supplies at low cost. Western experts have poured obsessive attention on the need to open the Russian gas market to alternative suppliers, such as through the adoption of rules that allow "third party access" to the Russian pipeline network and break the grip of Gazprom on trading and marketing of gas. Such initiatives are probably a fantasy, and the most likely outcome is that Russia will sustain and solidify its position as the world's largest gas producer and exporter while, at the same time, keeping Gazprom intact. Indeed, within the last year Russia has not only reasserted it special position as Russia's gas hegemon, but it has also used the power of the Russian government to help acquire assets that are making Gazprom a large state-owned oil producer as well.

Among the many problems created by Russia's dysfunctional system for owning and managing its gas infrastructure is economic inefficiency. At present, Russia yields just 85 cents of economic output per cubic meter of gas that it consumes. In contrast, other nations that share Russia's frigid latitudes are much more efficient—for example, Canada produces $8 and Finland $32 in income for each cubic meter of burned gas. If Russia used gas with Canadian efficiency then Russia would liberate 360bcm of gas, or nearly three times as much as it exports today to all the European Union. Such comparisons are obviously unfair because Russia and Canada differ in many ways, but they are a first order indication of the massive inefficiency that remains to be undone. Skeptics will argue that so much will be difficult to change in Russia, but it is sobering to recall that the same arguments were made about the U.S. in the early 1970s. Faced with the shock of higher energy prices—a rise not dissimilar to the increase in internal prices that could occur in Russia—Americans found myriad ways to save energy. In 1974 the Ford Foundation published *A Time To Choose*, a report by the leading experts of the day on the possible futures for U.S. energy consumption to the year 2000. The actual energy consumption in the U.S. in 2000 was equal to the lowest level that the Ford group imagined would be achievable. With sustained effort, markets can deliver striking changes in technology and efficiency at a profit.

Russia is hardly the only potential supplier in this future gas market. Other countries rich in gas resources could emerge as pivotal. Iran, with the world's second largest resources, is geologically well positioned. However, the Iranian political climate is a liability in the new world of global gas trading and private investment. Even more than in Russia, private investors in Iranian gas projects must contend with the risk that the political environment could shift, stranding investments. (And American companies are completely excluded from Iran due to U.S. sanctions.) Iran's largest gas field is offshore in the Persian Gulf and shared with Qatar, whose fortunes are rising because the government has been able to combine its rich gas resources with a political and commercial environment that investors believe is stable and conducive to long-term projects. Gas resources are abundant elsewhere in the world, and in some places have been able to offer similarly attractive commercial settings. Australia, Egypt and Libya are among the rising stars; Algeria's star appears to be fading; Trinidad, Nigeria, and Indonesia are among the other large established LNG suppliers that seem likely to remain important. But only Russia combines a pivotal position in both the bulk pipeline export of gas (thanks to its proximity to Europe) and a potentially large role as LNG supplier.

Possible Pressures and Roles for the L20

The fundamental advantages of gas over its competitors—especially coal—are strong and durable. The shift to gas is good news for environmental quality in the locales where it is burned instead of other fossil fuels. Because it emits much less CO_2 than all the other fossil fuels, gas will also lighten the pressure of climate change on the global environment. And because gas is deployed mainly for efficient and flexible generation of electric power, the shift to gas and electricity are strongly associated with economic modernization and growth. In every major economy, industrialization has been synonymous with electrification. Small and responsive gas power plants, coupled with advanced electronics, are key elements of advanced power grids that deliver highly reliable clean electricity needed for computers and other essential devices of the post-industrial information economy as well.

While the advantages for gas are strong, for large importers the shift to gas will raise troubling questions about security. This paper is part of a larger effort to explore possible agenda items for the L20—a standing forum of the leaders of about 20 key industrialized and developing countries. What could the L20 do to help advance the agenda for gas? I suggest four answers.

First, the L20 can help to articulate a vision for why a global gas market will aid security, not undermine it. That vision will require, initially, avoiding the wrong analogies with oil. In oil, the industrialized world responded to the risk of interrupted supplies by building and filling strategic stockpiles and coordinating through the International Energy Agency to manage such reserves as a single global public good. Pressure will arise for an analogous response to the globalization of the gas market, and a credible federal strategy for gas must articulate why a mandated stockpile approach to gas security would be extremely unwise. Compared with oil, it is much more costly to store gas, and in every large gas market there is already considerable amount of private storage that already responds to expected seasonal and annual swings in price. In managing sharp peaks in price, LNG is also playing a role. In 2004 the U.S. imported one cargo of LNG that had been stored temporarily in Spain, and onshore use of LNG is a long-standing part of U.S. storage. There are 96 onshore LNG storage facilities, dotted mainly across the Eastern United states, and dedicated to keeping gas on hand when demand for gas exceeds the capacity of the local pipeline network—most are in the Northeastern U.S. and deliver gas only a few days per year during cold snaps. There is not much else that federal policy should do to promote storage as a response to concerns about security.

Rather than storage, the most efficient way to reduce vulnerability to shocks in supply is by lubricating a more flexible demand. Through the 1990s, power plants and some industrial facilities gradually removed their capacity to switch between oil and gas; that, along with higher oil prices, explain why U.S. industry barely cut demand in response to the recent spike in gas prices; from 1999 to 2000, gas prices doubled and consumption still rose by nearly 4%. Some low-value applications, such as ammonia fertilizer producers, have cut or shut their production and moved overseas (e.g., Trinidad, where gas is plentiful and cheap), but most of the easy and automatic flexibility has been exhausted from the American system. In large measure, the relative cost of fuels and the location of industrial facilities are matters for markets to settle, but as the U.S. market becomes more dependent on imported gas and the flexibility of LNG cargoes rises, it is easy to see that a few percent of U.S. gas supply could quickly become unavailable; such amounts, while seemingly small, are larger than the change in supply that has caused gas prices for the last five years to be double the average of the previous half-decade. In the Atlantic basin, such a scenario could begin with a sharp rise in the need for imported gas, such as would arise if there were a severe disruption in Russian exports—such as occurred in the middle 1990s (albeit briefly) in the midst of turmoil in The Ukraine. (90% of all Russian gas exports cross Ukranian territory.) In the pacific basin, such a scenario could begin with a sharp rise in the need for gas in China, Japan or Korea. Indeed, in recent years Korea and Japan have demanded abnormally high amounts of LNG—due to very hot weather and because of persistent problems with Japan's nuclear industry, which has created a need for LNG as a replacement fuel. Worldwide, many scenarios arise. On the current trajectory, the Middle East could supply one-quarter to one-third of world LNG by 2020, and that neighborhood is famous for concentrated troubles that impede time-sensitive shipping. A strike in India's or China's coal mines could create a surge in demand for those countries rapidly expanding LNG facilities. And a prominent accident with LNG could create pervasive difficulties such as port closings and costly surveillance. As with any globally visible technology, such as nuclear power, trouble anywhere can create political opposition everywhere.

Second, the L20 can play a role in advancing key gas projects. In the past, gas infrastructure projects generally have created stability between supplier and user countries rather than dependencies. In Europe, notably, major international pipeline projects were political endeavors—such as the large pipelines built in the 1970s and 1980s from the Soviet Union under the orchestration of the German and French government and the novel underwater pipeline from Algeria to Sicily built with Italian technology and capital. These projects sought to use gas revenues and immovable pipes as means of binding these countries on the periphery to the European commercial and political core. (The Reagan administration in the height of the cold war saw things differently and tried to kill the largest Soviet pipeline project by withholding key technologies for gas compressors and pipelines and threatening trade sanctions against German suppliers. German and Soviet suppliers circumvented the sanctions and built their own pipes and compressors.) Especially for the Soviet Union this strategy has worked well.

A large role for gas in the future will require the construction of some key infrastructure projects. One is a pipeline network from Russia to China (and perhaps on to Korea). A second is a pipeline from either Iran in the West or Myanmar or Bangladesh in the East to India. A third is an expanded pipeline network from Bolivia to the rest of its neighbors. None of these projects can be created from the top down by an institution such as L20, but high-level blessing can help to focus minds and effort on finding ways to clear the barriers that are stopping these projects.

Third, the L20 can help to fix a problem that is likely to loom large for questions of energy security. Namely, questions about the gas dimension to energy security will arise through the parts of national regulatory systems that are rarely engaged in matters of national security strategy: electricity regulators. A well-articulated plan for assuring gas security (and for why a global gas market is not threatening to security) will help these regulators avoid spurious arguments that would hurt the prospects for gas. At present, many regulators are finding that the coal lobby is filling the vacuum with a litany of reasons on why locally abundant fuels (notably coal) should be favored for the future.

Fourth, the L20 would be uniquely positioned to pursue a comprehensive gas security strategy because it would engage key countries of geopolitical importance for current and future gas markets. Notably, it would involve key gas importers today (U.S. and Europe) and the likely large importers of tomorrow (China and India). It will include key net suppliers (notably Russia and Canada), but the L20 as currently conceived is unlikely to include other potential hegemons—notably Iran and Qatar. To be credible, the L20 will need to find a way to engage such countries on an ad hoc basis.

In some ways, the L20 will not have a strong advantage over the G8 in that both institutions involve Russia, and it seems to be essential that Russia be engaged in order to assure gas security. A coherent strategy for encouraging investment in Russia's gas industry must begin with the realization that outsiders will have little direct leverage. The Russian government's vision of its geopolitical position is built on control of hydrocarbons. The Russian state is reasserting its authority in oil and gas, creating a managed internal "market" that gives preference to strategically important sectors, and using the exports of oil and gas to create special positions with China, the EU and the United States. At the same time, Russia is aiming to create national energy champions—Gazprom, for example, is the kernel of a vertically integrated energy company. Not only does it control gas but its production of oil is also set to rise, and

Gazprom has taken a stake in the Russian electric power company and is also venturing into district heating services. According to this new logic, the waning of Russian power after the cold war is to be rebuilt through the control of hydrocarbons. Given this vision, it is not surprising that liberal western ideas such as open markets and free publication of data on gas trading—such as enshrined in the E.U.'s *Energy Charter Treaty*—have been rejected by Russia as unacceptable interference. A more subtle and responsive strategy is needed.

Part of the strategy is obvious and already being implemented. The west can serve Russian and western interests by diversifying transit routes out of Russia. New transit routes—such as the proposed Baltic Sea pipeline, which would allow Russian exports to bypass Belarus and Ukraine—will allow importing markets to reduce the risk of troubles in transit countries. A western strategy will also require encouraging Gazprom and other Russian companies as investors. Investment and operations outside Russia, at a world class level of performance, will offer a useful conduit for new technologies and ideas, which in turn will help Gazprom better manage its operations more efficiently. In addition to carrots, some sticks are also needed to engage Russia. Western nations must be prepared to make access to their markets conditional upon market-compatible behavior. The dangers are already evident in Europe where Gazprom has injected itself into nearly every market—mainly through cross-holdings that give it access to pipelines and to information that is essential to controlling markets. In central European markets the dangerous domination of Gazprom has already arrived; yet European competition authorities have been slow to impose clear rules against price fixing and market domination because some European states (notably Germany) fear that those same rules will be applied to break up their own national gas champions. Although most gas in Europe is still traded under contracts that are indexed to oil, the European gas market is in the midst of a shift to true gas-on-gas competition. That effort will fail without stronger market discipline, and the U.S. has a stake in cooperating with E.U. authorities to ensure that the transition is orderly since the integration of the U.S. and European markets means that anticompetitive practices in Europe will affect (albeit very slightly today) the operation of markets at home. Ideally, the *Energy Charter Treaty* would offer a framework for such competition, but that track has proved unproductive because the large treaty is inflexible and contains provisions that are incompatible with the divided federal systems of government that prevail in the North American market. A better track would be to build on the informal transatlantic cooperation on competition that already exists in other areas; indeed, that cooperation has been strained by conflicts over aircraft subsidies, Microsoft and other topics where the US and EU diverge. Here is a topic where they should agree.

Nuclear Energy:
Current Status and Future Prospects

Professor Burton Richter
Stanford University
October 1, 2005

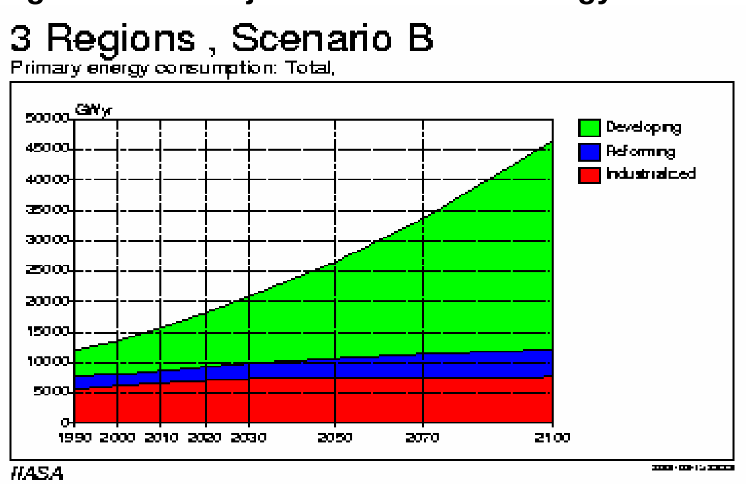
1. Introduction

Nuclear energy is undergoing a renaissance, driven by two very loosely-coupled needs; the first for much more energy to support economic growth worldwide, and the second to mitigate global warming driven by the emission of greenhouse gases from fossil fuel. With the current mix of fuels, growing the economy increases emissions and increased emissions lead to climate change that will eventually harm the economy. Nuclear energy offers one part of the way out of this circle. In this paper I discuss the reasons for and the size of the projected growth in nuclear energy; safety issues; and the coupled issues of waste disposition and proliferation prevention. An appendix describes the state of reactor technology and where it might be heading.

2. Why Nuclear?

Many forecasts of energy demand in the 21st century have been made and all give roughly the same answer. The International Institute of Applied Systems Analysis, for example, predicts in their mid-growth scenario (figure 1) primary energy demand increasing by a factor of two by mid-century and by nearly another factor of two by the end of this century. By the year 2030 the developing countries are projected to pass the industrialized ones in primary energy use, and China will pass the United States as the largest energy consumer. It is worth noting that economic growth in China and India is already higher than assumed in that scenario.

Fig. 1. IIASA Projection of Future Energy Demand



Supply constraints on two out of the three fossil fuels are already evident. Oil prices have surged and now are over $60 per barrel. Demand is rising at an average rate of about 1.5 million barrels per day per year (faster recently), requiring the output of another Saudi Arabia every ten years to keep up with increased demand.

While there is a lot of natural gas, there are transport constraints that are limiting availability to the big consumers. Natural gas prices have risen and now are at the unprecedented level of $9-$10 per million BTU.

The only fossil fuel in abundant supply is coal. However, it has serious pollution problems. Expensive technological fixes are required to control environmental problems that have large-scale economic consequences.

Concern about global warming is increasing and even the United States government has finally said that there is a problem. The Intergovernmental Panel on Climate Change (IPCC) forecasts, in the business-as-usual case, an increase in atmospheric carbon dioxide to 750 parts per million by the end of the century with a consequent global temperature rise of 2° to 5° C, less at the equator and more at the poles. We can surely adapt to this increase if it is small and occurs smoothly. If it is large and accompanied by instabilities in climate, economic and societal disruptions will be very severe.

The global-warming issue has caused prominent environmentalists to rethink their opposition to nuclear power. The question to be confronted is which devil would they rather live with, global warming or nuclear energy? James Lovelock, among others, has come down on the side of nuclear energy.

When economic self-interest and environmental self-interest both point in the same direction, things can begin to move in that direction. They now both point to the need for new large-scale energy sources and carbon-free energy is the most desirable. Nuclear energy is one such source. While it cannot be the entire solution to the energy supply and environmental problems, it can be an important part if the public can be assured that it is safe, that nuclear waste can be disposed of safely, and that the risk of weapons proliferation is not significantly increased by a major expansion.

3. Nuclear Power Growth Potential

At present there are about 440 reactors worldwide supplying 16% of world electricity (NEA Annual Report 2004). About 350 of these are in the OECD supplying 24% of their electricity. The country with the largest share of nuclear electricity is France at 78%, whose carbon-dioxide intensity (CO_2 per unit GDP in purchasing power parity terms) is half the world average (figure 2), encouraging for the environmentalists. About 30 new reactors are under construction now, mostly in Asia.

Fig. 2. CO_2 Intensity

Area	GDP (ppp) (Billions of U.S. Dollars)	CO_2/GDP Kg/$(ppp)
World	42,400	0.56
France	1,390	0.28

Projections for growth in nuclear power are uncertain because of uncertain costs along with the three potential problems mentioned earlier, safety, waste disposal, and proliferation risk. The IAEA projection (figure 3) of July 2004 for the year 2030 ranges from a high of 592 GWe (gigawatt-electrical) to a low of 423 GWe. This represents a net growth of between 16% and 60% over the next 25 years. The recent MIT study “The Future of Nuclear Power” (July 2003) projected about 1000 GWe by 2050 and a recent Electricite de France projection is for about 1300 GWe (private communication). The more aggressive growth numbers imply completions of about two 1-GWe power plants per month for the next 45 years.

Fig. 3. Nuclear Power Projection to 2030

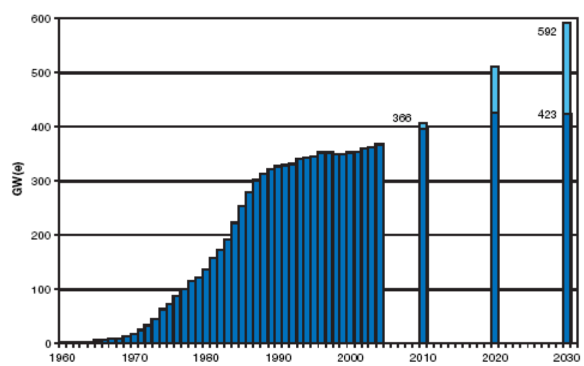


FIG.1. Historical growth in worldwide installed nuclear power capacity, 1960–2004, and the Agency's latest low and high projections through 2030 (low projections: dark blue bars; high projections: light blue bars). (Source: Energy, Electricity and Nuclear Power Estimates for the Period up to 2030, July 2004, *Reference Data Series No. 1, IAEA, Vienna (2004)).*

The cost of the new Finnish light water reactor (LWR) reactor is about Euro 1800 per KWe. Costs will come down with series production and locations more benign than northern Finland. Recent presentations to a DOE special committee on the future of nuclear energy in the U.S., by Westinghouse, General Electric and AREVA, claimed that cost of electricity from a new nuclear plant in the U.S. would be comparable to a coal plant after first-of-a-kind engineering costs have been recovered and after coming down the learning curve with five or so new plants. Even so, projections like those above will represent the expenditure of 1-2 trillion dollars on nuclear plants in the next 50 years. It is not clear that we have the trained personnel for the construction, operation, or regulatory needs of a system that large. However that is another story. We may not need all the people if the waste disposal and proliferation issues are not addressed soon.

4. Safety

There's little new to say on safety. Reactors of the Chernobyl type have never been used outside the old Soviet bloc. Even for reactors of that type, the accident would not have happened had not the operators, for reasons we will never know, systematically disabled all of the reactor's safety systems.

The new generation of light-water reactors has been designed to be simpler to operate and maintain than the old generation, and has been designed with more passive safety systems. Some designs are claimed to be passively safe in any kind of emergency.

With a strong regulation and inspection system, the safety of nuclear systems can be assured. Without one, the risks grow. No industry can be trusted to regulate itself when the consequences of a failure extend beyond the bounds of damage to that industry alone. Recent examples of corrosion problems in a U.S. reactor and in several Japanese reactors show again the need for rigorous inspections.

5. Spent Fuel Treatment

In discussing the safe disposition of spent fuel, I will set aside proliferation concerns for now, and return to them later. Looking separately at the three main elements of spent fuel (figure 4) might lead one to believe that there should be little problem. There is no real difficulty in principle with the uranium (U) which makes up the bulk of the spent fuel. It is not radioactive enough to be of concern; it contains more U-235 than natural ore and so could be input for enrichment, or could even be put back in the mines from which it came.

Fig. 4. Components of Spent Reactor Fuel

Component	Fission Fragments	Uranium	Long-Lived Component
Per Cent Of Total	4	95	1
Radioactivity	Intense	Negligible	Medium
Untreated required isolation time (years)	200	0	300,000

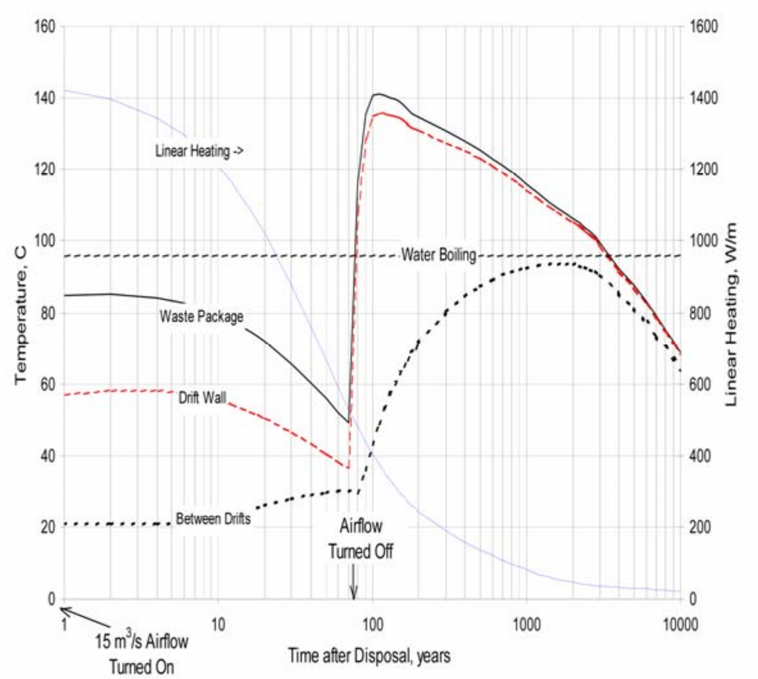
There is no scientific or engineering difficulty in dealing with fission fragments (FF) alone, the next most abundant component. The vast majority of them have to be stored for only a few hundred years. Robust containment is simple to build to last the requisite time. There are two long-lived FFs, Iodine-129 and Technetium (Tc)-99. No biological system has any ability to separate isotopes, so I-129 can simply be diluted with nonradioactive iodine. The Tc is relatively inert and only present at a low level. It can be handled with the actinides as described below.

The problem comes mainly from the last 1% of the spent fuel which is composed of plutonium (Pu) and the minor actinides, neptunium, americium and curium. For some of the components of this mix, the toxicities are high and the lifetimes are long. There are two general ways to protect the public from this material: isolation from the biosphere for hundreds of thousands of years, or transmutation by neutron bombardment to change them into more benign FFs.

Isolation is the principle behind the “once through” system as advocated by the United States since the late 1970s as a weapons-proliferation control mechanism.
The plutonium in the spent fuel is not separated from the rest of the material, and so cannot be used in a nuclear weapon. I do not believe the once-through system is workable in a world with a greatly expanded nuclear power program.. Its problem is a combination of public suspicion that the material cannot remain isolated from the biosphere for hundreds of thousands of years, and technical limitations.

The first technical problem comes from the heat generated in the first 1500 or so years of storage (figure 5) which limits the density of material that can be placed in a repository (the early heat generated from FFs is not difficult to deal with). The decay of plutonium-241 to americium-241 which then decays to neptunium-237 is the main source of heat during the first 1000 or so years. Limitations on the allowed temperature rise of the rock of a repository from this source determine its capacity.

Fig. 5. Computed Yucca Mountain Repository Temperatures for Direct Disposal of 25 Year Old, 50 GWD/MT PWR Fuel



The second technical problem is the very-long-term radiation. Here the same plutonium-to-americium-to-neptunium decay chain maximizes the long-lived component, requiring isolation from the biosphere for hundreds of thousands of years.

To use a United States example, if nuclear energy were to remain at the projected 20% fraction of U.S. electricity needs through the end of the century, the spent fuel in a once-through scenario would need nine repositories of the capacity of Yucca Mountain. If the number of reactors in the U.S. increases by mid-century to the 300 GWe projected in the MIT study, the U.S. would have to open a new Yucca Mountain every six or seven years. This would be quite a challenge since the U.S. has not been able to open the first one. In the world of expanded use of nuclear power, the once-through cycle does not seem workable.

The alternative to once-through is a reprocessing system that separates the major components, treating each appropriately and doing something specific to treat the component that produces the long-term risks. The most developed reprocessing system is that of France and I will use it as a model. They start by separating spent fuel into its three main components, FFs, uranium, and the actinides which are further split into Pu and the three minor actinides. They make mixed oxide fuel, MOX, by mixing the Pu with an appropriate amount of U. The extra U goes back to an enrichment facility. The fission fragments and minor actinides are vitrified for eventual emplacement in a repository. The glass used in vitrification appears to have a lifetime of many hundreds of thousands of years in the clay of the proposed French repository. The French Parliament has held a series of hearings early this year and is expected to soon issue its report on the acceptability of this system.

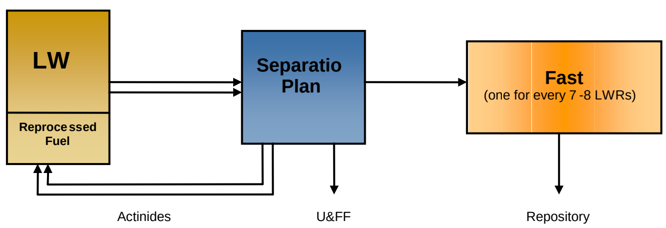
MOX fuel plus vitrification solves part of the problem but not all of it. The next question is what to do with the spent MOX fuel. The French plan is to keep it unreprocessed until fast-spectrum reactors are deployed commercially (see the appendix for a description of the reactor types). These fast-spectrum reactors have higher average neutron energy than the LWRs now in use and can burn a mix of plutonium and uranium-238 and, in principle, burn all of the minor actinides as well. It is possible to create a continuous recycling program where the plutonium from the spent MOX fuel is used to start the fast-spectrum system, the spent fuel from the fast-spectrum system is reprocessed; all the plutonium and minor actinides go back into new fuel, and so forth. In principle, nothing but fission fragments goes to a repository and these only need to be stored for a few hundred years.

This sounds good in principle, but there’s much work to do before putting it into practice. The only fast-spectrum system with which there is much experience is the sodium-cooled fast reactors (SFR). However, only plutonium-uranium fuel is qualified for the SFR. Fuel containing minor actinides is not. Facilities to test and qualify the new fuels are in short supply. The U.S. has foolishly killed off its Fast Flux Test Facility at Hanford. France plans to shut down the PHENIX reactor in 2009. The only facilities that will be left are in Japan and Russia. Clearly a coherent international program is needed to support and to use these remaining facilities in an international R&D program.

The two other fast-spectrum systems under discussion in the international Generation IV program, lead-cooled and gas-cooled, are far behind the SFR in readiness for deployment. In the U.S. there is talk of selecting a fast-spectrum candidate in 2012. In France the date is 2015. In both cases, it is doubtful that enough will be known about alternates to the SFR to allow them to be chosen.

The Nuclear Energy division of the U.S. DOE has been looking at a model system for treating spent fuel. The reference system (figure 6) uses both light-water reactors and fast-spectrum reactors. The light-water reactors are used to burn down the plutonium in the LWR spent fuel, followed by burning the remainder in fast-spectrum systems with continuous recycle. The idea is that Pu is stabilized in the thermal reactors and eventually burned down in the fast systems. One does not have to wait for large scale deployment of fast systems to begin the treatment of spent fuel.

Fig. 6. Two-Tier Schematic



The light-water reactors in the model burn half the plutonium. It is assumed that in the future, light-water reactors will reach a burn-up of 70 MW-d/kg and in that case it would take one recycle of an inert matrix fuel (plutonium plus minor actinides without additional uranium) or three recycles of MOX fuel to reach a 50% plutonium burn-up. The fast-spectrum system is configured as a burner rather than a breeder with a conversion ratio (plutonium out/plutonium in) of 0.25 or less. In this model one fast spectrum burner is required for every 7-8 LWRs. It is, thus, possible to deploy special burners and to begin a consumption of the spent fuel before the world has switched to fast-spectrum systems.

The only materials that go to a repository are fission fragments and the long-lived actinides that leak into the fission-fragment waste stream because of small inefficiencies in the separation process. If these can be held to about one percent or less, the required isolation time is on the order of 1000 years, a time for which isolation can be assured with very high confidence. Efficiencies of greater than 99% have been demonstrated on a laboratory scale.

The government could fund the construction and operation of the burners from the current 0.1 cent per KW-hr waste disposal fee built into the cost of nuclear electricity by selling the electricity and from savings from the much reduced cost of the simplified repository required.

If, for proliferation prevention reasons, one requires that the minor actinides be included in the LWR fuel it will take longer to deploy a system. Only standard MOX has been licensed for LWRs. For fast burners, no fuel containing the minor actinides have been licensed anywhere.

6. Proliferation Prevention

Preventing the proliferation of nuclear weapons is an important goal of the international community. Achieving this goal becomes more complex in a world with a much expanded nuclear-energy program involving more countries. Opportunities exist for diversion of weapons-usable material at both the front end of the nuclear fuel cycle, U-235 enrichment; and the back end of the nuclear fuel cycle, reprocessing and treatment of spent fuel. The more places this work is done, the harder it is to monitor.

Clandestine weapons development programs have already come from both ends of the fuel cycle. South Africa, which voluntarily gave up its weapons in an IAEA-supervised program, and Pakistan made their weapons from the front end of the fuel cycle. Libya was headed that way until it recently abandoned the attempt. There is uncertainty about the intentions of Iran.

India, Israel, and North Korea obtained their weapons material from the back end of the fuel cycle using heavy-water-moderated reactors to produce the necessary plutonium.

The level of technical sophistication of these countries ranges from very low to very high, yet all managed to succeed. The science behind nuclear weapons is well known and the technology seems to be not that hard to master through internal development or illicit acquisition. It should be clear to all that the only way to limit proliferation by nation states it through binding international agreements that include effective inspection as a deterrent, and effective sanctions when the deterrent fails.

The science and technology (S&T) community can give the diplomats improved tools that may make the monitoring that goes with agreements simpler and less overtly intrusive. These technical safeguards are the heart of the systems used to identify proliferation efforts at the earliest possible stage. They must search out theft and diversion of weapons-usable material as well as identifying clandestine facilities that could be used to make weapons-usable materials.

The development of advanced technical safeguards has not received much funding recently. An internationally-coordinated program for their development needs to be implemented, and proliferation resistance and monitoring technology should be an essential part of the design of all new reactors, enrichment plants, reprocessing facilities and fuel fabrication sites.

One issue that is being revisited is the relative proliferation resistance of the once-through fuel cycle compared to those of various reprocessing strategies. An analysis has been done recently by an international group of experts for the U.S. Department of Energy. Their report, “An Evaluation of Proliferation Resistant Characteristics of Light Water Reactor Fuels,” November 2004, is available on the DOE’s website (www.nuclear.gov) under Advisory Committee Reports. The methodology created in this analysis is to give a risk score for every phase of the nuclear fuel cycle and then sum the risks over time. An example comparison is shown in figure 7. The results of this analysis are shown in figure 8. Surprisingly, the once-through and all of the variants of reprocessing have about the same score. The increased risk during the phase where plutonium is available in reprocessing scenarios is balanced by the decreased risk of diversion during enrichment, where less enrichment is required, the increased radiation barrier after the second burn and the increased difficulty of fashioning the weapon from ever-more degraded materials. These scores should not be read as precision measurements. All they really say is that to sensible people once through is not that different from reprocessing.

Fig. 7.

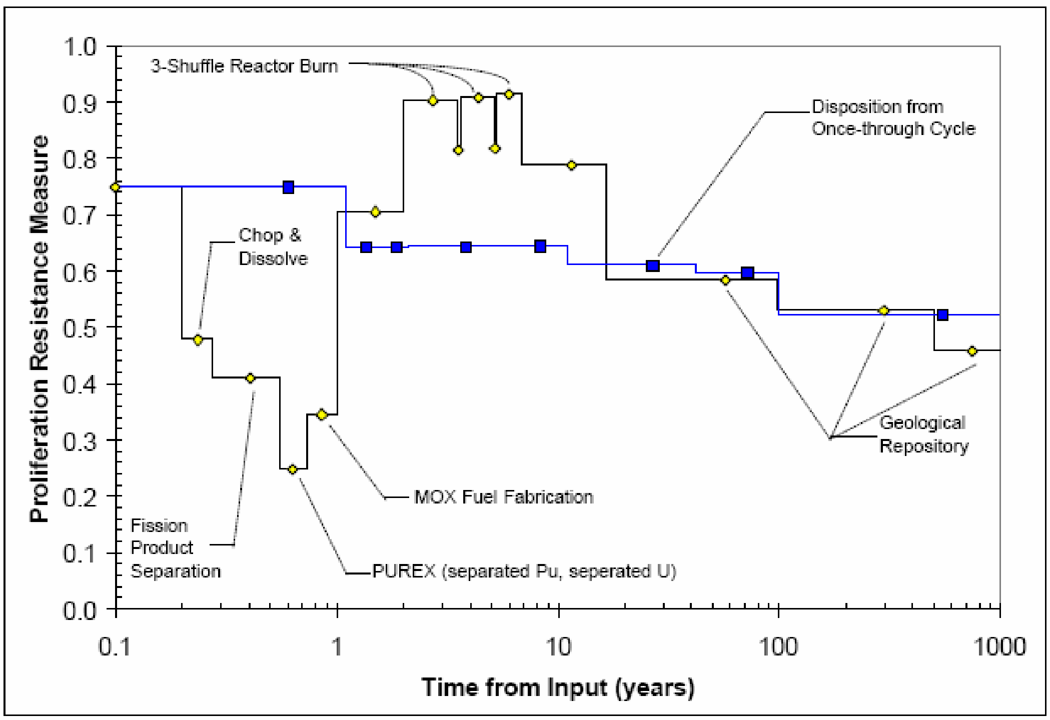


Figure 3 – Relative Proliferation Resistance Measure as a Function of Time for the PUREX/MOX Process (back-end of once-through cycle shown for comparison)

Fig. 8. Relative Proliferation Resistance Score (higher is better)

Cycle	Total Nuclear Security Measure
Once-Through PWR Cycle	0.657
LWR MOX w/ PUREX	0.641
LWR MOX w/ UREX	0.644
Inert Matrix Fuel w/ UREX	0.746
UREX with Np Doping	0.664
UREX with Np and Am Doping	0.665

The isotopic vectors from these various scenarios are shown in figure 9. As one goes down the table, heat generation and radiation levels increase, and it becomes more and more difficult to fashion a weapon from the residual plutonium. The last two entries in the table for IMF (Pu or Pu plus MA without the U that is in MOX) give heat and radiation levels that is very difficult to deal with. Needless to say this report has generated considerable controversy. A second and independent analysis is being done by a group in the international Generation IV program. It will be interesting to see if they get the same answer.

Recently the IAEA Director General Dr. ElBaradei and United States President Bush have proposed that internationalization of the nuclear fuel cycle begin to be seriously studied. In an internationalization scenario there are countries where enrichment and reprocessing occur. These are the supplier countries. The rest are user countries. Supplier countries make the nuclear fuel and take back spent fuel for reprocessing, separating the components into those that are to be disposed of and those that go back into new fuel.

Fig. 9. Plutonium Isotopic Mixture and Properties after Various Reactor Treatments (ANL)

Table 1. Mass and Radioactive Properties for Bare Critical Spheres of Plutonium[a] Metal.

	Plutonium Vector[b]	Critical Mass (*Rel. to WG-Pu*)	Decay Heat (W)	Neutron Source (n/sec)	γ Source (photons/sec)	γ Source (MeV/sec)
WG-Pu	0.02/**93.40**/ 6.04/0.50/ 0.04	1	24.9	5.97E+05	2.41E+12	2.54E+10
RG-Pu	2.63/**53.08**/ 25.11/11.82/ 7.36	1.3	255.6	5.96E+06	4.50E+13	4.56E+11
MOX-Pu	7.13/**43.80**/ 28.94/10.52/ 9.61	1.4	664.6	9.35E+06	1.17E+14	1.19E+12
IMF-Pu	15.76/**8.60**/ 32.44/14.65/ 28.55	2.1	2057.0	2.66E+07	3.64E+14	3.69E+12
IMF-HM[c]	15.76/**8.60**/ 32.44/14.65/ 28.55	2.2	5052.0	1.25E+10	9.54E+14	1.60E+13

[a]Except for weapons-grade, material is harvested from spent fuel assmebly five years after reactor discharge. Critical mass and other properties were calculated at the time of separation.
[b]Vector displayed as weight percents of Pu-238/Pu-239/Pu-240/Pu-241/Pu-242.
[c]Heavy metal in spent IMF assembly consists of 0.9% U, 3.5% Np, 79.0% Pu, 11.0% Am, and 5.6% Cm.

If such a scheme were to be satisfactorily implemented there would be enormous benefits to the user countries, particularly the smaller ones. They would not have to build enrichment facilities nor would they have to treat or dispose of spent fuel. Neither is economic on small scales and repository sites may not be available with the proper geology in small countries for 100,000-year storage. In return for these benefits, user countries would give up potential access to weapons-usable material from both the front end and the back ends of the fuel cycle.

If this is to work, an international regime has to be created that will give the user nations guaranteed access to the fuel that they require. This is not going to be easy and needs a geographically and politically diverse set of supplier countries.

Reducing the proliferation risk from the back end of the fuel cycle will be even more complex than from the front end. It is essential to do so because we have seen from the example of North Korea how quickly a country can “break out” from an international agreement and develop weapons if the material is available. North Korea withdrew from the Non-Proliferation Treaty at short notice, expelled the IAEA inspectors, and reprocessed the spent fuel from their Yongbyon reactor, thus acquiring the plutonium needed for bomb fabrication in a very short time.

However, the supplier countries that should take back the spent fuel for treatment are not likely to do so without a solution to the waste-disposal problem. In a world with a greatly expanded nuclear power program there will be a huge amount of spent fuel generated worldwide. The projections mentioned earlier predict more than a terawatt (electric) of nuclear capacity producing more than 20,000 tons of spent fuel per year. This spent fuel contains about 200 tons of plutonium and minor actinides and 800 tons of fission fragments. The once-through fuel cycle cannot handle it without requiring a new repository on the scale of Yucca Mountain every two or three years.

Reprocessing with continuous recycle in fast reactors can handle this scenario since only the fission fragments have to go to a repository and that repository need only contain them for a few hundred years rather than a few hundreds of thousands of years. The supplier-user scenario might develop as follows. First, every one uses LWRs and all of the enrichment is done by the supplier countries. Then the supplier countries begin to install fast-spectrum systems as burners. These would be used to supply their electricity needs as well as to burn down the actinides. Eventually, when uranium supplies begin to run short, the user countries would go over to fast-burner systems, while the supplier countries would have a combination of breeders and burners as required.

7. Conclusion

In summary, nuclear energy can be an important component of a strategy to give the world the energy resources it needs for economic development while reducing consumption of fossil fuels with their greenhouse-gas emissions. If this is to happen on a large scale, advances in both physical science and technology and political S&T will be required.

The physical S&T can produce better and safer reactors, better ways to dispose of spent fuel, and better safeguards technology. This can best be done in an international context to spread the cost and to create an international technical consensus on what should be done. Countries will be more comfortable with what comes out of such developments if they are part of them.

While the physical S&T development can best be done in an international context, the political S&T to create better mechanisms for proliferation control can only be done internationally. The IAEA seems to be the best place to start and the first baby steps may be in progress. However, it will be difficult for an organization as large as the IAEA to create a framework for a new international nuclear enterprise if too many voices are involved at the start. It might be better if a broadly-based, but compact, subgroup does the initial work. If I were setting up such a group, the minimum membership would include Canada, China, France, India, Japan, Russia, South Korea, United States, and representatives of the larger potential user states, Brazil and Indonesia, for example.

I think it will not be difficult to create mechanisms for the front end of the fuel cycle. The back end will be the problem and the most intractable issue is likely to be where the final waste product is stored.

Appendix 1

Reactor Types

This section aims to give a quick summary of the reactor types in use or under development. Three good general web sites for more information are the Uranium Information Center (www.uic.com.au), the World Nuclear Association (www.world-nuclear.org), and the DOE's Nuclear Energy division web site (www.nuclear.gov).

1. The Workhorses

Most of the world's power reactors are fueled with enriched uranium and cooled with light water (LWRs). They come in two varieties; pressurized water and boiling water cooled. For the purposes of this summary they are equivalent. Until recently the U-235 enrichment was about 3.5%. The fuel produced about 33 GWt-d/MT (gigawatts-thermal days per metric ton of heavy metal). Enrichment has been going up and the energy produced per MT has been going up as well. It is forecast that with enrichments of 5%-6%, burn-up of up to 70 GWt-d/MT will be achieved within a decade or so.

Work on very long-lived cores is in progress and Toshiba is willing to sell a 100-MWe reactor with a life time of 20 years without refueling. While these reactors are expensive, they may be economical for places far from standard power grids and where the very large standard reactors are not needed.

2. Heavy Water Moderated

The original version of this type of the reactor is the Canadian CANDU. These are fueled with natural uranium, heavy-water moderated, and heavy-water cooled. They are continuously refueled, eliminating the shutdowns required to refuel the LWRs. Advanced versions are being developed in Canada and India. These are still heavy-water moderated, but light-water cooled. In addition, they may use enriched uranium. Canada is promoting a system that uses 2 % enrichment which together with the light-water cooling is said to allow a considerable simplification in design with a consequent reduction in capital and operating costs.

3. Thorium Cycle Reactors

Thorium itself is not fissionable but has a large neutron capture cross-section leading to the production of U-233 which is fissionable. Thorium reactors have been operated for development purposes in Europe, Russia, India, and the United States. India, which has large reserves of thorium and small reserves of uranium, has said it plans to develop thorium-cycle reactors for power production. The Indian plan starts with a heavy-water reactor to produce plutonium. The plutonium is used with thorium in a reactor operating as a breeder to produce U-233. The U-233 is then used with thorium in an advanced heavy-water reactor operating as a U-233 breeder.

4. Gas-Cooled Reactors

Reactors using carbon dioxide as a coolant have operated for many years in the United Kingdom. This design is now out of favor. Helium-cooled reactors are under development in several places. The most advanced is the Pebble Bed Reactor whose tennis-ball-sized fuel elements are composed of a uranium nugget surrounded by a carbon coating. The fuel elements move continuously through the reactor and no down time is required for refueling. Most work is based on a German design. A German 15-MWe prototype operated from 1966 –1988. South Africa and China are building models at the 100 -200 MWe scale. These are to be modular allowing the construction of large plants by combining many modules.

5. Sodium-Cooled Reactor

This reactor uses uranium and plutonium, produces a "fast" neutron spectrum (higher average neutron energy that the "thermal" spectrum of the LWRs), and can operate as a breeder producing more fuel than it consumes. Such reactors can use U-238 with plutonium as a fuel, thereby increasing the fuel supply more than a 100-fold compared with the natural abundance of U-235.

6. Generation IV

The Generation IV International Forum (GIF) was formed in January 2000 by ten countries (Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, Switzerland, United Kingdom, and United States) and the European Union. The GIF looked at opportunities for development of the next generation of nuclear reactors and sorted through all the proposals selecting six for future R&D. These six are briefly described below.

> 6.1 Very High-Temperature Reactor: The VHTR is a thermal spectrum, helium gas-cooled reactor that is to operate at temperatures of 950° C or above. The main interest is in its potential to produce hydrogen. It would also have a higher thermal efficiency for electricity production. Hydrogen is to be produced through the sulfur-iodine process, but the efficiency of this process and its rate constants are not known at the temperatures being discussed. Difficult materials problems exist in building a reactor to operate at these high temperatures.
>
> 6.2 Super-Critical Water Reactor: This water-cooled thermal spectrum reactor operates with single-phase fluid flow above the critical point of water, hence its name. The purported advantages are higher thermal efficiency because of the higher temperature of the water allowed, and simplification in the design of the plant because there is no change in phase from water to steam.
>
> 6.3 Molten-Salt Reactor: This uses a bath of molten fluoride salts with an epithermal spectrum. It is capable of continuous fueling and no fuel rods have to be fabricated. A small molten-salt reactor was operated in the United States years ago. The main problem of this type of reactor is the extremely corrosive nature of the fluoride salts.

6.4 Sodium Fast Reactor: This is to be an advanced version of the reactor described in section 5.6. This kind of reactor has been operated for many years in the U.S., France, Russia, and Japan. Its fast spectrum makes it potentially effective in transmutation of nuclear waste as well as in breeding. The concern with this type of reactor has been with leaks of highly flammable sodium cooling fluid. Japan has a proposed simplified design that uses much less sodium in its cooling system than the previous designs.

6.5 Gas Fast Reactor: This fast-spectrum reactor is helium gas-cooled. It has a potentially higher electrical efficiency as well and is purported to have safety advantages.

6.6 Lead Fast Reactor: This fast system is cooled with molten lead. The only real experience with it is in the Alpha-class submarines of the former Soviet Union. Two of these submarines were lost at sea for unknown reasons. The rest are sitting in the docks in Russia with their reactors cold and their lead frozen. Russia has been unwilling to allow the dismantlement and inspection of the reactors to look at the state of the piping. Lead is a highly corrosive fluid.