Lecture 12: Minerals; Overview of energy sector problems

Minerals

The story of mineral resources is an interesting one, but we=ve going to have to go through it relatively quickly. The fact is that relatively little is happening in the mineral field. If I were giving this course 25 or 30 years ago, when people were in the middle of the first oil shocks and wondering if we were actually facing widespread shortagesBthis was when Ehrlich wrote *The End of Affluence*, as you may recallBthere was a lot being written about the quantities of different minerals, whether we should be stockpiling them and which ones, what sort of substitute materials we could find, mining the ocean floor and so on. Japan actually did spend a lot of money stockpiling strategic minerals in the 1970s, and lost a lot of money when the prices crashed in the 1980s. Since then, and with the big exception of oil, it=s become clear that no shortages have developed, none are expected and the whole issue has gone gently back to sleep. So I=ll just do a quick overview of mineral types and supplies and then turn to the much more live topic of energy supply.

Categories. We can divide the field of mineral resources in several ways. First, by relative abundance; the relevant distinction here is between the **abundant** and the **scarce** metals, the line between the two usually being drawn at whether the mineral in question comprises more or less than 0.1 percent of the composition of the crust of the earth. The second distinction is by the use of the metal. The first division is the constituents of steel, comprising **iron and the ferro-alloys**, the metals that are alloyed with iron to produce the different kinds of steel, including titanium, nickel, vanadium, tungsten, molybdenum and chromium. Iron of course is very abundant, comprising more than 17 percent of the earth=s crust, but the alloys are scarce, and so are relatively expensive; titanium costing several hundred dollars a pound. The ferro-alloys each impart a characteristic special physical property to the steel, such as hardness, tensile strength, resistance to deformation under high heat conditions or ductility, and are used where those characteristics are needed, hardness in drill bits, temperature resistance inside jet engines, and so on like that. Aside from the ferro-alloys, there are the so-called **base metals**, the common metals like lead, copper, tin, zinc, mercury and so on. Again, each has its own properties which make it appropriate for some specific use, copper for ductility and conductivity which makes it appropriate for electric wire, mercury for liquidity, so that it was used in thermometers; tin for nonreactivity with water, so it=s used to plate steel and prevent rust as well as in canned food and so on. The third is the **light metals**, aluminum and magnesium chief among them, used where the combination of strength and lightness is required, as in aircraft fuselages. Fourth are the **precious metals**, gold and silver, as well as platinum and the platinum series, including palladium. Fifth are the **exotic rare earths**, which have a number of unusual properties. Some at catalysts; others are extremely strong magnets and so on.

Ordinarily metals come in the form of ore, in which the metal is chemically combined with oxygen, usually, or possibly with sulfur or some other chemical, and so has different physical properties than those desired: Oxides of copper are poor conductors and flake when you try to draw them into wires. It=s the pure metal that has the ductility and conductivity. The oxide or sulfide is itself mixed in with other compounds, silicates and so forth. Iron is the most plentiful mineral, and iron-bearing ore can be over sixty percent iron, but the more usual figure for ore-bearing rock for the abundant metals is in the low single percents or tenths of a percent, and for the scarce metals lower than that.

Accordingly, the process of mining occurs in three stages, mining, beneficiating and smelting. Mining should be pretty evident: it=s retrieving the ore from the environment, digging it up or scooping it off the ocean floor or scraping it off the surface. Beneficiating is concentrating the mineral you want from the ore in its natural state, going from one to five percent or whatever. In this example, doing this reduces by four-fifths the amount of ore you need to smelt to get a given output of metal. What for? First, the labor involved in moving the slagBthe stuff you don=t wantBin and out of the smelting process; second, to greatly reduce fuel costs. As you will have guessed, smelting means reducing the mineral from its oxidized state to the pure metal. This is generally done by heat in furnaces, and so uses gigantic amounts of fuel. Reducing this by four-fifths is a significant saving, obviously.

One metal that does not follow this pattern is gold. Gold doesn=t form compounds with other elements and so is found in nature in its pure form, from grains to nut-size nuggets. When it=s found on the surface, it=s recovered by what=s called placer mining, in which the chief resource used is water pumped through high-pressure hoses directly onto the hillside in order to break up the surface rock into fragments, which are then searched for gold; note that, because gold is found in pure form in nature, beneficiating and smelting are unnecessary. This placer mining is of course extremely disruptive of the environment, in effect accelerating the natural erosion process by a factor of 1000 or so.

Shortages

In terms of world consumption. You=ll remember the bet that Julian Simon made with Paul Ehrlich. The bet was that Ehrlich could pick any five commodities in 1980; he=d win the bet if the average price of these commodities rose during the 1980s (remember, he predicted that industrial society would collapse because of resource shortage in the 1980s); Simon would win if the average price fell, corrected for inflation. Ehrlich picked nickel, copper, tungsten, chromium and tin. What actually happened was (a) not only did the averaged price of the five commodities fall, but the price of every single one fell, and (b) not corrected for inflation; and remember, Ehrlich picked the commodities. As I recall, according to the reader there=s only one material that presents a danger of running short, namely mercury, which is not exactly the key to world civilization. Mercury, like lead and arsenic, is now known to be poisonous, and so it=s been phased out of uses in which it was brought into close contact with people, as in body thermometers. With this single exception, there is no case of any mineral in short supply.

Strategic minerals. As we will soon see in the case of oil, and in fact in energy resources generally, where a given resource can be foundBwho has control of itBcan be as important as how much of it there is. So I thought I=d include at least one article on the geographic distribution of minerals.

This issue is sometimes put, as this article puts it, as a matter of national security, of the degree of dependence of a given country, in the case the United States, on external sources of critical mineralsBthat is, of minerals the absence of which would make a significant part of domestic industrial production impracticable. According to this article, the US is in a poor position in terms of critical minerals, in terms of how many critical minerals it imports, and also in terms of how large a percentage of use is imported. This is not surprisingBthe US covers six percent of the earth=s surface, and there is no guarantee that this small percentage of the earth will contain large amounts of tungsten or vanadium. But the US economy is much larger than six percent of the world economy, and is also the country with one of the most advanced manufacturing industries, and so does use large amounts of vanadium, tungsten and what have you. Interestingly, the same gap between resource base and productivity also characterize the other leading industrial economies, Japan, Korea and Western Europe, and in fact is more acute there than here.

So here we are, dependent on imports for most of these mineral resources. Is that grounds for concern? It depends on who has the stuff, and generally speaking, while most of most of the earth=s surface is not within the US, it is within the jurisdiction of countries that are part of the world trading economy, so the fact that resources are located in these countries is not cause for concern. When you scan down this list, the fact that some critical resource is located in Canada, Australia, Brazil, Norway, Turkey or Thailand should not and I believe is not keeping anyone up at night. To the extent that some of these countries, such as the Congo, formerly Zaire, the home of a large part of the cobalt supplyBare not politically stable, the way to deal with that is by stockpiling ahead of a crisis. The downside of stockpiling is that if you stockpile tons of stuff and the price then goes down, you lose a lot of money and look like an idiot.

In addition to stockpiling, production of the mineral may be so dispersed that instability in one producer may not have a big effect. Cobalt is also found in Canada and Zambia, for example. The Congo has been in a state of more or less total collapse since 1996, but I haven=t heard of any cobalt shortage, or any other shortage. As long as there are multiple suppliers, improving technologies and, best of all, substitutes for any one mineral, there just are no mineral supply problems. Conversely, and this is the real point, problems can arise if the mineral is used in a key industry, if there are no available substitutes for it, and if its supply is controlled by one or very few suppliers; if the industry is not that important, if there are substitute materials available or if there are multiple suppliers of that material, it's not easy to see how a problem could arise.

So with that I'll turn to the energy sector.

Why energy is important

It=s literally impossible to overstate the importance of the energy sector, because energy is the key to every kind of human activity; it gives you the ability to do anything at all. Traditional society was low in energy use, but with the increase in population came a need for vastly expanded agricultural production, for industrialization, for transportation enabling food markets and industrialization to proceed, and with both industrialization and transportation comes the need for vastly expanded energy consumption. No energy means no industry and an inability to sustain our present population.

Today I want to set the basics of the energy field, in terms of what the specific problems are and are not. As we'll see, there are two main problems, and what those problems are will structure the way that we look at this field. different kinds of energy are, how interchangeable they are, and as part of that, what make oil so key and so problematic; what present demand levels are and what future demand levels are likely to be. Having arrived at a basic overview of the field, we can then look at the subfields of energy and what their future will look like.

What the problem isn't

One of the major problems is **not** that we're running short of energy supplies. The history of energy use is that we find more energy faster that we use it—that R increases as least as quickly as U, so that there's at least as much energy resource at the end of any discrete period we want to name than there was at the beginning. To repeat something from the first week, when I introduced the Y = R/U concept, as of 1919 there were 14 years of energy in reserve at then-current rates of use; at the time of the oil embargo of 1973, there were 25 years of the oil resource, even though rates of use had been increasing for 50-odd years, and now, despite further increases, there are 40 years of the oil resource. Moreover, oil is the resource in shortest supply: there are 60 years of natural gas and 200 years of coal. The amount of uranium that could support nuclear energy has never been calculated, but it must be gigantic. Not only that, we've learned how to turn coal and tar sands into oil, so even if oil were running out we would have deep reserves of these other materials. I want to repeat, shortage of energy resources is not likely to be a problem for the rest of this century at a bare minimum.

The first big problem: greenhouse gases

So what are the problems? There are basically two of them. The first is the very rapid rate of climate change apparently caused by using carbon-based fuels for combustion, which when combusted produce carbon dioxide, which tends to absorb heat and so to keep it in the atmosphere rather than radiating it back into space. The more carbon dioxide is generated, the worse the problem is expected to get. Moreover, to anticipate the next lecture a bit, the big picture is not encouraging. As of 2000, the world was using 402 quads of energy or a bit more; a quad is a quadrillion BTUs or British thermal units, the amount it takes to heat a pound of water by one degree FahrenheitBof which 86 percent were generated by burning carbon-based fuels—gas, oil, coal and biomass, and the remaining 14 percent about evenly divided between nuclear and renewable energy sources—hydropower, wind, solar and so on. In 2020, according to the projection in the reader, over 50 percent more energy will be generated—611 quads to be exact, of which 87 percent will be generated burning carbon fuels. In other words, whatever we're doing now to change the climate—that very rapid rise in temperatures I discussed last time—we'll be doing about 54 percent more of it in 2020.

Moreover, carbon dioxide is not the only component in global warming. Every kind of thermal energy production involves the burning of a hydrocarbon, a chemical compound in the form CxHy, to produce energy: CxHy + O_2 yields CO_2 + H_2O + e. Both end products are greenhouse gases, which means they absorb heat and so lead to increased global warming. Of the two, the water molecule is a better heat retainer but there=s already so much water and water vapor in the world that the additional amount produced by hydrocarbon combustion is negligible. On the other hand, the addition produced by CO_2 is likely to be very important. At the start of the industrial era, the amount of CO_2 was measured in the low hundreds of parts per millionB300 or so ppm. Human activity can significantly increase the amount of CO_2 in the atmosphere, from 300 ppm to 400 or 500, and so can significantly change the heat-retaining properties of the atmosphere.

So the first thing is CO_2 production, which is inherently part of the combustion process. In addition to that, none of these fuels are chemically pure, but contain higher or lower amounts of chemical impurities which are also oxidized in the combustion reaction and so produce various chemical byproducts. These impurities are chiefly sulfur and nitrogen compounds. Sulfur, when oxidized, produces sulfur dioxide, a toxin and greenhouse gas, and also sulfites and sulfates which in combination with water vapor produce sulfurous and sulfuric acid and is chiefly responsible for acid rain. Nitrogen byproducts include various nitrogen-oxides in the form NxOy, which is responsible for brown smog and air pollution. There are also other byproducts, including soot from coal or wood combustion, which is particulate carbon or unoxidized carbon, CO (carbon monoxide) which is partially oxidized, and various other elements in smaller quantities, including phosphorous and traces of metals and other elements.

Among the combustion fuel sources, the sources closest to the original organic matter have the highest concentrations of impurities, so that wood, peat and other forms of biomass produce the greatest concentrations of impurities, soft coal or lignite the next worst, then hard coal, heavy oil, light oil and finally natural gas, CH_4, which is nearly free of impurities. So this is the first problem.

The reason greenhouse gases are dumped into the atmosphere is a variant of the familiar Tragedy of the Commons. In effect, the atmosphere is a commons, a free-access dump. Like the factories dumping sludge in the river, it=s a free dumping ground for combustion products and by-products. As with the factories by the river, the use of the atmosphere as a home away from home for greenhouse gases, acid particles and soot is a negative externalityB negative because it=s a cost item, external because someone other than the producer is paying for the cost.

In the case of the river, the answer is to internalize the cost, to cause the producer to pay for using the resource. To do this, you need a law to either forbid the dumping or cause the dumper to pay fees for the resource use, so that the fees can be put to work restoring the resource. In the case of global warming, what=s required isBwhat? What is a treaty but an international agreement that has the force of law in the individual signers?

So in this context, the Kyoto Treaty was an attempt to replace the tragedy of using the earth=s atmosphere as a commons, with international law. For reasons I=ll get to in a few minutes, even though Kyoto was signed and submitted for ratification in 1997, it did not come into effect for seven years, and until February 2005, I and I think most people, believed it would never come into effect. The result is that comparatively little analysis was done on its terms, since it looked like there was nothing to analyze. When it did come into effect, I put the text of the Kyoto protocol for the reader, since I wasn=t aware of any secondary material about it.

You=ll notice that there are two documents, the Framework Convention on Climate Change (1992) and the later Kyoto Protocol (1997). The Framework Convention did just that, set the framework in which the later Kyoto Protocol operated. The FCCC divided signatories into Annex I countries, basically the developed economies of North America, Europe, Japan, Russia, Australia and New Zealand, and the non-Annex I countries, basically everybody else. This is the basic fact that affects everything that follows. The Kyoto Treaty basically committed its national signatories to reducing the amount of greenhouse gas emissions each nation produced to a figure around their 1992 level of emissionsBin some cases a few percent higher than their 1992 levels, in other cases a few percent lower; the developing nations of Asia, Latin America and Africa, whose use of energy per capita is of course far below that of the United States, western Europe or Japan, were exempted, even though the fastest growth in energy use in percentage terms is taking place in Latin America, where energy use is expected to more than double, and the fastest growth in absolute terms is taking place in Asia, with China and India leading the pack. China and India are not only the two biggest growth poles in energy consumption, but relatively dirty users as well. China uses a lot of soft coal in thermal plants, and India a lot of biomass for domestic energy production.

While the treaty was being negotiated during the mid-1990s, a round robin of Senators signed a statement announcing they would not vote to ratify the treaty in that form. Two-thirds of the Senate has to vote yes to confirm a treaty, so 34 senators voting No can block ratification. In this case, 95 senators signed the round robin announcing they would vote to reject Kyoto, so signing the treaty was useless. Because of the round robin, the treaty was never submitted to the Senate for ratification, so there was never any question of whether the United States would adhere to it.

Article 25 of the Kyoto Protocol provides that the Protocol will come into effect when countries representing 55 percent of the greenhouse gas generation among all the Annex 1 countriesBnot among all the countries in the world, just the GHG generated by Japan, Europe and North AmericaBwhen countries accounting for 55 percent of that subset of greenhouse gas ratified the protocol. At that time, 1997, the US represented about 30 percent of that subset, Russia a further 15 percent and Australia between 2 and

3 percent. If these three countries refused to ratify, which was the position each of them took, then Kyoto would never come into force. Every other country listed in Annex I could and I think did ratify, secure in the knowledge that the protocol would not become effective, so that their ratification would commit them to nothing. In February 2005, seven years after Kyoto had been presented for signature, Russia reversed course and did ratify, thus putting the protocol into effect. The reason is that Kyoto provides for cash payments from countries that are producing more than their allocated share of greenhouse gases to countries that are paying less. All or almost all of the countries of western Europe, not believing that they would be bound by Kyoto, did not reduce their greenhouse gas emissions and are now overproducing them; Russia, still in an industrial depression following the collapse of the Soviet Union, is producing less gas than in 1992, and is therefore in a position to collect from Europe.

Because Kyoto is now ratified, let's pay somewhat closer attention to its provisions. The key provisions are these: Article 3 commits each Annex I signatory to cut greenhouse gas generation to a certain percentage, generally between 92 and 102 percent, of the amount of greenhouse gas generated in 1992. The signatory is required to achieve those cuts by 2008 and to maintain greenhouse gas generation at that level until 2012. After 2012, Kyoto terminates, and something else will have to be negotiated to take its place. These negotiations are now in progress.

The other key provisions are Articles 4 and 6. Article 4 enables two countries to club together for the purposes of meeting the Kyoto obligations, so that the two countries sum their permissible level of greenhouse gas generation together and meet or do not meet the target together. Article 6 permits countries to trade surplus and deficit greenhouse gas emissions. In other words, if Country A has produced some hundreds of tons of CO2 under its target number, and Countries B and C are over, B and C can bid against each other to buy A=s deficit, so A is financially rewarded for being under target and B or C is penalized.

However, there are a couple of reasons why I=m not sure that Article 6 is going to amount to much. The first is that as far as I know there aren=t any A countries. All the Annex I signatories are in a surplus position, so there aren=t any deficits for them to buy. Possibly because it was not anticipated that Kyoto would go into effect, every country is producing GHG substantially over its target figure, three years to go before the targets need to be met.

The other problem is even more fundamental. There isn=t any enforcement mechanism under Kyoto as far as I can see. Suppose Lithuania fails to meet its GHG targetBwhat happens? Is any penalty suffered? Is there any way to force or cause Lithuania to lower its GHG emissions? This is the perennial problem in dealing with sovereign statesBthere isn=t anybody in higher authority to make them live up to their commitments. So whether anything will come of Kyoto remains to be seen.

The other development happened two years ago. Six countriesBthe US, China, Japan, India, South Korea and AustraliaBhave negotiated an agreement by which they will jointly develop and exchange techniques for reducing GHG emissions from thermal plants. Three of these countriesBChina, Australia and the US-are major coal exporters, and four of themBIndia, China, Korea and the USBare major coal users, so all of them have an interest in coal use. Developing clean or cleaner coal burning technologies is in their interest specifically and everyone else=s generally. So this sounds nice but it really doesn=t go that far. The fact is the Kyoto signatories have an obligation to develop and circulate technologies that cut GHS omissionsBsee Article 10Bso agreeing to this means that these six countries are selecting one of maybe 20 Kyoto obligations and agreeing to abide by that one. Not the greatest concession I ever saw.

I want to close with three points about Kyoto. The first has to do with the structure of the treaty and its effect on American politics. The omission of China and India from Kyoto compliance omitted the two countries with the largest absolute increases in GHG omissions. The only way you can even hope to get any treaty through the Senate is if there=s a consensus of opinion behind it, and that can=t happen as long as India and China are not on board. In other words, I think the division of the world into Annex I countries and everybody else made no sense in physical terms. To be fair, we should remember that the first protocol was negotiated in 1992, when the Indian and Chinese economies were a small fraction of the size they are today, but still, these exclusions are not very smart politically.

Second point: even if Kyoto had been better drafted, I don=t know if it would have been ratified, and the reason I say so is the fundamental lack of seriousness of both American political parties on this issue. The Clinton administration signed a treaty they knew had no chance at all of being ratified but which gave them a photo-op when it was signed, which was typical of the look good-feel good type of policy that Clinton did too much of. Bush took office opposing Kyoto but promising to develop something better. Five years later, we have this deal, which at least is dealing with the right people but not moving the ball forward very far at all, so this may also be more cosmetic than real. The reason that both the past administrations can get away with stuff like this is that ratifying or not ratifying Kyoto isn=t really a pressing political problem for either of them. Thanks to the cost-benefit mismatch I alluded to earlier, the people who pay the cost of thermoelectric generation are diffused all over the world, whereas the people who get the benefit are all concentrated here at home. As you can imagine, there=s not a lot of political pressure being exerted by the people who are causing the negative externalities to internalize the costs.

Changing history of supply patterns. Moreover, when we look at the history of supply patterns we soon see that solving the Kyoto problem won't be easy, since if anything thermal fuels have been getting more dominant rather than less as time goes by. There were two candidates, hydropower or nuclear that, it was once thought, would supply huge amounts of clean, non-polluting power. But neither candidate succeeded in displacing thermal fuels, and new candidates have yet to prove themselves.

So let's briefly sketch the history of energy use over the past two centuries, during the industrial age, the age in which power was supplied by sources other than human beings and animals. The first main energy source was coal, in firesBto warm houses instead of wood, in furnaces to smelt metals such as iron and in steam engines for power; this was true through the nineteenth century. The first half of the twentieth century saw the rise of three other main sources to accompany coal, the first oil and then natural gas, and finally hydropower **(8)**. These new sources were used in two new waysBfirst for transportation by auto, invented at the end of the nineteenth century but only becoming really widespread after World War II, and second for electricity, which of course has a myriad of uses and is primarily responsible for the industrial age itself. In the second half of the twentieth century, nuclear power was developed for electricity production.

The importance of these different sources has been changing, but basically the story is of the continued dominance of fossil fuels against the challenge of first hydropower and then nuclear power. The first half of the twentieth century was the great age of hydropower, particularly in the American West with the creation of some of the great dams of the world, the Hoover Dam on the Colorado and the Grand Coulee on the Columbia prominent among them. In today=s world, the great dam-building country is China, most famously on the Yangtse with the Three Gorges Dam; but of course there are literally thousands of other dams in China. As we saw a few minutes ago, China has by far the fastest growing demand for energy, and is looking for energy from all sorts of sources, including Central Asia=s oil and gas and its own coal and hydropower.

Hydropower was once touted as the perfect energy source. It's 97 percent efficient-97 percent of the kinetic energy of falling water is converted to electricity. It produces no pollution or greenhouse gas; once in place, it depletes no fuel and is practically cost free; it relies on the hydrologic cycleBon rainfallBand so is completely renewable; and unlike nuclear or thermal plants, which require hours to stop and start, hydropower can turn on and off with the flick of a switch, and so is ideal for meeting short-term fluctuations in energy demandBas between 5 am and 5 pm, for example.

Yet the overall picture is shifting against hydropower and back in the direction of thermal power. There are three main reasons for this, the first environmental and the second economic. On the environmental side, impoundment structures involve flooding, and particularly of riverain sites that, in Asia at least, are the homes of tens or hundreds of thousands of people. The resettlement of people in such numbers is nowadays almost beyond contemplation, except in the sort of countryBlike China or MyanmarBthat can ignore local political discontent. In such countries, the government can decide that the national interest in energy supply can override the local interests of people that don't want to beuprooted, and act accordingly. In countries where the government is responsive to public opinion, the concentrated interest of people who don't want to be uprooted has to be taken into account, and can defeat the more diffuse interest in energy development.

Moreover, hydropower development is inherently limtied. Its energy comes from the fall of water from higher to lower altitude. Once the river is totally regulated—once there's a succession of dams and lakes strectching the length of the river—there simply is no further potential for development.

On the economic side, hydropower is if anything the victim of its own success. Hydroelectric plants are highly efficient, harnessing over 95 percent of the potential energy available in falling water; in other words, hydropower plants are already operating at or near the practical limit of efficient production. By contrast, thermal plants, which produce power by a complex processBfossil fuels are burned to release heat, which turns water into steam to rotate the turbine blades—until recently achieved energy efficiencies of only around 38 percent. This has changed, however, in the last decade, as thermal plants have increasingly been redesigned as combined-cycle plants. In these plants, heat is used to maintain water at temperatures at which it changes not to steam, but to a superheated fluid that retains the flow characteristics of a liquid and the pressure characteristics of a gas; this improves the efficiency of energy transfer in the generation process and boosts the efficiency of energy production from 38 to roughly 42 percent, implying a cost savings on the order of 10 to 12 percent (42/38 = 1.105 or 10.5 percent). The effect of this savings is a shift in the indifference curve between thermal and hydropower in the direction of thermal power; that is, as the efficiency of thermal plants increases, the point at which marginal customers shift between thermal power and hydropower itself tends to shift in favor of thermal.

Nuclear versus thermal. Nuclear power, like hydropower, also faces a limited future. There was a time, and not so long ago, when nuclear power was also touted as the great source for electric power. Putting the question of waste aside, nuclear power is also pollution-free and greenhouse-gas free and was supposed to be cheap to run.

Nuclear power tended to break down on the issue of safety, in part triggered by Three Mile Island, where there were no casualties and no measurable increase in radioactivity in the environment, and of course much more emphatically at Chernobyl in the Ukraine, where there were some dozens of deaths immediately, widespread fallout and increased deaths from cancer estimated in the thousands over the following decades, over a wide area of northern and eastern Europe. Chernobyl, unlike every nuclear plant outside the former Soviet Union, had no containment structure, so that a catastrophic breakdown implicated not only the building itself but the surrounding environment. So what happened at Chernobyl is not exactly a guide to what=s going on in the rest of the world. Nevertheless, the perceived risks of nuclear power have so far made it increasingly difficultBin fact more or less impossibleBto fund new nuclear plants.

The risks of nuclear power are different in kind from those of other power sources. Oil and more particularly coal involves the virtual certainty of a small number of fatalities among coal miners and oilfield workers, and also a virtual certainty of diffuse environmental effects such as increased pollution and increased greenhouse gas production, as I=ll get back to it a minute. The tradeoff between nuclear and thermal fuels involves balancing incommensurate considerations, between the certainty of a few dozen casualties and general but relatively low-level environmental degradation on the one hand versus a vanishingly small chance of a great disaster. I=ll return to this point tomorrow. But the point for right now is that the political and economic effect of the perceived risks of nuclear power have meant a turn away from it.

Nuclear power also faces the problem of storage of its waste products. Right now, nuclear waste is dispersed around the 104 operating nuclear plants in the country, awaiting permanent storage. After decades of negotiation, an agreement was reached to store it in Yucca Mountain in Nevada. But even if this comes to pass—and there is some doubt about that--Yucca Mountain won't be ready to accept wastes until 2020, and by that time all the designated storage sites will be filled by existing wastes, which means another negotiation will be necessary in order to find another depot for further wastes. Meanwhile, California has banned further nuclear construction until a solution to the waste problem is discovered.

There is still a third problem with nuclear power. In order to get a plan in operation, plans must be drawn and a permit applied for, which can take years, followed by further years of litigation and more years after that of construction. No one is going to want to inest tens of millions of dollars now to get power in 2022. It's not a very certain or rewarding investment climate.

The bottom line

So the bottom line is that the belief of several decades ago, that most of the growth in energy demand would be taken up by nuclear and hydro, has proved false. Meanwhile, the alternative fuels, solar, tidal, geothermal and whatnot, amount to a fraction of one percent of total energy consumption. Of these, wind or solar have reasonable chances of providing a substantial contribution to the power picture, but not yet. So far, the bottom line is that the main source of growth in energy supply is thermalBcoal, oil and gas.

So before I close the book on pollution, global warming and lack of seriousness, I want to say one more thing. Climate change is a real and serious problem, and some hard choices will have to be made. It=s not enough to be against something. Of course you can be against pollution or greenhouse gases or acid rain or nuclear waste or dams or resettlement. Who the hell is for them? The question, given that everything has downsides, that tradeoffs are inevitable, is--what are you for? This is the important and interesting question, because people have to live and the economic system has to function. A proposal that doesn=t take these rather basic facts into account is doomed to failure and in fact is not worth listening to. Providing an adequate answer requires informationBit requires that you know how many supplies there are, what the economic and environmental cost will be, what demand will be, how demand can be modified, and in the light of all this information, to take a stand and be for something. If you don=t do this, you=re not doing serious economic or environmental policy thinking, but moral preening.

The three factors of the second problem

The second problem comes about because of the confluence of three elements. If any of those elements were not present, the problem would be solvable; it's the fact of the three together that makes the problem what it is.

We can think about the energy sector in several ways. First, what is the nature of the energy sourceBcoal, oil, gas, biomass, nuclear, hydropower, and less conventional energy sources like tidal, geothermal, solar and wind power. Second, what is the energy used forBthe production of electricity, vehicle movement, home heating, and so forth.

Combustible and non-combustible sources. So let=s look at each of these divisions, beginning with dividing energy sources between energy produced by combustion of hydrocarbons--coal, oil, gas and biomass on the one hand and everything else on the other hand. Combustion sources are all put together in the same category because they all produce energy the same way, through the same exothermic chemical reaction CxHy + O_2 yields CO_2 + H_2O + e. The e or energy is used in a variety of ways. In electrical generating plants, it heats water to produce steam, which turns the blades of turbines to generate electricity, so that heat energy is converted into electrical energy; electricity in turn can do very many things: it can heat homes, cook food, cool it in refrigerators, run machines, move cars and trains, in fact there are very few things it can=t do. In internal combustion engines, the heat of the reaction causes the reaction products, which are in the form of gases, to expand and move the pistons in the engine, by which means heat energy s converted to mechanical energy. In other uses, like cooking fires using wood or natural gas, or in home heating oil the heat energy is used directly as heat.

Energy end-uses. There are four main end-uses of primary energy sources, the first two of whichBelectricity and transportation--involve the conversion of a primary form of energy into another form. Probably the most important use is the conversion of primary energyB whether combustion, hydropower, nuclear power or whateverBinto electricity. The second main use is for transportation, which generally involves fuel combustion, practically always in the form of oil, not gas or wood, though electric motors and hybrid motors do exist. About half of the almost 40 percent of energy consumption represented by oil, or 20 percent of total energy consumption, is devoted to transportation. The third use is for home heating, which is again almost exclusively through combustion, though again electricity can be used for home heating. Number 4 is everything else you can think of.

Considering the different end-uses to which energy can be put raises the question of substitutability: to what extent can one source be substituted for another if the first source is limited, either in terms of sheer physical availability or political interruption. The best way of guarding against an interruption or shortfall from any one source is diversification of energy supplies among various sources.

Nuclear and hydropower plants can be used only to produce electricity. Natural gas and coal are used to produce electricity in thermoelectric plants and can be used for home heating. Oil is also used for electricity production and home heating, for which there is good substitutability, but until electric vehicles can be put in large-scale production oil is more or less irreplaceable for transportation.

In other words, of the three main end-uses, electrical generation, transportation and home heating, there is good substitutability for electrical generation. If a nuclear or hydro plant goes off-line, a thermal plant can substitute for it, and vice-versa. As we saw during the California energy crisis in 2002, the only problem is the lag time in building new plants: it takes anywhere from a few months, in the case of a thermal plant, to several years in the case of hydropower, to get new capacity on line. The answer is to have reserve capacity, so you can switch back and forth among different kinds of supply in response to price or demand fluctuations. This in turn dampens or buffers the fluctuations. If the price of natural gas goes up sharply, and power generators switch to hydro or coal or whatever, the demand for natural gas slackens and the price tends to stabilize.

The situation with home heating is similar to electricity generation but a bit stickier. Once again, different kinds of fuels, from oil to gas to coal to electricity, can be used to heat homes. The problem is that it=s not really feasible for an individual homeowner to maintain several different kinds of furnaces and switch back and forth depending on changes in the prices of different fuels, so individual consumers are stuck when there=s a shortage or price rise. Over the longer term, a major increase in the price of one of the fuels will induce architects and building contractors to move away from that fuel. So in this longer-term sense there is substitutability for home heating also.

But when you come to the third major use, transportation, you have a completely different situation. There=s only one fuel source for transportation, namely oil. This is the first major problem with oil, namely that you have to have it to make trains, planes and automobiles go. Incidentally, based on what I=ve said so far, what can be done about this situation? This best analogy between auto-based transportation and the other major uses of fuel is to home heatingBlots of individual end-users, which makes conversion difficult on an individual level, but en masse, and over a slightly greater time-scale, a partial answer is what? As in the case of home heating, where architects and builders tend to move away from the more expensive kind of hat to the cheaper kind, the partial answer is to have different kinds of automobile engines, so that car companies can lean one way or the other depending on the long-term changes in fuel cost. Right now there=s a year wait for the hybrid car. My wife is committed to buying one, and so are other people. But as for right now, oil supplies at least 99 percent of the world=s transportation, and that can=t change overnight. So that's the first element—that there's basically only one energy source for the entire transportation sector.

The second element has to do with where the oil supply is located. The largest pools seem to be found around these flat, shallow seasBthe Gulf of Mexico, the Caspian Sea, the South China Sea and most of all the Persian Gulf. Two-thirds of the world=s proven oil reserves are within a 300-mile radius of the head of the Persian Gulf, where Kuwait, Saudi Arabia, Iran and Iraq come together. There are other oil sources, both existging and developable, but the majority of the currently known oil reserves—something like 70 percent of them, in fact—are around the Persian Gulf. This differentiates oil from coal, which is not nearly so unevenly distributedBthere are major coal deposits in most of the great land masses of the world, in the United States, Russia, China, Brazil, western Europe, Australia and Canada. So this is the classic situation for having a strategic reserve problem—an absolutely key industry requiring a material for which there are no substitutes, and the supply in the hands of a small number of suppliers.

The third element has to do with the fact that, since the end of the Cold War, and indeed for some time before that, the Persian Gulf and the region around it is the most politically fractured zone in the world. In one sense, the US is less dependent on oil supplies from the Persian Gulf than western Europe or Japan; the relevant figures are that the US obtains 20 percent of its oil from the Middle East (with about 45 percent produced domestically and the other 35 percent from Mexico, Venezuela and Africa); Europe obtains about 43 percent from the Middle East, with Africa and Russia, as well as the North Sea, producing the rest; while Japan obtains 75 percent of its oil supplies from the Middle East as well as the production from Alaska=s north slope**.** But who gets which oil from where is not fundamentally relevant. The US is not as directly dependent on Middle Eastern oil as Europe, which receives more than half its energy from there, or Japan, which receives about 80 percent, but that is not really the point. Disruption of the supply to Europe or Japan would of course lead those countries to drastically bid up the price of all available supplies, which would obviously have a major effect in the US, and even more fundamentally than that the economic turmoil and disruption on industry all around the world would have still more profound and far-reaching effects. Lee Hamilton, the former Democratic chair of the House Foreign Relations Committee, has said that maintaining the flow of oil from the Middle East is a vital interest of the United States, and I don=t see how that position can possibly be contradicted.

So unless and until completely new and different fuel sources are developed, protecting the flow of oil from the Middle East is obviously of primary concern to the US. During the run-up to the Iraq war, you=ll recall that the charge was made that it was a war for oil. I=m pretty well convinced that=s not trueBoil supplies were not critically short then and aren=t now, and more to the point the risk of disruption to the oil supply was a motive not to do it rather than a motive to do it, at least in the short run, but the point I=m trying to make now is that the idea that this is an accusationB that the US is accused of paying attention to the oil supplyBtells me how out to lunch the accusers are, how they seem to come from some other planet. Of course the US pays attention to the oil supply, for all the reasons I=ve just mentioned and more. What would you expect? To recap a bit, energy is the key commodity, the thing that makes all other things possible. There are various kinds of energy, all of which can substitute for each other to produce electricity, the biggest single kind of energy use. But the second biggest kind of energy use, transportation, uses energy from only one source, oil, and as it happens the largest source of the least substitutable sort of the most crucial commodity in the world is found in the most politically unstable part of the world, the Middle East. This very unfortunate combination of circumstances makes the politics of the Middle East of prime concern to everybody, and is the only really major reason that Middle Eastern politics should be of interest. I think this is obvious common sense, and the idea that it=s some sort of accusation is preposterous.

So having disposed of that, or at least so I hope, I want to spend a minute or two on the politics of the Middle East. This is basically a resources course and not a course on politics, but here the two are so closely knotted that it=s really rather absurd not to discuss them together. The basic fact about the Middle East is there are all sorts of intersecting political fault lines there. Consider the fact that there have been three main interruptions in oil supply, in 1973, 1979 and 1990, all in the Middle East but each from a different cause. The first was the Arab oil boycott during the 1973 Arab-Israeli war, the second was caused by the Iranian revolution of 1979 and the cutoff of Iranian oil after that, and the third by the Iraqi invasion of Kuwait in 1990. So there are many different kinds of conflicts going on around the Persian Gulf. The Arab-Israeli conflict is one, internal political instability within several of the middle eastern countries is anotherBthis is serious if one of the countries is a major producer-- and interstate rivalries involving oil producers is a third. So at first glance it seems as if all these are all different sorts of problems that by very bad luck happen to coexist in the same place.

But there are commonalities among these problems as well. The basic difficulty is not only that these different kinds of fault lines all exist. In addition to that, precisely because they=re all in the same part of the world, they tend to react on each other: the West=s support for Israel made the Shah=s support of the West seem more dubious and helped arouse opposition to him. In addition, all have the common thread of opposition to impingement from the west, from the modern world, and that opposition increasingly takes on a religious tone. Thirty years ago, the main form of opposition was nationalist socialism, as with Nasser and Saddam Hussein when he first got started. More recently, given the failures of nationalist socialism, opposition increasingly takes on a religious tone, which tends to make each problem more intractable, more impossible of cure or compromise.

The fundamentals of fundamentalism don=t vary a lot from one religion to another. In every case, the fundamentalist is under the delusion that he has a straight pipeline to God and knows the truth about everything. This gives rather a different complexion to his political ideas. Where others believe in the separation of church and state, the fundamentalist believes that the only purpose of having a state, of having laws at all, is to enforce the truth that everyone should acknowledge, and that=s revealed by religion.

The difference between the western world and the world of Islam is not the nature of fundamentalism, which is more or less equally disagreeable everywhere, but the fact that fundamentalism is much stronger in the Middle East than in the west. The historic reasonBthe cause or causesBof why it=s stronger in broad terms probably has something to do with an incomplete transition from traditional to modern society. The effects are easier to see. It=s difficult for a fundamentalist to live in a society not governed by religious law, and more or less impossible for a non-believer to live in a society governed by religious law. So there=s an endemic state of war of two kinds, secession wars all along the borders of IslamBfrom Nigeria to Chechnya to Xinjiang to Indonesia to ThailandBtrying to separate from than the non-Muslim secular states to create states governed by Islamic law, and civil wars within Islam, from Algeria to Sudan to Turkey, as fundamentalists within Islamic societies try to impose a religious government on those societies.

The three elements together. So to state the three elements together, the transportation sector depends on one sort of energy, and supplies of that energy source are largely found in only one location, and that location is the most politically unstable region in the world. Change any one of these elements and the problem starts to lose its bite. If the transportation sector were not dependent on oil, or if oil didn't come from the Middle East or if the Middle East were politically stable, this second problem would not be a serious one. So one way to solve this problem is to have the transportation sector not dependent on oil—electric vehicles, hydrogen-powered vehicles, anything like that. The second solution is using non-Middle Eastern supplies of oil. The third is to politically stabilize the Middle East. That was the basic concept behind the Iraq war, which actually had the effect of making it worse.

The point is to keep distinct what solution is proposed for what problem. Solutions that apply to Problem A may or may not apply to Problem B. For example, finding a jillion barrels of oil in Kansas would solve Problem B but not do anything about Problem A; conversely, building a machine that can suck carbon dioxide out of the atmosphere would solve Problem A but would do nothing about Problem B. Some proposals would alleviate both problems, or at least that's the claim. Hydrogen-fueled cars would constitute a non-oil transportation system, and so would affect problem B. It may also affect problem A, since burning hydrogen doesn't produce any carbon compounds or other pollutants. But there isn't a lot of free hydrogen running around, so getting hydrogen may require some energy input—electrolyzing water or other hydrocompounds, for example. If the energy to do that comes from a coal-burning electricity plant, it doesn't really help Problem A at all. So the hydrogen car helps to solve Problem B—it's a non-oil transportation fuel, but it doesn't solve A; rather, it depends on the existence of something else—windmills or whatever—to generate energy in a way that doesn't contribute to Problem A.

Similarly, biofuels—corn or sugar raised to be distilled into ethanol—are supposedly carbon-neutral, since the carbon dioxide generated by burning ethanol is supposed to find its way back into new plants. But raising those plants, harvesting them and cooking them for ethanol requires energy inputs; if those inputs are from a non-thermal source, there is no net contribution to the thermal problem; otherwise, there is. In other words, biofuels are like hydrogen: they're really a non-oil transportation source, and so contribute to solving Problem B; their impact on Problem A depends on the existence of something else—windmills or whatever—to generate energy in a way that does or doesn't contribute to Problem A.