

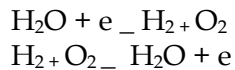
Lecture 13

Overview

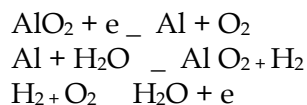
At the end of the last lecture, I pointed out that there were two main problems having to do with energy, the first being anthropogenic climate change caused by the use of carbon fuels, which I'll call Problem A, and the second the union of three separate elements, the fact that transportation is almost completely dependent on one fuel source, oil, second that oil supplies, unlike coal, natural gas, or uranium for that matter, are geographically concentrated around the Persian Gulf, and third that the Persian Gulf is the most politically unstable area in the world, which I'll call Problem B. Solutions to Problem A involve energy supplies that don't add carbon dioxide to the atmosphere, and solutions to Problem B involve one of the three elements of the problem: developing non-oil based methods of transportation, finding sources of oil not in the Persian Gulf, or decreasing the political instability of the Middle East.

These are two separable problems, but since each involves one of the thermal fuels, oil, there is sometimes confusion about which problem is being addressed by a given proposal. Thus, hydrogen is sometimes touted as a non-carbon dioxide generating fuel, and ethanol, distilled from one sort of plant or another, is sometimes touted as a carbon-neutral fuel, since the carbon dioxide generated by burning the ethanol is then reabsorbed by the new crop being raised to be distilled into ethanol. The trouble with this idea is that, unlike oil or coal, there isn't a lot of free hydrogen on the earth's surface, or a lot of free ethanol for that matter.

The hydrogen has to be generated from molecules containing hydrogen atoms. In one process, an electric current is passed through water, dissociating it into hydrogen and oxygen. The hydrogen is then collected, put in fuel tanks and combusted to move vehicles; the combustion product is water. In other words, we start with water, add energy, get hydrogen and oxygen and turn them back into water, releasing energy:



In another process, aluminum is added to water in the presence of gallium, and the oxygen in the water leaves the hydrogen to form aluminum oxide; the liberated hydrogen is then collected and used as fuel. Once again, though, we don't have a lot of free aluminum on the earth's surface; instead, we have to manufacture it from aluminum ore, that is, aluminum oxide, a process that again uses electricity. In other words, it's another circular reaction, and in fact a double circular reaction, first using energy to dissociate aluminum oxide to get aluminum, then combining the aluminum with water, producing aluminum oxide and hydrogen, and then combining hydrogen and oxygen to get water and release energy:



Since no circular process is 100 percent efficient, they all lose energy. So using hydrogen fuel doesn't add to energy supplies, but in fact takes away from them.

Moreover, the use of hydrogen fuel doesn't itself have any effect on Problem A, one way or the other. If the electricity used to generate the hydrogen in either process is derived from a non-thermal source – wind, solar, hydro, nuclear – then the whole process doesn't add to Problem A; if the electricity does come from a thermoelectric plant, then it actually makes Problem A worse. So hydrogen doesn't solve Problem A at all, but depends on something else to solve Problem A. What hydrogen does do is provide a non-oil transportation source, and so help with Problem B.

Something similar is true of ethanol. We don't have a lot of free ethanol running around, but instead we distill it from plants. When ethanol burns, it produces carbon dioxide, which is reabsorbed by the next crop of plants. This looks like, and is, a circular, energy-consuming reaction, but a lot of the energy that makes the process go involves growing the crop and so is derived from the sun. Some of the energy, however, is not derived from the sun, including the energy involved in reaping the crop and distilling the plant matter into alcohol. Once again, then, ethanol use does not help or hurt Problem A directly, and may make the situation worse if the energy involved in distilling or transporting the ethanol is from a carbon source. What ethanol does do is help with Problem B, since it's a non-oil transportation fuel source.

To take yet another example, the electric car is non-polluting if and only if the materials in the battery, lead or lithium or whatever, are mined and smelted using non-thermal sources. The significance of the electric car is not that it cuts greenhouse gas emissions – again, that depends on how it's made-but that it's a non-oil transportation source. So it's important to bear in mind which solution goes with which problem.

The Socolow article. The next thing to think about is how each of these problems is likely to be solved. I think the Socolow article is very illuminating in this regard. What the article basically says is that, as we've already seen, continuing to add carbon dioxide to the atmosphere will lead to accelerating temperatures. In order to stabilize the amount of carbon dioxide, we need to add less. Socolow claims that continuing present trends will add an additional 175 billion tons of carbon dioxide to the atmosphere over the next 50 years, so that a successful strategy will prevent those 175 billion tons from being added. There is no single source from which 175 billion tons can be saved, but adopting a package of seven strategies, each of which will save 25 billion tons, will save the 175 billion. Socolow claims that 15 strategies, which he outlines, will each save 25 billion tons, so selecting and implementing seven of the 15 will get the job done. These strategies are of all kinds, from using less energy to using energy more efficiently (i.e., driving cars less is an example of the first, cars with higher gas mileage is an example of the second), substituting nuclear, wind and solar generation for thermal, capturing carbon dioxide in power plants, stopping deforestation, since forests act as carbon sponges, and so forth. We'll go into the Socolow article in detail in Lecture 15.

Still other wedges, or 25 billion ton savings, aside from those listed by Socolow, are possible. For example, as I mentioned last week, it's possible to absorb carbon dioxide from the air. Of course, when a lot of carbon dioxide is being generated at one

point, as for example at a coal-burning electric power plant, it makes more sense to absorb and store the stuff at source, but when it's being produced all over the place, as in ten million car exhausts or ten million homes heated by natural gas, you can't collect it from all these dispersed sources but instead from the air at large. There are absorbers, and so the question is how much it costs to absorb a billion tons of carbon dioxide as opposed to how much it would cost not to generate it in the first place by, say, using solar power instead.

I think the same sort of logic – one slice at a time--applies to Problem 2. The problem is the total dependence of the transportation sector on one fuel source, which comes from the most unstable part of the world. No one strategy is going to make the oil market so loose that the problem ends, but a sheaf of strategies. Some of these strategies will appear on the R or resource supply side, and others on the U or rate of use side. Examples of U-type strategies for Problem B include hydrogen, ethanol and electric cars; examples of R-type strategies for Problem B include developing new and different kinds of oil supplies. Examples of U-type strategies for Problem A include using more insulation and less home heating to keep buildings warm; examples of R-type strategies for Problem A include developing non-thermal ways of generating energy we now derive from gas, coal or oil, including nuclear, hydro, wind, solar and geothermal.

If we have a big sheaf of possible solutions, and for two different problems at that, how do we choose among them? One criterion is cost-effectiveness – how much different strategies cost to achieve the same end. Another criterion may be which strategies work on both problems simultaneously, or which pairs of strategies work in combination on both problems. For example, increasing average gas mileage works on Problem B, by tending to loosen oil supplies, and Problem A as well, by adding less carbon dioxide to the atmosphere per million miles driven. Still a third criterion may be avoiding creating another problem – let's call it Problem C – such as having nuclear waste we can't readily dispose of.

At the same time, it's important to keep in mind that no solution is likely to be cost-free. As I said last week, the difference between coal and nuclear is not that one has safety concerns and the other doesn't. In fact, both involve safety concerns, but of different kinds, nuclear a very small chance of a catastrophe, and coal a virtual certainty of relatively low numbers of fatalities each year. By the same token, wind farms kill birds, but not using wind farms may drown polar bears. The search for a solution with no downsides at all is almost certainly futile; instead, the idea is to find the sheaf of solutions that provide the most upsides for the fewest downsides.

I would add that the basic problem, underlying all the others, is the transition from traditional to modern society and the concomitant sextupling of the human population and the expansion of the human and human-supporting habitat at the expense of everything else. This is true when the rice paddy supplants the swamp, when the cornfield replaces the prairie, when the plantation replaces at least part of the forest, and so forth. But, having embarked on that great transition, there's really no undoing it. You may notice that the people who bemoan the increased size of the human footprint, like Br'er Ehrlich, don't volunteer to step off themselves; and in fact practically nobody

volunteers for that. The fundamental point is that we have this increased human footprint, and rather than deplore that fact the only intelligent thing to do is deal with it as intelligently as we can figure out.

So with this basic framework in mind, I want to spend this week looking at the solutions to both Problem A and Problem B. Probably the thermal problem is the more serious one, but it's also the more complex one. The conceptual work we have to do to get hold of the oil problem is less onerous and so I'd like to start with that.

Geography of supply and demand

You can get a quick overview of supply and demand from this chart. Basically, the color or area represents production, and the solid line represents consumption. So when the solid line is outside the area, consumption exceeds production and when the solid line is inside the area, production exceeds consumption.

In the UK, production and consumption are roughly in balance because of oil and gas from the North Sea, but elsewhere there is imbalance. The biggest imbalance on the consumption side is in Northeast Asia—Japan and Korea—with almost no energy production but very high consumption, while the biggest imbalance of production over consumption is of course in the Middle East. When this chart was constructed eight or so years ago, China was in balance, but the size of the Chinese economy has since doubled or a bit more, and China's energy demand level along with it, so that China is now a major energy importer, and its energy imports are growing all the time, even though it's also adding to its domestic coal and hydropower output as well.

International trade in energy varies with the type of energy. Coal is less energy-dense than oil; that is, a given mass of coal releases much less energy when combusted than oil—I believe one-quarter as much. This was the reason that all the shipping in the world switched from coal-burning to oil about 100 years ago: ships could travel much further with the same amount of space devoted to fuel storage. For the same reason, there is much more international trade in oil than in coal—the transportation costs per million BTUs is much less. Natural gas is easiest to transport by pipeline from the wellhead directly to the point of use—the thermoelectric plant or heating furnace—and so most international trade is continental rather than oceanic, as from Canada to the US or from Russia to western Europe. It is possible to liquefy natural gas and transport it in tanker ships, but the explosive potential of LNG is not negligible so docking facilities are few and dispersed. Other types of energy sources—hydropower dams or wind farms—are site-specific and can't be transported at all, although the electricity from them can be—from Quebec to New York or from Laos to Thailand, for example.

At any rate, the imbalance between energy production and consumption, combined with the fact that oil is the easiest of the major fuels to transport, means that there is a gigantic international trade in oil, with trade measured in millions of barrels per day; for example, Japan imports 1.6 million barrels per day. Practically all of the 30 percent of world oil production from the Mideast is produced for export, as is the majority of oil from Mexico and Venezuela in the western hemisphere and from Angola and Nigeria in Africa.

The three biggest producers are the US, Saudi Arabia and Russia, with almost all US production consumed by the domestic market, although some Alaskan oil goes to Japan, which is about as close to Valdez as the US West Coast is; another illustration of the fact that this is an international market, not one in which national supplies are or should be earmarked for domestic consumption. But even though the US is a top producer, its domestic market is so large that US consumption is more than twice current production; about 44 percent of domestic demand is supplied by the US itself, and the other 56 percent by imports. Most of those imports come from Latin American and African producers, while about 20 percent of imports come from the Middle East.

Sealanes and chokepoints. There are three potentially major chokepoints in the international flow of oil. The first is at the upper end of the Persian Gulf, at the refineries and docks of Saudi Arabia and Kuwait, quite close to Iraq. The second is at the southern end of the Gulf: About 14 million barrels a day of oil flows past the Strait of Hormuz at the eastern end of the Persian Gulf, and most of that About 8 million barrels flows through the Straits of Malacca on its way to China and Northeast Asia. The Straits is the third major chokepoint, where all the trade from Japan, Korea and China on the one side and the Middle East, India and Europe on the other passes.

First and second-tier producers. So oil is very unevenly distributed, with mismatches all over the place: big consumers with little or no domestic supply, like Japan and South Korea, having therefore to import most of their supply, and most of the exportable surplus found in a few countries, and most of them in the Middle East. There is one large exporter, Russia, outside the Middle East; within it, supplies are very unevenly distributed, with the largest producer, Saudi Arabia, putting around 10 million barrels a day on line, which is as much as the next three largest producers combined. As you can see, with the exception of Russia the next largest producers after Saudi Arabia are all in the 3 million barrel a day class. Call these three-million a day producers the second-tier countries. There's enough give in the world oil supply that the system can absorb having one second-tier producer off-line at a time, but having more than one second-tier producer offline results in big price increases. This happened three years ago, with Venezuela having a general strike and Iraq in a war.

Since then, the Venezuelan situation has eased but prices have not. This shows that the relationship between oil supply and demand has tightened: the increased demand for oil, particularly from developing Asia – India, China and Southeast Asia, is running ahead of supply. To put it another way, U is growing faster than R and the price of oil, concomitantly, is rising. The effect is that the system is tighter, more rigid, now than formerly. One second-tier producer off-line means the system is too tight, and two second-tier producers off-line mean price spikes. Moreover, there are several perennial candidates for crisis: Nigeria is typically having one, Iraq is not too healthy, and so forth. Moreover, the loss of Saudi production would be an immediate major crisis. Of course, Saudi Arabia is a have power, and have powers tend not to rock the boat Why should they? But a political revolution in Saudi Arabia, as happened in Iran in 1979, would be major and would require a major response.

What to do about it

So having gotten some feel for the scope of the oil problem, the next question is what to do about it. Just as there are a number of variables on the supply side as well as on the demand side, so there are a number of things we can do, some affecting supply and others demand.

Strategic reserves. Since the original oil shocks of the 1970s, the major industrialized countries have all developed strategic oil reserves, amounting to about 90 days= supply. The effect is that a sudden cutoff of Saudi oil wouldn=t bring everything to a complete stop immediately. But this is expensive, since you have the cost of storage as well as the cost of purchase, so developing countries haven=t been able to afford this and don=t have it. So, again, a disruption in oil supply would lead to the bidding up of whatever supplies were continuing to flow, so countries with a reserve would not be shielded from such increases. They are temporarily shielded from the consequences of a fuel cutoff.

Other oil sources. The key fact is that oil production is at an all-time high and is constantly increasing, so that all producers are at full stretch except Saudi Arabia and Qatar, which have reserve capacity. The fact that so much of the world supply comes from its most unstable area is itself a motive to diversify supplies.

There are several new sources that are or could be coming on line. Among those now arriving are Russian supplies, both around the Caspian Sea and around Sakhalin Island north of Japan. Each source is strategically located next to a major consumer, the Caspian fields near Europe and the Sea of Japan fields near Japan. Oil is already Russia=s main export. The other successor states of the Soviet Union around the Caspian Sea Azerbaijan and Kazakhstan also have major oil supplies in their part of the Caspian.

Another potential source is the South China Sea, where there are reported to be 48 billion barrels of oil, half as much as in Saudi Arabia. This source is not currently being developed because there are conflicting territorial claims by six of the nations around the South China Sea, including China and Nationalist China or Taiwan, if you count that as a separate country, Vietnam, the Philippines, Malaysia and little Brunei. There are a bunch of small, uninhabited islands, sandbars and reefs collectively referred to as the Spratley Islands right in the middle of the fairly shallow South China Sea, and the surrounding nations have territorial claims over different islands based on traditions and reports of various ancient mariners having landed on one or another of these islands. Of course, the islands are of no importance in themselves, but are important because of-what? The 200-mile Exclusive Economic Zone provided in the LOS, which would come into effect if any of these claims were ever proved. In the meanwhile, no one wants to invest billions of dollars based on an oil lease of doubtful legality, so the oil is still undeveloped pending some resolution of all these claims.

The Spratleys, and the oil around them, are closest to the Philippines. As you know, the Philippines had a long history of colonialism. Manila was founded by Spain as far back as the 1570s. A little over 300 years later, the US took over the islands from Spain after the Spanish-American War of 1898, and the Philippines became the cornerstone of the American military position in the Far East, chiefly including the naval

base at Subic Bay and the airbase at Clark Field. After decolonization in 1946, the US retained the bases under twenty and twenty-five year leases.

The fact that US military bases remained on Philippine soil was felt as a grievance by Philippine nationalists and leftists, and this anti-American feeling grew especially strong after the end of the Marcos dictatorship in 1986, since American support for Marcos had continued until quite late in the game. As it happened, the leases were coming to an end in 1991, and negotiations for renewal of the leases began. But the negotiations were quite difficult. In addition, it was unclear whether any lease would be ratified by the Philippine Senate. Many senators were on record that the Philippines had no foreign enemy and that the existence of the bases did the Philippines no good but only made the islands a military target for powers hostile to the US. In the middle of the negotiations, the Mount Pinatubo volcano erupted and buried Clark Field under several feet of volcanic ash. Although Clark Field was at least temporarily worthless after the explosion, the Philippine negotiators demanded a higher rent on the ground that they needed more money. At this point it became clear that the negotiation would not be successful. The leases were allowed to expire and the Americans left Subic and Clark amid some bad feeling on both sides.

The anti-base position, that the Philippines had no foreign enemies and no need for the bases, proved to be true for about two years and a half. Then, in 1994, the Chinese navy landed on Mischief Reef, quite close to the west coast of Palawan Island, and set up what they rather humorously referred to as a fishing village. The Philippine government protested, but of course the protest was shrugged off by the Chinese; the presence of military might may not make right but it doesn't do it any harm, and the absence of military might doesn't do it much good. The Philippines, a very poor country, has no navy or air force worth mentioning and no way of being able to afford one.

So no effort was made to dislodge the Chinese base on Mischief Reef. Instead, each of the six claimants except Brunei set up bases of its own. The result is that there's now a hodgepodge of scores of different bases set up by the Philippines, Vietnam, Malaysia and the two Chinas, with no order among them and no clear geographic claim to oil in one spot as opposed to another.

Who gains control of this oil depends on what happens to the region as a whole. The big story in mainland Southeast Asia is the growth of Chinese influence. China is the only friend of the repressive government of Burma. During the Asian financial crisis of eight years ago, China came to the rescue of the national bank of Laos, which was facing severe currency depreciation, and increased its imports from Thailand, which was undergoing the same problem. In 2000, a new Thai government was elected with its base in northern Thailand, the area close to China, and with a program of enhancing trade ties with China. Since then, major river ports on the Mekong river have been developed in both China and Thailand, and the two countries have entered into a free trade agreement. The interesting case is Vietnam, which has always had a two-sided relationship with China, on the one hand fearing China's attempts to control it but on the other hand borrowing much of China's form of government and social organization. This is a pattern that goes back more than a thousand years. It's especially acute right

now. On the one hand, China and Vietnam fought a war as recently as 1979, the issue being whether a Chinese-backed government or a Vietnamese-backed government would control Cambodia, which is right next door to the Mekong delta and Vietnam's biggest food source. On the other hand, Vietnam and China are two of the very last Communist countries in the world, and are facing the very same political problem, namely why should a one-party Communist government, whose mission in life is supposed to be controlling economic production and distribution in the name of socialism, why is this government continuing its political monopoly when the whole economy is being decontrolled and turned over to the free market? Faced with this really insoluble question, the Communist governments of China and Vietnam each have an interest in clubbing together. So Sino-Viet relations over the next decade or two will be interesting.

So what will become of all the oil in the South China Sea? In addition to the Philippines and Vietnam, individual countries, there's also an Association of Southeast Asian Nations or ASEAN. Fifteen years ago, the member countries of ASEAN formed the ASEAN Free Trade Area, or AFTA. At this time (1992 to 1994) the great economic boom that Thailand and some of the other Southeast Asian countries had enjoyed was starting to cool off, and foreign investors were starting to pay a lot more attention to China. AFTA was formed to make Southeast Asia more attractive to foreign investors, and so to enable ASEAN to compete more effectively with China. But AFTA was a case of too little, too late; investment flows turned away from Southeast Asia and toward China, with the result that Southeast Asian economic expansion couldn't be maintained. Southeast Asia's boom times of the early 1990s turned to the financial crisis of 1998.

So how are China and Southeast Asia relating now, and how will they relate in the future? I said a minute ago that AFTA was formed to enable ASEAN to compete more effectively with China, but failed. Just lately (I mean within the couple of years) China and ASEAN have formed a giant free trade area of their own, so the economies of Southeast Asia and China will be increasingly linked together. As this evolves, China and Southeast Asia will have every reason to develop the oil resource of the South China Sea cooperatively rather than as rivals.

In terms of world oil supplies, it doesn't matter who develops the oil as long as it is developed. If China is able to get a large amount of its oil from the South China Sea, it will be bidding for oil less intensely elsewhere, and the upward pressure on prices caused by China's economic growth will be diminished. On the national scale, being the owner of a lot of oil is very valuable, obviously. On the world scale, any increase in oil supply helps ease the oil market, regardless of who the owner of the oil is.

The same sorts of considerations apply to China's 2005 attempt to buy Unocal, an American oil company. Some people expressed concern that China would have first dibs on whatever oil Unocal controls. That's true as far as it goes but it really doesn't matter. Unocal doesn't earmark its oil for Americans or the American market, but sells it to whoever bids for it. If China did gain control of Unocal and did earmark Unocal's oil for the Chinese market, then China to that extent would be less interested in buying oil from other producers and the oil of those other producers will flow to other oil consumers. This business of who owns which oil company is a complete red herring.

By the same token, the fact that the US is less dependent than Europe or Japan on Middle East oil is nothing to congratulate ourselves on. The US gets 20 percent of its oil from the Middle East, while Europe gets half and Japan gets three-quarters. But a cut in supplies from the Middle East would cause Japan and Europe to bid frantically for any remaining supplies, and that would cause a gigantic price rise and shortage here and everywhere else in the world.

Non-conventional oil supplies. In addition to liquid oil you pump from the ground, there are three other sources of oil. First: oil from coal. This technology is over sixty years old, going back to World War II, when Germany was cut off from the world oil market by the British navy. Although some could be imported from Rumania and from Russia before the German attack on Russia in 1941, these supplies were insufficient, so Germany used some of its plentiful coal and converted it into scarce oil. Of course, this was more inherently more expensive than using imported oil, since it represented an extra step in the production process—it's obviously cheaper to start with oil than to start with something else and turn it into oil—and it was also dirtier, since coal almost always contains more impurities than oil. But, as in the case of desalinizing sea water, it can be done, so that coal supplies can be substituted for oil if the need arises.

The second is oil-bearing rock or oil shale, which exists in the Rocky Mountain states—Colorado and Wyoming—apparently in gigantic quantities. The rock has to be pulverized, impurities remain, and apparently huge amounts of water are needed to wash the debris away (although I suppose this doesn't have to be high-grade water and so can be reused), so using oil shale is both more expensive and dirtier than using oil; but oil shale can be used if oil supplies were ever to run out. In terms of the oil market, if, due to political instability or actual shortage, the price of oil were ever to exceed the cost of converting shale, we would use shale. This would mean that the price of oil would have to double, which of course would be miserable for the economy and would basically mean the production of less stuff at a higher cost, but the other way of looking at this is that the existence of oil shale sets a price ceiling above which the price of oil can't possibly go. Again, just as desalinating water costs three times as much as fresh water, turning from fresh to desalinated means bearing a heavier cost for a critical commodity, but the other side of the coin is that there's so much seawater that we can't possibly run out of it, and the top cost of desalination is the top price of water. Something of the same is true of shale—it's dirty and expensive, too expensive to contribute to oil supplies now, but it could be used if oil supplies do diminish, and the cost of shale conversion is the top price of oil.

The third source is tar sands, or oil-bearing sands which are found in large quantities in western Canada and elsewhere. This is sort of the coal situation again: it's easier to start with oil than to start with tar and turn it into oil, but if the price of oil rises to a certain point, it makes sense to do it. In fact, at \$60 a barrel oil is well past that point, and tar sand oil production is being carried on at present.

Over the long haul, the existence of huge and so-far untouched quantities of oil-bearing materials mean that the amount of oil resources is measured not in decades but in centuries. Over the next few decades, however, it is not expected that unconventional

oil sources will make up more than a small fraction—say ten percent—of total oil supply. Unconventional sources can barely compete with cleaner and cheaper conventional sources. But adding ten percent to world oil supply like adding another Iran and Nigeria; certainly nothing sneeze at.

Cut oil demand. So much on the supply side. The fact that the least substitutable energy source is disproportionately concentrated in the most unstable part of the world means that this problem will continue indefinitely into the future. New sources of oil, like the South China Sea, will be discovered and developed, but the increased demand from China, India, Brazil and other fast-growing countries means that oil supplies will continue to be tight even though more supplies will come on line. The solution is to change the transportation system so that it's not dependent on oil.

On the demand side, the whole thing revolves around transportation. Remember, the only reason oil is so key is that it's the only energy source that can play a major role in transportation. But it's at least possible to develop other means of transportation, either less dependent on oil or not dependent on oil at all.

Ethanol and hydrogen. Both of these are presented as Problem A solutions, because they either produce no carbon dioxide, in the case of hydrogen, or because the carbon dioxide they produce, in the case of ethanol, is reabsorbed by the next ethanol crop. In fact, they're both Problem B solutions, that depend on other technologies to have a Problem A effect—on non-thermal electricity sources to produce the hydrogen or the crop used for ethanol, and for the ethanol distillery.

This is not a knock. Solving Problem B would be nice, and this is one area where government can actually play a constructive role. Hydrogen suffers from a coordination problem—there won't be any hydrogen users unless there's a chain of hydrogen filling stations, and there won't be any filling stations unless there are a lot of users. These coordination problems are solvable, and in fact government can help to solve them, with low-term, low cost loans to hydrogen producers and filling stations, for example. The thing is, what's true of hydrogen today was true 33 years ago at the time of the first oil crisis, and you can see how much hydrogen we're using. The complete lack of leadership from both political parties is probably the single biggest factor in getting us to where we are now.

Electric cars. I answered a question by David last week about the electric car by talking about the mass ratio between the fuel and engine on the one hand and the rest of the car on the other. This is similar to the difference between oil and coal as a fuel for steamships. Basically, you have a certain mass of gasoline in your car and that mass will propel the car say 250 miles. That same mass of batteries will propel the car perhaps 50 miles. Obviously, batteries in the present form will not replace combustion for air transport, for trucks or for long-distance commuters.

Nonetheless, I was a bit too ready to dismiss the electric car, not as a complete solution but as workable for those people who never or almost never need their car for more than a 50 mile round trip. The problem is that few people are going to own two cars, one of which is capable of going only short distances, even if they mostly go short

distances. It would be like having two computers because one only did word processing, and the other had a lot more features. In that situation, nobody would bother with the limited-function computer, and it may be the same thing here. This seems to me to be another very good case for subsidization, especially since many of the potential consumers of this product will be retirees who would probably be glad of a price break. On the other hand, these are low-impact users – the kind of people who drive 100 miles a week or less, so the fact that they would stop using gasoline would not be that much of a contribution to Problem B. Still, it would help.

Higher mileage standards. Getting more mileage from cars can work on both Problem A and Problem B: Problem A because fewer greenhouse gases are generated and Problem B because lower gas consumption makes the oil market less tight; it's a way of working on the U side of R/U. Since it works directly on both major problems, it's very understandably a very popular remedy. The trouble is it's a remedy that isn't really tried much, at least at the federal level. Fuel standards are exactly where they were 15 years ago. There's currently a bill to raise fuel standards by 50 percent over the next 15 years – from the low 20's per gallon to the mid-30's, which is modest enough. This bill has just passed the Senate, but the current Chairman of the House Committee on Energy and Commerce, Rep. Dingell, is from Detroit and is opposed to the bill, which therefore may not go anywhere. It's another case of special concentrated interests defeating diffuse general interests.

Public transportation: urban mass transit. Another proposal is substituting mass transit – BART and buses – for cars. BART runs on electricity, and so is a Problem B solution, lowering the U side of the oil R/U equation, and a Problem A solution only if the electricity comes from a non-thermal source: it's the electric car all over again. But the question is whether mass transit is a cost-effective way of solving Problem B.

This issue is particularly acute in the Bay Area: traffic is a mess, we think of ourselves as anti-pollution, and BART is a minor part of our transportation picture. Yet the traffic situation in the Bay Area is a mess, and particularly here in the East Bay. The Eastshore Freeway is jammed, and as much now that a fifth lane has been added as it was before. There's only one road link between San Francisco and the East Bay, the Bay Bridge, which is now 71 years old and jammed more often than not, at any time of day. There are other bad links as well – the 101 freeway from San Rafael to the Golden Gate, for example. The basic problem is that the population has been growing more quickly than new transportation infrastructure is being built.

There's a conventional wisdom that the way out of this problem is by investing in mass transit and public transit, in BART and buses rather than in more roads for cars. We do have a BART system, but it's not used that much – the cars are half-empty much of the time. Maybe the reason is that it costs a lot more than twice the price of the New York subway for longer trips, and that's true despite heavy subsidies from the state to the BART system. Or maybe it's because there are a lot of places BART doesn't go. If you want to go to the Aquarium in Golden Gate Park, or anywhere west of Civic Center for that matter, BART is more or less useless to you. So the question is whether we should invest more in BART to extend the system further, or whether that would be throwing good money after bad.

The real heart of the problem is low ridership. Since most of the costs of a rapid transit system are the initial costs of constructing it, a system with few riders is a financial disaster. A rapid transit system can work financially only with high-volume ridership, and so it works only in cities in which high-volume ridership is available. Such cities are those not only with high population, but with high density, high population per square mile. New York, with 25,000 plus people per square mile, is the American city with the highest density, and by no coincidence it is the city with by far the most highly developed subway system. Another good example is Chicago.

The rule of thumb among transportation engineers is that the minimum acceptable density for a subway system is 10,000 people per square mile. The density of the Bay Area is just about 10,000 people per square mile. In other words, BART is a marginal operation, dependent on very heavy subsidies to keep its budget in balance. This is still another example of a self-limiting system. The relatively low density of the Bay Area makes it financially infeasible to build an extensive subway system on the model of New York. On the other hand, the skeletal system that can be afforded is by that token of limited utility.

The bottom line is that the age of the city and its suitability to rapid transit are correlative. Cities whose major period of physical growth occurred before the rise of the automobile before World War I, just as a rule of thumb were for that very reason built densely and so can support rapid transit systems. Cities whose major period of growth occurred after the rise of the automobile are for that very reason built less densely and so cannot support rapid transit except with massive subsidies. Conversely, the central cores of older Eastern cities, those which can support rapid transit, cannot support large numbers of parked or moving cars; Western cities whose major period of growth was in the twentieth century, and particularly after World War II, were built in the context of large-volume auto traffic and so were built with the ability to move large volumes of traffic. Examples of such cities are Houston, Los Angeles and San Diego.

The key contrast is between New York and Los Angeles. New York, with over 25,000 people per square mile, can support one of the most highly articulated subway systems in the world; Los Angeles has more than twice the area of New York but half its population. It follows that the LA subway system was a costly boondoggle. The bottom line is that the utility of rapid transit systems in the newer, west coast cities is limited.

Buses. Nevertheless, it's important to have a healthy public transportation system. People tend to choose cars if they can afford them, but a lot of people can't afford them, and a city geared to the car leaves such people high and dry. Again, Los Angeles is notorious for this. In addition, the automobile capacity of even the most auto-friendly city is limited.

Given the very high capital costs of a rapid transit system, the main alternative is the bus. Once again, the marginal cost of picking up additional passengers is close to nil. In other words, it costs no more to run a bus with 40 people aboard than one with

10, but the full bus makes four times the money as the nearly empty one. There is therefore a tendency for transit systems to run fewer buses than are comfortable for their passengers, since a system with crowded buses is much cheaper to run than a system with half-empty ones. If you want to move 40,000 people, you can put 40 people in each of 1000 buses or 20 people in each of 2000. The second case is more comfortable for the riders and means a faster trip, since the bus is stopping and starting less frequently. On the other hand, the cost of the first alternative is half that of the second, so the transit company will tend to favor the first alternative. In other words, bus traffic will tend to be crowded, perhaps as crowded as the ridership will tolerate. It will also tend to have infrequent service during off-peak hours, and so will be inconvenient for that reason too.

People prefer the personal transportation for a lot of reasons—shorter travel time, more flexibility, greater convenience and so forth. The key to successful public transportation is to close these gaps to the greatest possible extent, to make the bus as fast and as convenient as possible. The problem is that the economics of the bus push in the other direction—to high crowding which means less comfortable and longer trips. This tension between economics and desirability probably means that bus travel can be made attractive only if it is subsidized, allowing the purchase of more buses and the hiring of more drivers than strictly economic considerations would allow.

Taxes and subsidies generally. So far, I've mentioned several ways in which subsidies can affect energy use, by encouraging—actually creating incentives for—buses, hydrogen fuel, electric cars and so forth. When the government subsidizes something, people tend to produce more of it. Conversely, when the government taxes the production of something, people tend to produce less of it, and when the government taxes the use of something, people tend to use less of it. So it is with the R and U of energy: subsidizing the different kinds of R would lead to more of them; taxing U would lead to less of it.

This is what makes the past and present energy bills so fascinating. The last energy bill, passed in 2005 when the Republicans controlled both houses of Congress, contained subsidies for coal producers, nuclear power generators and domestic oil producers, and no taxes on consumption at all. Needless to say, representatives of the oil industry contributed generously to Republican candidates in the previous and subsequent election. The current bill, pending before the now-Democratic congress, will remove subsidies for nuclear power, lower the subsidies for coal, tax oil production and subsidize wind, solar and biomass production.

As usual in this field, and in fact in every field the government operates in, the bill is a combination of policy, in other words actually dealing with Problem A and Problem B, and politics, in other words rewarding your friends and punishing your enemies. The 2005 bill did that, rewarding the contributors of the party then in power, and the current bill is the same, punishing those contributors and rewarding other interests. This is not unexpected: Lincoln Steffens once defined politics as the intersection of business and government, and it's absurd to think of it any other way. The trouble is that, as the Bible says, no man can serve two masters, and the Congress is always in the position of trying to do exactly that, making coherent policy on the one hand and doing its political thing on the other. The result is often incoherence, of the

two horses, to change the metaphor, pulling in opposite directions at the same time. As one example, the current bill contains a provision to prosecute excessive prices for gasoline. In other words, the Democrats are in favor of cutting greenhouse gases by insuring continued low prices for gasoline.

Combined strategies generally. I think Problem B is serious enough that, to my mind at least, all the horses ought to be pulling in the same direction. On the R side, new supplies of all kinds should be subsidized, with especial attention to non-oil types of transportation, and the subsidies paid by taxes on the U side. Moreover, non-oil transportation will help with Problem A only if the fuel – hydrogen, alcohol, biomass or whatever – is generated by non-thermal means, so special attention should be paid to such means. Taxing oil production is a way to make Problem B worse, and keeping gas prices low is a way to make both problems worse.

Gasoline taxes specifically. Gasoline taxes are often cited as a way to cut gasoline consumption. Things do normally work this way – if you tax something you get less of it. In the case of gasoline, however, not much can be expected in the way of cutting consumption from more gasoline taxes. Over the past four years, gasoline prices have doubled, but the total number of miles driven has hardly changed at all. This tells us that gasoline demand is quite inelastic – that people will not respond to higher gas prices by driving a lot less, particularly if no substitute is readily available. Nonetheless, the revenue raised by gasoline taxes can be applied to subsidize other energy subsectors, such as solving the hydrogen coordination problem, which in turn will provide a substitute. The more direct way of lowering gasoline demand is by raising average fuel economy standards.

Other thermal fuels

I now want to switch focus from oil to the other thermal fuels, coal, natural gas and biomass. As you=ll see, there are no major issues with availability of any of these fuels, but there are a couple of interesting points to make.

Coal. There are four main things to say about coal: it=s more abundant than oil or gas, it=s more widely distributed, it=s dirtier and it=s harder to get out.

As for abundance, there are now forty years= proven reserves of oil but 200 years= worth of coal. Coal is in such long supply that there=s no concentrated effort to find more out-of-the-way sources as there is for oil. Because there=s so much of it, it=s widely distributed, with major coal deposits in North and South America, Europe, Russia, and China. There may also be unworked deposits in Africa and Australia, but energy use in those continents is fairly lowBAfrica because it hasn=t yet industrialized and Australia because its population is so scanty.

Because coal is so widely distributed, the mismatch between production and consumption is less severe in coal than in oil. China is now the leading coal producer and consumer, and the US is second in both categories. Other countries with large amounts of coal production and consumption include Germany, England, South Africa and Russia.

In addition to being more widely and evenly distributed than oil or gas, coal is bulkier than oil and gas, producing less heat energy when burned per unit weight. Because of its greater bulk, transportation costs are higher for coal than for oil, so less coal is traded internationally than is the case with oil. Whereas more than half of oil is traded internationally, only 11 percent of mined coal finds its way onto the world market, although this is expected to increase to 13 percent as China's demand for energy in all forms continues to grow.

Third point: Coal is dirtier than oil and gas. In other words, it contains a higher percentage of chemical impurities, the presence of other elements than carbon and hydrogen. These elements chiefly include S, sulfur, and N, nitrogen. When coal is burned, the sulfur oxidizes to sulfites, the SO_3 radical, and sulfates, the SO_4 radical. These radicals in turn combine with water to produce sulfuric as sulfurous acid, ie, acid rain. Nitrogen oxidizes into a number of different compounds, all in the form $NxOy$, and which together are a major component of smog. Other coal-generated smog components include solid particulates or soot, carbon particles that are not combusted.

Coal-fired thermal plants can be scrubbed fairly effectively, but these techniques are expensive—they divert energy. In poor countries, the tendency is not to use these techniques. The effect is that poor countries with big power demands and large coal deposits tend to have a lot of smog. I'm chiefly thinking of China in this regard. In Beijing, which is infamous in this regard, the average amount of smog is three times the worst day that Los Angeles ever saw.

The last point is that, because it's a solid, you can't just pump coal out of the ground the way you can with oil and gas, which are fluids. You have to go down and get it, and underground work can be dangerous. There are cave-ins and there are gas explosions. Because coal production is so diffuse, you don't have major catastrophes with thousands of people killed, but you do have dozens or scores of people trapped underground or blown up by coal gas explosions, and, because there are so many coal mines, it's a statistical certainty that there will be several such accidents a year.

Natural gas. Natural gas is more widely distributed than oil, with major sources found in Russia, around the Caspian Sea, Canada, the United States and elsewhere. Because natural gas has to be either pumped directly into a distribution pipeline or liquified and deliquified, international trade is either between geographically proximate producers and consumers (as in the case of Canada exporting natural gas to the United States, or Russia to western Europe) or in the form of LNG, which is the fastest growing form of energy exports. Developing countries that have severe air pollution problems, notably India and China, are increasing their use of natural gas, which is less polluting and represents a diversification of supply sources. Given China's unstoppable appetite for energy and rapidly increasing wealth-- the Chinese economy grew at over nine percent last year—BI would expect a gas pipeline connection across Central Asia to China for overland natural gas transport.

The effect of overland natural gas pipeline development is the integration of the producing and consuming economies that are connected by the lines; for example, natural gas is produced in Argentina in order to generate electricity in Uruguay which is

exported to Brazil, furthering the economic integration of the Mercosur (Southern Common Market) economies; Canada and Mexico export natural gas to the US, similarly furthering the integration of the economies of North America. In what may be the most significant present international connection, Russia exports huge amounts of natural gas to Europe, a development that goes back to the last decade of the Soviet Union. It was then frowned upon by the US, on the grounds that it would give the Soviet Union undue influence over western Europe; but since the end of the Cold War and the inability of the Russian state enterprises to compete on the world stage, the export of raw materials is one of the economic mainstays of the new Russia and so one of the main props of its economic and political stability. In the future, the overland connection between Turkmenistan and the ROW may be equally important, at least to that part of the world. Possibilities include west to the Caspian, across to Baku and then to Georgia and Turkey, or south to Iran, or east to China.

Biomass. Biomass actually has two meanings, which should be kept distinct. The first meaning relates to traditional fuels, including wood and charcoal, as well as other organic products like peat, animal dung and so forth. As we saw when we were looking at timber last week, biomass in this sense is much more widespread than is generally believed: something like forty percent of all the wood taken in the world is for firewood, rather than for construction material. In some parts of the world, biomass is even more significant, comprising 80 percent, I believe, of domestic fuel use on India; and eastern China was largely deforested, even before the modern era, because of the need for fuel. The same thing is true of large parts of sub-Saharan Africa.

As in the case of coal, biomass in this sense contains a lot of organic impurities, and in fact if you want to rank thermal fuels, natural gas has the fewest impurities, oil the next fewest, hard coal next, then soft coal and finally biomass; the rule is that the closer you are to the natural state the more impurities the fuel will contain. The result is that very high degrees of air pollution, lots of smoke and haze also characterizes the countries that use biomass combustion. Has anyone here been to India?

The other sense of biomass is as a gasoline substitute, with plants being raised for conversion into alcohol. This is presented, not as polluting, but as carbon-neutral, since the carbon dioxide produced by ethanol combustion is reabsorbed by the oncoming crop. This is true as far as it goes, but more energy is required to plant, fertilize and harvest the crop and distill the alcohol, with different crops having different energy input/output ratios. Corn, which is the largest ethanol source in the US, has a ratio of 70:100, in addition to using up all sorts of cropland. Sugar, which is the most prominent source in Brazil, has a ratio of 10:100. The fact that we use corn is widely and obviously correctly attributed to the strength of the rural states in the Senate, and not to anything that makes sense from an energy point of view.

Tradeoffs. I want to conclude with the idea that costs and benefits are inescapable, whatever strategy or combination of strategies is adopted. Each of the major sources of energy has its drawbacks: coal has acid rain and pollution, and the certainty of a couple of hundred miners getting killed every year. Oil involves all the political problems we know about. Hydropower involves resettling some thousands or hundreds of thousands of people and disrupting their lives. Nuclear power has the

threat of accidentBhow big the threat is we=ll hear from Mike Lederer tomorrow. What I=m getting at is, it=s not enough to say you don=t like acid rain or nuclear waste. Who does? What you have to do is be aware that any alternative has drawbacks, and figure out a strategy that will minimize those drawbacks. It=s a safe bet that you won=t find any strategy with no drawbacks, so that standing out and insisting on a cost-free solution is a way of guaranteeing that there=ll be no solution at all.