MITOCW | 15. Non-Renewable Energy Resources

RICHARD SCHMALENSEE: So today, we're going to talk about non-renewable sources-- boring, dull, fossil stuff. The main reason for talking about this stuff is it's really important. It's about 92% of US primary energy. And if you look global, and you look just at marketed energy, forgetting gathered wood and related stuff, it's also about 92%.

And this is an EIA graph that basically shows the evolution of primary energy supply from 1850 to 2000 or 2010. The point of this graph is it changes slowly. 1850 is all wood and a little coal. Coal gets big, coal shrinks, coal's still important.

Oil's nothing, oil gets very big, hasn't shrunk much. And renewables-- with a good glass, you can kind of see them up here. So these things change slowly. Fossil markets are important. They will continue to be important.

What I'm going to do is a little bit theory, because you have to hear about Hotelling when we talk about non-renewable natural resources, and then talk about why Hotelling doesn't quite work, but why the key insight holds, and then just go through some markets. So I'll start natural gas today. I'm going to finish it up on Wednesday,

Wednesday, I want to have a discussion basically on fracking, and its related technologies and implications. If you look at the readings, there are some pros, some cons, some neutral. It is probably the biggest energy development in my lifetime, and it has lots of pluses and minuses, which I hope we can explore a bit, which we won't resolve. They'll be resolved in your lifetimes, but this is a big deal, not just in the US where I'll focus, but globally.

So the Hotelling decision, the Hotelling theory, is pretty straightforward. You imagine you have 1,000 barrels of oil in the ground. You have a valve. You can pump it out whenever you choose to pump it out.

It costs you $30 a barrel to pump it out. And you can produce it whenever you want. The price of oil today is $80 a barrel. If you know the future, this theory says, how do you decide when to produce? Brendan.

AUDIENCE: You just choose the days when the oil prices are the highest per barrel. I mean, the oil per barrel price is the highest.

RICHARD SCHMALENSEE: You want to discount, maybe?

AUDIENCE: Yeah.

RICHARD SCHMALENSEE: So you might want to maximize discounted net revenue. Marginal cost is the same, by assumption. So yeah, you'd want to maximize that.

So you choose a time T or a set of T's, if they're are all equivalent, and pump it out. Is that clear? That's sort of how you decide.

You've got a choice of time now. So you look period by period. You say, when is the good time? You'd pump it out then.

Now, the interesting question is, suppose the whole world looks like this. Suppose everybody's got an oil well exactly like yours. What has to happen to the price of oil? Kirsten, want to take a shot? What's the price of oil have to do?

AUDIENCE: It has to respond to demand. If all the oil wells are exactly the same, then you're assuming that [INAUDIBLE].

RICHARD SCHMALENSEE: Well, I'm sitting here. I have 1,000 barrels in the ground. Everybody's got 1,000 barrels in the ground. There are a lot of us, so it's competitive.

And I have perfect foresight. I can see where the price of oil is going. So if that market with all of us with wells like that and a known demand curve, let's say, is going to be in equilibrium, what has to happen to price?

OK, let me push you a little bit. Suppose the price today-- suppose it's two periods, and call that thing up there "discounted net price." Suppose discounted net price today is higher than discounted net price tomorrow. When do I produce?

AUDIENCE: Today.

RICHARD SCHMALENSEE: Today. And if we're identical and we all produce today, what happens to today's price?

AUDIENCE: Goes down.

RICHARD SCHMALENSEE: Goes down, so it probably isn't going to be higher than tomorrow's. Suppose it's lower than tomorrow's. What do we all do?

AUDIENCE: Wait till tomorrow.

RICHARD SCHMALENSEE: And if we all wait--

AUDIENCE: Then it goes down.

RICHARD SCHMALENSEE: If we all wait, then today's price goes up, because nobody's producing. If it's equal to tomorrow's, then we sort of don't care when we produce. And it kind of can be in equilibrium then, if it's equal.

But if it's not equal, it can't be an equilibrium between the two days. Everybody see that? If the discounted net price is different in two periods, it can't be in equilibrium, because either you'll switch out of one or you'll switch into the other, and that'll upset the price.

So if today's price is low, if I expect the price to rise rapidly, I won't produce. Neither will anybody else. Today's price won't be low if nobody's producing. That's not an equilibrium.

If today's price is high relative to my expectations tomorrow, I'm going to produce. And if we all produce, it can't stay high. The only way you can have an equilibrium is if this quantity, price minus marginal cost, rises at the rate of interest. If that rises at the rate of interest, then I don't care when I produce.

Basically the other way to think about it, that I think maybe is the most useful, is I've got a choice between leaving the oil in the ground and leaving my money in the bank, hypothetically getting interest rate R. Sorry, I have a choice between leaving the oil in the ground and getting whatever I get based on the future price of oil, or pumping the oil out and putting the money in the bank. So I can either invest in oil or in the bank. And unless those two are equal, I won't be in equilibrium.

And the mechanism I went through with Kirsten is if you're out of equilibrium, if this equality doesn't hold for all t, then we will, all of us in a competitive market, make changes in production decisions that move you in the direction of equilibrium. So if tomorrow's price is low relative to today's, we produce today, which lowers today's prices, so that can't be an equilibrium. If today's price is low relative to tomorrow, we all wait, which raises today's price.

Only if that equality holds do we not have an incentive, all of us, to shift production dramatically. So it's investing. It's leaving it in the oil versus leaving it in the ground versus putting it in the bank. If those two aren't equal, you readjust.

Is that pretty straightforward at this stage? OK, one thing that's interesting about this story is you'll notice that price is above marginal cost everywhere, even though by assumption it's a competitive market. How can that be?

Well, that's because when you produce today, you incur not only the marginal production costs, but you incur an opportunity cost. With only 1,000 barrels, if I produce today, I lose the chance of producing that barrel in the future. So part of the cost of producing today is that opportunity cost, which is why the equilibrium has price above marginal cost.

If price is equal to marginal cost at all times, nobody's going to produce. Why would I produce today, given that prices might be better tomorrow, blah, blah, blah? So that's the basic Hotelling story-- that under competitive conditions, price rises at the rate of interest.

This is the usual picture with time. Price minus marginal cost rises at the rate of interest or simply enough-- with the given demand curve, you're basically running up the demand curve until you run out of whatever it is. And this has quantity on the axis and this time on the axis, so that you can't go immediately from one to the other, but you see the point.

And for simple cases, you can just write it out. You can solve the equations. So under these assumptions, it doesn't matter when you produce the oil if you're a competitor, because all these have the same discounted net revenue.

And if a monopoly has all the oil and you're a competitor, you might want to produce now because what the monopolist will do will have marginal revenue minus marginal cost rise at the interest rate. And if that doesn't make sense to you, don't worry about it. We're not coming back to it. So you may want to produce today.

Now, this is a really nice theory. This is very elegant. It's very simple. I didn't have to wave my hands too rapidly, I think, to explain it.

There's only one tiny problem with it-- prices don't rise at the rate of interest. These are oil prices. These are 2010 dollars, so the lighter line is the real price of oil.

And that is not a smooth curve rising at the rate of interest at any time in any place. So the first thing you have to ask is, is that theory fundamentally crazy or is it too simplified by a bit? And the answer is, I think, it's too simplified.

And I'm going to talk a little bit about what it leaves out, without trying to do anything more complex than that. It's important. So there are a bunch of things it leaves out.

I think the most important one is exploration, because you don't have 1,000 barrels in your well ever. You don't know what you've got. If you think about-- just focus on oil-- you look for promising geology.

You explore it. You drill to prove the reserves. You refine your estimates. A former teacher of mine just said Hotelling is wrong. It's not a tank of oil, it's an inventory.

As an oil company, you build inventory, and then you run down inventory. So reserves at any time are the result of a set of decisions. But the decisions have this same dimension.

When do you explore? When do you invest? When do you lease a tract? When do you drill? How many wells do you drill?

Those are all when decisions. Those are all intratemporal decisions. And you have to think about today's price and tomorrow's price.

And if you think today's price is really low and tomorrow's price is going to be better, you wait. If you think today's prices are high and you can get the oil out in a hurry, you move ahead. So this same notion that's in the simple model, that says I've got to think about the path of price to make decisions, holds true, but these are much more complicated decisions. and in the face of uncertainty, because you don't really know reserves or demand or anything else.

And interesting little number-- from proved reserves, you can look up a definition, but it means reasonably likely you can get that oil out at commercial costs. So from the end of 1976 to the end of 2009, proved oil reserves in the US fell by 10.26 billion barrels. How much do you think was produced over that period? How many of you think more than 20 billion barrels was produced over that period?

Reserves fell by 10.26. How many think that over that period, more than 20 were produced? OK, how many over 30? Anybody think over 40?

78 and a half-- continuing process of exploration, discovery, proving the reserves, expanding the field, investing in recovery. Reserves are an inventory. You still have to decide when, some cases if.

You can lease a tract that you can drill in. You may decide not to drill. You have a certain amount of time. You decide not to pick up the option.

But all these decisions are when decisions, but that's why we're going to run out of oil because reserves are low. Reserves are always low. This is the point. There's no point in building up huge reserves, which is an activity of exploration, and investment, and discovery, and so forth.

There's no point building up reserves you're not going to need for 50 years. Why make that investment now? So that's one story. Exploration is a big story. It involves a lot of when decisions, just like the simple model.

The other part of the story is depletion. And depletion operates at two levels-- a given oil field will eventually stop producing. You will have all the oil out.

But a given geographic region like the US, it gets harder and harder. There's a reason we're drilling miles off the coast in the Gulf of Mexico and miles down. The first wells in Pennsylvania, the oil was coming out of the ground. They basically used buckets.

It's a little harder now. Cost rises. The other side of the coin, of course, is that we're getting better at it.

And people in the oil business talk about the price of oil as a race between depletion and innovation. It's harder to find it. It's harder to get it out of the ground. We're getting better at finding it and better at getting it out of the ground.

There's no guarantee that technology wins that race. So far it's done quite well, but these massive things offshore-- we'll see how far that goes. And of course, you don't know.

But one of the things-- you don't know the supply, demand, what competitors are doing. So a lot of the fluctuations in price you see are due to just uncertainty. People misguess.

There is a recession. The demand falls. There's a sudden, boom that people hadn't anticipated. Demand rises.

And particularly in oil, where we spend a fair amount of time, there isn't much flexibility. It's not quite like that Hotelling model where you basically have a valve. When you've drilled and there's pressure in the field, you tend not to shut a well in.

That has a variety of consequences. So in the short run-- and it's expensive to store oil. I mean, you store it. It is stored, but it's not stored in gigantic quantity. So there's relatively inelastic supply.

When we talked about demand curves, we talked about relatively inelastic demand. And that means you've got a steep supply curve-- let's see-- a steep supply curve and a steep demand curve. And when they move, price is very volatile. At the risk of-- well, there's no eraser so I'm saved having to use the blackboard, but imagine a steep demand curve and a steep supply curve-- little fluctuations move price. Thank you.

And of course, it's not a competitive market. There's OPEC. OPEC has a variety of motivations that are complicated. And modeling and trying to understand OPEC, people make nice livings trying to do that.

So that's sort of what's missing. Oh, and of course, politics. Why in heaven's name would you drill miles deep, miles offshore, when you can produce oil in Saudi Arabia for $3 or $4 a barrel? Why are we spending these and doing these incredible feats of technology, risky technology? And the answer is, it's not a unified world market politically.

OK, comments about any of that? Questions about any of that? OK, I'm now going to, to the extent that time permits, sort of walk through. Prosper, did you have your hand up or were you just-- thought it was up here. I didn't know.

OK, I'm now going to just walk through these markets-- first oil, then coal, then uranium, and then I'll start natural gas. Oil, again, some basic facts, some numbers, blah, blah, blah. Oh, the key thing-- I was told this years ago, that the key thing to pass yourself off as an energy economist, the key number you need to without fail-- write this down-- 42 gallons in a barrel. That's the number, 42 gallons in a barrel-- very esoteric. That's the number, 42 gallons.

Oil is a global market. It's best model is a pool. Supply goes in the pool, demand comes out of the pool.

It's moved by pipelines and tankers. Tankers can change direction in mid-ocean. They often do. Active markets, spot market, futures markets-- it's there are good data on all of these markets.

During the first Gulf War, it was a source of some-- there were a lot of people saying we should shut down the futures markets because the futures markets were showing high prices. Because oil was tough because Iraq had suddenly come off the market. The argument that won the day against shutting down the futures market was that the futures market was predicting a rapid decline in the price of oil.

You could do a term structure. You could say, what does the market predict January, February, March, April, and so forth? And the futures market was saying, we expect this to be a short war.

And it was possible to make-- I was one of those who made it-- the argument that why would you shut off something that is, in fact, A, useful, and B, providing exactly the signal that you want to send-- that it'll be a short war. So very, very active markets, global. The production is concentrated, as we know, a lot of it in unstable places.

OPEC is a complicated cartel. Saudi Arabia has been the big player, and about the only holder of excess capacity for most of the period. And price has been volatile. So let me elaborate a little bit.

International oil trade in 2010 was about 65% of production. So about 65% of world production crossed an international border. And if you look at the big numbers here-- that's a big number, that's a big number, that's a big number-- the big sources are Russian oil going mainly to Europe, but also some to China-- Russian oil.

Middle Eastern oil going everywhere, including to the US. Canadian oil coming to the US. In fact, Venezuelan oil coming to the US. But importantly, the Mid East, if you add up those numbers, that's a lot of numbers. And you add up, look at the Russian numbers, they're pretty significant.

Globally, the Middle East is about 30%. This is not a great chart, but the Middle East is this bar. It's about 30% of world production.

It's over half of proved reserves. So this is reserves over time. And this is a nice graph. All these things are from the BP Statistical Report, which is-- again, you can't read it, but it's a good reference.

Look first at how global reserves have expanded, and they've continued to expand for a long time. Global reserves have gone up by almost 40% between 1990 and 2010. The Middle East still has over half, 54.4.

Its share has declined from 66 to 54. So people are exploring. And they're exploring outside the Middle East, as well as inside the Middle East, which is why the Middle Eastern share has declined.

This is OPEC's share of the world market over time, world output. And it has varied. These are the countries in the Persian Gulf, including Saudi Arabia, that offloads into the Gulf.

In reaction to the first energy shock, you got lots of investment outside OPEC to expand capacity. And OPEC's share of output fell. It rose again.

This runs out in 1997, and I haven't seen a graph that continues, but it will have declined since 1997. But it's varied. It's varied over time.

Even at 30%, OPEC had the ability to make a significant difference to world prices. Again, short-run supply, inelastic, short-run demand, inelastic, very steep demand curve. Change supply a little bit, you can move price. So OPEC has had that ability.

This is the final oil slide. This makes a point. It's really important to keep in mind when you listen to the media.

This is a ranking of-- it's 2007 is the latest I could find, but it's companies ranked by worldwide reserves. And the key thing is there is ExxonMobil. ExxonMobil that we think of as this giant company on the world market is, on the world market, not a giant company. There's Saudi, there's Iran, there's Qatar, which is mostly gas, but there's Iraq, there's Venezuela, there's Abu Dhabi, there's Kuwait.

And you have to come pretty far down-- and those are all government companies. Those are all state-owned enterprises, creatures of the government. You've got to come pretty far down before you get-- and there is Gazprom, Nigeria, Kuwait, PetroChina, even.

You've got to come pretty far down before you get to ExxonMobil. The Brazilian firm has just found a huge oil field off Brazil. So that will come up.

The big companies are government companies. The big players are governments. It's a single world market. Questions about oil? Yes.

AUDIENCE: So the Middle East reserves have declined as a proportion. Do you think it's because they just don't have an incentive to explore now, they have so much?

RICHARD SCHMALENSEE: Well, they have explored. I think they're just not as aggressive. Model them as a monopoly facing competitors. They might not be aggressive.

They still have a pretty commanding position-- over half of reserves, running now about 30% of production. I think they're just not being as aggressive. I mean, you're not drilling miles offshore in the Persian Gulf. You're drilling miles offshore in Louisiana.

So you're drilling in the North Sea in very difficult conditions. The Saudis don't have to do that, and they don't. They could be more aggressive. I don't know if there's anything in the Persian Gulf, but there are big fields that aren't being pushed.

But this isn't trivial. They have expanded their reserves. And they've obviously produced a lot in this period, as well as expanding reserves, so they're not just sitting there. But they're less aggressive. Question about?

AUDIENCE: Yeah, I don't know if [INAUDIBLE] the oil price. Would you happen to know the volatility of the oil price compared to, I don't know, the stock market volatility?

RICHARD SCHMALENSEE: Well, it's really fascinating, isn't it? I mean, when you go back here-- so this is in dollars, not inflation-corrected dollars. So there's this long period. Yeah, it's volatile when you take it up to 2010, but this is-- we've lost the axis-- this is between $1, $2, and $3 down here.

So this is between $1 and $3. I guess it's fairly volatile, but frankly, $3 a barrel for oil, 42 gallons, $3 for half that in gasoline, and then distribution charges, not a big deal. This is hard to match, the spike at $80 and the spike that we're still debating in 2008, I guess, or 2007, whichever one that hit in. I forget.

That's just remarkably volatile. This one we understand. That was politics. That was a huge supply cut.

This appears to be a significant, unanticipated increase in demand with very inelastic short-run supply. But it is still being debated. There are people who say, well that must be speculation.

And you say, well, yeah, but if you bought oil at those high prices, you took delivery. People actually got the stuff. People were taking delivery at these prices. That isn't paper. That's barrels of oil coming off a tanker.

So it's hard to tell a speculative story, I think. I think it's supply and demand, but you're right-- that's just that's as volatile as anything you're ever going to see. And nobody expects volatility to go back to all these good, old days because the politics haven't gotten any simpler.

If there is a war in Iran, you will see a heck of a spike. And in fact, we and the Europeans and others are in the process of putting sanctions on Iran designed to limit their exports. Well, if the Saudis don't pick up the slack, we'll see another spike. We'll see. Anything else?

AUDIENCE: So the cost of production was $3, $4?

RICHARD SCHMALENSEE: I'm making up a number, but the cost of production in the Middle East is well below the market price.

AUDIENCE: And I'm just wondering if it's $5, and the cost of a barrel of oil is $100 [INAUDIBLE].

RICHARD SCHMALENSEE: Well, remember, the price is always going to be above marginal production cost because of the opportunity cost argument. So that's not a big surprise. And the low-cost producers in the Middle East are not behaving like pure competitors. They're restricting output.

So yeah, there was a time when the price of oil was, I don't know-- well, look here-- when the price of oil in the '73 shock went up to-- and I think it-- I can't quite read this. Oh, this is some sort of blended price, which I don't quite get. But the price of oil quadrupled. The cost of oil didn't quadruple.

And it stayed high. Look at the money of the day, which is where we all live. It went up dramatically.

Oh, you know what the problem is? I think this is in-- what is it dollars per-- yes, I never understood. No, it's per barrel, OK. I thought it was per ton of oil equivalent.

But the price quadrupled in a few months. And the cost didn't. That was pure market power.

And if they were making money at these prices, they were making a lot of money at those prices. The journals were full of articles about recycling petrodollars, and where were they going to invest them, and so forth. They managed to manage to figure out ways to waste them, so that was all solved. But yeah, that's--

And the cost now, who knows what the cost of production is now? There's also a number that you see floating around. It's called the "finding cost."

There's one thing is the cost of drilling and getting it out of the ground. The other is the cost of finding it, which is the exploration, and proving, and so forth. And those costs have gone up a bit.

The cost of producing it out of an big known Saudi reserve is turning a valve, almost, short run. Long run, you've got to-- medium run, you've got to put the piping and stuff in. Long run, you've got to find it.

Medium run, cost pretty low, well below price-- not off Louisiana. That's not far below the price. That's expensive stuff.

So you have a range of costs. You have a range of behaviors in this market. Anything else on oil, questions on oil? Yeah.

AUDIENCE: Did the sanctions on Iran have an effect on the supply and demand.

RICHARD SCHMALENSEE: What would have an effect?

AUDIENCE: The sanctions on Iran because when Iran sells it, it can, pretty much, with a phone call, go anywhere else in the world. Really, is it--

RICHARD SCHMALENSEE: I don't know the answer. I know the problem is, if we don't buy oil from Iran, who cares? Because they can sell to other people and they'll just displace other suppliers.

So this was like when the Arabs refused to sell oil to the US in the '70s. We had been buying from them. We bought from others. And their oil went to others, and so forth.

If the US, and the EU, and Japan, let's say, have effective refusals to buy Iranian oil, that's enough that it might be hard for them to find demand elsewhere. It gets to be a quantitative question. If we can block enough exits for them, they may have a hard time selling it.

The question is, who buys then? So I just don't know whether it's had an effect or whether people really think it's going to have an effect. There are a lot of people-- I mean, a lot of the other sanctions have had an effect on Iran.

You read discussions about living in Iran these days. It's not very good. The economy is pretty much in the toilet, but how much of that's the oil sanctions and how much is everything else we've done, I just don't know. OK. Anything else? Yeah, Scott.

AUDIENCE: Can we go back to the slide with the picture where the oil from different countries are going? I had a question about something.

RICHARD SCHMALENSEE: Yeah-- not quickly. There.

AUDIENCE: All right. So it looks like the oil from the US is going into Mexico, and then the oil from Mexico is going into the US.

RICHARD SCHMALENSEE: Yeah, there's a little border trade. It's not a big number.

AUDIENCE: So is that because it's cheaper to buy oil from Mexico than to produce it ourselves?

RICHARD SCHMALENSEE: Well, some of it is just geography. I mean, I'm little surprised by that. You always see it in the numbers, that we're exporting something to somebody.

It must be-- and some of this is refined product rather than crude. So yeah, maybe we have a refinery here that it makes sense to export refined product to Monterrey. And they happen to have-- I don't know where they're-- I don't think they have any fields up here.

I'm not sure what they're exporting to us, but I'm assuming that some of this is refined product. I don't know why would be shipping crude. And I talk about this as if it's easy, but this is pipeline, the US-Mexico's pipeline. It's almost certainly not tanker.

And of course, it's where are the pipelines, where are the demands. You could imagine as Monterrey grows in Mexico, it might be cheaper since it's in the north. It might be cheaper to supply it from the southern US than from farther south in Mexico.

And maybe this is tanker. Maybe they put stuff and take it to the West Coast. I don't know, but you've got to figure this has as much to do with transport costs, pipeline location, shipping cost, refineries, as getting it out of the ground.

Mexico has a little bit of a problem. Mexico has a constitutional bar against foreigners owning natural resources. And that means they've operated with a state-owned oil company since the 1911-- no, since the 1930s when they kicked out the foreigners completely.

And the state-owned oil company has been inefficient and has had a hard time getting technology. So they're facing production declines, and facing constitutional problems of how do you bring in foreign technology. So it's sort of an interesting question. Yeah.

AUDIENCE: Oh, sorry, just to throw some light on that. When I worked at JPM on the crude oil desk, one of the things they used to always talk about was the geographic difference between a defense district called PAD 5 over there, which includes all of the West Coast. And there's severe geographical limitations that don't allow oil to actually be transported. So they actually trade completely differently in terms of oil pricing. And because a lot of our oil comes from Cushing, Oklahoma, which is like that central point over there, they might have to exchange it across international lines, even if it's crude oil.

RICHARD SCHMALENSEE: You think it might be refined in Mexico and brought back as product. Yeah.

AUDIENCE: [INAUDIBLE].

RICHARD SCHMALENSEE: Yeah, that's a nice point. They're called PADs, or Petroleum Allocation Districts, or something like that. It's a Cold War term, I think.

AUDIENCE: Defense district also included somewhere. It was created during wartime.

RICHARD SCHMALENSEE: Yeah, I think that's a World War II thing. It's not real easy to pump anything across the Rocky Mountains. And so the West Coast tends to operate separately.

Alaskan oil tends to come down here, even though it'd be better to sell it to Japan. And of course, Canadian oil-- you know the Keystone Pipeline debate, if you've been following it. Where Canadian oil goes is another interesting question.

But yeah, that's interesting. It may be that it's cheaper to get Mexican oil into California than to get oil from elsewhere in the US, and that some US oil-- this is the puzzler, that we're shipping. It may be to be refined in Mexico. It may be refined product into the north of Mexico if they're short of refinery capacity.

AUDIENCE: I think the oil pipelines go straight into Cushing.

RICHARD SCHMALENSEE: Yeah.

AUDIENCE: They might not be able to even reverse the flow, which they've actually been doing recently. But back then, maybe, when this was made, they weren't able to reverse it. So they have to move it and then actually physically bring it around.

RICHARD SCHMALENSEE: Well, these are 2010. these are 2010 data. So--

AUDIENCE: I think the reversal happened just this year.

RICHARD SCHMALENSEE: This year. OK, happy to learn. Anything else? OK, let me go to coal.

Coal is concentrated. As that earlier case indicated, we're probably the OPEC of coal or the Saudi Arabia of coal. It is traded. Coal trades internationally, and I'll show you some numbers on that.

But it has a high weight to value ratio. So it's not quite as easy to handle as oil and it's not quite as valuable as oil. So it's like international trade in rocks. There is some, but there isn't that much because it's expensive.

Markets are mainly national. There are some differences. We tend to have lower prices than elsewhere.

This isn't a business where there are a lot of spot markets and futures markets. There are some, but it's mostly long-term contracts. And the world fact is this unbelievable recent increase in the Chinese use of coal that we talked about earlier-- "unbelievable" is the wrong term, but it's huge.

I have to say I revised this from last year's lecture. And the Chinese numbers are dramatically different. It's kind of shocking.

This is production and reserves. So you will see we have over a quarter of the world's coal reserves. China sort of comes in-- well, Russia comes in second at 18%. China comes in third, but look at that-- the Chinese produce almost half the coal in the world, 48% as of 2010.

That's a number that deserves to be in red. It was somewhere in the 20s the last time I did this. Well, I did it two years ago, so somewhere in the 20s or 30s.

But it's relatively concentrated. These five countries account for 80% of output and three-quarters of reserves. Again, these are reserves, of course. Does that mean we've looked for coal everywhere in the world? No.

Does that mean there isn't a lot of coal in places we haven't looked? No. But we've looked in these places, and we found a lot of it in the US and a lot of it in China and Russia. There may be some-- people talk about coal in Africa, but there hasn't been that much exploration.

Only about 15% of production of coal crosses international lines. So it really isn't like oil. These are the big exporters.

And I didn't add up the shares, but you can do that. We do export out of both coasts, but I think mostly the East Coast to Europe. The big exporters, though, are Australia and Indonesia.

And if you look at who the big importers are, you can see immediately where it goes. Not only does China produce a lot of coal, but they're the second-leading importer of coal. So you have Australian and Indonesian coal going, to a decent approximation, China, Japan, and South Korea-- again, fairly concentrated.

Expensive, not cheap to ship this stuff, but huge demands. Japan has no energy. China has coal, but China needs more coal than it can produce in the short run. So that's the flow. I don't have a good picture.

Not a world market. You can't read this well, but these are Japanese prices in this column. Those are the ones that matter. Either column, you will see they're higher than the US prices typically. And the European prices are a bit higher than the US prices typically.

You can't do that for oil. The price of oil is pretty uniform. But you can for coal.

And this is the graph that's shocking. This is world coal use. You see it rising gently and then exploding. And if you look behind that picture, the explosion is mostly China.

In the US, it's worth looking at states. Production is fairly concentrated. Wyoming coal is mined mostly big strip-mining operations, massive strip-mining operations, close to the surface.

Surface is taken off. You go down. You strip away a layer of coal.

This coal tends to have a low sulfur content, the Western coal, the Wyoming coal. So it's less polluting on that dimension. There is a mix of low- and high-sulfur coal in these main mining regions in the East, West Virginia, Kentucky, and Pennsylvania.

So those five states account for almost three-quarters of production. Consumption is much less concentrated. This is for power plants, but that's almost all coal consumption-- Texas, Ohio-- these are the states with cheap electric rates because they burn a lot of coal.

I got anything else on coal? Yeah, that's about it on coal. Questions, comments, reactions about coal? Not the most exciting of products, but very important and dirty-- not to be prejudicial. Anything?

OK, I'll say a little bit about uranium. There isn't much that you can find about uranium-- essentially nothing in the BP book. And I'm focusing on uranium rather than nuclear power because that's the nonrenewable part, is uranium. But it's also relatively unimportant. I mean, it's not an important component of the cost of nuclear electricity.

It does seem to be a global market. I'll explain that in a little bit. Reserves are fairly dispersed. I mean, again, not clear there's been extensive exploration in lots of these places. You remember the yellowcake from Niger, very exciting in the run-up to the second Gulf War.

I had a price graph. It's not very interesting. It's mostly long-term prices. They're are just flat from the mid '80s through the mid '90s, or the early '80s through the mid '90s. And then they began to escalate.

And basically in that early period, people just stopped producing uranium. And now they've tripled. There's new mining activity.

There's really no organized market as there is for oil, or even to some extent for coal. These are long-term contracts. There's a spot market. It's not very interesting. It's very thin.

We import almost all of the uranium we use in US reactors-- 92%, a lot of it from Australia and Canada, and then from Russia and a couple of the 'Stans. And production is more concentrated than reserves, so those countries have 93% of production. Kazakhstan is a big producer, Canada, Australia, and then it falls off relatively rapidly. We account for about 3% of global production.

So not a terribly exciting, not a terribly big market. Anything about uranium? This is fairly boring stuff, but you sort of do need to have some basic factual understanding of what these markets look like if you're going to be in the energy business.

Let me do gas. Gas is more interesting. You may at some point have wondered why we call it "natural gas." It's not all that obvious, but it's because beginning in 1816 we produced gas from coal. I don't know how early in Europe, but in this country in 1816.

You heat coal. It gives off gas. You put the gas in a pipe. You ship it around the city and use it for lighting.

That was gas. Natural gas was the innovation-- that you didn't produce it from coal. You got it naturally, hence "natural gas."

It can be moved by pipeline. To move it by ship, you have to liquefy it, cool it, and compress it. It is not a global market. As we'll talk about next time, that might change-- lots of interesting discussions there. That might change.

This is circa 2010. This will change. We produce about 85% of the gas we consume. Most of the rest is from Canada, so North America is pretty much self-sufficient in gas.

Most of our imports-- no, it's not on this slide. The way the prices work, US prices tend to be below European prices. European prices are determined by Russian gas prices, and they're much lower than Asian prices, because Asia's gas tends to come via liquefied natural gas, which is expensive.

Historically, if I were doing this-- well, when I did this class two years ago, this sort of stopped here. Gas reserves are associated with oil. They tend to be in politically unstable places. The gas we know most about is in unstable regions in the Middle East and, if you think it's unstable, Russia.

But that has changed dramatically in literally the last three or four years. Shale gas can be produced cheaply, not necessarily without environmental costs, but cheaply. And once again, the US is lucky-- we have a lot of it.

We now have the ability to produce a lot of gas cheaply with environmental costs, potentially. We think China has that same ability. Some European countries do.

We're told it's under Paris. Paris is resisting drilling-- makes a good story, even if it's not true. Might be true.

I want to focus on this change on Wednesday, because as I say, this is the biggest energy change, certainly in my lifetime. Well, maybe OPEC was bigger, but it's close to OPEC in terms of a change in the energy landscape.

But what we do about it is subject to serious debate. And I want to try to outline that and get you to engage a little bit. There are those who say we should not be using this technology.

New York State does not allow it. North Dakota eagerly embraces it, is thrilled to have jobs, actually, in North Dakota, and boomtowns, and cheap liquor, and everything else-- all the other good things that come with a boomtown. But as a country, we have some issues.

There's a question of its impact on climate change. You sort of think cheap gas would be good, but what if it leaks? So I want to spend next time on that.

Today, I want to just go through some sort of pre-fracking facts, if I can say that, and lay the groundwork. So this is gas trade. Most of it-- well, 70% of it-- moves via pipelines.

And again, if you focus on the big numbers, you see Russian gas moving into Europe. And you see gas from the Middle East, importantly, moving to Asia. But it's not moving by pipeline across China. It's moving liquefied by tanker.

There are some exports from Indonesia, some exports from Australia, and a little gas into the US. Big imports from Canada, relatively speaking, and I guess we export to Mexico-- again, just because we can. That's got to be just geography.

As I say, most of it's by pipeline. If you look at the output, Russia is the big producer. Russia produces 15% of the natural gas in the world. The Middle East together-- and it's really hard to see it on this lousy picture-- produces 14%.

Reserves-- once again, Russia is producing a lot out of its 24% of the world reserves. The Middle East has 40% proved reserves as of 2010. The US had 5%.

This picture will change because you see now, with shale gas, estimates of recoverable gas-- not yet a proven reserve-- are anomalous. So as exploration adds to this inventory, the US number will rise. I don't know if the Middle East has shale or Russia has shale.

China will show up on the picture. And if they allow drilling in Poland, Poland, I'm told, has a fair amount. So that picture will change. This is just with a proved reserve.

But again, it's the same picture as oil. The one exception-- and I guess this is a little bit interesting-- you'll see the share of the Middle East actually rises. Not only does it rise in absolute value, of course, it rises in share.

And you will recall when we did the climate change negotiations, you were in Qatar or "cutter" as it's sometimes called. That's their discovery of their enormous natural gas reserves. That's one formerly poor, little country finding it is sitting on an enormous amount of natural gas, and that's the Middle Eastern change primarily.

Other people are developing, of course, but that's what's going on there. And as I say, that North America, which I guess is this one-- that will change over time because we have a lot of gas. But it's not yet proven, not yet proved reserves. It's oh, my god, look at what's almost certainly down there, but it's not--

We have a lot of pipelines. This is how you move natural gas. This is just a map of the US pipeline network.

And here we are at the end of the straw, as they say. So every so often, there isn't enough gas coming up to Massachusetts-- most of the time, not a problem. You hear about the Henry Hub. Well, if you follow this business, you hear about Henry Hub.

Henry Hub is about there. There's a lot of offshore pipelines, but Henry Hub is in southern Louisiana a little bit east of the center. And it's where something like 13 pipelines come in-- nine interstate and four intrastate.

And when you hear the Henry Hub price, pricing of natural gas in wholesale markets is mostly the price at the Henry Hub plus transport cost. So people do futures markets based on Henry Hub, and then you add in transport costs. You do a contract on a Henry Hub price and a transport.

So when I say gas moves mainly by pipelines, it moves in the US a lot by pipelines. You can also tell by the pipelines where it comes from. At the moment, it comes from Louisiana, Texas. It comes from offshore.

That's northern Louisiana. That's Oklahoma. And that's mainly it.

That will change. It's coming from North Dakota, where you don't see a lot of pipelines. It's relatively easy to build gas pipelines in this country, so they will be built.

Natural gas-- these are prices. So this is the US Henry Hub price in red, the UK price, the Japanese price, and the German price. You will see in recent years, at least, there's the US price, there's the UK price, there is the German price, which is a Russian price, and there's the Japanese price.

So you can sort of see why there's some interest in this country in exporting natural gas. If you can actually produce it for that price and sell it to Japan, you might eat half the difference in transport, but that's a huge margin. So we have built terminals to import natural gas that are now being converted to export. Well, they're trying to convert them to export.

And here is a historical price series that cuts off. I thought this was a defect of the way I got the picture, but I now see in terms of the flow here, it's a feature. This cuts off about 2009. We will explore the rest on Wednesday.

You see the price is volatile. That's a doubling in less than a year. That's a doubling. That's almost a tripling. That's another doubling.

So historically, gas price volatility not quite as bad as oil volatility, but it's been there. We'll see going forward the picture looks a little different. We'll see whether that's likely to continue.

You've been very quiet after oil, so I'll need to see if you have questions or comments. Because I don't want to go into fracking today. I'll wait till Wednesday. Comments on gas? Yeah.

AUDIENCE: So gas tends to occur with oil as in wherever there's an oil reserve they're surrounded by gas or something?

RICHARD SCHMALENSEE: Often. Not always, but often. Because these are fossils. These are dead dinosaurs and trees.

AUDIENCE: So a lot of companies are oil and gas companies, often, not coal and gas companies?

RICHARD SCHMALENSEE: Yeah, because they tend to be co-located. There is gas. There's coalbed methane. There is some joint occurrence of gas and coal.

Historically, coal companies ignored it, because it's a little tricky to recover. There's more recovery now of coalbed methane. And the percentages differ a lot from place to place-- oil versus gas.

In Qatar, for instance, it's almost all gas. In some places it's almost all oil. But there tends to be-- well, the Middle East has lots of both. So in that broad sense, that they co-locate. Yeah, Andrew.

AUDIENCE: Two questions. One thing that you mentioned was about the price. Does it track, or did it used to track oil price at all, natural gas, I mean?

RICHARD SCHMALENSEE: Yeah, that's a good point. It doesn't here. Back in the day when oil was used to generate electricity, you had so-called "substitution" at the burner tip, that the ability of power plants to switch between natural gas and oil tended to link their prices pretty tightly. The Russian price to Europe-- prices, since it's not just one price-- but the Russian prices to Europe tend to be linked by contract to the oil price.

In the US, since we don't generate much-- we don't effectively know electricity from oil-- there's some, but it's not much, old diesels-- that burner tip substitution doesn't link and there's no contractual link. Now, per unit of energy, gas is enormously cheaper than oil in the US-- enormously cheaper. I'm trying to remember the ratio.

Is it 10 to 1? It can't be that high, but it's pretty high. It's a big difference. So even if you could burn oil in a power plant, you wouldn't today. And you haven't for a long time because of the price difference.

AUDIENCE: The other question would be [INAUDIBLE] you mentioned that there is no world market for natural gas. And I'm just wondering, and I was going to mention that people link it to oil, which doesn't make a lot of sense to me. I was wondering, and you mentioned something that it's about-- we might see a world market for natural gas. What are the reasons that they have not [INAUDIBLE]?

RICHARD SCHMALENSEE: Cost, transport cost.

AUDIENCE: Because I would assume just because you have-- the technology is there and you see the differences--

RICHARD SCHMALENSEE: Oh, the technology is there, but to liquefy the gas-- to compress it and liquefy it costs money. The tankers are expensive. The terminal facilities are expensive.

So that's the reason why-- Japan can import lots of gas, but it's not a world market in the sense of a world price. Because the market has been traditionally very different from the-- North America is pipelines, boom, boom, boom. And that's pretty unified. Pipelines are pretty cheap-- all things equal, pipelines are pretty cheap.

But liquefying the stuff, and putting it on board ship, and moving it across the ocean is an expensive proposition, which is why the Asian price has been so much higher than the European price. Now, as people say, suppose the US really produces this stuff at scale and begins to export in quantity to Asia to take into account that price difference. Just geographically, we're in a position to undermine Russian pricing to Europe and in a position to undercut Middle Eastern pricing to Asia.

We don't have that much gas, but we have enough, some people argue, to unify the world in price terms. Some people say that's nuts. So it comes down to the numbers, and how much we produce, and is there gas in China.

If there's a lot of gas in China, at cost comparable to ours, then you begin to see world gas prices of around $5 to $6 instead of these $12, $13, $14 prices in Asia. There's a possibility, but it's not going to happen through-- well, it can happen through LNG, but it is expensive. It is expensive. Yeah. [INAUDIBLE].

AUDIENCE: What's the carbon intensity vis-a-vis oil?

RICHARD SCHMALENSEE: Excuse me, what?

AUDIENCE: What's the carbon intensity vis-a-vis oil?

RICHARD SCHMALENSEE: It's less carbon intensive than oil. It's methane. It's CH_4. Oil tends to have a good deal more.

Oil varies. I can't give you a ratio. I should be able to, but I can't. You can look it up.

But it's about-- the one number that it does stick in my head and this is because it's a power plant number-- using natural gas in a power plant as compared to coal gives you about half the CO_2 emissions. Oil will be somewhere in between, and different grades-- Canadian heavy oil may be more carbon intensive than light crude from Saudi Arabia. I just don't know the answer, but somewhere in between.

Anything else? Prosper?

AUDIENCE: Is coal gas still being purchased internationally? Also, are there countries where using coal gas is more cheaper than importing--

RICHARD SCHMALENSEE: Importing LNG?

AUDIENCE: --natural gas?

RICHARD SCHMALENSEE: I hate to admit that there's something I completely don't know, but I don't know. It wouldn't surprise me. If a country has coal supplies, doesn't have gas, and doesn't have good port facilities, then it would make sense to do coal gasification.

There are places where-- again, much of it's done-- there's talk of and some use of gas from coal to burn in power plants because you're basically leaving some of the carbon behind. So you're getting combined cycle efficiency, less carbon emissions. But whether it's in use at scale, I don't know.

The South Africans were doing-- they were mostly doing liquid fuel. I don't know that they-- hmm?

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: Yeah, they built one. It may still be working actually, but I thought that was mostly for liquids.

AUDIENCE: There's a company here, [INAUDIBLE], that actually [INAUDIBLE]. That's pretty much just the only place [INAUDIBLE].

RICHARD SCHMALENSEE: That's doing coal gasification, but that's not for use as gas. It's probably for use in electricity generation, or is it for use in gas?

AUDIENCE: Right now, most of [INAUDIBLE]

RICHARD SCHMALENSEE: Yeah, electricity, so yeah, I can't rule out it being put in pipes for heating and lighting someplace, but I don't know of any place. Interesting question. Yeah. Anything else? Yeah, Ryan.

AUDIENCE: So natural gas might replace some coal because it's cheaper, in some instances. Will it replace oil in a transportation sector or is that just out of the question for a while?

RICHARD SCHMALENSEE: Well, that's a good question. One of the optional readings for Wednesday is this MIT Future of Natural Gas Study. And one of the things they investigate is exactly that.

If you think about one of the issues that arises is energy density. Gasoline is just this marvelous stuff because in a relatively small space, you could store enough energy to move a ton and a half vehicle 200 miles. Gas is hard to get that kind of density unless you liquefy it.

If you liquefy it, of course, you've got all this problem of keeping it cold and keeping the pressure. So on the other hand, per BTU, it's so much cheaper than oil, than gasoline or diesel. So there's a lot of discussion.

We will probably see, assuming prices hold, we'll probably see a lot of use of gas in urban fleets. You already see some, because a bus fleet or a taxi fleet where you don't have to travel far from a place you can refuel, you refuel often. And it's worth it if it's just a whole lot cheaper to refuel a couple of times a day to save money.

There are no technical problems building engines to run on the stuff. That happens now. You can buy cars that can run on natural gas.

It's just the refueling infrastructure and the cruising range is a problem for cars. People are talking. So urban fleets, yeah, delivery vehicles, yeah, taxi cabs, yeah.

There's talk about using liquefied natural gas for long-haul trucks where you don't need that many fueling stations. You need them on the main routes. So instead of having to have them all over the country, you can have a few at certain intervals. And because you're hauling a lot, it may be worthwhile to put all that stuff on a truck.

Again, the world divides into those people who think it's the natural next step and those people who think that's crazy. And I don't know the answer. We'll find out. We'll find out.

It's interesting. And again, what drives it is the enormous-- and I'll get the number for next time-- the anomalous per-BTU difference between gas and oil right now. And we'll see gas prices are probably unsustainably low at the moment. But they're going to stay low for a while, I think.

OK, anything else? Questions, comments, speeches? All right, we'll do hydraulic fracking, the new world of natural gas, the boomtown in North Dakota, earthquakes in Ohio, flammable drinking water in New York State, and all of those good stories next time. And we'll figure out how to solve it.