The Outlook for Energy Alternatives

John Reilly and Sergey Paltsev
Joint Program on the Science and Policy of Global Change
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, MA 02139

Whether new energy alternatives can compete over the next few decades depends on the price of fuels. Energy markets, like agricultural markets, seem to be subject to massive disruptions every 20 or 30 years, and we are in the midst of one of those disruptions as this is written. Our approach in this paper is to offer a quick overview of what has happened in energy markets over the past 40 years or so. If we can understand where we are now and how we got here then we may have some hope that we can understand where we are going. Will we see a repeat of that history—what now looks different and what is similar? I use this as a backdrop to then discuss some alternative future scenarios based on our Emissions Prediction and Policy Analysis (EPPA) model. My focus in that section will be on US energy markets but the model is global and so behind the numbers I present are projected growth abroad and its implications for resource use and depletion, development of alternatives, and competition for them.

Energy Markets over the Past 40 Years

The 1970's was a period of turmoil in energy markets and of high energy prices. The proximate cause of high oil prices was first an oil embargo created by the Organization of Petroleum Exporting Countries (OPEC) in the early part of the decade followed up by the Iran-Iraq war and other tensions in the Middle East in the later part of the decade that also cut into supply, and caused another wave of price increases. The US response was to create a new Department of Energy, and under that Department create a number of initiatives that were supposed to solve the energy crisis. If the energy crisis was simply high oil and energy prices, indeed, it was solved by the mid-1980's as crude oil prices plunged to very low levels.

Looking just a little deeper into the "solution" to the crisis one finds it had little or nothing to do with the DOE initiatives, and in the "solution" were the seeds of the current energy market problems. Among the Federal initiatives was a massive effort called Project Independence under which the plan was for the US to supply all of its energy domestically. Under this plan there were efforts to demonstrate and produce synthetic fuel from vast US resources of coal. There was also much interest in shale oil. Those projects and goals collapsed with the price of oil, and rather than the US becoming energy independent, our dependence on foreign oil increased dramatically. Other initiatives of the time include the development of the Strategic Petroleum Reserve (SPR), Corporate Average Fuel Economy standards for vehicles, Federal excise tax exemptions for ethanol, natural gas price regulation, creation of a National Renewable Energy Laboratory to develop renewables, and research on fusion energy.

Some of these initiatives may have been modestly successful: In times of high oil prices the SPR dangles over the market to potentially offer a way to keep prices in line, although if it had an effect in 2008, when oil prices rose briefly to $140 per barrel, it is only in comparison to some imagined higher level that might have been if there was no SPR. Its main stated purpose remains as a mechanism to be used under an oil embargo which was not the source of price rises in 2008. Vehicle efficiency has improved fairly dramatically since the 1970's and perhaps CAFÉ pushed this along, but support for further tightening of CAFÉ was absent with fuel prices low. Instead, much of the personal vehicle fleet found the light truck loop hole in CAFÉ so that over time more than one half of the vehicle fleet was subject to looser standards. Whether that trend was hastened or caused by the CAFÉ rules or was mostly a coincident change in consumer preferences remains subject to debate. In any case, significant technical improvements in engine and drive train efficiency were directed to enhancing the power and performance of vehicles rather than increasing mileage. Natural gas price regulation was a disaster, eventually abandoned, and only after that did we see supply response in the US.

Expansion of the Federal R&D budget for energy research in the 1970's mostly collapsed with oil prices. In a large part, the collapse was due to the cancellation of large demonstration projects that were seen as a failure because the alternatives being developed under them were far more expensive than the now collapsed price of oil. Fusion power is still mostly a dream. Solar photovoltaics have found a role in places where grid connection is difficult but are not contributing a significant source of power. Wind energy appears closer to commercial competitiveness but the current success of these technologies is due to tax incentives and other subsidies that significantly lower the private sector cost, but this is paid instead by the taxpayer as a tax expenditure (lost tax revenue that must be made up with other taxes). And it is not clear that current wind costs fully address the variability of these generation sources through some type of storage or back-up. If the wind is not blowing on that hot August day when electricity demand is at its peak the system needs a KW for KW backup capacity unless there is large storage of some form somewhere. Either back-up or storage would add to the cost of relying on variable renewables. An excise tax exemption on ethanol has persisted, and created a viable ethanol industry but did not do much to bring along cellulosic production technologies. While the corn-based ethanol industry is large by some standards the contribution to the US fuel supply has been irrelevantly small over most of the period. Perhaps the unintended benefit of the ethanol excise tax exemption was that when Methyl Tertiary Butyl Ether (MTBE), an additive blended with fuels to reduce carbon monoxide emissions, was determined to be environmentally unsafe fuel blenders were able to switch to using ethanol as an oxygenate, taking advantage of an industry that already existed.

Basically, none of the exotic alternatives to conventional fossil fuels have really panned out yet in any significant way and so the 1970's R&D to develop them cannot be seen as responsible for lower prices in the 1980's and 1990's. Coincidentally, the events surrounding nuclear power, resistance to siting and eventually the 3-Mile Island accident, meant no more construction of nuclear power plants for many years and so the one alternative to fossil fuels that appeared viable was actually taken out of the mix, although several plants that were under construction continued to come on line into the 1980's.

If none of these things "solved" the energy crisis then what did? The 1970's oil shocks caught energy markets off guard and we saw short-run run-ups because there was little flexibility. But with time, more conventional resources were brought on line. The lesson OPEC learned from the 1970's and 1980's was that pushing the price high in the short term would lead to its collapse and so they at least claim to seek price stability, trying to find that price that would generate revenue for them but that would not bring on alternatives or greatly reduce demand, collapsing the price and leaving them with little revenue. Much of the solution appears to have been due to reductions in demand. Energy use which had been growing each year flattened out through much of the 1980's even with low prices and continued economic growth. Here debate remains with regard to how much of this was purely a response to the high prices (and expectations at least for a while that low prices were temporary) and how much was due to various regulatory programs to promote efficiency including such things as the CAFÉ standards.

Economic change in centrally regions of the world likely contributed to lower worldwide demand growth from the mid-1980's through the 1990's. Economic reforms in China starting in the 1980's led to a large improvement in the energy/GDP ratio there that continued through 2000. The Soviet Union collapse and Eastern Europe modernization dramatically cut energy use in those regions, in part by slashing economic activity. Thus, even as demand growth was returning to the US and other regions as the memory of high prices of the 1970's faded, reduced demand pressure on global energy markets from China, Eastern Europe, and the Soviet Union kept overall global demand growth slow through the 1990's. And, Russia was able to develop and export its natural gas and petroleum resources, adding to global supplies. In the electricity markets the rapid build of power plants from the 1960's and 1970's and long planning horizon for them actually led to significant over-capacity by the 1980's and so there was little need to build anything. As time went on, the utility sector managed to make much better use of the capacity it had, capacity factors of base load plants improved, and with gas inexpensive once natural gas price regulation disappeared it became a good way to add capacity without the huge capital investment and long lead times of coal or nuclear. It was also a relatively clean fuel.

The slow growth in energy demand in the 1980's and continuing through the 1990's kept prices low and as a result investment in further development of conventional resources (or alternatives) was low. One trend observed by many analysts is that more of the remaining oil resources were owned by State companies, as conventional resources in other regions were produced, giving the international oil companies (IOCs) less direct control over the development of these supplies. Many of these state-owned resources are not in the most stable places. The IOCs are often invited in when their capital and technology is needed, and then invited out once the resource was developed and the country re-evaluated the agreements under which profits from the development were shared. With such high risk on investments, and continuing low oil prices, investment lagged especially in these regions. That leads us to the situation today where an ever larger share of the undeveloped conventional resources is in countries where the investment climate is risky, and concerns about stability of supply exist.

The above summary of the last 40 years of energy markets offers a fairly casual set of explanations for the observed trends. Is there firm empirical evidence that would quantity the contribution of each? The demand story is a lagged response to the oil price shock that persisted for perhaps a decade where a pure price response is confounded with the coincident regulatory policies to promote efficiency. And in part the efficiency regulations and programs were a response to high energy prices—when prices remained low for a long time there was little public appetite to tighten these regulations further. Were they even necessary or would prices have done most of the job themselves—or vice versa are consumers too confused about how to reduce energy use to effectively respond to prices without regulatory policy? Separately attributing demand reductions to these two potential causes is difficult, and if the two are jointly responsible and the causes intertwined definitive attribution is impossible.

The changes in Soviet Union, China, and Eastern Europe were one time events where the huge inefficiency of energy use in these planned economies was replaced by an energy using infrastructure that was more consistent with market prices, albeit it took 10 years or more to fully realize the event and so it is another long and variable lagged response. Similarly, any supply response has a relatively long lag. And for investments in energy efficiency or in supply enhancement the relevant price is the expected future price over the life of the investment. At the height of oil prices in the late 1970's well-respected modeling exercises were assuming 6% real price increases through the end of the century. When prices start running up the initial reaction is often that the run-up is temporary, and so the expectation is that prices will return to low levels, limiting the increase in investment. With limited investment supply and demand response is limited, which then leads to ever higher prices. Sooner or later investors decide prices are here to stay or the short term gains from high prices are enough to offset the risk that they might fall. Once prices start falling, how long does the memory of high prices persist so that investors will pay extra for energy efficiency or continue to expand supply figuring the price decline is temporary?[1] Given the many coincident occurrences on both the supply and demand side, good reasons to believe that full responses would lag for several years, and a likely changing way in which observed prices were affecting the unobserved price expectations to which investors are actually responding, it is essentially impossible to statistically separate and attribute price changes to each of these causes.

The Current Situation and Near-Term Outlook

How does the past explain the present and what is the implication for the future? After the 1970's all of the forces were moving in a direction to drive prices down. The low prices and fading memory of high prices led to rising energy consumption and low investment in the development of new resources, which should have brought about rising prices and if this all could have been foreseen rise would have been tempered by more investment in resource development and less profligate consumption. The beginning of higher prices might have started in the 1990's if changes in China, Soviet Union, and Eastern Europe had not occurred. But those events, by unexpectedly weakening demand, extended the era of very low prices another 10 years or so and exacerbated the lack of investment in new resources and energy efficiency. By the early part of this decade we were ready for the perfect storm which was played out in 2008 in oil and energy markets, although there was a foretaste of it in gas markets before that. In some sense the high

---

[1] If agents had perfect foresight these spikes and declines would be smoothed out, but the reality of situation is that it is very hard to put together all the information on how all components of demand and supply will respond and over what time frame, so that one can avoid over-investing to upside price shocks, and under-investing in price troughs. The herd-instinct—every one holding back, the rushing in, then rushing out tends to exaggerate the shock effect.

prices of the last few years are an echo of the 1970's events. And, while the proximate cause of the high prices of those decades were an embargo and political events, the low prices leading up to those events likely contributed to the sharp rise in prices because just as in the recent price run-up a tightening market for oil exploded when political problems in supplying regions combined with strong demand growth. With the markets tight, the Iraq war and tensions in other oil and gas supply regions combined with unexpectedly rapid economic growth in many regions all together led to spiraling prices before new resources could be brought on line. If this was in part speculation, the speculative effect on prices was supported by the tight market conditions, and a short-sighted view on the possibility of lower prices. The persistence of low prices for many years had led to disinvestment in the industries that support resource development. The lack of direct control of the IOCs in State-owned resources and the risks of entering into development agreements further limited supply response.

We have now come out on the other side of the price spike of 2008. It had led to the beginning of some large changes in energy use, investment in conventional resources, and in alternatives. The collapse of oil prices, while not surprising given that it is a repeat of the 1970's and 1980's, probably came faster and harder than anyone expected. With oil prices at $140 briefly they were six to seven times what they were just a few years earlier. With that massive a price increase any logic would suggest that many investments that were not economic at $25/barrel on both resource development and demand reduction suddenly were. The economics of investment in new resource developments was somewhat hard to penetrate as these price run-ups occurred because with the run-up in the fuel prices the prices for equipment/expertise in the resource developments industries also went up. That made it look like the cost of development was in part, at least, a driver for these much high prices. However, these cost run-ups were probably largely a result of the attempt to expand very rapidly. There is no obvious fundamental limit on the inputs that go into expanding these resource development industries and so with time these industries might have caught up with the demand for them and cost of development would have eased. The beginning of investments in energy supply and demand reductions were seen everywhere. Car buyers in the US abandoned large SUVs for fuel efficient vehicles, Canadian oil sands couldn't be developed fast enough, ethanol experienced a boom that is believed to have contributed to high food prices, and interest in shale oil, shale gas, and conversion of coal to liquids was again high. Finally, some of the investment in R&D on renewables may have paid off as they appeared to now have some traction, albeit with tax subsidies. Nuclear plants were again proposed.

Had it not been for the economic crisis that was mostly coincidence rather than caused by the high energy prices, oil prices might have eased down rather than collapsed. But instead we have a collapse, and given the collapse we must ask how much of the investment in alternatives will persist? Will consumers soon forget high gasoline prices and get back in SUVs? With regard to oil, I believe that prices in the $75 to $100 range are adequate to support considerable expansion of conventional resources, heavy oil/oil sands, and remote resources deep offshore, or in the Arctic regions of Russia, or even coal liquids technology. This could meet demand growth at least for another couple of decades. A deep and prolonged recession might restrain demand growth while some of the investments started over the past few years of high prices are coming on line. This combination could then keep prices below $50 for some years and lead to cancelation of many investments and deter new investments. If we were to witness then another set of one-off events, for example, suppose a deep recession lead to real political problems in China, India, or some of the other rapidly growing developing regions and in so doing leads to stagnant economic growth. This would be a repeat—of a somewhat different character—of Soviet Union/Eastern Europe/China—events of the 1990's. That could then extend low prices and low investment in resource development still further. And, then if finally these things get sorted out again we would be right back in a position to see energy prices explode. This cycle could play out over 10 to 20 years.

If we recover from the recession in a year or so and the developing countries continue to develop then I think we will see oil prices in the $75 to $100 range over the next couple of decades, consistent with the cost of developing marginal resources and some of the less expensive alternatives, and perhaps to $150 by 2050. This higher price scenario is actually the preferred one, as underlying it is the assumption of smooth economic growth, and an economic climate in energy markets that support investments needed to expand supply, and continued signals on the demand side that reflect the full cost of energy resource development. If this can happen then maybe we can avoid the boom-bust cycle in energy markets and at least damp the echo of past energy market crises.

What is missing in this scenario? Answer: Greenhouse gases and climate policy. With expansion of the resource development industries the costs of developing fossil resources will fall back. Around 2003 estimates of oil sands development was that the cost was less than $30 barrel. With competition for labor, equipment, and such casual estimates were that these costs were at least $80 by 2008. But with the intense pressure off of development these will likely fall. Coal prices had risen to historic highs but there are ample resources worldwide so that with mine expansion these could fall again. China is actively pursuing producing liquid fuel from coal and so that alternative fuel may come on significantly as conventional oil peaks. And coal liquids are likely producible with oil prices in the $75 to$100 per barrel range but if that is to have carbon capture and storage a price incentive to do so would be needed. Much development of natural gas and LNG facilities were underway and with many of these resources far away from demand LNG in Africa and the Middle East or new large pipeline developments in Russia/Asia will make these resources available to markets for a nominal rent so that the major final cost will be the transport cost and that is probably not much more than $4.00 mm BTU. At these prices gas and coal will compete for electricity generation and conventional fuels will supply transportation. Renewable electricity sources will be hard pressed to compete and will go only so far as tax credits/subsidies and mandates will carry them. Second generation biofuels cannot compete, in my view, if gasoline prices are only in the $2.00 to $4.00 range. Hybrid vehicles are only nominally competitive at the upper end of this price range, and unless battery technology advances dramatically so that the cost is much lower these fuel prices do not provide much incentive to develop and adopt electric vehicles. This path will thus lead to continued reliance on fossil fuels and an unabated increase in CO_2 emissions.

Climate policy—some attempt to price CO_2 or to otherwise favor alternatives—is one of the big changes from the 1970's. Then, US energy policy identified shale oil and coal as domestic resources that would solve the energy crisis. Today there is private investment in these technologies but even there it is with at least an eye toward carbon capture and storage. A CO_2 price is a reality in Europe and there is enough talk of it in the US that developers of electric generation facilities or new fuels production facilities must give some weight to the likelihood that an investment in a facility that releases CO_2 or produces fossil fuel is at some economic risk from a CO_2 price within the lifetime of the investment. Has this threat already had some impact on investment and investment choices? That is hard to say. The uncertainty in whether such policies would be in place or not could have contributed to reluctance to invest in major new resource development and thus actually contributed to the 2008 price run-up. The evidence for this is weak at best. The oil sands development in Canada and China's growth of coal-fired generation occurred at a pace few imagined was possible and so it doesn't appear that investments in these developments were held back fearing CO_2 prices. Environmental NGO and public pressure combined with concern about investment risk among some utilities may have limited expansion of coal generation in the US but other projects went forward perhaps because utilities hoped to get allowances for free in some proportion to their emissions. Hence, development of more coal generation capacity would be rewarded with a greater number of free allowances. Globally emissions growth accelerated from the early 1990's rate of 0.6%/yr, to a late 1990's rate of 1.1% per year to well over 2% per year from 2000 through 2008. Thus, the more talk about greenhouse gas mitigation the faster emissions grew.   That evidence suggests that energy development proceeded for the most part as if CO_2 emissions would not be capped, or if so better to produce soon while it was still possible.

Scenarios of Future Fuel Use and Energy Alternatives Using the MIT EPPA Model

The EPPA Model

We use results from simulations conducted with the MIT Emissions Prediction and Policy Analysis (EPPA) model. The standard version of the EPPA model is a multi-region, multi-sector recursive-dynamic representation of the global economy (Paltsev et al., 2005).[2] The recursive solution approach means that current period investment, savings, and consumption decisions are made on the basis of current period prices. The level of aggregation of the model is presented in **Table 1**.

The table broadly identifies final demand sectors and energy supply and conversion sectors. Final demand sectors include five industrial sectors and two household demands, transportation and other household activities (space conditioning, lighting, etc.), as shown in the table. Energy supply and conversion sectors are modeled in enough detail to identify fuels and technologies with different CO_2 emissions and to represent both fossil and non-fossil advanced technologies. The synthetic coal gas industry produces a perfect substitute for natural gas. The oil shale industry produces a perfect substitute for refined oil. All electricity generation technologies produce perfectly substitutable electricity except for Solar and Wind which is modeled as producing an imperfect substitute, reflecting its diurnal and seasonal variability. For this work, we add a Solar and Wind technology with non-CO_2 emitting storage/backup that is a perfect substitute for other technologies. Solar and Wind without storage is less costly and

---

[2] The EPPA model can also be solved as a forward looking model. See Babiker *et al.*,2008).

represents the ability to integrate some level of these variable sources into the existing grid. Solar and Wind with Storage is more expensive as it includes the cost of storage. Here it is assumed that pumped hydro (or use of existing hydro capacity to follow the load and smooth out variable supply), compressed air, other storage media, or redundant capacity accompanies expansion of these variable renewable sources. This storage or redundant capacity only needs to be accessible to the grid such that it can be used to manage supply to meet the load—it could include strategies for storage at the use site or other strategies to manage the load to better follow the variable supply. We discuss this approach in more detail in Section V. Biomass use is included both in transport fuel where it is a perfect substitute for refined oil and electric generation.

Table 1. EPPA Model Details.

Country or Region[†]	Sectors	Factors
Developed	***Final Demand Sectors***	Capital
United States (USA)	Agriculture	Labor
Canada (CAN)	Services	Crude Oil Resources
Japan (JPN)	Energy-Intensive Products	Natural Gas Resources
European Union+ (EUR)	Other Industries Products	Coal Resources
Australia & New Zealand (ANZ)	Transportation	Shale Oil Resources
Former Soviet Union (FSU)	Household Transportation	Nuclear Resources
Eastern Europe (EET)	Other Household Demand	Hydro Resources
Developing	***Energy Supply & Conversion***	Wind/Solar Resources
India (IND)	Electric Generation	Land
China (CHN)	Conventional Fossil	
Indonesia (IDZ)	Hydro	
Higher Income East Asia (ASI)	Existing Nuclear	
Mexico (MEX)	Wind&Solar	
Central & South America (LAM)	Wind&Solar w/ Storage*	
Middle East (MES)	Biomass	
Africa (AFR)	Advanced Gas	
Rest of World (ROW)	Advanced Gas with CCS	
	Advanced Coal with CCS	
	Advanced Nuclear	
	Fuels	
	Coal	
	Crude Oil	
	Refined Oil	
	Natural Gas	
	Oil from Shale	
	Synthetic Gas	
	Liquids from Biomass	

[†] Specific detail on regional groupings is provided in Paltsev *et al.* (2005).

*Only for those scenarios focusing on a renewable portfolio standard.

There are 16 geographical regions represented explicitly in the model including major countries (the US, Japan, Canada, China, India, and Indonesia) and 10 regions that are an aggregations of countries. While the results in this paper focus on the US, economic and population growth and policies assumed to be in place abroad affect world markets, depletion of resources, and therefore the US economy through international trade.

The model includes representation of abatement of non-CO_2 greenhouse gas emissions (CH_4, N_2O, HFCs, PFCs and SF_6) and the calculations consider both the emissions mitigation that occurs as a byproduct of actions directed at CO_2 and reductions resulting from gas-specific control measures. Targeted control measures include reductions in the emissions of: CO_2 from the combustion of fossil fuels; the industrial gases that replace CFCs controlled by the Montreal Protocol and produced at aluminum smelters; CH_4 from fossil energy production and use, agriculture, and waste, and N_2O from fossil fuel combustion, chemical production and improved fertilizer use. More detail on how abatement costs are represented for these substances is provided in Hyman et al. (2003).

When emissions constraints on certain countries, gases, or sectors are imposed in a CGE model such as EPPA, the model calculates a shadow value of the constraint which is interpretable as a price that would be obtained under an allowance market that developed under a cap and trade system. The solution algorithm of the EPPA model finds least-cost reductions for each gas in each sector and if emissions trading is allowed it equilibrates the prices among sectors and gases (using GWP weights). This set of conditions, often referred to as “what” and “where” flexibility, will tend to lead to least-cost abatement. Without these conditions abatement costs will vary among sources and that will affect the estimated welfare cost—abatement will be least-cost within a sector or region or for a specific gas, but will not be equilibrated among them. The mixed complementarity solution approach of the model means that least-cost is defined in terms of the tax inclusive prices (for fuels, electricity, capital, labor, and other goods) faced by producers and consumers given the technology set at any point in time. It does not necessarily lead to a welfare optimum if there are distortions (e.g. taxes) and to the extent the behavior of individual agents have macroeconomic consequences such as affecting the terms of trade of a country/region. We simulate banking and borrowing, which implies foresight, by forcing the theoretical perfect foresight result that the CO_2-e price path must rise at the discount rate, assumed to be 4%. We do this by choosing an initial price so that the cumulative emissions are consistent with the policy target over the horizon of the policy. Allowing banking and borrowing is sometimes referred to as “when” flexibility. A price path rising at the discount rate means that the discounted price is equal in all time periods which is the temporal equivalent of equating the price across sectors or regions.

Embodied in the model are a set of assumptions about the cost of technologies and the availability of resources on which they rely. In previous sections we discussed in broad terms the history of energy markets and expectations for them in the future. While that discussion occurred without quantification of key assumptions it reflected much of our experience simulating the model over many different situations. Similarly the previous discussion reflects similar assumptions about technology cost and resources availability as contained in the model. The previous discussion is thus not a completely independent assessment from the modeling results. The 5-year time step of the model generally means it does not produce the volatility in prices we see in actual energy markets. At best, if we shocked the model with such events, we might hope to see price volatility like one would see if you took a price series where the prices were 5-year averages. The short run rigidities and role of expectations that operate in the short term are simply not represented in the model. Is it still useful? In the longer term the basic fundamentals of resources, resource utilization technologies, demand growth, and technology alternatives should drive the market. As the previous discussion suggested, it appears that markets can diverge from these smooth paths substantially with effects lasting for a decade or more, and certainly new shocks along the way can extend or shorten the cycle. And these shock events may sew the seeds of an echo event some years in the future. However, the model forces some reconciliation of supply and demand factors. The popular press is often asking—why didn't we learn our lesson after the last energy crises and stay in fuel efficient cars and wean ourselves of fossil fuels? The problem is that successful demand response, leads to lower prices for fossil fuels and thus undermines some the more efficient choices, or at least weakens the appetite for going much further.

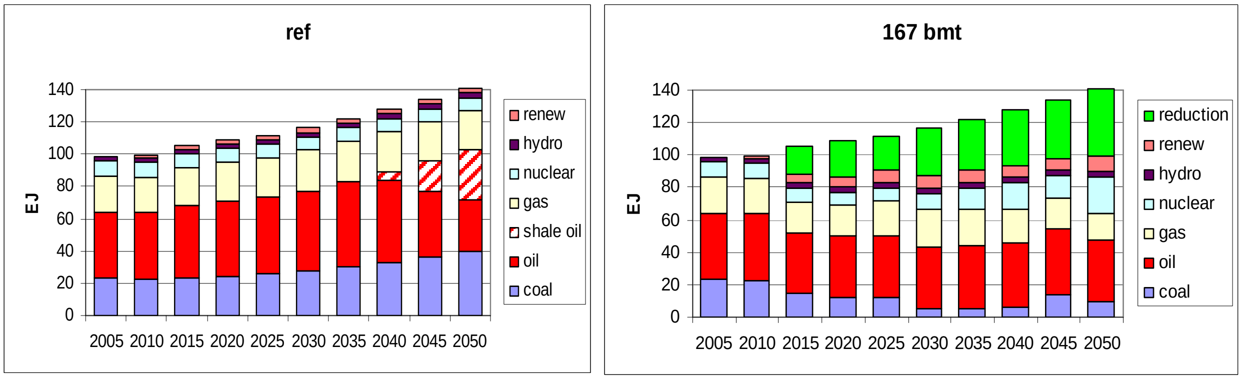
A No Policy and Climate Policy Scenario

We focus on two scenarios: A no climate policy scenario and a stringent climate policy consistent with a goal of getting GHG emissions to about 80 percent below current levels by 2050. The climate policy restricts cumulative GHG emissions in the US to no more than 167 billion metric tons between 2012 and 2050, and we refer to this case as the 167 bmt case. The rest of the world pursues no policy in the no policy case and in the US policy case developed countries reduce to 50% below 1990 levels by 2050, China, India, Russia, and Brazil start in 2030 on a linear path to 50% below their 2030 emissions level by 2070. The rest of the developing countries delay action beyond the 2050 horizon of our study (see Paltsev, *et al.* 2009). At the broadest level, technological choices manifest themselves in energy demand response to energy/CO_2 prices and changes in the sources of primary fuels. At a more detailed level electricity generation and transportation are key sectors where technology alternatives are needed if a GHG cap is to be achieved. We thus focus on these three areas—Primary energy demand and supply by fuel type; electric generation, and transportation.

Energy Demand and Supply by Fuel Type

Energy supply under the no policy and 167 bmt policy cases are shown in Figure 1. The most significant changes due to the policy are the reduction in overall energy demand and the reduction in coal use. Not so apparent here is the increase in nuclear and renewable energy (wind, biomass, and solar). That is because they are accounted as the energy content of the electricity produced or biofuel produced. Coal is used mainly in electricity production and given the efficiency of conversion of coal to electricity it takes about 3 EJ of coal to produce 1 EJ of electricity. Thus the accounting provided here exaggerates the coal use relative to nuclear, hydro, solar, and wind. It also makes it appear that shifts from coal generated electricity to these other electricity sources to be demand reduction—there is a demand reduction for primary fossil fuels but the reduction in electricity supplied to consumers is much less than this would make it appear. In the next sections we will look more closely at the electricity sector and in transportation.

Figure 1. Primary Energy Supply and Demand Response, Reference and Policy



Panel a. No policy

Panel b. 167 bmt Policy

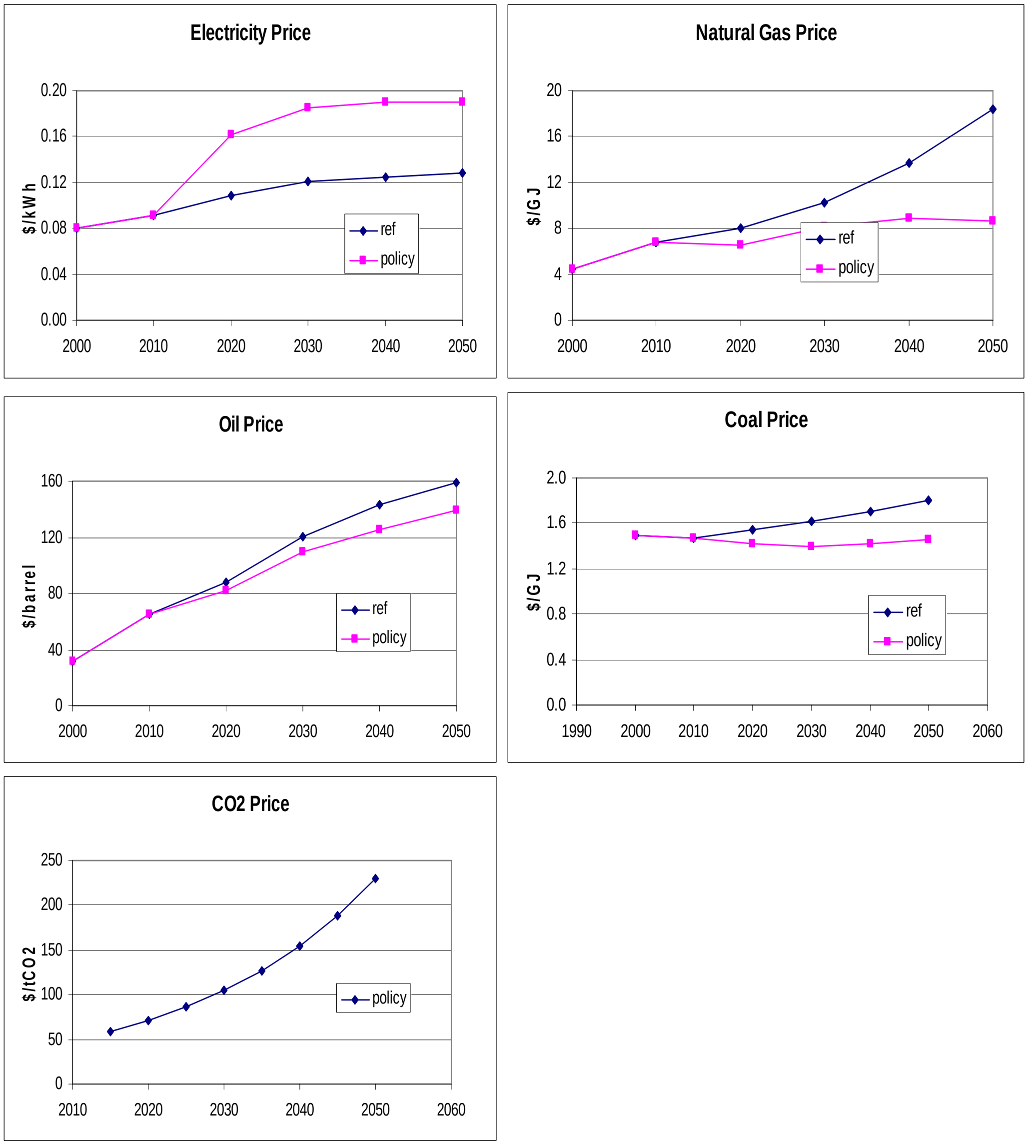
Figure 2 shows the energy and CO_2-e prices we project in the reference and the policy case. We show the prices on fuels that do not include the CO_2 charge. If the CO_2 policy were implemented upstream then one would expect much of the CO_2 charge to be passed through to consumers. As shown, the impact on fuels prices of the policy is to decrease them—this is the portion of the CO_2 charge that is passed back to fuel producers. With the CO_2 charge added, the end-use prices would be higher and the difference between that price and the reference price is the part of the CO_2 charge that is passed forward to consumers. Note that fuel prices are determined in a global market and the CO_2 policy abroad is also affecting the difference in the reference and policy prices. Electricity prices include the CO_2 charge (and the higher cost of generation sources that are substitutes for fossil generation). There is no simple estimate of the pass through of CO_2 charges in the electricity price because the generation choices and carbon intensity of generation changes. Table 2 provides the extra cost for a $27/ton CO2 prices for fuels

Table 2. Relationship Between a $27/tonne CO_2 Price and the Charge on Fuels, Compared to Base Fuel Prices in 2005.

Fuel	Base Cost ($2005)	Added Cost ($)	Added Cost (%)
Crude Oil ($/bbl)	$60.0	$12.2	20%
Regular Gasoline ($/gal)	$2.39	$0.26	11%
Heating Oil ($/gal)	$2.34	$0.29	12%
Wellhead Natural Gas ($/tcf)	$10.17	$1.49	15%
Residential Natural Gas ($/tcf)	$15.30	$1.50	10%
Utility Coal ($/short ton)	$32.6	$55.3	170%
Electricity (c/kWh)	$9.6	$1.76	18%

in conventional measures. This is simple the CO_2 content of a gallon gasoline, barrel of oil, thousand cubic feet of gas, etc. The electricity estimate is based on the average CO2 emissions in the electricity sector in 2005 but as indicated above that is less relevant to future electricity because the CO_2 emissions per kwh will be lower while generation costs for low CO_2 technologies will be higher. The actual price projections show rises in all

Figure 2. Fuel and Electricity Price Indices, CO_2-e Prices; Reference and Policy

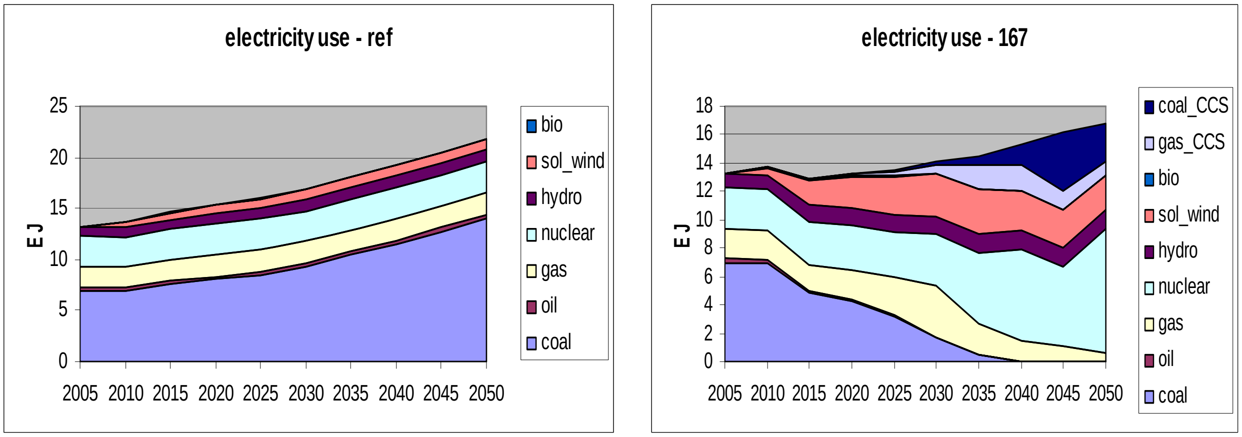


fuel prices in the no policy case. These increases are the result of gradual depletion of the highest grades and most easily accessible resources, and so production costs rise. Our projections are over a 5-year period and so do not show the run-up in oil prices of 2008. (And, the model does not project the shocks that were likely responsible for that increase and so would not easily replicate it.) The model results thus suggest that the high prices of 2008 were notsupported by long run fundamentals but was likely due to the disequilibrium conditions we described earlier. However, by 2050 that level of prices is consistent with our projections. The policy tends to flatten out coal and gas prices. The CO_2 prices starts at about \$55/ton CO_2-e and rises to nearly \$250. The smooth rise is the result of the banking assumption—that the market will equate the net present value price of CO_2 across time periods.

Electricity Generation

Figure 3 shows more detail on electricity generation sources. Without the CO_2 policy the sector continues to rely heavily on coal. With the policy a broader mix of generation sources are used. Nuclear power is the largest contributor and there is also substantial expansion of solar and wind power. Gas and coal with carbon capture and storage technology also enter. In other policy simulations reported in Paltsev, et al. (2009) we show that choice of generation alternatives is quite sensitive to the assumptions about the costs of providing reliable electricity from these sources. If nuclear is more costly or difficult to site, then coal with CCS competes more effectively. If neither of these sources are available at reasonable cost, then a combination of natural gas and wind and solar energy supplies electricity generation needs. On the other hand, the costs of renewable resources may escalate more sharply when they are a bigger share of generation because of the need for back-up and storage which would add to the cost of making sure electricity was reliably available to meet demand peaks during periods when these resources were unavailable (lack of wind, cloudy days, etc.).

Figure 3. Electricity Generations Sources in the Reference and Policy Cases.

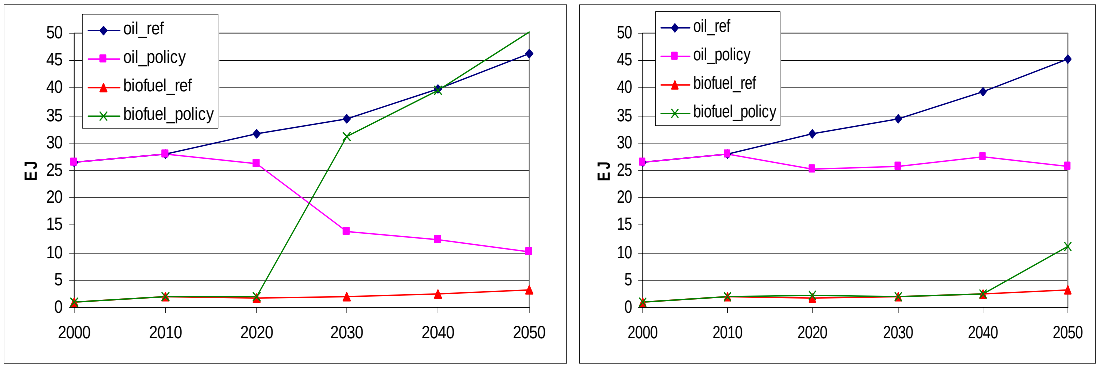


Transportation Alternatives

Transportation is another important sector in the economy that will be affected by CO_2 mitigation policy. The base scenarios presented above assume that cellulosic biofuels have cost that his 3 times the price of gasoline in our base year of 1997. This would be about $4.50 cents per gallon of gasoline equivalent. Since ethanol has only about 2/3 of the energy of gasoline, at $4.50 ethanol would need to sell at about $3.00 per gallon to provide the same number of miles per dollar of fuel. (We have use retail prices as an example here which would include Federal and State excise taxes as well as retail and transportation costs. Thus, the actual price to ethanol produces would probably be on the order of $2.00 to $2.30 per gallon. We consider here a more optimistic technology case for ethanol where is would competitive with gasoline at $3.00 gallon. Here the price to ethanol produces would be in the $1.00 to $1.30 per gallon range accounting for the energy content difference, excise taxes, and retail mark-up over producer prices. Panel b shows transportation fuel use with and without the climate policy consistent with the simulations presented above with biofuels at a cost mark-up of 3 times 1997 gasoline prices. In this situation advanced biofuels only enter after 2040. Conventional corn-based ethanol increases slowly shown with red triangles. The green line (biofuels in the policy case) only diverges from the reference after 2040 and that is due to the competitivness of cellulosic based fuels. The CO_2 policy is met in this case largely through reductions in demand because conventional fuels (labeled oil in the figure) fall from the reference and remain basically flat. Cellulosic biofuels adds to supply only after 2040. In contrast when biofuels are competitive with gas at $3.00 per gallon, the dominate the market, and oil use falls off pretty dramatically. This is a scenario where fuel cost is actually lower than the reference and total fuel use (ethanol plus oil) is actually a quite a lot higher than the reference.

Figure 5. Fuels and Fuel Use in Transportation

Panel a: Cellulosic Biofuels at ~$3.00/gal* Panel b. Cellulosic Biofuels at ~$4.50/gal*



*Gasoline gallon equivalent, adjusting for lower energy content of ethanol.

In other work (Karplus, et al., 2009) we included the possibility of plug-in electric vehicles (PHEVs) as another alternative in transportation. Currently it is believed that to get the all electric range necessary the battery would add 30 to 60% to the cost of the vehicle. At that the lower end of that cost climate policy could make them competitive but if low cost, carbon neutral biofuels are available that might significantly delay PHEVs. If the batter cost can come down so that the vehicle is no more than 15% more than a standard vehicle, then the economics of PHEVs are much more favorable even without climate policy. However, the CO_2 benefit of PHEVs without climate policy is not as significant because the grid electricity has not been cleaned up.

Conclusions

Predicting the success of energy alternatives in the future depends on future energy prices but those prices depend on the cost of conventional and alternative energy sources and demand response to prices. One thus needs to investigate the potential for alternatives within the structure of model of global markets for energy. There are many uncertainties in any projection of the future, as recent volatility in energy markets attests. For longer term considerations one needs to look at fundmental factors that will affect markets and then see volatility to short run events as likely divergence from those long term factors. That said, the energy shocks we have observed have had longer term effects, and one shock may sew the seeds of future shocks a couple of decades hence. Whether that echo is amplified or damped may depend on coincident events that extend or limit the duration of the shock.

The recent spike was likely amplified by the couple of decades of depressed energy prices that provided little incentive for investment in resource development, creating a condition where once demand growth resumed markets tightened and political turmoil combined to create very high prices. Those likely were unsustainable but the economic crises helped to create a more precipitous fall. If the global economy recovers and we return to relatively stable economic times, it is likely that oil prices will be in the \$75 to \$100 per barrel range over the next couple of decades, perhaps rising to \$150 barrel by 2050. Natural gas and coal prices are also likely be lower than we have seen in the recent past. There are a variety of fossil fuel resources that can be developed, and some of the alternatives (oil sands, shale oil, synthetic fuels from coal) while more expensive to produce than conventional crude oil are probably less expensive than non-fossil alternatives absent a significant price on CO_2 emissions.

In such a no climate policy scenario we see moderate and gradual price increases but continued reliance on gasoline/diesel in transportation and coal and gas in electric generation. Under the stringent climate policies now be discussed, the mix of energy technologies would need to be vastly different. Conventional fuels in transportaion and coal without carbon capture and storage in electric generation are not viable under such policies. At this point, nuclear appears to have a cost advantage and is further along the development line than CCS but if nuclear licensing is a problem or the cost of nuclear escalates, CCS may be viable. Renewables role currently depends on subsidies and the extent of its long term contribution depends on the cost of back-up capacity or storage. The potential for biofuels in the near term depends heavily on their cost. Even under a climate policy they may not be competitive until after 2040 if one needs gasoline at \$4.50 per gallon to make them competitive.

References

Babiker, M., A. Gurgel, S. Paltsev & J. Reilly, 2008. A Forward Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model, MIT Joint Program for the Science and Policy of Global Change, Report 161, (May).

Karplus, V.J, S. Paltsev, and J. M. Reilly, 2009. Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis, MIT Joint Program on the Science and Policy of Global Change, in press, Cambridge, Massachusetts.

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker, 2005. *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4*, MIT Joint Program on the Science and Policy of Global Change, Report 125, Cambridge, Massachusetts. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt125.pdf

Paltsev, S., J.M. Reilly, H. D. Jacoby, J. Morris, 2009. The Cost of Climate Policy in the USA, Energy Economics, (in Review).