WASHINGTON ROUNDTABLE
ON SCIENCE & PUBLIC POLICY

Potential and Prospects Of Cellulosic Ethanol

by

Aristides A. N. Patrinos and Lawrence Kumins

GEORGE C. Marshall INSTITUTE
Washington, D.C.

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Larry Kumins, Vice President for Research and Analysis at EPRINC, previously served as a research specialist in energy policy at the Congressional Research Service (CRS) in the U.S. Library of Congress. He has over 30 years experience in undertaking assessments and research on a wide range of oil and natural gas policy and economic issues. Mr. Kumins is a recognized expert on fuel supply, trends in supply and demand in petroleum product markets, natural gas regulatory policy, oil imports and exports, OPEC and world oil market developments.

Potential and Prospects of Cellulosic Ethanol[*]

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July 25, 2007

Mark Herlong: Good afternoon. I am Mark Herlong, Program Director of the George Marshall Institute, substituting for Jeff Kueter, who usually plays the role of moderator, who is currently attending a conference in Philadelphia. It is my pleasure to welcome you to this latest installation of our Washington Roundtable on Science and Public Policy. The Roundtable series is designed to bring together public policy makers with scientists, engineers, and other experts to discuss issues of importance.

Ethanol derived from corn and sugarcane is already in wide use, but they are far from ideal sources of fuel; corn in particular is an energy- and money-intensive crop and the diversion of corn from the human and animal diet has already raised food prices in the U.S. The potential benefits of cellulosic-based fuels are widely acknowledged, but such fuels may be years away from widespread use. Some advocates envision commercially competitive cellulosic ethanol within two years, while others are more cautious; the Department of Energy has set a goal of replacing 30% of U.S. transportation fuels with biofuels by 2030. This panel discussion will consider the scientific, technical and economic hurdles that must be crossed before use of cellulosic fuels will become commonplace.

Joining us today are Dr. Aristides Patrinos, President of Synthetic Genomics, Inc., who directs research activities in microbial genome research, structural biology, and global environmental change. Dr. Patrinos played a historic role in the successful Human Genome Project, the founding of the U.S. Department of Energy's Joint Genome Institute and the design and launch of DOE's visionary genomics. He is a leading authority on structural biology, nuclear medicine and health effects.

Following Dr. Patrinos will be Mr. Larry Kumins, Vice President for Research and Analysis at EPRINC, who previously served as a research specialist in energy policy at the Congressional Research Service (CRS) in the U.S. Library of Congress. He has over 30 years experience in undertaking assessments and research on a wide range of oil and natural gas policy and economic issues. Mr. Kumins is a recognized expert on fuel supply, trends in supply and demand in petroleum product markets, natural gas regulatory policy, oil imports and exports, OPEC and world oil market developments.

[*] The views expressed by the author are solely those of the author and may not represent those of any institution with which he is affiliated.

Dr. Aristides Patrinos: Good afternoon, everyone. I would like to thank you for this opportunity to speak a little bit, perhaps not too disjointedly, about a subject that has occupied my time and energy for the last few years. I came to you this morning from a talk I gave my colleagues at the J. Craig Venter Institute and the subject was climate change. I told them the story of climate change, mostly as a story told to biologists who knew very little except perhaps what they have read in the papers. I was amazed in preparing for the talk at how long the story goes further back. With us in the audience is Michael McCracken, one of the early champions of the science of climate change and someone who has introduced a lot of rigor and a lot of value to the enterprise. What also did not escape me, as it doesn't escape you, is the fact that climate change is an issue that is very emotional as well. It has transcended the scientific domain into almost a religious issue; in fact, I remember a cartoon about a kid at the dinner table saying something like, "Well, first we couldn't speak about religion and now we can't even talk about the weather!"

In reflecting a little bit, I left the government eighteen months ago; there are a few times when I feel lucky to have done that and other times when I don't. I do feel lucky when I speak in public because I don't have any of the constraints that I had in the past, which were constraints correctly imposed on somebody who was the voice of government in any kind of forum where he or she spoke. If I were in the Department of Energy and I would be coming to a roundtable like this, I probably would have had several handlers and I would have had several dry runs and a long list of things that I should and should not say. Whatever I put into my message would probably be somewhat limited. Again, I am not being necessarily critical; I am just saying that that is the way things are. Whereas today I don't really have any such constraints and I can speak more openly about some of the issues that surround cellulosic ethanol, which is the subject of today's roundtable.

I started with climate change and I will pick it up again as I proceed here. I know that there is still among some folks in the audience some concern and even some doubt about whether climate change is as serious or as important a problem as some may think. Not that I want to avoid an argument; I just don't think necessarily that we should take up the subject of today's roundtable based on the climate change driver. I think climate change is a serious problem and that it is a reasonable insurance policy to take it on, if indeed it is as serious as some think it is. But taking it on through cellulosic ethanol now has perhaps stronger drivers, as does more generally the whole subject of renewable biofuels. Cellulosic ethanol is the first in line, the first to capture attention, but in fact it may end up not being the fuel that we all focus on. We need to take on some of these strong campaigns for other reasons, and the first one is the fact that we can grow it domestically and shed our reliance on imported oil. We need to do it sooner rather than later and we need to do it more aggressively, as aggressively as we can. More and more, the oil we import is coming from parts of the world that don't like us very much, and I don't think that is likely to change any time soon. So it behooves us to do it for that purpose. I think that it becomes a matter of energy security.

I think it presents also a tremendous entrepreneurial and industrial opportunity. Having been a public servant and now wanting to be an entrepreneur, I see that in many ways. It gives an opportunity for parts of our country that economically have not done perhaps as well as the two coasts. It gives them a new area of industry, a new area of enterprise to venture in and therefore raise the standard of living and keep most young people in the heartlands with better jobs. It is a very valuable and important new enterprise also for domestic policy. Moreover, and thinking beyond just the boundaries of our country, I think for the world it is a tremendously important opportunity. The places where biofuels will be developed and the biomass for the biofuels will be grown and produced and processed are places where we get the most photons and they will be around the equator, of course. If you look at the map, many places around the equator and thereabouts are depressed economically and places where there will be tremendous opportunities to raise the standard of living, and in some ways to improve the lot of humanity in places where humanity is suffering. I think that would be good public policy and good foreign policy for us as well, if we encourage it. I am thinking about places like Indonesia and Malaysia, places in Africa and Central America and Mexico. In fact, you see very many enlightened people today in the business world investing in this emerging enterprise. They see opportunities first and foremost to make money – that is their objective, of course – but also to improve the standard of living of the people who live in those areas and also in some way avoid some of the internal conflicts that develop as a result of the inequities that exist in some of these places. If for those two reasons alone, I think the cause of cellulosic ethanol and biofuels in general needs to be taken up and therefore we can almost set aside the climate change issue that seems to invoke so much unnecessary emotion at times. That is for the arguments for biofuels and cellulosic ethanol.

I had a wonderful career in government. I was one of the most fortunate people among the public servants that were and are my friends. I happened to be at the right place at the right time to have a front row seat and sometimes even a small role in some of the most important, impactful research activities that the federal government started. One was the U.S. Global Change Research Program, back in the late 1980s when it was launched. The other was the Human Genome Project that was launched, interestingly enough, and I am sure that still most of you don't know, by the Department of Energy in 1986, against the conventional wisdom of the time, against the established biological community and even against the National Institutes of Health (NIH). It took prodding from some enlightened people on the Hill, including Senator Domenici (he is still Saint Pete for me) and also some of the folks in the Department of Energy among our political masters at the time. Eventually the Office of Technology Assessment and the National Academies of Science embraced the Human Genome Project and it became a joint project of the National Institutes of Health. I mention it because it is important to highlight how certain scientific initiatives start and how they evolve.

Even though I am no longer an interested party, I would say that it is important to keep the funding of research in this country as diverse as we can. We should always fight this concept of a Department of Science that every new administration – and we will have a new one in eighteen months – conjures up as an important and perhaps easy way by which they can clean up the enterprise by consolidating it. So you who vote and who are active, keep that in mind as you advocate, because it is a terrible mistake. We are where we are in terms of being at the top of the world because of the diversity of our people and the diversity of the scientific approaches and yes, because of the diversity of the funding sources. I am not saying that just for my old friends at DOE, who funded biology against all odds for many years, including very recently, before I left, when there were some movements actually to eliminate the biological programs at the Department of Energy. It was the Department of Energy that launched the Human Genome Project, which was completed successfully in 2003 and first announced, in terms of completing the first draft, about seven years ago in a White House ceremony. It was the Department of Energy that made it possible. The project itself is considered the dawn of the new era of biology. So if you are wondering how this is coming to cellulosic ethanol, hold on for just a few more minutes.

Biology was always, and still is to a large extent, a small science. I don't mean this in any derogatory way; I mean that it is a small science in terms of how it is practiced. A professor, a biologist, a scientist with a few post-docs and a few technicians: that's a big lab for biology. It has always been that way, as opposed to the physical sciences, where physicists are very comfortable with big budgets, big teams, and big machines that smash things together so that they can understand energy and mass at the fundamental level. Biologists have always been small thinkers, in a sense, with respect to the scope of their undertaking. That was one of the reasons that they opposed the Human Genome Project, because they were afraid that it would take away from their enterprise, which was essentially the pursuit of small science. They also were driven and are still driven by hypothesis-driven science. To them, the notion that you would carry out a project where you collect data didn't make any sense unless you had some sort of hypothesis. Does this particular gene really influence that particular disease? So you postulate a hypothesis, you get a couple hundred thousand dollars, and over four years you answer "yes, sometimes" or "no, unless." And this was a nice research project. The notion that you would just pour in all this money – and we did request $3 billion when the project was first launched – and that all you would acquire is these vast amounts of data, a very small percentage of which would be of some value such as the stuff that coded for proteins, to them was unheard of. But for people that were nested in the bosom of the physical sciences, where it was customary to be outrageous and outlandish in your demands, it was very natural, and that is how it happened.

Now the Human Genome Project is known because of its name and because of its relationship and context with human health and disease and medicine, and rightfully so. I mean we are all humans; we all want to see the benefits of this particular research

paying off for us or our children or grandchildren, in terms of better healthcare, better medicine and the like. It is customary that people focus on this. But while this incredible revolution in biology was happening with the introduction of automation, large-scale sequencing, large teams, computing, informatics and the like, there was another, quieter revolution happening. At the forefront of that revolution was my current boss, Craig Venter, also known for his contribution to the Human Genome Project, albeit in a different way. He was the guy who in 1995 was funded by the Department of Energy, I take great pride in saying, to sequence the microbial genome using a technique that was rejected by the peer review system at the time called "shotgun sequencing." That quiet revolution of microbial genomics introduced this new area of research, this new scientific vista, that has a potential of impacting humanity far more significantly and greatly than anything we will do on the human medicine front. That particular field of science will solve many of the problems that are frankly intractable with respect to how we use resources on this planet, how we clean up the messes we have created and will keep creating, and how we will handle the large-scale environmental problems that we face and will face in the future, if development continues at the current rate.

We have entered the era of industrial biotechnology, in my view, mostly through discoveries in the microbial world. The plant world benefited as well. It was sort of the third area of interest that came along. The first was the multi-cellular creatures like ourselves, because we were in the driver's seat; that got all the attention, the mouse and the rat, because they are animals that we experiment with in the laboratory. But the investigation of the microbial world was the real revolution, because first of all it changed the whole field of microbiology. Up until that time, the only microbes we knew were the ones that we wanted to kill because they were bad for us. We had some notion that others existed out there doing good things, but our knowledge of them was pretty limited. We found out through sequencing and generally through microbial genomics that the microbial world out there is vast, much greater, much more diverse than we ever imagined. Sixty percent of all the biomass, the living mass, on this planet is microbial in nature. It is unicellular and more ubiquitous than anything. It exists everywhere: extremophile microbes live in the bottom of the ocean, thrive at 100°C, and can survive millions of rads of radiation and keep on ticking. These are the virtuosos of the living world. They have been around for billions of years and have perfected all the processes of life. We wouldn't be able to survive without them; it is the microbes in your guts that are digesting your food, not you. If they go on strike, you starve. It is the microbes in the root zones of plants that are responsible for how plants process phosphorus and nitrogen to survive. Microbes are doing everything; they are mediating life at every level. And we are discovering them and understanding them everywhere. Studying them and understanding them will help us tap their capabilities and help us harness the unique prowess they have for anything you could imagine.

The part that I am getting to is for biofuels. As we understand how microbes function, as we understand how they perform all these incredible tasks and we understand them at a level where we can actually put them together synthetically, no pun in-

tended, so we can maximize or optimize some of those capabilities. Now that we have sequenced the genomes of hundreds of microbes, for example, we are putting them all on the "tree of life," which is frankly not a tree. It used to be that we thought there were three parts of the tree of life. It is more like a "vine of life." But as I said, only a tiny twig of that tree is the visible world, we and all the other multi-cellular creatures. All the diversity is in the unicellular world. We put the microbes that we discover on these branches and we are discovering more and more of these species. Craig Venter has done a tremendous job in the last few years through the Sorcerer Expedition, circumnavigating the globe and taking samples from seawater, filtering it for the DNA, analyzing it and inferring the diversity of species that have been encountered. They pour all those genes from all that DNA into the databases, thus enlarging, in a sense, their repertoire of applications that we can exploit ultimately for many of the needs that we have and for the challenges that we face. So this is an introduction about when you want to think about cellulosic ethanol. The human race has been producing ethanol for quite some time, albeit for other and perhaps more enjoyable needs. So it is not like there is anything super-new in this pursuit for producing ethanol from biomass.

I was delighted to have been invited to this same room a few weeks ago. Secretary Bodman and Under Secretary Orbach were here to announce the three bio-energy centers that DOE is funding to the tune of $25 million per year per center, with many applications in biological energy and cellulosic ethanol very much at the center. That is something that I worked very hard on before I left government and I was so pleased to see the event coming to such closure, with these awards, and to have come actually on the seventh anniversary to the day of the White House announcement of the completion of the first draft of the Human Genome Project, something that Dr. Orbach mentioned in his introductory remarks. Government needs to invest still in some of the basic research that underpins this enterprise of biofuels. A lot of basic research still needs to be done and it will provide the foundation for many of the discoveries that we will see in the years ahead in the public sector and in the private sector. The private sector is also stepping up to the plate for the reasons I have already described: the opportunities to make a difference, to make money and to affect the cultures and the social machinery of many countries.

So there is a role for everybody in this enterprise and I am delighted to have played a role in the first and trying to play a role in the second. I am very encouraged the more I look into this issue now. I am more focused than I was when I was in the Department of Energy, where the portfolio of research was broader. And even though my heart was in a couple of other areas, it turns out that the time I spent there was mostly in the areas where we had problems, which were not necessarily the areas which captured my interest. Now I am a lot more focused on the problem of biofuels and bio-energy. From my little perch, I see tremendous opportunity out there. I can't tell you that the discovery is imminent because it is still in the realm of basic research, but I am very encouraged with the quality of people that have been trained in this field, in both the public sector and the private sector, in academic settings and industrial set-

tings. I believe that the breakthrough is inevitable, given the quality of people and their prowess and the value of the tools that have been thrust to us by the revolution in genomics. It is just a question of time and the proper balance.

As I said before, I want to stress that cellulosic ethanol is not necessarily the panacea. As you know, ethanol itself has its problems: it has some water-related problems and it doesn't pack perhaps as much energy as gasoline, although that may be also a factor of how you tune your car. It is the first natural step. But thinking ahead, we should be a lot more expansive because biotechnology will give us an opportunity to create any kind of fuel we can imagine. Gasoline is actually a mixture of fuels and there is no reason why we can't conjure up something similar with biotechnology. There is no reason why we can't re-engineer photosynthesis so it can be a lot more efficient than 1 percent, as it currently is. People like to think that Nature is perfect and optimal. That is not true. I always say that Nature is a messy housewife that sort of stumbled into the world we have almost by chance. There is nothing wrong in terms of trying to engineer her to improve her and make her more efficient. It may be far in the future, but photosynthesis can be made more efficient than 1 percent and then most of our problems will go away. We can grow better and bigger plants, we can make them more productive, and we can improve their traits. Certainly with genomics we can make them much healthier. I think the possibilities are endless.

I want to conclude by dwelling just a little bit on something that I said that may have raised some eyebrows and that is the whole notion of synthetic biology or synthetic genomics, which happens to be our company name. I do respect and appreciate some of the concerns that people have, whether they are private citizens, public officials or scientists or managers, about the notion of "meddling with Nature" and starting something that may have unintended consequences. Even though I respect and appreciate that concern, I am personally not worried about it and I think that I can argue the case for us being more proactive with respect to exploring the science. Whether we apply it to the degree and the level that we need or have the opportunity to is a different issue, but exploring the science and doing it openly and in the public domain is something that I feel we need to do and be very aggressive about it. Biotechnology is quite frankly a cheap science to pursue, and our best bet, in terms of staying ahead of the bad guys, is having as much information available to our scientists as possible and as quickly as possible so that they can deliver the countermeasures that are needed to prevent the bad guys doing us any harm. It is not like during the nuclear weapons era, when we could put things behind a fence. Nuclear material can be safeguarded. In biology, an average lab in a garage can do just as much as any sophisticated biology laboratory anywhere. So I am all for more public and open availability of this information. There may be places and opportunities for more synthetic biology to play a role in biofuels. In terms of efficiency, I think we are already doing it in a large scale with recombinant DNA, and as you know, there are many applications of recombinant DNA in agriculture with genetically engineered plants and so on. Despite the opposition by some groups, it has generally been very successful and will continue to be so, in my

view. So along those lines, I think we will continue and we can do even better as our tools get better. We can be more efficient and we can even be safer, because we will have these particular tools. I make the analogy that we have been re-engineering the biosphere since we have come down from the trees, except we have been doing it with blunt instruments and now we have surgical instruments and we can do it much better and more efficiently and more safely. Thank you for your attention and your time and the opportunity to say my piece.

Lawrence Kumins: Let me tell you a little bit about EPRINC. It is the Energy Policy Research Foundation Inc. and the successor organization to the Petroleum Industry Research Foundation Inc. (PIRINC). PIRINC was founded in New York City in 1944 as a public policy shop that explained market and policy phenomena which were of broad-scale public interest. It folded up at the beginning of this year and it was re-imagined here in D.C. as EPRINC. My colleague Lou Pugliaresi is President and I am Vice President. We try to bring policy analysis and industry economics to bear on relevant energy issues.

Today I am going to talk about ethanol, which is sort of the next new thing. We are going to run through the background and the current landscape, consumption and pricing, the gasoline pool and the vehicle fleets, investment issues and some energy security items as well. The landscape is depicted by the rapid increase in ethanol consumption through 2006. We see this as a *one-time* event and I will explain more later, but its rapid growth from 2002 to 2006 probably realized two-thirds of the ultimate near-term market. Future growth will be predicated on ethanol's ability to replace gasoline as a primary fuel, that is, future growth beyond that incremental one-third. Gasoline replacement by ethanol is constrained by two factors: the gasoline/ethanol distribution infrastructure does not deliver ethanol for gasoline blending everywhere in the country, and there are physical limitations on existing vehicles – all 240 million of them – as to how much ethanol they can use in combination with gasoline.

For more background, ethanol has been around since the internal combustion engine was invented. It is a high-octane fuel and has been used as an octane booster off and on over the years. It received renewed interest with the Energy Tax Act of 1978, which offered a 4 cents/gallon blending credit for "gasohol." That is 4 cents per gallon of "gasohol" and it worked out to 40 cents per gallon of neat ethanol. The American Jobs Creation Act of 2004 made that more streamlined and a little bit enhanced as well, offering 51 cents per gallon for ethanol blended. What does that mean? The folks who blend ethanol into gasoline get a 51-cent tax credit for every gallon of ethanol they blend into gasoline. The Energy Policy Act of 2005 (EPAct05) mandates more use of ethanol, 4 billion gallons in 2006 and 7.5 billion gallons in 2012 thereafter. Current consumption, because of this boom in ethanol use in the last year, exceeds 6 billion gallons annually.

Between 2002 and 2006, ethanol consumption increased by a factor of 2.5, from 2.1 billion gallons to 5.4 billion gallons, which is pretty impressive growth. This gives the illusion of boundless consumption of ethanol out there in the future. It would be a mistake to translate that growth rate *ad infinitum*. The reason it became such a hot item in 2006 was that a gasoline-blending component, which is really crucial to making gasoline, called MTBE and ether was removed from the gasoline pool because of public displeasure with some of its characteristics. It went away last year in a great big hurry. The MTBE phase-out had been going out since 2000 when public opposition to it began to grow. Consumption had peaked at about 300,000 barrels per day and it was totally zeroed-out last year. Ethanol phased in and, lo and behold, about 400,000 barrels a day of ethanol were blended into the gasoline pool to replace MTBE, to add oxygen to the gasoline mix to make it burn cleaner, to add octane and O_2, and to add actually physical gallons to the gasoline supply. But keep in mind, ethanol at this point is only a replacement for MTBE.

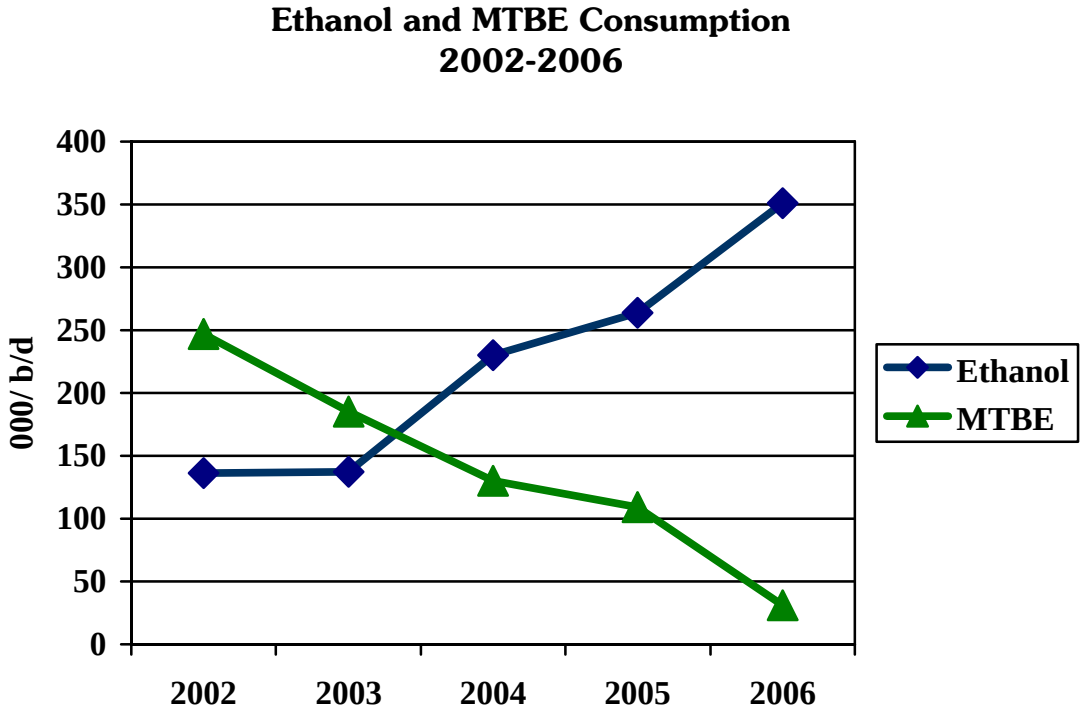

Figure 1

In Figure 1 you can see graphically the ramp-down of MTBE and the ramp-up of ethanol sales.

In Figure 2, you see some interesting pricing phenomena that led to almost a tulip-mania style bubble for ethanol. Ethanol is seen peaking in the middle of last summer at almost $4.50 a gallon, in contrast to gasoline, which also had sort of a run-up last year, at $2.25. It certainly spurred interest in producing ethanol; it was hugely profitable. As things settled down and domestic ethanol production ramped up with

the opening of more and more ethanol plants, prices began to converge. You can see them crossing over in recent months, where ethanol became cheaper than gasoline as the supply increased. U.S. ethanol plant capacity grew, with 119 operating plants capable of meeting all our needs right now: the capacity is 6.2 billion gallons/year or 400,000 barrels/day. There are 86 plants actually under construction and they will double the amount of capacity to over 800,000 barrels/day, getting up to 10 percent of all the gasoline consumed in the country. That is a noteworthy number; the amount of capacity will exceed the EPAct05 2012 mandate.

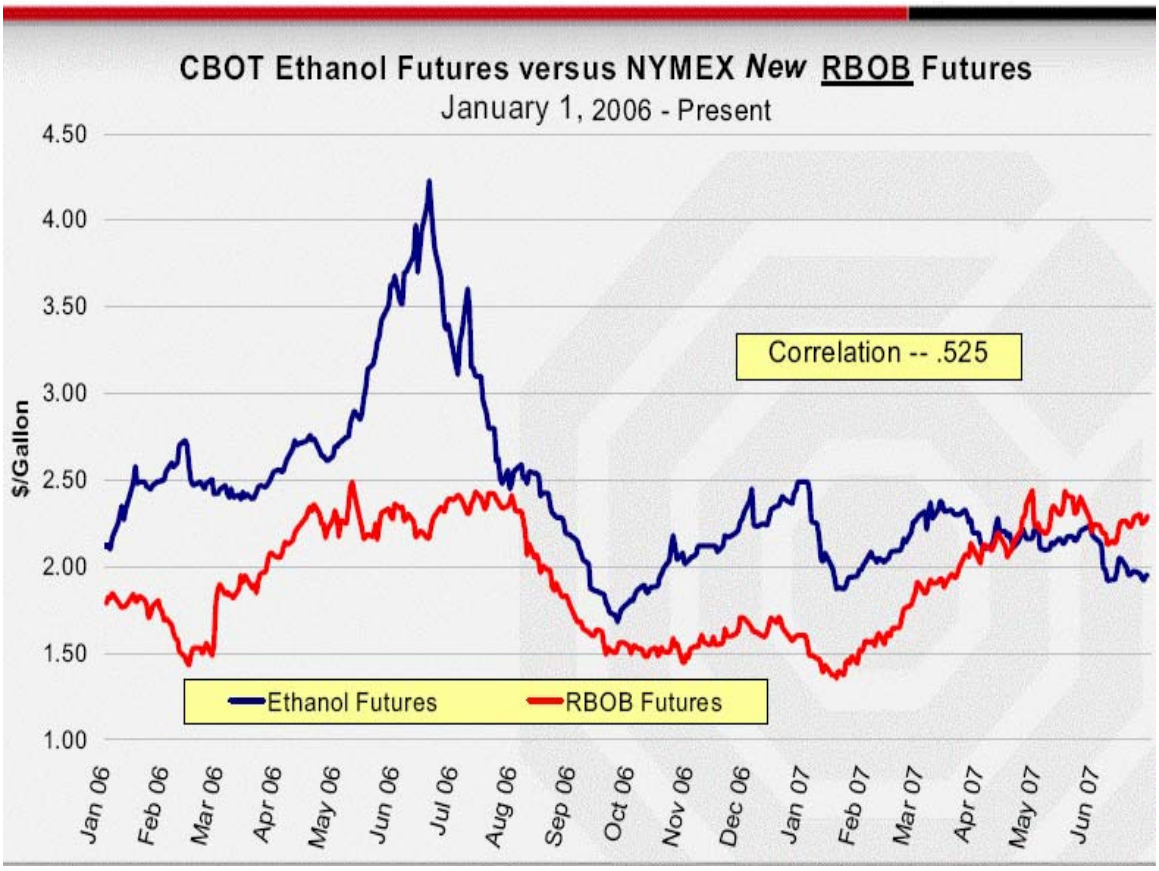

Figure 2

All this ethanol is made from corn and you can see the interesting paths of ethanol prices and corn prices on the same chart (Figure 3). The demand for ethanol and then for corn, particularly last year, doubled the price of corn. The prices fell earlier this year, but for the future months, they are back. Plants are buying more corn and driving corn prices up, and plants are increasing the supply of ethanol and prices of ethanol are going down. We have high corn demand and an ethanol oversupply.

What does that mean for prices? (Figure 3). This year we had record corn plantings. They were the highest since 1944 Corn acreage increased 15 percent. Of course, that came at the expense of other crops, notably cotton (acreage down 20 percent) and soybeans (acreage down 11 percent), so there are price implications here.

Cotton and soybean prices will be higher because of smaller plantings. We know that corn prices are high and look like they will go higher by 2008. This has impacts on inflation that are a concern to those in the public policy game and we will focus a little bit more on that.

Corn Prices are Rising Relative to Ethanol Prices;
Ethanol Profitability Declining

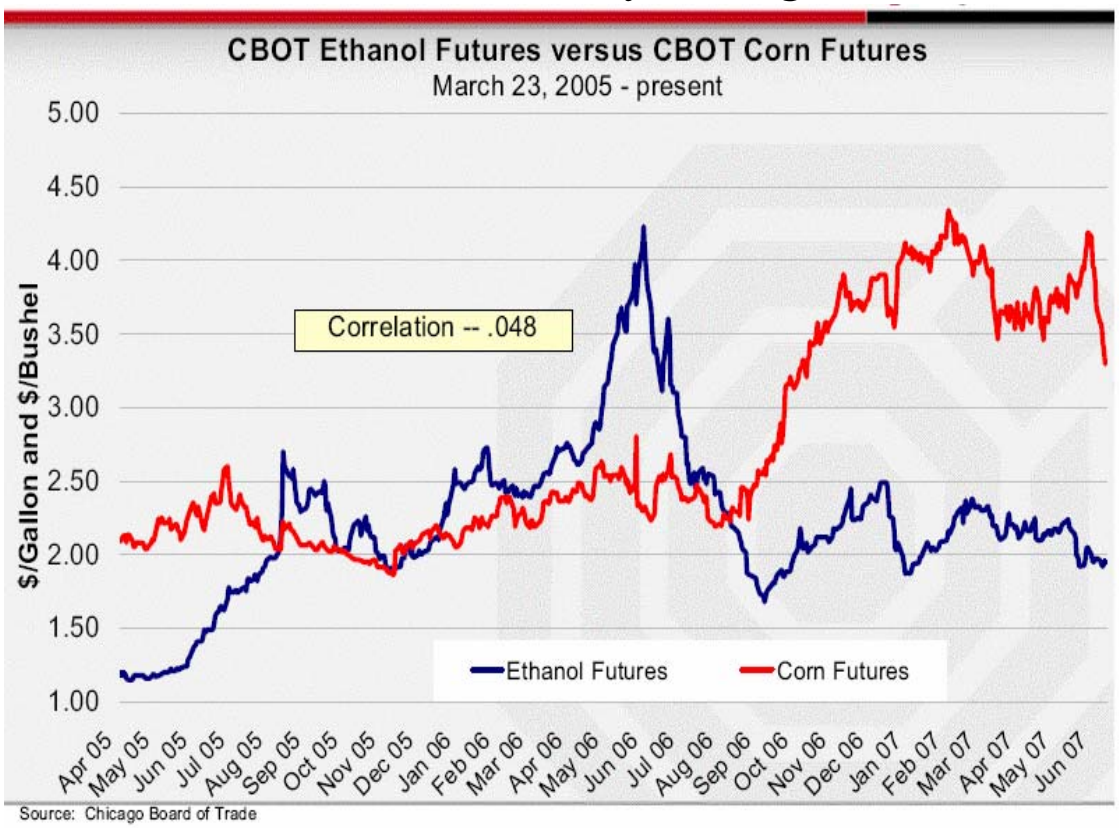

Figure 3

We should say that ethanol is not the new oil; it is something new and different. Or maybe it is the same old thing, but a new fashion statement. Ethanol's BTU content, that is, its energy content, is only two-thirds that of the same amount of gasoline. Volumes of ethanol don't hold comparable energy values, either. Wholesale prices of ethanol currently are $1.90, which translates to about $2.80 a gallon for wholesale gasoline; that is with no tax, no dealer markup and no transportation costs.

There are physical issues here. The mix tends to separate, it attracts water and it can't be shipped by pipeline. That is a really important consideration. Most of the petroleum and most of the motor fuels in the country are shipped at one point or another by pipeline. It is just essential to get this stuff around in a cost-effective way. Ethanol is transported mostly by rail at four times the cost of delivering a petroleum product to a consumer. The ethanol/gasoline mixture has a short shelf life and has to be blended locally. Then there is the confusing issue that the ethanol industry measures

in gallons per year and the petroleum industry measures in barrels per day. This produces the optics of large numbers.

There are also issues with the auto fleet, which has been slow to take up ethanol. Keep in mind that less than 5 percent of a gallon of average gasoline is ethanol. 10 percent is the nominal number for "gasohol," the mixture that can be used in automobiles. It is much less than that on average because of the lack of universal distribution around the country. Not every place in the country uses ethanol-blended gasoline and this limits the market, among other things. We have talked about the transportation constraints. Some higher blends of ethanol are used and there is much talk about flexible-fuel vehicles (FFVs) capable of using E-85, that is, 85 percent ethanol. Out of the 237 million vehicles on the road, only 6 million are FFVs and most of them don't burn E-85. There are only 1,200 retail establishments that sell that fuel around the country. Interestingly, the President has elicited a promise or a pledge from the Big Three automakers that half their 2012 output will be flexible-fuel vehicles. Foreign makers have not shown much interest in doing the same; they have other ways of achieving energy efficiency and high miles per gallon. But in 2017, which is a milestone year, given the President's goal of "20 in 10," there will be 280 million vehicles on the road in the United States and not many of them will be flexible-fuel vehicles. And even if Detroit is successful, only 25 percent of the new vehicles sold in any given year will be FFVs.

% Ethanol	Billions Gallons/ Year	B/D (000)	Fundamental Factor	Price Implication
~ 5%	~8	500	Necessary- Complimentary—The current situation; replacing MTBE	Higher than Gasoline
5% - 8%	~12	750	Enhancing Gasoline Performance and Increasing supply Volumes	Converging on Gasoline Price
10%	~15	1,000	Max % current vehicles can use Limited by Distribution Infrastructure	Price Competition among Ethanol Producers
Much greater than 10%	35	2,300	Exceeds likely Auto Fleet Capability	Market Oversupplied—Serious Price Erosion

Table 1

What does all this mean? There is an easy amount of ethanol that can be absorbed in the gasoline pool (Table 1). That is about 5 percent and that is where we are now, about 8 billion gallons a year or half a million barrels a day. The reality is that that is a necessary and complimentary component of the gasoline pool. It is the cur-

rent situation and it is the replacement of MTBE. And it is an economic environment that can figure to have higher ethanol prices than gasoline prices. But we have a lot of production capability in the works, under construction and soon to come on line. More ethanol will be hard to absorb into the gasoline pool, given the 10 percent effective cap and the lack of distribution facilities. Certainly gasoline performance can be enhanced and increasing volumes supplied, but at the same time, with all this capacity coming on line, we are going to see ethanol prices converge on gasoline prices on a Btu adjusted basis. Ten percent is sort of the theoretical maximum, which would be hard to achieve because of the distribution conflicts that I have outlined; that is the maximum that can be used in current vehicles and price competition among ethanol producers is likely as those new plants come on line. Those plants will produce 15 billion gallons a year. This capacity is almost there right now, given the facilities that are under construction. So we are concerned that prices might go down for ethanol and leave a lot of stranded investment, the possibility of ethanol producers seeking additional federal subsidies, and unintended consequences of that nature.

Finally, in out-years like 2017, there are proposals for much greater amounts of ethanol over the 10 percent plan that is currently the cap. How that might be achieved is an interesting question, given the ability of automakers, and it is only domestic automakers espousing this plan; they only sell half the cars in the country, at best. How that might happen is a question that needs to be addressed. A market for high percentage ethanol blends is just assumed and it is assumed that auto manufacturers will warranty cars using greater blends and higher concentrations of ethanol, above the 10 percent limit which is the warranty cut-off on most automobiles.

Having said that, what is the role for cellulosic ethanol in the gasoline fuel? First of all, it must transition from lab to commercial activity. That hasn't happened. Cellulosic ethanol would be a good supplement for corn-ethanol, which is an essential part of the gasoline pool now. We can't make gasoline without ethanol. It would minimize crop cycle risk. It would alleviate the situation where agricultural consumers and energy consumers are in conflict, competing for the same stuff. It would mitigate the inflationary impact of ethanol on agricultural commodities, which is not measured because we tend to have price indexes that are computed without food and energy, sort of sweeping under the rug some very real price pressures in the economy.

Consumption still won't exceed 10 percent of the gasoline without substantial changes in the stock of capital: pipeline transport and terminal facilities, retail facilities (there are only those 1,200 stations dispensing E-85), universal distribution across the country and a change in the automobile stock to facilitate the use of higher concentrations of ethanol and gasoline. I note that investors have been quick to back ethanol production, with those 200 new ethanol plants out there, but infrastructure has attracted little interest. Financing infrastructure, like pipelines, is quite a challenge. There are special vehicles for doing that used in the pipeline industry, master limited partnerships and things of that nature, but these are difficult projects to get bankrolled

and Wall Street has shown less interest in these investments than ethanol plant. So bankrolling pipelines and terminals is not easy.

We are concerned about ethanol investment because investment in refining has lagged at the same time that ethanol plant investment has been robust. Refining capacity only grew by 600,000 barrels a day in the past few years and at the same time imports of refined oil products grew by 1 million barrels a day. We have a new energy security issue emerging: not only do we depend on other nation's crude oil; we depend on other countries' refining capacity to keep our gas tanks full. All this has resulted in very high capacity utilization refineries without the ability to deal with outages, scheduled maintenance, etc. And we have the current gasoline price situation; gasoline went from $2.15 a gallon in January to $3.25 in June, mostly due to refinery outages. Challenged refinery capacity has become its own energy security issue.

I should note that ethanol and oil compete for capital pool and they also compete for the same materials and services in new facility construction. We are concerned that ethanol may be crowding out investment in petroleum refining, which is where we get our motor fuels traditionally. With the recent developments in the ethanol market, with ethanol becoming such an important component of motor fuel supply and what is seen as a threat of additional ethanol mandates by folks investing in long-lived oil-refining assets and transportation assets, it has had a chilling impact on refinery investment. Many investment plans have been rolled back. Remember, we are short on refining capacity. We import over 1 million barrels a day of gasoline and every time that number drops under 1 million barrels a day, it shows up in higher prices at the pump. So we are concerned about some energy security goals and minimizing risk.

We certainly want to see controlled growth in petroleum imports (everybody does) and maybe even a reduction. We want to see the economy buffered from price shocks caused by adverse world market events. And we want to see U.S. refinery capacity catch up with consumption and seek reduced risk from refinery mishaps, which have certainly been a factor in the past couple of years in gasoline price volatility. But we are concerned about depending on an agricultural commodity to do this. That would introduce new risks because of the crop cycle. The implication is that cellulosic ethanol would play a good role here and it would be good to see some of that crop risk replaced with something more stable.

So that briefly is our pitch on ethanol, its role in the energy economy and what the near-term outlook might be. We are concerned that recent price increases in the uptake of ethanol, increased demand, has created a little bit of a tulip-mania and we are beginning to see reorganization in the ethanol industry, such as it is, with some consolidation going on, declining prices of ethanol, higher corn prices, higher feedstock prices and maybe some compression in the margins of ethanol manufactures. Stay tuned; it is early in the game and there is a lot to play out. We will see how it all shakes

out, but remember, there is a constraint on how much ethanol can actually be absorbed by the energy economy which we live in today. Thank you.

Questions and answers.

Question: Wouldn't Brazil always have a comparative advantage over the U.S. because they are on the equator and have sugar cane? How could we ever compete with them?

Kumins: They have two comparative advantages. One is the climate, as you mentioned, and the other is that it is easier to make ethanol from sugar than from corn. Sugar ferments right into alcohol and cornstarch has to be converted to sugar to make alcohol. So we have tariffs on imported ethanol.

Question: You mentioned the difficulty of infrastructure in transport. If we are going to switch to greater use of ethanol, whether corn-based or cellulosic, you are saying it would require an investment in infrastructure to make it possible. Is there any precedent in the development of the energy industry in this country where the federal government subsidized infrastructure?

Kumins: Yes, during World War II, the federal government bankrolled a bunch of pipelines so that gasoline and whatnot didn't have to be transported up the coast by tankers, which were vulnerable to submarines. Those pipelines were eventually spun off to private owners. But really in the context of the times that they were built, trivial amounts of money were involved. Now building a pipeline is a huge, capital-intensive effort and the question is who is going to fund this? Will the federal government fund it as an assistance program to the ethanol industry? It is quite a challenge and often overlooked. Infrastructure is apparently boring stuff to investors and ethanol entrepreneurs as well. If you are in the oil business it is your lifeline, but it is not perceived as such in this new "oil" game.

Question: The automobile industry would have to manufacture cars that could use fuels that had greater ethanol content.

Kumins: Correct, and then people would have to buy them. And once they bought them, they would have to put that kind of fuel in them. They are manufacturing some; there are 6 million of these vehicles on the road, but not many of them get by those 1,200 gas pumps that dispense E-85.

Question: I have a question for each speaker. For Ari, is there any thought about doing something about farming the oceans, trying to gather biomass from the oceans? And for Mr. Kumins, could you give us a sense of what the difference in price is for a flex-fuel vehicle versus a regular fuel vehicle for retrofitting vehicles and what might happen if one goes to plug-in hybrids, where you might have a turbine that runs on

ethanol? I thought racecars run purely on ethanol. Is it very expensive to switch? What's holding everything up?

Patrinos: With respect to the question that you posed to me, there are thoughts along those lines. The first, and one that is already at the research stage very aggressively, is the whole notion of using micro-algae to produce biodiesel. This idea has been around awhile. The Department of Energy funded the Aquatic Species Program for ten years. They terminated the program in the mid-1990s because the price of a barrel of oil was $10, so there was no value seen. Now that oil is seven times more expensive, there is an added impetus. There is also an important component to this, and that is if you produce biodiesel from algae efficiently, you are not necessarily competing with food, because you can grow some of those micro-algae in brackish waters or in remote areas or arid climates. There is even an additional value: if you combine it with power plants, you can have the CO_2 directly feeding the micro-algae. All the algae really need is CO_2 and sunlight and they produce the oil that is the basic biodiesel. There are some more exploratory programs, alongside the one that you describe, from the ocean itself, but those are at the very formative stages, whereas for the micro-algae to biodiesel there are at least ten initiatives in this country alone that are pursuing this particular approach.

Kumins: How much more does a flex-fuel vehicle cost to produce than a traditional vehicle? The answer is not a whole lot, probably much less than $1,000, just because it is using different materials in critical areas that would be impacted by ethanol's corrosive characteristics on some materials, seals and fuel system plumbing and things like that. So it is not much. Retrofitting that stuff is likely prohibitive. I have never seen any proposal that had cost figures to do that.

Question: I have a question for Dr. Patrinos. You mentioned the cultural effect of crops for cellulosic ethanol along the equator. I guess you were saying that it could benefit the level of poverty of the folks down there. Time after time you see examples in oil-producing countries where that hasn't happened. What guarantee is there that it would happen? How do you make that happen? And secondly, if you go to cellulosic fuel crops, isn't there a risk that you produce less food crops and also you accelerate the destruction of rain forests?

Patrinos: For the second question, at least from the "back of the envelope" calculations that I have made, we can do very well feeding the world. As you may know, the problem of food is mostly a problem of distribution; it is not amount. So I don't think there is an issue about fuel competing with food, except in rare cases and in some situations. That is one of the reasons that I think using cornstarch to produce ethanol is not ultimately a viable solution. We have to go another way. With respect to the first question, it is a good question. I certainly have no guarantees that this new enterprise will be more successful in terms of improving the lot of humanity where it needs to be improved. I have a sense, however, that anything based more on agriculture,

which is what this will be based on, and that has to be more distributed, by its very nature, has a greater chance of permeating society and being integrated in the social structure than something that requires high technology and is very localized.

Question: This is more of a comment than a question, but I think it dovetails with both of your comments. Dr. Patrinos had mentioned microbes that would produce hydrocarbons and that would be a good thing. I represent the Catalysis and Biocatalysis Program at the National Science Foundation and I can tell you that there are inorganic catalysts that are in use today that will convert sugar to gasoline and diesel and jet fuel. We have had a road-map workshop at the end of last month and we will be producing a report in a month or so and we hope to have our own briefing. Ethanol is fine in the short term, but our goal is that with inorganic catalysts to produce "green gasoline," we can actually fill in the gap in the long term such that we won't have to come up with a new infrastructure. The green fuels that we are talking about producing will fit right into the delivery infrastructure as well as the existing petroleum refining system. I offer that for your consideration. In a sense, this is bringing the expertise of the petroleum refinery business to bear on biomass; it is this business of inorganic catalysis as opposed to enzymes, and I think it has a lot to offer.

Patrinos: You certainly convince me and I very much agree with you that we need to pursue all approaches to solve the challenge that we face. We are pursuing a biological approach, but there is room for everybody in this game.

Question: Along the lines of producing gasoline and diesel fuel, what about gasification technologies? I wonder whether or not you have looked at that. In particular, Bob Williams of Princeton University has published some information saying that if you did it with coal and biomass together and did CO_2 capture and storage, you came up with data that looked pretty convincing. I am not vouchsafing that the data is good, but it seemed like an intriguing approach that used basically conventional technology.

Kumins: There is all sorts of science out there: coal to liquids, coal to gas, natural gas to liquids and things of that nature. They are on the near-term horizon, but they are not viable yet. There is a number of natural gas to liquids projects getting under way in the Middle East. As policy analysts, I think we have to sit tight and see how that pans out. But there is certainly a lot of science there and many opportunities for working with hydrocarbons that are "stranded," if you will, such as gas in the Middle East and coal in the United States.

Question: I am thinking of liquefied natural gas (LNG), which may be coming down in price in the future, but probably will go back up. That makes those gasification projects rather unappealing, from what people thought ten years ago. LNG has made the hurdles to the producers much higher than CTL demands.

Kumins: Sure, but it is still in limited supply and not every country with gas reserves is set up to do the liquefaction. It is still an emerging industry with some interesting price fluctuations, particularly last winter. It is not full-scale yet.

Question: I am Lou Pugliaresi, the President of EPRINC. First, those of you who are trying to take notes can pull this off our website. I would like to make a couple of comments, though, to drive home the point on the ethanol paper. When you have a foreign policy masquerading as energy policy, these are the kinds of outcomes we get. Because if you think about Larry's presentation, ethanol probably could make it in the marketplace without any subsidies as a replacement for MTBE. It was quite valuable for the first 6 million gallons, because refiners needed it to get the "wetness," to hit the RVP targets, as well as provide octane. So it is unfortunate that the Congress decided to do this, because we are missing the traditional signals that say, okay, maybe we need to slow down. And then as we talk about all these different things, whatever they might be, it is very important for us to remember, as those of us who lived through the 1970s do, that inexhaustible does not mean inexpensive. There are many things that are inexhaustible and many great technologies out there and probably we don't want the government to choose among them. But we do want the government to fund basic research, so things can express themselves in the marketplace.

Another issue that gets lost here a lot is the question, what is the problem we are trying to fix here? Dr. Patrinos mentioned that oil is commonly found in many places that are unstable right now. But we have to remember that we are part of the integrated world oil market. To the extent that we back out of oil, we are only going to get a piece of revenue, maybe a quarter, maybe a third. We are not going to get it all because it is a highly fungible, highly integrated market and a disruption somewhere is disruption everywhere. I lived through the 1970s and now I am watching it all happen again and wondering whether it is going to have the same outcome. We probably don't want the government picking the winners and losers. We probably want a system where many alternatives can come to the fore and where the market signals can play a larger role in deciding which ones will come forward and which ones will not. And finally on the ethanol issue, I don't know if everyone quite understood that when Larry said that it is not a petroleum product, he was referring to the infrastructure. That means that you cannot put it into the U.S. distribution system. You cannot take ethanol and stick it in a petroleum pipeline; that highly limits its functionality.

Question: Given the constraints that you have outlined about ethanol and the fact that many of our eastern states are looking at a low-carbon fuel standard, how might the petroleum industry respond to a low-carbon fuel standard in the northeast states?

Kumins: That is a tough one to answer and I don't know that ethanol is one of the answers. By burning ethanol you are still combusting hydrocarbons.

Question: Especially if you do a life-cycle calculation.

Question: Would you speculate on what might be done to reduce carbon?

Kumins: I can't, to tell you the truth. If you are going to combust hydrocarbons and have an economy based on that, you are going to get CO_2. There is no way around that. How CO_2 is mitigated is one of the most controversial issues of our time.

Patrinos: Cellulosic ethanol would be better certainly than cornstarch ethanol in terms of its life cycle. Other renewable fuels like the biodiesel that I described have a "two-for" because it actually uses the CO_2 that you want to get rid of as the feedstock for the actual oil. I think it is true that many of these ideas are still very much at the research phase and that is why significant investments are made that way. But I am optimistic that we will be able to get around some of these problems.

Kumins: I would like to underline what Dr. Patrinos said. There may well be some really sophisticated, high-tech solutions to this sort of thing, just along the lines that he was outlining, and that may be the way that things go in the future, given the advancement of science.

Question: Are you suggesting that we ought to be looking much more closely at electric vehicles and trying to find solutions for low-carbon production electricity?

Patrinos: The only alternative would be nuclear. Otherwise you would still have to burn hydrocarbons to produce electricity.

Question: Would biomass as a fuel be considered carbon neutral?

Patrinos: Well, it is more carbon neutral than burning fossil fuels, which is biomass that has been stored for millions of years.

Question: I wonder whether the Sorcerer expedition uncovered anything that has direct implications for improving cellulosic ethanol?

Patrinos: I have no doubt that all that information that is now in the public database is fueling research in many laboratories and universities around the country, around the world in fact, and I would bet that some good ideas will come out of this. Some of them may in fact hold the secret to unlocking the cellulosic ethanol mystery.

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