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3 HEARING ON ``EFFECTS OF DEVELOPMENTS IN SYNTHETIC GENOMICS''

4 THURSDAY, MAY 27, 2010

5 House of Representatives,

6 Committee on Energy and Commerce

7 Washington, D.C.

8 The Committee met, pursuant to call, at 9:08 a.m., in

9 Room 2123 of the Rayburn House Office Building, Hon. Henry A.

10 Waxman [Chairman of the Committee] presiding.

11 Members present: Representatives Waxman, Markey,

12 Pallone, Gordon, Eshoo, Barrow, Castor, McNerney, Barton,

13 Shimkus, Pitts, Bono Mack, Burgess, Gingrey, Scalise,

14 Griffith, and Latta.

15 Staff present: Phil Barnett, Staff Director; Bruce

16 Wolpe, Senior Advisor; Karen Nelson, Deputy Committee Staff

17 Director for Health; Ruth Katz, Chief Public Health Counsel;

18 Naomi Seiler, Counsel; Robert Clark, Policy Advisor; Stephen

Cha, Professional Staff Member; Allison Corr, Special Assistant; Eric Flamm, FDA Detailee; Greg Dotson, Chief Counsel, Energy and Environment; Lorie Schmidt, Senior Counsel; Alex Barron, Professional Staff Member; Melissa Cheatham, Professional Staff Member; Karen Lightfoot, Communications Director, Senior Policy Advisor; Elizabeth Letter, Special Assistant; Lindsay Vidal, Special Assistant; Earley Green, Chief Clerk; Jen Berenholz, Deputy Clerk; Mitchell Smiley, Special Assistant; Clay Alspach, Counsel, Health; Ryan Long, Chief Counsel, Health; and Andrea Spring, Professional Staff Member, E&E.

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The {Chairman.} The meeting of the committee will please come to order. While we expect to call on our witnesses and have them give us their testimony at ten o’clock, I did want to have this hour available for members to be able to make opening statements. I will make my opening statement and Mr. Barton will make his opening statement just before we begin the testimony. But I want to call on members who wish to make opening statements and to recognize them at this time for that opportunity. So let me--Mr. Burgess?

Dr. {Burgess.} Well, Mr. Chairman, actually I didn’t realize this was the arrangement. I will waive an opening statement in deference time for questions because of the firepower we have on our panel this morning. So I will waive the opening statement.

[The prepared statement of Dr. Burgess follows:]

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The {Chairman.} Okay. Very good. We are not going to give you extra time. We will just have--those are the rules of subcommittee. Any other members seek recognition for an opening statement? Yes, Mr. Latta?

Mr. {Latta.} Well, thanks, Mr. Chairman. If I may, I would like to waive opening statement, just submit my opening statement for the record please, my written statement.

[The prepared statement of Mr. Latta follows:]

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The {Chairman.} Certainly. We--without objection, we are going to allow all members to submit written opening statements and this is an opportunity for those who want to give their opening statements at this--in an oral presentation at the committee meeting. Gentleman from Georgia, Mr. Gingrey?

Dr. {Gingrey.} Mr. Chairman, thank you. Certainly, I look forward to hearing from these high powered witnesses as my colleague from Texas, my physician colleague just said, in exploring these issues further. However, it seems a bit ironic that we are holding a hearing on the future of medicine and synthetic biology when the future of our health system, I submit, indeed is in doubt.

A new study by Towers Watson found that one in six employers are likely to reduce employment and retirement plan contribution, such as 401(k)’s, to pay for health reform. Forty-three percent of employers are likely to eliminate or reduce retiree medical programs because of this bill that we just passed. Ninety percent of employers believe healthcare reform will increase their organization’s healthcare costs. Employers like AT&T are already filing billion dollar losses with the SEC.

Today, we should be meeting to explore why the Democrats

health reform bill is hurting so many employers and subsequently, their employees. Such a hearing might also explore how spending trillions of dollars to turn our healthcare over to government bureaucrats may indeed very--may ruin the very market we need to produce groundbreaking new treatments like these witnesses are going to describe to us in this hearing today.

With that, Mr. Chairman, I will yield back my remaining time.

[The prepared statement of Dr. Gingrey follows:]

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The {Chairman.} Thank you. The gentleman yields back his time. Mr. Pitts?

Mr. {Pitts.} Thank you, Mr. Chairman and thank you for scheduling this hearing. Synthetic biology or synthetic genomics has been in the headlines recently with the news last week that Dr. Venter, who is testifying this morning, has developed the first self-replicating cell to be made from synthesized DNA. Advances in synthetic biology or synthetic genomics have potential applications across a wide variety of fields, healthcare and energy and the environment, to name a few, and synthetic genomics can already be used to produce medications and may possibly aid in tissue reconstruction.

In the future, these techniques could be used to create biofuels or lessen pollution and while these are exciting prospects, I think we all need to learn more about this science of synthetic biology and synthetic genomics. I also think we should carefully investigate the moral, the ethical issues, as well as public health and safety issues, that advances in the field are raising and I look forward to hearing from our distinguished witnesses, learning from them today. Thank you, Mr. Chairman and I yield back.

[The prepared statement of Mr. Pitts follows:]

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The {Chairman.} Thank you very much, Mr. Pitts. Mr. McNerney, do you wish to make an opening statement?

Mr. {McNerney.} Thank you, Mr. Chairman and I want to thank the panel for coming--what a distinguished list of speakers and they have made tremendous advances in the field and a lot more to come. Of course, there is always the risk that is associated with these sort of advances and we want to make sure that we are on good standing with those risks but the potential for good, in my opinion, outweighs the risk at this point, as long as we keep mindful of that, and I just want to say I am a little disappointed that our colleague from Georgia decided to make this into a political spectacle, but that is what happens in this committee.

But welcome aboard. I look forward to your testimony and thank you.

[The prepared statement of Mr. McNerney follows:]

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The {Chairman.} Thank you, Mr. McNerney.

Any other member wish to be recognized for the purpose of giving an oral opening statement? We are going to recess until ten o’clock. We will then begin the hearing, with opening statements from the chairman and the ranking member, the chairman of the two subcommittees that have a specific interest in this, the energy and environment subcommittee and the health subcommittee and the chairman and the ranking members of those subcommittees as well and then we were going to call on this very distinguished panel.

So we are going to recess now and all other members will have an opportunity to put an opening statement, in writing, in the record. We are in recess until ten o’clock.

[Recess.]

The {Chairman.} The meeting of the committee will come to order.

The scope and depth of scientific research in America is unrivaled. As a result, we and others around the world live healthier lives and enjoy of the many advantages of modern technology. As policymakers, we want to foster promising discoveries, while ensuring that research is conducted and applied responsibly. To this end, it is our job to understand what the science does and does not entail. We

need to separate splashy headlines and science fiction scenarios from the reality of what scientists are doing and where their research might lead.

Last Thursday, we learned that researchers had taken a major step forward by synthesizing the entire set of genetic instructions for a bacteria and using it to reprogram another bacterial cell. Observers as diverse as the American Society for Microbiology and a Vatican City newspaper have noted the potential benefits of this research. Today, we will learn more about this and other advances in synthetic biology, the science of constructing or adapting DNA cells and tissues. We will explore potential applications to improve health, protect the environment, and meet our energy needs.

We have also discussed the ethical implications and the need to responsibly manage risks. Of course, this field did not just spring up. Scientists have been harnessing the power of DNA for decades. While most research involves one celled organisms, like bacteria or yeast, the results are far reaching. For example, in 1982, the FDA approved human insulin from a gene inserted into yeast cells. Genetic engineering has been used to make human growth hormone, hepatitis vaccine, and other products and as we will hear, newer methods are already leading to important medical applications. Synthetic biology also has a potential to

reduce our dependence on oil and to address climate change. Research is underway to develop microbes that would produce oil, giving us a renewable fuel that could be used interchangeably with gasoline, without creating more global warming pollution. Research can also lead to oil eating microbes, an application that, as the Gulf spill unfortunately demonstrates, would be extremely useful. The promise of synthetic biology does not diminish the importance of it being conducted and applied responsibly, as is true whenever science advances.

We must weigh and manage the safety, health, and environmental risks posed by this evolving science. Fortunately, this assessment can build on existing regulatory frameworks and I am pleased to see that President Obama has just asked his bioethics commission to conduct a thorough analysis of these issues. I look forward to hearing more from today from three leaders in the field of synthetic biology, Dr. Craig Venter, Dr. Jay Keasling, and Dr. Drew Endy. They will explain their work and its current and potential applications.

Dr. Kaebnick of The Hastings Center will offer a framework for discussing the ethical questions related to synthetic biology, questions about risk, and also about fundamental beliefs about life and we also look forward, as

always, to learning from Dr. Fauci on NIH's role in synthetic biology and how the agency's current approach can adapt to advances in the science. Before we call on our witnesses, I want to recognize the ranking member of the committee, Mr. Barton, for opening statement.

[The prepared statement of Mr. Waxman follows:]

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Mr. {Barton.} Good. Thank you, Chairman Waxman. I sincerely do appreciate you scheduling this hearing today. It is good to have a hearing about positive--at least what I consider to be potentially very positive developments in the field of bioresearch. We are going to hear today from scientists at the Craig Venter Institute and others. They announced, not too long ago, that they had created the first living organism with a completely synthetic genome. Just amazing. They have used more than 1,000 sections of preassembled units of DNA to create an altered version of a bacteria that causes arthritis in goats. It is an odd thing to recreate, but they have done it. Their version is a little jazzier than the original, apparently. It is blue and includes the scientists' names in code. I want the next one to be red. Okay? You have done one for the blue side, now do one for the red side.

I hear that there are many potential applications of this new technology for both energy and health innovations. In fact, the first biotech patent is for a microorganism that could clean up oil spills and that is really good news. Companies are also looking into enhancing algae to make it a better producer of ethanol or perhaps even to produce oil. One of our witnesses today has reengineered a yeast to help

produce an antimalarial drug. I am also told that this technology could be especially valuable in producing vaccines for fast mutating viruses, such as influenza.

We must not only review the potential benefits of this new technology though, Mr. Chairman. We must also look at the possible ethical and safety implications. It is very important that safeguards prevent new viruses from being created and accidently, or maybe even intentionally, released to infect humans or animals. It also creates additional bioterrorism risk if terrorists erode nations, using the technology for bad purposes. Although we are a long way from using synthetic genomes to create large life forms, this is also a long-term concern.

I hope to hear from the witnesses what sort of voluntary and mandatory safeguards and procedures should be put into place to ensure that we see only the benefits from these exciting new developments. Mr. Chairman, the rest of my statement, which is three pages, is about the healthcare bill. I am not going to spoil this hearing by reading all that because this is an important hearing and I wanted to be positive and focus on the positive implications. I do hope though in the near future though, Mr. Chairman, that we could be in to schedule some hearings about the implications of the new healthcare law. We are having a Republican meeting this

afternoon, briefing at one o’clock in the Visitor’s Center. So I am not going to put that into the record. I will simply say that hopefully in the future, we can hold some hearings on that new bill, new law.

But for this hearing today, I am sincerely appreciative of our witnesses. I think this is a good thing for the committee to be doing and look forward to positive interaction in the question and answer period.

[The prepared statement of Mr. Barton follows:]

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The {Chairman.} Thank you very much, Mr. Barton. I want to recognize the chairman of our health subcommittee, Mr. Pallone, for an opening statement.

Mr. {Pallone.} Thank you, Mr. Chairman and thank you for calling what I consider a very important hearing. It is certainly going to be beneficial to hear directly from our witnesses on the effects of the developments in synthetics genomics. Advancements in science over the past several decades have led to exciting developments in medical treatments and today, we will learn about the current state of research to effectively synthesize or modify DNA, explore the applications of this research related to health and energy and discuss the frameworks for ensuring compliance with ethical and regulatory guidelines.

Research in the ‘70s and ‘80s related to recombinant DNA technology led to one of the most notable early successes for advances in drug development. In 1982, human insulin became the first of many FDA approved medicines which utilizes technology and later, the first recombinant vaccine was produced for the hepatitis B virus. New strategies related to combining engineering and biological techniques have strengthened advancements and science related to genetic cellular and tissue level biology and one of our witnesses

today, Dr. Jay Keasling--hope I am pronouncing it properly--will testify about the innovative work he has done related to production of the anti-malarial drug, artemisinin. The disease malaria kills over a million people each year and it second only to tuberculosis in its impact on world health. This disease spread by mosquitoes is endemic in 90 countries and infects one in ten of the world’s population and malaria is a major cause of death globally and a significant threat to the health of children. The drug Artemisinin is currently far too expensive for the people in developing countries who need it the most and advances in drug production has the potential to dramatically lower the price of this treatment, which will be notable advance for global health.

Our good friend and frequent witness from the NIH, Dr. Fauci--I hope I am pronouncing it--is also here with us today. Dr. Fauci, the director of the National Institute of Allergy and Infectious Diseases, will discuss the role of the NIH and research using recombinant DNA and synthetic biology. NIAID supported research have sequenced the complete genomes of hundreds of disease-causing organisms, such as malaria, tuberculosis, and seasonal and pandemic influenza. NIAID has been a leader in providing support to research applying recombinant DNA technologies, genomics, and other related disciplines to the study of these infectious disease and we

will also hear from Dr. J. Craig Venter of the J. Craig Venter Institute about the exciting work he and his colleagues have recently published this week and how this team believes their work will lead to greater application in vaccine and energy production.

Advancements in science must always be balanced by strict and appropriate ethical guidelines. Clearly, there are many who remain concerned that someone with nefarious intentions could take advantage of new technologies and create a biological weapon and we are fortunate to have with us today Gregory Kaebnick, a research scholar at The Hastings Center. The Center is an independent, nonpartisan, nonprofit research institute that has been studying ethical issues in medicine, health policy, medical research, and biotechnology since 1969. Mr. Kaebnick will address concerns related to biosafety, deliberate misuse and governance of bioethical issues, including the role of NIH recombinant DHA advisory committee and the institutional biosafety committees at research universities that receive federal funding.

These boards, along with President Obama’s presidential commission for the study of bioethical issues, provide important oversight and safety measures that accompany our advancements in scientific discovery.

Again, thank you, Mr. Chairman. I know that this is,

frankly, I think, very interesting material but not easily understood and I know that, you know, we need to do more hearings like this and of course, it is--since it goes beyond health into energy and other issues, it is important that we have it at the full committee level. So thank you, Mr. Chairman.

[The prepared statement of Mr. Pallone follows:]

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The {Chairman.} Thank you very much. Now I would like to recognize the ranking member of the subcommittee, the gentleman from Illinois.

Mr. {Shimkus.} Thank you, Mr. Chairman, and welcome to the panel. Synthetic genomes have a great potential to make advancements in health in humans, as well as reducing Americans dependent upon foreign energy and so I welcome you all here to help educate us. From perfecting drugs, detecting and preventing infections, strengthening human tissue and developing enzymes that break down plant waste and convert into biofuels, synthetic genomes hold a great potential in the health area.

There are some ethical and safety concerns we must remain mindful of as this technology advances but the opportunity for growth is certainly encouraging.

Having said that, I wish I was as magnanimous as my ranking member, but I have asked this question for about four weeks straight now for hearings on a healthcare law and I will use my time to address some concerns in that vein. You know, another week and another opportunity lost to address issues that are pressing in this healthcare law. The committee has seemingly dropped everything for this hearing, including cancelling a previously scheduled hearing, yet

there has never, ever been a hearing on the actual health reform law that we passed.

Every day we are hearing from constituents with questions and concerns on how the new law will affect them and businesses, small and large, are trying to understand how they can keep their doors open and provide insurance to their employees. The state of Virginia recently estimated the impact of the unfunded mandate on states will be 40 percent more than their initial estimate. Will all states have similar unsustainable increases? The Medicare flier sent this week by the administrator highlights improvements of Medicare Advantage. But the CMS actuary report says 50 percent of seniors will lose their Medicare Advantage plans and for the other 50 percent, CBO said their benefits will be gutted an average of $816 per senior. How can we look at these seniors and tell them these are improvements? Last week, the administration taunted the tax incentives for small businesses and how it would provide relief to small firms. CBO says only 12 percent of businesses would see any relief at all, even with fewer eligible for the small tax credit and to get that full tax credit, you have 10 or less employees making an average of $25,000 or less. This leaves 88 percent of the entire small business workforce employed at a small firm that won’t get any tax credit at all.

I sent a letter to Chairman Pallone last week requesting a hearing on the impact on small business. We look forward to a response on that request in the near future. There was recently also a letter from Republicans on the committee, requesting a hearing with the CMS Actuary on the report. To my knowledge, we have not had a response. Could that have been on the schedule today? Can we, as members of this committee, honestly say these concerns in the public do not rise to the level of greater immediate importance? I am hopeful the committee will hold formal hearings. But we have asked on several occasions and our requests have been ignored.

Starting this afternoon at 1:00 p.m. in the Capitol Visitor’s Center, the Republican Healthcare Solution Group will hold its first of a series of forums on the new health reform law. Today, we will have expert witnesses testifying on the true cost of the health reform law, as cost estimates continue to rise for families, businesses, and taxpayers as a whole. Press has been invited. We will be webcasting and Tweeting live, as well as posting the video on the hearing online. I would encourage anyone interested in the impact of this government takeover of healthcare to contact any office on the Republican side for more details. With that, Mr. Chairman, thank you and I yield back my time.

[The prepared statement of Mr. Shimkus follows:]

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The {Chairman.} Thank you very much, Mr. Shimkus. I would like to talk about the necessary war in Iraq, the deficits that we are experienced because of unpaid for tax credits for the upper income, and other very bad decisions made by the Republican administration, but that is not what this is all about. We have another hearing scheduled. This is May, 2010. We are a number of months off from an election. Had this been made 2009, you might have heard the same story. Seems like campaigns go on forever--

Mr. {Shimkus.} Would the chairman yield for one second?

The {Chairman.} Sure.

Mr. {Shimkus.} Yeah, I remember in the Medicare debate, when you continued to push for the Actuary to have a hearing here, after the fact. We are just asking—I am just doing the same thing that you did when you were in the minority and I think that when the CMS Actuary has an opportunity to give us the real numbers and we have asked numerous times that, you know, we--and there is issues out there that we could fix. We should do that.

The {Chairman.} The gentleman and I--I would be pleased to discuss it with you further but I want to proceed with this--

Mr. {Shimkus.} Thank you, Mr. Chairman.

The {Chairman.} --hearing. Thank you for the points. Our witnesses today, Dr. J. Craig Venter is the president and founder of the J. Craig Venter Institute, the not-for-profit genomics research institute. He is also the founder and chief executive officer of Synthetic Genomics Incorporated.

Dr. Jay Keasling is a professor in the Department of Chemical Engineering and Bioengineering at the University of California Berkley. He is also acting deputy director of the Lawrence Berkley National Lab and chief executive officer of the DOE funded Joint BioEnergy Institute.

Dr. Drew Endy is an assistant professor in the Department of Bioengineering at Stanford University, president of the BioBricks Foundation and director of BioFab, the international open facility advancing biotechnology.

Dr. Gregory Kaebnick is a research scholar at The Hastings Center, a nonpartisan bioethics research institution. He is also editor of the Bioethics Journal, The Hastings Center report and Dr. Anthony Fauci is the director of the National Institute of Allergy and Infectious Diseases and the National Institutes of Health.

We are pleased to welcome all of you today at our hearing. It is the custom of all oversight hearings to ask that the witnesses testify under oath so I would like to ask if you would please rise and hold up your right hand.

[Witnesses sworn]

The {Chairman.} The record will indicate each of the witnesses answered in the affirmative. We are anxious to hear what you have to say. If you do want to comment on the health insurance plan adopted by the Congress, save that for another hearing. But we have got a lot of information that we want to learn about from you. Dr. Venter, why don’t we start with you?

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^TESTIMONY OF J. CRAIG VENTER, Ph.D., FOUNDER, CHAIRMAN AND PRESIDENT, J. CRAIG VENTER INSTITUTE; JAY D. KEASLING, Ph.D., ACTING DEPUTY DIRECTOR, LAWRENCE BERKLEY NATIONAL LABORATORY; DREW ENDY, Ph.D., ASSISTANT PROFESSOR, STANFORD UNIVERSITY, PRESIDENT, BIOBRICKS FOUNDATION; GREGORY E. KAEBNICK, Ph.D., EDITOR, HASTINGS CENTER REPORT, ASSOCIATE FOR PHILOSOPHICAL STUDIES, THE HASTINGS CENTER; AND ANTHONY S. FAUCI, M.D., NATIONAL INSTITUTE OF ALLERGY AND INFECTIOUS DISEASES, NATIONAL INSTITUTES OF HEALTH

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^TESTIMONY OF J. CRAIG VENTER

} Mr. {Venter.} Chairman Waxman, Mr. Barton, committee members, thank you for the opportunity to be here today. I will just make a few introductory comments to explain what it is we announced last week with our publication in science. We announced the first synthetic species. Its genome was read, encoded in the computer, as we have been doing since 1995. Now we have been able to reverse that process. We have been able to start with a digital code in the computer, four bottles of chemicals, and write the over one million letters of genetic code for this small microbe. We then were able to transplant that into a recipient cell. The synthetic

genome took over that cell and converted that cell into a new species. The only genome in that species is the synthetic genome. All the proteins there are made from that synthetic code and that is why we call it a synthetic cell. What it is not, it is not life from scratch. We used a living cell and converted it into a new cell, based on this synthetic genome. But it is the first cell to have its parent being a computer and this is the first, even though there has been a long trend, a real merging of the digital world and the biological world, we can now start in the digital computer and go out and write new software of life, the software's DNA.

This is a baby step, in our view. This is a proof of concept. This organism was not made for any other purpose, other than for the proof of concept. We have been working on this for 15 years, since we sequenced the first two genomes in history in 1995, trying to have the tools to understand a minimal cellular life. But over the course of that time, we have clearly become aware of other possibilities and uses for this powerful technology and we have been exploring that. I started, along with Hamilton Smith and two others, a new biotech company a few years back called Synthetic Genomics in La Joya, California, aimed to build on these new tools, these new technologies. One of our partners is Exxon Mobil. We are trying to look at algae to make new sources of

hydrocarbons that can go into the refineries, starting with carbon dioxide. We have seen, for this last month, a very visible reminder about oil coming out of the ground. We don’t see CO2 in the atmosphere but we can certainly see the oil on the water and the beaches in the Gulf.

I feel very strongly we need to wean ourselves off of oil. If we can start with carbon dioxide as the feed stock, it could be a tremendous advance. Looking at tens of thousands of species of algae, there is nothing out there that we found yet that has the power to get up to the billions of gallons of fuel that are needed. So the tools of molecular biology, the modern tools, including the ones we have just developed are going to be key to that success. We also see potentially next year’s flu vaccine could come from these tools that we developed, not from the synthetic cell but the ability to write the genetic code and we have funding from NIH, actually from Dr. Fauci’s institute, to start building the segments of all the flu viruses that we have been sequencing with funding from the NIH, we will have these on the shelf and we could very rapidly, we think in less than one day, build new vaccine candidates in contrast to the months that it currently takes. These could feed in. One of our partners is Novartis. They are building an NVCK cell facility that these new candidates could go into rapidly

producing vaccines. These are powerful tools that give us a new way to look at the world.

The last thing I will mention is we, I think almost unprecedented in science, asked for ethical review of this research before we did the first experiments. This was back in 1997. This was done at the University of Pennsylvania. They published our results in Science in 1999. We have had ongoing discussion, trying to drive the discussion. We have had funding from the Sloan Foundation, along with MIT. The reports have been published looking at the security. In fact, many of my colleagues here have been looking at these issues and driving them. So the scientists, I think, not only are being responsible, we are asking the questions before anybody else has.

We have worked with different administrations. In 2003, our early work was funded by the Department of Energy. The Secretary of Energy held a press conference with our announcement then of a synthetic virus. This work has been vetted in the past administration through the White House and came down on a side of open scientific publication, which I think is a real victory for science.

I have briefed the Administration and many members of Congress before our announcement. We think this is an important initial step in science, gives us some tools to go

a long way. So Mr. Chairman, Mr. Barton, committee members, if you will incorporate--I ask my statement get incorporated into the record and thank you for the opportunity.

[The prepared statement of Mr. Venter follows:]

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The {Chairman.} Thank you very much, Dr. Venter. By the way, all of your statements, all your prepared statements will be in the record in their entirety and I am going to run a clock and it will turn red when the time is up. But if you are in the middle of discussing something, you can go ahead and complete your thoughts. We are not going to run strictly by the clock but it is a way of giving us guidance.

Dr. Keasling, we want to hear from you.

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^TESTIMONY OF JAY D. KEASLING

} Mr. {Keasling.} Chairman Waxman, Ranking Member Barton, and distinguished members of the committee, thank you very much for holding this hearing and for inviting me to testify.

Synthetic biology is the engineering of biology with standardized, well characterized biological components, much like we might build a computer from various components, like a hard drive, a sound card, a video card, and a power supply. Using these standardized, well characterized components, synthetic biologists are making biological engineering more reliable, easier, and less expensive than with traditional genetic engineering techniques and the resulting engineered organisms will be safer. Not only will synthetic biology enable a host of important applications to solve societal problems, it will decrease the cost of doing biological research.

Federal funding has played an important role in the development of synthetic biology. The National Science Foundation has funded the Synthetic Biology Engineering Research Center, SynBERC, which brings together many of the pioneers of synthetic biology to create new biological components, set standards for connections between these

components, and demonstrate the use of these components in important applications.

SynBERC investigators are also steadying safety, security, preparedness, and ethics around this new field of synthetic biology to ensure that these powerful technologies are used safely and wisely.

One of the most important and well-known applications of synthetic biology has been our work on engineering yeast to produce the antimalarial drug, artemisinin. There are 300 to 500 million cases of malaria at any one time, with one to three million people dying every year of the disease. Ninety percent are children under the age of five. While traditional quinine-based drugs are no longer effective, plant derived artemisinin combination therapies are highly effective but cost prohibitive for much of the world. Soon artemisinin will be in short supply, which will mean that millions of children will die needlessly. To decrease the cost and increase the supply of artemisinin, we engineered brewer’s yeast to produce a precursor to the drug, by transferring into the yeast, the genes responsible for making the drug and the plant that makes it naturally. The resulting process for producing artemisinin is akin to brewing beer. The engineered yeast consumes sugar and secretes a precursor to artemisinin that can be readily

converted into the drug. Through funding from the Bill and Melinda Gates Foundation, we completed the science in three years, largely due to access to well characterized biological components. The microbial production process has been licensed to Sanofi Aventis and--which will scale the process and produce the drug in the next 2 years, selling it at cost in the developing world. We predict that this process, when fully implemented, will save a large fraction of the two million or so children who dies every year from malaria. Fortuitously, artemisinin is also a hydrocarbon, which is the fundamental building block of transportation fuels.

Through advances in synthetic biology, we can reengineer this artemisinin producing yeast to produce biofuels that will work within our existing transportation infrastructure. The Joint BioEnergy Institute in Emeryville, California, one of three DOE funded research--bioenergy research centers, is using the advances in synthetic biology to engineer microbes to transform sugars into--from cellulose and starch into hydrocarbon based biofuels that have the same quality of the fuels currently produced from petroleum. These new advanced biofuels will not require a change in our transportation infrastructure that would be necessary if ethanol were used as a pure fuel. In addition, these advanced biofuels will reduce the production of greenhouse gases, reduce our

dependence on foreign oil, and could reinvigorate the U.S. agriculture economy. I am from a farm, by the way.

My research is the foundation for two California-based advanced biofuel companies that are currently employing hundreds of people and in the next 2 years, they will have fuels out on the market. Very similar technologies are being used by JBEI to engineer plants to become efficient producers of cellulose, with minimal input of water and fertilizer. Indeed, the advances in synthetic biology will allow us to have plentiful food to feed the population and biomass for fuels.

Many other applications could benefit from advances in synthetic biology, including nitrogen fixing crops that do not need ammonia-based fertilizers, microbes engineered to produce all the chemicals currently produced from petroleum, and entirely new classes as drugs to fight cancer, infections of bacteria, and a host of other diseases.

I hope that my testimony has illustrated for you the remarkable potential of synthetic biology and important role that it has to play in our Nation’s research and innovative--innovation enterprise. Your actions in the support of Congress will determine whether the efforts described today are ultimately successful. This is a marathon, not a sprint, and requires consistent and continuous nurturing and case.

Finally, thank you for holding this important hearing and for inviting me to participate. Please let me know if I may be of any assistance. I am happy to answer any questions at the conclusion.

[The prepared statement of Mr. Keasling follows:]

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The {Chairman.} Thank you very much for your testimony. Dr. Endy?

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^TESTIMONY OF DREW ENDY

} Mr. {Endy.} Thank you and good morning, Chairman Waxman, Ranking Member Barton, and members of the committee. In addition to my professional appointments, let me note that I serve on the Committee of Science, Technology, and Law at the National Academies, have recently been nominated to the National Science Advisory Board for Biosecurity, and was an ad hoc member of the Recombinant DNA Advisory Committee as the biosafety guidelines were recently updated to account for advances in synthetic biology and other matters.

I thought I would start by introducing some of our own work. In 2005, my lab, then at MIT, published a redesign for the genome of a virus. We did not have access to the advanced DNA and genome synthesis tools that are bringing us here today and so the students in my lab spent the entirety of a research budget, about $200,000, struggling to build 12,000 base pairs of designer DNA, 12,000 letters. We made 600 changes to the virus genome, all at once, and we are very curious just to see if it would work.

To our great relief, the virus was capable of reproducing. Before you are alarmed, I will quickly note that the virus grew half as well as the natural isolate.

That was our first experience with synthetic biology and synthetic genomics.

Also at MIT, I was involved in the development of six new courses, comprising part of what is now the new undergraduate major in biological engineering. Imagine being a teenager, matriculating at MIT, and having the possibility of becoming a biological engineer, much like you might become an electrical engineer or chemical engineer. What would you expect to learn? Well, one of the things that came out of those six courses, under Randy Rettberg's leadership, is now known as iGEM. It is the International Genetically Engineered Machines competition. This is a worldwide event. It is akin to a genetic engineering Olympics for undergraduates and so now each summer, thousands of students at hundreds of universities around the world compete and work together to build engineered genetic systems that solve problems they define. For example, we have students engineering bacteria to detect pollutants in the environment and change colors so that people might more cheaply be able to find out where problems are.

As a third example, now at Stanford, my lab is struggling to implement data storage systems inside living cells. We basically want to be able to control a small amount of information, one, two, three, or four bits, inside

a yeast cell or inside a liver cell. We are not trying to replace computers. We are trying to bring computers into life so that we can act on information in places where we haven't been able to previously. For example, imagine being able to count how many times a cell has divided. That would let you study aging. It would let you begin to consider reprogramming aging. It would help to instrument cancer research and reprogram cancer or perhaps development in regenerative medicine applications.

In all of our work, we find ourselves speaking as an engineer to be very poor as engineers of biology. The genetic programs we write tend to be 10 or 20,000 base pairs or letters of DNA law. I would have no idea how to take advantage of a million base pair fragment of synthetic DNA today and quickly program up a thousand different genes and get it to do something useful.

As it has been mentioned previously, the needs of the engineering community and the scientific community to get better at putting together the pieces of DNA and the pieces of biology to solve useful problems, will be a formidable basic research challenge for decades.

Let me turn briefly to issues of bioenergy and the national policy around bioenergy. I want to make one point quite quickly that I think is an old story and in the

excitement around bioenergy, it might have been short stepped. Here is my favorite bioenergy application. In 1980, researchers figured out that you could improve laundry detergents for treating stains on clothing by using enzymes, adapted to function at cold water wash temperatures. This was an early genetic engineering project. The impact of widespread deployment of this enzyme throughout the Nation is to reduce the need for domestic hot water heating. The estimate in 1980 was the reduction in oil equivalent was about 100,000 barrels a day. One enzyme integrated upstream into our daily lives can have a net energy impact of 100,000 barrels of oil a day. I hope that is greater than the current spill in the Gulf of Mexico and if you look at biofuels as a complement to this, which are individually and independently important, 100,000 barrels of oil a day might be 100 to 200,000 acres of cropland or about 1/2000th of our cropland. So the point I would simply like to note here is as we have forward to bioenergy investments, in addition to biofuels, I would urge us to consider how future applications of biotechnology could be more directly integrated into our daily lives and upstream existence in ways that are responsible.

In the brief time I have left, let me note that I think the tools that bring us here today around genome construction

raise a number of specific issues having to do with safety, security, and property rights. I will not go into those in detail here but would welcome questions on the matter. Thank you.

[The prepared statement of Mr. Endy follows:]

********** INSERT 3 **********

The {Chairman.} Thank you very much. Dr. Kaebnick?

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^TESTIMONY OF GREGORY E. KAEBNICK

} Mr. {Kaebnick.} Mr. Chairman, Ranking Member Barton, and--

The {Chairman.} There is a button on the base of the mic, yeah.

Mr. {Kaebnick.} There we go.

The {Chairman.} Good.

Mr. {Kaebnick.} Mr. Chairman, Ranking Member Barton, and distinguished members of the committee, thank you for inviting me here and for bringing attention to the ethical issues of this field. My name is Greg Kaebnick, I am a research scholar at The Hastings Center, nonpartisan, nonprofit, non--independent research institute that studies ethical issues in medicine and the biological sciences, editor of one of our journal, The Hastings Center Report. We are now in a 2-year project funded by the Alfred P. Sloan Foundation to investigate the ethical issues of synthetic biology.

What I want to do this morning is just to set synthetic biology within a widely used framework for we are thinking about ethics of biotechnologies and then comment very briefly on its governance.

The ethical issues fall into two broad categories. First are intrinsic concerns, as they are called, which are about whether the science is good bad in and of itself, aside from consequences. Many people have an intrinsic objection to cloning human beings, for example. They just feel it is wrong to do full stop.

The second category involves concerns about potential consequences, risk and benefits for example. The classic intrinsic concerns about synthetic biology are that scientists are playing God, as people often say, or that life is something more than just a soup of interacting chemicals that we can see in a microscope, maybe something sacred, and scientists are overstepping their bounds in creating it.

You might worry also that synthetic biology will undermine the moral value of life, even if you don’t believe that life is something more than interacting chemicals. I think beliefs about the specialness of life or the sacredness of life, for those who put it that way, are not undercut by this science. We are just talking about microbes at this point. More importantly, whatever value we do attach to microbial life, we can also find in the life of a synthesized microbe as well.

Yet another possible intrinsic objection to synthetic biology is environmentalists. We might think that it is an

intrinsically undesirable intrusion into nature. Of course, even environmentalists accept that forests may sometimes be logged, so there is a question of balance here, a question of where to draw the line. If synthetic biology turned out to be beneficial to the environment, many environmentalists, myself included, would find it attractive.

Intrinsic moral concerns are important and can be important for policy, but in the case of synthetic biology as it now stands, I do not think they point the way toward regulation. I think the field should be judged and governed on the basis of the second category of moral concerns, the consequences. The field holds significant promise of benefit. There are also, however, morally serious risks. First, there are concerns about justice. Some worry that synthetic biology could be such a powerful way of making and distributing goods, that if we aren’t careful about how it is used, the benefits from it, who owns it, there could be long-term social and environmental harms.

Two other kinds of concern are about possible physical dangers. There are concerns about accidents, organisms escaping and running amuck, and about deliberate misuse. I once heard a microbiologist say that he was very enthusiastic about synthetic biology and the only thing that worries him is the possibility of catastrophe.

Synthetic biology aims at simplicity and control. One of the themes of traditional biology though is that living things usually turn out to be more complex than we thought. I believe we should guard against an overconfidence that we understand the risks of this field. We should not assume that synthetic organisms will shed the unpredictability. Inherent life tends to find a way, so might artificial life.

I would not at all call for a general moratorium on the work. I would offer some broad recommendations for how to proceed. We need, I think, first, more study of the emergence plausibility and impact of potential risks. Second, a strategy for studying the risks that brings together different disciplines and perspectives. Third, a strategy that is grounded in good science, not sheer speculation, but is flexible enough to look for the unexpected. And fourth, an analysis of whether our current regulatory framework is adequate and we should also continue the conversation about ethics.

Thank you for this opportunity to share my thoughts.

[The prepared statement of Mr. Kaebnick follows:]

********** INSERT 4 **********

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The {Chairman.} Thank you very much, Dr. Gaebnick. Dr. Fauci?

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^TESTIMONY OF ANTHONY S. FAUCI

} Dr. {Fauci.} Thank you, Mr. Chairman, Ranking Member Barton, members of the committee.

The {Chairman.} Is your mic on?

Dr. {Fauci.} Yes, it is.

The {Chairman.} Okay.

Dr. {Fauci.} Thank you for the opportunity to discuss with you for a couple of minutes and certainly answer any questions that you would like on the role of the NIH in genome research and related research activities.

[Slide]

I have here on the first visual that you could see on the screen that this is an enervative process that has been going on with NIH support in the arena of recombinant DNA technology and genomics for decades. It has everything and even things that I have recently testified before a subcommittee of this committee on, everything from the sequencing of the human genome to the sequencing of thousands of viruses and over a thousand bacteria and other microbes. Just a couple of weeks ago, we had a hearing here, shared by Mr. Pallone, Chairman Pallone, on antibiotic resistance and we spoke of the power of the tools of sequencing and

recombinant DNA technology. Also, we are studying the mind microbiome, which is the flora that is contained in the human body and how it relates to both health and disease. Also, the whole arena of recombinant DNA technology, the fundamental basic and applied researched that emanated from that, largely with support from the NIH, has actually resulted in a transformation of the field of the biotech industry and all of the very good things that have occurred regarding drugs and vaccines that you have already heard of, as well as a variety of other issues related to this.

[Slide]

On the second visual, it is very interesting. I did a search just a couple of days ago and I just plugged into Pubmed three components, recombinant DNA, technology, genome or genomics and it turns out that almost 800,000 papers have been published on this so we are not talking about a field that was born yesterday. As you have heard from Dr. Venter, he has been working on this for decades.

[Slide]

So if you go over to the next visual, I think this is important and might explain it. It is really a continuum. Synthetic biology is a continuum of a process of understanding genes and genomics that has been going on for a very long time. First, the sequencing or finding out the

natural blueprint of a genome from nature. Then there was synthesis of fragments of that, genome segments or genes themselves, again, from naturally occurring blueprints, and there came the insertion of genes, either splicing out from one and putting it into another or synthesizing little fragments and putting it into a vector that can have that particular microbe or whatever do what you would like it to do, like produce insulin or human growth hormone or what have you. What you have heard today, and will hear during the question period, is the synthesis of whole genome from a naturally occurring blueprint. The next step being, and this is going to be very, very difficult, how you can synthesize genes and genome and circuits that are really novel, that can make them de novo do what you want them to do. So it really is a continuum over many years.

I won’t dwell on what was already said by several of the panelists. The extraordinary potential good applications of synthetic biology, related from everything from the environment to energy to agriculture and to the area that I and my institution are most interested in, is medicine and health. Dr. Kaebnick gave you a very nice summary of some of the ethical concerns and how he feels confident that we are on the right track here. Let me give you some specifics about that.

[Slide]

If you go to this next visual here, there are a number of areas of review and oversight that really have followed along very nicely the history of the emerging field of recombinant DNA technology. When scientists first realized the power of the tools of recombinant DNA technology, they themselves did what we call self-scrutiny and self-policing. They got together and what was born of that is what we know now of the Recombinant DNA Advisory Committee or the RAC, which is housed at NIH, which sets forth the guidelines for the use of these technologies. In 2003, Dr. Venter, in a very transparent way, brought before us, we had DOE funding at the time and he came to me and others to talk about what the best approach would be, at the time that he had synthesized a virus, a much smaller microbe than what he has just done now, and out of that came the birth of what is now known as the National Science Advisory Board for BioSecurity, or NSABB, which is also housed at the NIH, which is involved in the same sort of philosophical approach as the RAC. A lot of overlap and inter-digitation there, but also concerned not only about biosafety, but about biosecurity. We can talk a bit in the question period about what is also going on about how we are going to bring into the arena of synthetic biology, the reviews and the oversights that we have had for

the pre-synthetic era, namely just the sequencing and recombinant DNA technology era.

You have also heard and you mentioned in your own statement, Mr. Chairman, that President Obama, on the 20th of May, has asked his commission for the study of bioethical issues, to examine this, and within 6 months to come back to him with a report of anything that might need to be done.

[Slide]

And on this last visual, I just want to tell you how I think everyone at this table thinks. What these guidelines have really established, not only for the people with government funding, in which you have some sort of a stick that you can make sure these guidelines are followed, but also it has created in the field what we call a culture of responsibility, namely to get the people involved in doing this work to realize and to understand that even when you are trying to do something good, you have got to be very careful, careful about the safety of the people that are working with you and careful about the security of what others might use in a nefarious way. So I have shown here on this, it really is a balance, the balance of fostering and enabling scientific research and innovation with some extraordinary potential, as you have heard from the other witnesses, with making sure, according to the guidelines that I just

mentioned, that we do prevent the dangerous uses of this technology.

I would be happy to answer any questions. Thank you.

[The prepared statement of Dr. Fauci follows:]

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The {Chairman.} Thank you very much for your testimony. I am going to now recognize members for 5 minute intervals to ask questions. I will start with myself.

Dr. Venter, this is a remarkable advance for science. You have described it as the software of life. I know at one point you said it was a computer created life and some of the writers about your announcement almost acted as if this is the creation of Frankenstein. Now to put it in perspective, without in any way diminishing what you achieved, the--you had to have a life to build on. You didn’t develop a life from scratch. Isn’t that right?

Mr. {Venter.} That is absolutely correct. We, as Dr. Fauci said, we copied basically a genome of known organism. As Mr. Barton said, a goat pathogen, but we removed 14 genes that according to the scientific letter chart result of that--control its pathogenicities, so we have changed it so it is no longer a goat pathogen. But if you think about doing the very first experiment, we had to start with a control--something that would work. If we went to the bottom phase of Dr. Fauci’s slide of trying to design something new, the odds are pretty low that it would have worked. Ninety-nine out of 100 of our experiments failed. Even with one error out of a million in the genetic code, we did not get life. So we

copied life and we used a living cell to boot up that life. So it is, as all life on this planet, it has been life out of life. It is not new life from scratch.

The {Chairman.} And as I understand it, the genome for this bacteria is about a million base pairs they use to make up strands of DNA. If we compare that with a human being, we are talking about one million to around three billion. Is that correct?

Mr. {Venter.} Well, sir we have--if we count the genome components from both our parents, we have six billion letters in our genetic code. If you were looking under a microscope and you could see the human chromosomes, the piece we just made would be so small as to be invisible. So it is a gargantuan leap from what we did to anything in human beings.

The {Chairman.} So people who are worried about human beings being created should relax. But meanwhile, this is a very dramatic and important step and I want to ask you more about the potential for this--for these technologies to improve health and healthcare. We are always concerned about vaccines, whether it is a vaccine for influenza or HIV. Let me just ask you about the flu vaccine first. There have been problems with using chicken eggs to make flu vaccine. It is a long, labor intensive process and the flu virus is changing and it is hard to keep up with it. Does your innovation add

to the cell-based technology for influenza vaccine production and what can you project for us in the future there?

Mr. {Venter.} Yes, in fact, it provides a new front end for the cell-based technology. So with these fragments that we are going to be building with NIH funding, if as we saw with H1N1, we are sequencing and tracking all these viruses, we can in 24 hours or less, with the hands of Dan Gibson sitting behind me, reconstruct new vaccine candidates that could go immediately into these cell systems for testing. So it would eliminate at least three months, possibly more. But there are other potential advantages because now we can synthesize so many different pieces. Diseases that we have not been able to get good vaccines against, such as HIV, such as the common cold, because the virus mutates so quickly, at least the hypothetical possibility exists to make sufficient antigen components to cover a wide range in a single injection, perhaps just getting a flu shot once a decade instead of once a year.

The {Chairman.} Well, HIV is a major concern and Dr. Fauci and I have been dealing with each other on that for decades now. What--tell me more about your thinking of a possible vaccine potential using this technology. How does it get us closer to accomplishing that goal?

Mr. {Venter.} Well, I might defer to Dr. Fauci on that-

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The {Chairman.} Okay.

Mr. {Venter.} --he is the world's expert on HIV but I think the rapid mutation of the virus is what, from my understanding, has made it--once you make a vaccine, the virus just moves on beyond it.

The {Chairman.} Dr. Fauci, you want to add anything here?

Dr. {Fauci.} Yeah, it is a bit more complicated with HIV, Mr. Chairman, because what Dr. Venter was describing for influenza was being able to synthesize essentially all the possible prime mutations of--you know, when we make an influenza vaccine, we make it against mostly the hemagglutinin and that is how, you know, H3N2, H2N1, H1N1, H stands for the hemagglutinin and if you are able to synthesize fragments and get, just by computational biology, you get all the possible prime mutations, you can get a head start of having those things all ready to go in a vector that you might use recombinant DNA technology to get that off the shelf more rapidly because you know what the antigen is in influenza. You don't need to synthesize a whole genome. You could just synthesize all of the possible components that you want the body to make an immune response. So it could save time when you make the initial assessment of what kind of

vaccine you want and then you could just jump right into it because you already have it in the computer on the shelf. HIV is a different story because we don’t even know yet what the particular protein antigen or on the envelope of that virus is that is going to induce protection. But when we do, and as you mentioned, we have testified a lot about the difficulties and that when we do, I think some of the technologies might help in being able to get an entire array of confirmations already predetermined by synthesizing them. But it is not ready for that now because we still don’t know what the particular component of that virus induces the immune response that we want.

The {Chairman.} Okay. Thank you very much. Mr. Barton?

Mr. {Barton.} Thank you, Mr. Chairman. I am not sure I am competent to ask questions in this field. It is obviously a huge intellectual challenge and a real accomplishment but the non-biologic mind of mine, I am a little bit overwhelmed by it. I will say though before I start asking questions and I kind of like the traditional way of making human beings. It is fun and it is recreational, therapeutic, and there are a lot of positives and you have these little babies that you get to let your wife raise. I mean, it is a fun thing. I am trying to understand the significance of what has transpired.

Dr. Venter, what your group did, is there--you did something by create--putting things together that in and of themselves had no life but you were able to put them together so that there was life? I mean, what is it that you have accomplished that was not accomplished before you accomplished it? What is the, in layman's terms, what has transpired that is a real leap forward?

Mr. {Venter.} Well, let me first assure you we do not want to replace any of those human processes. I am a fan of them myself.

Mr. {Barton.} I am--we are of like mind on that.

Mr. {Venter.} So probably the best way to describe what we did, it provides a new understanding of life. When we look at these tiny microbial cells, any photographs of them, like anything we see in life, look like a fixed entity. But what is happening second to second is that genetic code is being read, making new proteins. There is turnover of these proteins. So it is a dynamic system constantly working. DNA is the software of life. If you take out the genetic code, the cell dies very quickly. That would happen to us as well. That is why radiation damage is so damaging to us. If we put in new genetic code, that cell starts reading the new genetic code, starts making new proteins and converts that cell into another species. I mean, it is the basis of life at the most

dramatic level.

Mr. {Barton.} Well, what did you do differently or uniquely that all these other gentlemen are patting you on the back for and saying way to go? You did--

Mr. {Venter.} We started with the computer and wrote new genetic codes, starting with four bottles of chemicals. So--

Mr. {Barton.} So you created that? I mean, you put together a genetic code that didn’t exist in life, in the real world?

Mr. {Venter.} It was largely copied off the living goat pathogen but we modified it substantially. There are 46 names written in the genetic code. It is the first species with its own website built into its genetic code. There are some quotations from literature and we eliminated the 14 genes associated with pathogens--

Mr. {Barton.} And that had not been done before?

Mr. {Venter.} That has never been done before.

Mr. {Barton.} Okay. And now that you have done it--

Mr. {Venter.} I actually did that in the cell, converting it into a new cell. Now the only genetic code in that cell is this synthetic molecule that we made and all the proteins, all the characteristics of that cell are driven from this synthetic DNA molecule. It is self-replicating.

It is a real cell. It is not an artificial cell--

Mr. {Barton.} But it is a cell that did not exist before--

Mr. {Venter.} That is correct.

Mr. {Barton.} --the new variety.

Mr. {Venter.} The new variety is a great description.

Mr. {Barton.} Okay. All right. Now what you did, is it proprietary? Is it patentable or is it universal knowledge that anybody can take advantage of?

Mr. {Venter.} It is all of those.

Mr. {Barton.} It is all of those.

Mr. {Venter.} We published our paper in the Journal of Science. It is open in the scientific literature. Synthetics genomics that funded this work has also filed for patent applications on it. As you know, there has been a recent debate about whether naturally occurring DNA is patentable. All that goes back several decades to the Chakrabarty decision of the Supreme Court, saying that life forms are patentable. This is clearly the first life form totally developed out of a computer and by humans, so it is much closer to a human invention.

Mr. {Barton.} Okay. Now best case, what is the best thing in a practical layman’s understandable sense that could come out of what you did? If you would--a cure for cancer--

could a cure for Alzheimer's, a cure for congressional ineptitude of solving the budget deficit? I mean--

Mr. {Venter.} Now we are looking for miracles.

Mr. {Barton.} Well, why not? Why not?

Mr. {Venter.} So let me say in with the work of my colleagues, as well, I liken this to the early days of the electronics industry, where we have a number of design components and I viewed now the 40 million genes, most of which have been discovered by my institute, as design components for the future and I do not think we can imagine all the discoveries. Some of the students in Drew's classes come up with amazing little circuits out of biology. I hope in terms of our own work the immediate applications.

We are trying to do it synthetic genomics, is for example, with Exxon, see if we can capture back substantial amounts of carbon dioxide and convert it into new hydrocarbons that could go into refinery to replace taking oil out of the ground. I would be totally satisfied if that is our only accomplishment.

Mr. {Barton.} I know my time has expired but I want to ask Dr. Fauci a question, if I could. What is the biggest ethical challenge from a regulatory or a moral standpoint to what Dr. Venter has discovered or accomplished?

Dr. {Fauci.} Well, at this point, when you are dealing

with microbes, I think the ethical challenge is probably in the field mostly of safety and security that someone does not use this technology in a nefarious manner. When you leapfrog ahead and I think that the chairman asked a question and Dr. Venter answered it appropriately, you are talking about a microbe. You are not talking about creating the human being. But for the present time, it is to make sure that the balance of benefit for humanity in the areas that I mentioned in my testimony, agriculture, medicine, energy, et cetera, clearly weigh very, very heavily down and we do all the things appropriately and in an iterative process, Mr. Barton, to look at implications and that was the reason why the President himself, in his letter of May 20, to the Commission on Bioethics said I want you to look into this and in an open, transparent discussion figure out what the implications of this might be.

Mr. {Barton.} Okay. Well, thank you, panel and thank you, Mr. Chairman. I do hope they discover a way to create a synthetic genome that would predispose folks to vote Republican. If they can work on that, I will support you funding that research to try that on a practical application basis. Thank you.

The {Chairman.} Thank you, Mr. Barton.

Mr. Pallone?

Mr. {Pallone.} Mr. Barton's comment there kind of intrigued me because I think that you cannot really program somebody to be political or not.

Mr. {Barton.} You can try.

Mr. {Pallone.} You can? All right. Well, whatever.

I wanted to follow up on Dr. Fauci. When you talk about the nefarious aspect of this and obviously there is some concern about that and you mentioned it in your testimony too, and of course, we think about, you know, weapons of mass destructive and you know, that type of thing. This committee oversees the select agent program at the Centers for Disease Control, which oversees the handling of many biological agents and the concern is that the genetic instructions for these agents are not themselves under the prevue of this program. Nightmare scenario, for example, is if someone orders parts of DNA for a biological agent, such as smallpox from five--four to five different DNA segment manufacturers, reassembles them, and creates a weapon of mass destruction, how do we safeguard to insure that that scenario doesn't develop?

Dr. {Fauci.} Thank you for that question. That is an excellent question and in anticipation of the era of synthetic biology, you know that the CDC, when someone wants to get a select agent to work with, they have to go through

some very, very strict scrutiny, and as you appropriately pointed out, if people can order from a company a genome segment, not the whole organism, if they have the technological capability, they may be to theoretically put it together, though that is really a stretch because we have Dr. Venter, who took years and years and years to do that. But in any event, if they wanted to do that, what has happened now is that the NSABB, that I mentioned to you in one of the safeguards and the areas of review and oversight, recommended to the Department of Health and Human Services to have what is called a voluntary approach on the part of the companies that make these segments. So you would get on the phone and order I would like an X-length segment of a particular sequence, that if it has to do with something that could be related to a select agent, that the person would be queried as to who you are, what your qualifications are, where you work, what you intend to do with that. To develop a consciousness of that, you don’t want to be giving these segments out to anybody. That has been put in the federal register on November the 27th of 2009 for public comment and it is in the process now of reviewing for what particular action will be taken in that. So in anticipation of this, that has been going on.

Mr. {Pallone.} Is there anything else that could be

used to safeguard against, you know, that scenario other than the guidance that you mentioned? Are there any other precautions that could be taken?

Dr. {Fauci.} You know, I--yes, but let me answer that question, Mr. Pallone, in a way that I think some people get a little bit confused about the balance between what can be done good and what can be done bad. Right now, microbes themselves, in their own evolutionary capacity to mutate, to change when you try and treat, to have someone manipulate, without even going near synthetic biology, the possibility of doing really bad things exists. The bad guys are not going to listen to any rules. They are going to do what they want. They do not even need this technology. So this technology has a much greater applicability to doing something really good because this type of technology doesn’t exist to do--for example, you have heard of some of the things that could be done. There is not a microbe out there saying you know what I am really waiting to do, mutate myself so I could make billions of gallons of fuel. But there are a lot of microbes that are already out there mutating, that anybody can manipulate.

Mr. {Pallone.} So you are--if you know, again, I am trying to understand you as best I can, you are saying that this new technology really doesn’t add much to the ability to

do bad stuff. It is--

Dr. {Fauci.} I--

Mr. {Pallone.} That is pretty much already out there.

Dr. {Fauci.} Overall, Mr. Pallone, the answer is I agree with that statement. It adds much more to what can be done in a positive sense than it pushes the envelope of what you can do in the bad sense. Because there are already enough things existing out there that if people with nefarious motives wanted to do it, they could do it. They do not need synthetic biology to do it.

Mr. {Pallone.} Okay. Well, that is very valuable. Thank you. Thank you, Mr. Chairman.

The {Chairman.} Thank you, Mr. Pallone.

Mr. Pitts?

Mr. {Pitts.} Did he say me? Thank you, Mr. Chairman. Dr. Fauci, did you say there are NIH guidelines that apply to research on synthetic biology?

Dr. {Fauci.} Thank you for that question. Right now, the current guidelines that emanate out of the RAC or the Recombinant DNA Advisory Committee and the NSABB do not currently involve synthetic biology. However, because of the anticipation of what we are talking about here today, the Recombinant DNA Advisory Committee put out for public comment guidelines that they are proposing would apply to synthetic

biology.

Mr. {Pitts.} All right.

Dr. {Fauci.} That has been out for public comment. The comments are in. They are being analyzed and we anticipate in June of this year that the guidelines will be revised.

Mr. {Pitts.} And would these guidelines apply only to institutions that accept federal funding?

Dr. {Fauci.} As with the Recombinant DNA Advisory Committee, with regard to what you can do about it, mainly withdraw federal funding, the stick part of that applies to organizations that receive federal funding. But I want to reiterate what I said in my opening statement, that the guidelines of the Recombinant DNA Advisory Committee have created in institutions not only in the United States, but throughout the world, private industry or what have you, a culture of responsibility so that even though the government cannot withdraw funds, when people out there work with these technologies, it is almost unheard of to not adhere to the guidelines of the recombinant DNA technology. So over decades, it has created what we call a culture of responsibility.

Mr. {Pitts.} But there are no other federal biosafety guidelines that would apply to other people that use the technology?

Dr. {Fauci.} There are guidelines that they use, but there is no enforcement in the sense of a private industry deciding they may want to do that. But we have now over three decades of experience of the private industry adhering very, very closely to the recombinant DNA guidelines.

Mr. {Pitts.} Okay. Dr. Venter, now can synthetic genomes replicate, did you say?

Mr. {Venter.} So the cell that I made or that our team made is self-replicated and is replicated over a billion times--

Mr. {Pitts.} And--

Mr. {Venter.} --that is part of the definition of life.

Mr. {Pitts.} --is there the potential to replicate a synthetic genome in a transplantable organ?

Mr. {Venter.} I am not sure I understand the question.

Mr. {Pitts.} You can--you can implant this into a transplantable organ?

Mr. {Venter.} The cell that we made only grows in the laboratory and in extremely rich media. This species was initially confined to goats and occasionally to sheep as sort of a commensal organism. It doesn’t grow in human tissue and with the modifications we made, we don’t think it will grow outside of the laboratory in any form. But we have not tested it in animals yet.

Mr. {Pitts.} How far away do you think we are from that scenario?

Mr. {Venter.} From the scenario of microbes growing in a transplantable organ?

Mr. {Pitts.} Yeah.

Mr. {Venter.} Well, one of the studies that was published in the same issue of Science and Dr. Fauci referred to it of what we doing with the microbiome project, you have 200 trillion microbes on your body and in your body right now and you only have a 100 trillion human cells. So it is pretty hard to get any human tissue anything that is not contaminated with a wide range of microbes. We live in a microbial environment. Synthetic genomics offers nothing new there at all.

Mr. {Pitts.} Okay. Now as far as the possible misuse of the technology was raised using to create a disease or weapon of mass destruction. What type of restraint is there in the regulatory field or out there that would prevent that? Anyone can respond.

Mr. {Venter.} I will defer to Dr. Fauci or somebody else.

Dr. {Fauci.} Yes, thank you for that question. I actually went over it but I would happy to briefly review it.

There are guidelines for anyone who receives federal

funding that need to be adhered to from both a biosafety and most recently, with the new boards that we have for biosecurity and bio-assurity. The guidelines themselves are enforceable by the withdrawal of federal funding. However, it has been our uniform experience, that even those organizations that do not take any federal funding, when they do work in the area of recombinant DNA technology, and remember this synthetic biology that we are talking about today is not a technique that is out there for everyone to use. It took Dr. Venter many, many years to get to the point where we are today is that even if you stick just with recombinant DNA technology, that even those who don’t have the federal funding have over the decades uniformly adhered to those guidelines.

If you talk about bad people wanting to do bad things, guidelines don’t stop them. So if someone wants to use the technology that is available widely to try and engineer a microbe to be resistant to a particular drug, they are going to do that in a nefarious, secretive way that a guideline would not at all have anything--any deterrence on that. So the issue that we try to do is to make sure that since these technologies can do so much good, to make sure that people don’t inadvertently, mistakenly, accidentally do something bad and that is what the guidelines are for, for the people

with the expertise with the people who are trying to do very good things with them don’t inadvertently hurt themselves, others, or create something that they wish they did not create. But when you are talking about what kinds of--beyond guidelines, what kind of enforcement do we have, the people who are going to break that are not going to be out there publicly looking to be enforced. It is going to be in a manner that is nefarious and secretive.

The {Chairman.} Thank you, Mr. Pitts.

Mr. {Pitts.} Thank you.

The {Chairman.} Ms. Eshoo?

Ms. {Eshoo.} Mr. Chairman, thank you for holding this hearing. We go to many hearings and some have a feeling of drudgery to them and there are other adjectives that one--that come to mind. This is really stunning and I am very, very grateful to each one of you for being here today and what you are doing is extraordinary. Thank you, Dr. Endy, for coming. Dr. Endy is, as he said, is from Stanford University, which I am so proud to represent. Lawrence Livermore is here. You really represent, I think, the genius of the country in this area and Dr. Fauci, you always honor us with your presence and your knowledge. I can’t help but think that in the 20th century that it was marked by the advances that we made in the physical sciences and that what

you are presenting here today is that the 21st century that America will be know or can be known for the mark that we will make in the life sciences. So I thank you for the work that you are doing. I think it is stunning. I think it is hopeful and as I try to bring together, you know, the whole issue of synthetics biology, in many ways, it is a description of what goes on in my district because it is a combination of the engineering of the high technology and the biology and again, I think it is not only stunning, I think it is exciting. What I would like to learn from you are what--how far off some of the practical applications of this--of synthetic biology is. The committee has spent some time, of course, we were--spent a lot of time on H1N1 and how it would be handled and the whole issue of--you know, the problems of using chicken eggs and the time that, you know, that the process is long and labor intensive. So we worked hard to ensure the development of the cell-based alternatives that would then be used to reduce production time by weeks. So Dr. Venter, I would like to know from you or maybe you can help us by answering the following question. How does your innovation add to these cell-based technologies for influenza vaccine production?

Mr. {Venter.} Well, thank you very much for your question and your kind comments.

Ms. {Eshoo.} Thank you.

Mr. {Venter.} It is an exciting time in this field. So the ability to now write the genetic code, to actually build DNA fragments and put them together to make larger pieces gives us the ability to reconstitute small things, like the influenza virus, very quickly. So as Dr. Fauci said, with H1N1, there was a variation and the H and the N genes that created a new biological response, we think with these new techniques in less than 24 hours if, as soon as a new virus was detected, we could have new candidates out there that could go into, for example, the new facility that Novartis has built, based on cell lines to much more rapidly and reproducibly produce vaccines that we are in the process of testing that this year and if it is successful, the flu vaccine you get next year could be a result of these new technologies.

Ms. {Eshoo.} That is exciting. I wish I had an hour to ask you questions but let me ask this of the entire panel, and that is, what recommendations do you have to the Congress on what we should be doing to facilitate the use of synthetic biology in the development of innovative and affordable drugs?

Mr. {Venter.} Well, if I can start, I think it is an excellent question. As I said, we probably can’t even

imagine all the ideas. When I talk to students, I tell them we are primarily limited now by our imaginations. We need to make sure that is a primary limitation as our imaginations develop in these new areas going forward. I think it is a very exciting time that could influence almost every aspect of human life and we want to drive that forward. We want to prevent frivolous uses. It would be tragic if somebody could call in to one of these companies and order Ebola virus via the--just to inadvertently make something to cause trouble and I think the guidelines coming out of NIH are a great step in the direction to prohibit these frivolous uses. So--

Mr. {Keasling.} I would like to put a plug in for basic science and foundation of research so a lot of the technologies that we have developed in the applications are based on basic science and funding for basic science. So it continued funding for basic science, I think is an important step in supporting synthetic biology. I would also like to compare and contrast the ease of funding research that is application based versus foundational based. A lot of my work is application based so it was relatively easy to get funding for production of biofuels or for production even of an antimalarial drug for Bill and Melinda Gates Foundation. Much more difficult is to get funding for foundational work, such as the funding we are getting from the National Science

Foundation for the Synthetic Biology and Engineering Research Center. This allows us to develop the tools and the technologies so that they are available to any number of problems that might come up. So funding for foundational research, I think, is incredibly important.

Ms. {Eshoo.} Thank you.

Mr. {Kaebnick.} I wonder if you could imagine a hearing around 1952 with John von Neumann and his team of early computer engineers and asking the same sorts of questions. What should we be doing now to fund the applications in computing that will lead to Silicon Valley? So let us move to today. Well, what should we be doing now to fund the future of Silicon Valley, which might also become known as Carbon, Nitrous, and Phosphorus Valley, the elements that comprise life? And it is not, as Dr. Keasling and Venter are saying, only driven by the applications. It is the investment in the basic tools.

Let me give you one very specific example. Consider the manufacturing of silicon wafers, upon which microprocessors are built. Think of the public and private investments over decades, just in getting better at building silicon wafers and how the entire computing and information technology industries are based upon those foundational investments.

Now let us consider synthetic biology. All of synthetic

biology genomics depends on being able to synthesize and construct genetic material, the information and coding molecule that defines life. What is our national strategic initiative at getting better at building DNA? We don't have one. Arguably, you could make the case that genetic material is at least as important as doped silicon going into a computer. So one specific recommendation I add to just basic funding is to look at core strategic priorities that could define the tool kit, powering the next generation of biotechnology, such as a national strategic DNA synthesis and construction initiative.

Ms. {Eshoo.} Thank you very much.

Dr. {Fauci.} Well, thank you for that question, Ms. Eshoo. I would think the committee, at least from a historical standpoint, has been extraordinarily supportive of what we do at NIH. I have testified before this committee many times and its subcommittees and the only thing I ask of you is to continue to do what you do. We will be transparent with you. Do not overregulate something that needs care and responsibility and integrity and work with us in making sure we lay the foundation that that transparency, integrity and responsibility are there. We will try our best but we really rely very much on your support that you have given us over so many years. So thank you for that.

Ms. {Eshoo.} Thank you.

The {Chairman.} Thank you, Ms. Eshoo.

Ms. {Eshoo.} Thank you for each of you--thank you, Mr. Chairman.

The {Chairman.} Dr. Burgess?

Dr. {Burgess.} Thank you, Mr. Chairman. While there is so many places to go, Dr. Venter, let me just ask you. I think the question that Mr. Pitts was trying to pose to you is would it be possible utilizing your techniques to grow a new pancreas or a pancreatic cell that then could be given to a person with diabetes?

Mr. {Venter.} Well, thank you for the question. I am sorry I did not understand that.

Dr. {Burgess.} Well, perhaps not that specifically but, as an end--as a goal, with your basic science applied to say the treatment of diabetes, would it be possible to bioengineer, for you to build the software, the lab, that would create a cell that could produce insulin when it was given to a person and have it perhaps reside at their liver and take over the function of a failed pancreas?

Mr. {Venter.} Well, it is an excellent question. In fact, the production of insulin was one of the very first biotech products, once these early techniques were developed at Stanford and University of California, San Francisco, to

start producing human insulin genetically. People are working on a variety of genetic circuits to see if small units could be built, where you would have the appropriate regulation. People have been doing this electronically. I think this opens the avenue to do genetically.

Dr. {Burgess.} Well, correct, because then you have all of the cellular mediators of insulin response and you wouldn’t have to rely upon some of sort outside electronic mediated response if you could actually grow a pancreatic with the antigenicity that would duplicate the person who was receiving it.

Mr. {Venter.} But make--let me make it clear. It is not growing a pancreatic cell. It would be making a small circuit that could work maybe within one of those cells--

Dr. {Burgess.} Well, let me ask you this--

Mr. {Venter.} --they are so many decades, maybe centuries away from reproducing a human cell--

Dr. {Burgess.} Now wait a minute. Fifteen years ago, in 1995, if someone said how long will it take you to get your computer to make a goat virus with your name and address imprinted into it and all the pathogens removed, what would you have estimated as the timeline there?

Mr. {Venter.} I actually thought it was going to be a whole lot faster. We feel bad it has taken us so long.

Dr. {Burgess.} Well, I do too then. We will rescind the funding then. On the--

Mr. {Venter.} It was privately funded then.

Dr. {Burgess.} Let me--and that is an excellent point and I--

Mr. {Venter.} We got your goat.

Dr. {Burgess.} I wish Ms. Eshoo was still here. The--what you guys are capable of doing with private funding, without government interference, I mean, I shudder to think what computers would look like if we had been in charge of developing those silicon wafers but that is a separate story. On the issue and I don’t know whether to ask this of Dr. Venter of Dr. Fauci, but on the issue of the nefarious activities that might occur, but so much of what I have seen in Congress, we don’t actually choose to be nefarious but our uneducated consequences are sometimes extremely pernicious. What if we created the artificial life form, the viral equivalent of the zebra mussel, for example, not particularly pernicious in and of itself, but because it replicates so fast and it is so invasive and tenacious that it clogs up waterways and this sort of thing, what do we have to protect us from say the unintended consequence of one of these experiments gone wild?

Mr. {Venter.} It is an excellent question and it is one

of the top two questions I get when I am speaking about this topic around the world. People are worried about the unintended environmental consequences and we have now close to a 40 year history with molecular biology, with scientists such as ourselves putting genes from almost every species in the bacteria E. coli in the laboratory, with no unintended consequences and the reason for that is that bacteria is designed where it can’t survive outside of the laboratory. We have argued this as a key tenet for this new field. We need to design into future genomes the ability to have suicide genes--

Dr. {Burgess.} Well, I was going to ask you do you have a killswitch that you designed into it or a blowup protector if I could sure that term.

Mr. {Venter.} --the variety of these to do that exactly. In fact, the exciting part of this is we can now use artificial amino acids so that these organisms could grow only in a very well chemically defined environment and never survive in the environment and I think these are very important aspects of this whole field, that we and others have been pushing for from the beginning. If we are going to make a synthetic algae, about 40 percent of the oxygen that you and I are breathing right now comes from these algae in the ocean. We don’t want to mess up that process.

Dr. {Burgess.} Right, we don’t want to compete with them. You are correct. Dr. Fauci, last August, you were good enough to talk to me about the following months might hold with the H1N1 virus and not having a vaccine at that point and how to advise people were taking care of patients who might be pregnant and teach schoolchildren. The ability to deliver that vaccine eight weeks earlier because of this type of technique, that would have been significant last August. Would it not?

Dr. {Fauci.} Absolutely. As you know from our painful experience that we, at the peak of the time that the virus was at its worst, we were still essentially waiting for the full component of the vaccine. So if we had had an eight week more lead time that the availability of the vaccine would have coincided with the demand, we had a dichotomy between demand and supply that would have actually eliminated that gap.

Dr. {Burgess.} Right, as we bore down on the beginning of a school year, which obviously was going to throw another wrinkle into that. Now you brought up and you really didn’t expound upon it but--

The {Chairman.} Dr. Burgess, we are going to have votes in around 15 minutes. I wanted to--

Dr. {Burgess.} Okay. I would point out to the chairman

that other members of Congress have been allowed considerable--

The {Chairman.} No, you are absolutely right that we won’t have time for everybody.

Dr. {Burgess.} But this is an important question. It deals with oversight--

The {Chairman.} Please ask it.

Dr. {Burgess.} --and we did swear the witnesses in.

Dr. Fauci, you brought up the issue of reviews and oversight of the synthetic--as we enter the synthetic era and perhaps you can respond to this in writing offline if it would be helpful, but would you give us the benefit of your wisdom on the direction that oversight of this committee should take in the synthetic era?

Dr. {Fauci.} I would be happy to do that in writing but as I mentioned, I think the kind of support that you have given for the oversight mechanisms that we have already been put in place and you are now updating and upgrading the guidelines that are out for public comment, that have come back now to incorporate the synthetic biology aspect of it.

Dr. {Burgess.} Would you--

The {Chairman.} Mr.--Dr. Burgess--

Dr. {Burgess.} --perhaps come before us and talk about that at length?

The {Chairman.} --it really is not fair to the others because we will have to refuse any time to the junior members and it would not really be fair. Probably will end up on your side. Ms. Castor?

Ms. {Castor.} Thank you, Mr. Chairman Waxman, for calling this very interesting hearing. I would like to thank all of you for your testimony. The work you are doing is fascinating and it is important and it is obviously that synthetic biology holds such great promise for Americans, whether it is medicine and health or energy, or the environment.

Dr. Keasling, I would like to ask you some questions. This committee has been working very hard on clean energy technologies and it is our challenge is to make energy clean and affordable and this--and BP’s deep water horizon oil disaster has been forced on us really highlights the need for our country to focus on clean energy technologies. I understand that Amyris, a company you founded, used synthetic biology to develop a promising method for reaching these goals using--by producing diesel from sugar cane.

Mr. {Keasling.} That is correct.

Ms. {Castor.} Could you tell me how this process works? What advantage did synthetic biology provide in producing this biodiesel that conventional technologies could not?

Mr. {Keasling.} Right, thanks for that question. So it is a very simple process. The yeast that we have engineered consumes sugar and turns it into a diesel fuel that the yeast pumps out of the cell and it floats to the top and you skim it off. The way this technology or what enables this is that we took the genes that encode enzymes that would transform the sugar into the fuels. So we take these genes from various different organisms and we put them into brewer's yeast. In fact, we put them into industrial strains of yeast that have been widely used for many decades, so these are safe organisms and the process is very much akin to brewing beer. Now what is so great about this fuel that you get out is that it is extremely clean. It reduces greenhouse gas emission by about 80 percent because it is derived from sugar, which comes from sugar cane and that uses carbon dioxide and sunlight to fix that carbon dioxide and it is very environmentally friendly. It has been certified by the U.S. EPA and it is a very clean fuel. What is more is it actually gives extremely good fuel mileage on a gallon of this renewable energy when it is used even pure in the diesel tanks.

Ms. {Castor.} Are you going to be able to take the next step to jet fuel or--

Mr. {Keasling.} That is right.

Ms. {Castor.} --smart gasoline?

Mr. {Keasling.} In fact, we are working quite extensively on that now, Amyris and at the Joint BioEnergy Institute, using the same synthetic biology techniques to now engineer yeast and E. coli to produce jet fuels.

Ms. {Castor.} And how does it compare to the current diesel fuel that is already available and how well does it work in trucks or other equipment?

Mr. {Keasling.} And so we have done extensive testing of this fuel with manufacturers of engines. So Cummins, for instance, has done extensive testing of this fuel and many other manufacturers. We now have alliances with airplane manufacturers and engine manufacturers for airplanes so that we can test these new generation of jet fuels in those engines.

Ms. {Castor.} Is it affordable yet?

Mr. {Keasling.} We project that when we are up to the yields we need to be, we can produce this for under $4 a gallon and of course, affordability also depends on the competition and so right now that would be nearly affordable.

Ms. {Castor.} Now your production process right now, it is not really--you are doing a lot currently. It is not just a long term goal but you are doing this in Brazil.

Mr. {Keasling.} That is correct.

Ms. {Castor.} Why not--why Brazil and why not the U.S.?

Mr. {Keasling.} Brazil has some of the cheapest sources of sugar. They also have an infrastructure that is built for producing fuels. Currently, they are producing ethanol. Ethanol is obviously not the best fuel and it can't be used in diesel engines. We can use very similar processes and we are, in fact, refitting those microbes that would normally produce that ethanol to now produce diesel fuel. So we are down manufacture--building facilities that will now manufacture this fuel. But Amyris and the Joint BioEnergy Institute hope that we can do this in the U.S. in the very near term. The way we are starting with this, at least from Amyris' perspective, is by going into Alabama and other states in the south where sugar cane can be grown and doing tests on this and in fact, there is an alliance now in Alabama with the U.S. Air Force to try to study the production of jet fuels.

Eventually, through the technologies that we are developing in the Joint BioEnergy Institute, we will be able to use our plentiful sources of cellulosic biomass, which is primarily sugar and turn that sugar into the same types of fuels.

Ms. {Castor.} Thank you very much.

The {Chairman.} Thank you, Ms. Castor. Mr. Gingrey?

Dr. {Gingrey.} Mr. Chairman, thank you. I have heard some discussion about how you can in the laboratory in this new technique, synthetic biology, produce genes and even entire genome and then there was some discussion of course about H1N1 and the rapid production of vaccine against that virus and it made me think to ask this question and in fact, I will--I don't know who to ask it of. Maybe you should go in the order of your SAT scores but actually, I will probably ask Dr. Fauci to begin.

The {Chairman.} Maybe we should recognize members on that.

Dr. {Gingrey.} Well, I may be the last one to speak, Mr. Chairman. But the idea of knowing what is in, let us say, a virus from the DNA perspective, is that more difficult now than being able to take these four thiamine, adenosine, guynime, cytosine, whatever these amino acid payers and be able to put together and form a gene or in fact, in some instances, form a complete genome? But to be able to do that, you really need to know what you are trying to produce.

Dr. {Fauci.} Right.

Dr. {Gingrey.} How difficult is it, Dr. Fauci, and I will ask you first, to know really what is--once you have isolated a virus, is that the tough part?

Dr. {Fauci.} Right.

Dr. {Gingrey.} Knowing exactly, you know, the multiple chains and--

Dr. {Fauci.} That is really easy. If you get the naturally occurring virus and you sequence it, you are reading the blueprint of nature. If you want to then sequence components of that, different genes, it is relatively easy now by common techniques to sequence little genome fragments. You could then take those and stick it into something that will code it to make that protein very easily. The difficulty that was had until now and it is still difficult but before what we are talking about is to take an entire genome of a much bigger length than a little snippet, and to synthesize it based on the blueprint that you see in the computer that was a result of your sequencing it, which was really easy. It was difficult a long time ago but it is really easy right now.

So the microbe that Dr. Venter and I will certainly leave it to him to explain more, that he synthesized was on the basis of a blueprint that nature already told us what that blueprint is. Sometimes when you sequence, there are some mistakes. Unfortunately, for Dr. Venter, there were a couple of mistakes in that sequence that actually lost him a few months, if not longer, but if you get the sequence right, you can then synthesize fragments but now you can synthesize

the who thing and take it and stick it in another bacteria, get rid of its resident genes, and let this new synthetic one start coding.

The real challenge is going to be if you want to do something that is entirely new, is how do you put together the circuitry from gene to gene to do something that nature hasn’t been your teacher, hasn’t told you how to do it because when you have the sequence, nature has already told you what the right sequence is. You just need to synthesize it. The challenge is that the field is going to be facing is that how do you get those new circuits, and there are a lot of people working on these little circuitries, to figure out how you can then make the optimal organism to do optimally with what the panel members were talking about.

Dr. {Gingrey.} Dr. Fauci, thank you and the minute that I have left, maybe one of the other panelists would also like to comment or elaborate on that same question.

Mr. {Venter.} I don’t think I can improve on Dr. Fauci’s answer.

Dr. {Gingrey.} Anybody else?

Well, that is great, Mr. Chairman. In the interest of time and my other colleagues, I will yield back the 44 seconds. Thank you very much, Dr. Fauci.

The {Chairman.} Thank you, Dr. Gingrey, for being so

generous. Mr. Gordon?

Mr. {Gordon.} Thank you, Mr. Chairman. I want to--I will probably be brief in just echoing Anna's earlier comments about thanks for you bringing this hearing together and about synthetic biology clearly is going to be a major frontier for the 21st century and you are already pioneers in that and we are glad that you are here. We need to continue this conversation and I think the country that is going to lead in innovation of synthetic biology is the one that is going to lead the world in creating jobs, creating wealth for its people, and there is going to have to be a federal partnership in some ways for that early R&D. Other countries are doing it. We are going to have to do it here and we are doing it.

As a matter of fact, Dr. Venter through the Department of Energy, got some of his early funding that way and as a matter of fact, in this new America Competes Act that we are in the process of dealing with now, within the Office of Science and the Department of Energy, we are requiring them to develop a plan on how synthetic biology research can be focused on their mission in terms of energy security and environmental cleanup and those sorts of things, which also indicates that there are different pots of money around the federal government doing work here.

Just like we found in nano research, there are 25 different federal agencies dealing with nano, 15 of them providing some resources. So through the National Nanotechnology Initiative, we put up an umbrella to coordinate that. Just last year, we did the same thing with solar, with water, with stem education. So my question is, should we have some type of a coordinating counsel within the federal government to coordinate the funding in synthetic biology and within that, should there also not mandates, but maybe, and not picking winners or losers, but taking some areas of emphasis? So that will be my first question and then I will follow that on something similar.

Anyone wants--Dr. Venter?

Mr. {Venter.} Thank you for your comments and your question. I agree with you. I think this technology has a chance to be one of the most important--

Mr. {Gordon.} Oh yeah, yeah.

Mr. {Venter.} --economic drivers for the future.

Mr. {Gordon.} Sure.

Mr. {Venter.} And the only thing I think would be tragic for this country is for something, you know, quite dramatic not to happen with federal funding. Federal funding seems to follow innovations in my view. It seldom leads them. This is a chance to change that as we drive the kind

of tools that--

Mr. {Gordon.} But should we have some kind of a coordinating agency within the federal government, coordinating where the various areas, where NIH, where DOE or other places that are doing research on synthetic biology?

Mr. {Venter.} I would defer to others. I am not sure I am qualified to comment on that, whether that would be good or bad.

Mr. {Endy.} Very good question, if I could just offer a perspective. One of the characteristics of synthetic biology is just bringing researchers and others together from very different backgrounds and it would strike me as a wonderful opportunity to create some guiding framework or a leading umbrella that would provide the venue for which engineers and scientists, ethicists and others could come together. So, for example, we have a lot to learn from not just electrical engineering and chemical engineering but every type of engineering. We need the benefit of experts at places like NIST, combined with the expertise at NIH and NSF and DOE and everywhere else. And so how are we going to bring those folks together and then bring them together with the emphasis to help us make best decisions upstream of the work as we have done an okay job with in getting started but now need to scale. So I am very positively responsive to the question.

Mr. {Gordon.} Well, is anybody who is not and, you know, I think we will--I want to try to follow up on that. The other part of that, going back to the earlier discussion about the semiconductor industry and you know, there are--we lead the world in semiconductor production. Eighty percent of our production goes oversees and 75 percent of the jobs and the money stays here in this country and so I think--and a lot of that was from this somatic, the earlier partnership between the federal government and the industry. So one, we could say maybe this coordinating body. Should we also look at that somatic model and see if there should be some--a partnership is created with public dollars, private dollars, and if so, how would you see that being structured?

Mr. {Endy.} The short answer is yes. I think the question about how to best structure it deserves some good thought.

If you look at the last 35 years of biotechnology, there hasn’t been a tremendous, although at the research level, there has been a tremendous amount of sharing and cooperation. In terms of translating that into commercialization, there is not always as much of that as you might hope to see. So one of the lessons we might take from the emergence of other technology platforms is to create a mixture of partnerships that support, among other things,

open technology platforms. Going further than that, I think it really would, at this point, be worth serious consideration and follow up to figure out the best ways to structure things and I don't know that it is going to be a naïve one to one mapping of past experiences that worked in other fields. I think biology and the technology built upon biology is new in many ways. So we got to sort it out.

Mr. {Gordon.} And can the industry--obviously, there are proprietary advantages that folks want but are there some breakthrough areas that everybody needs and that would we want to focus on, you know, on some breakthroughs?

Dr. {Fauci.} I would--

Mr. {Gordon.} Dr. Venter, take it on over to any of you. To get it into the private sector, do you need some kind of fundamental breakthrough?

Mr. {Venter.} And I get some excellent questions so the million based pair genome we made cost us a little over $800,000, just for the chemicals to make it. DNA synthesis is followed well behind our ability to read the genetic code. Your--from how 10 years ago, it cost the taxpayers over three billion dollars to get one of the two first drafts of the human genome. The technology is now enabling that to happen for maybe on the order of $10,000. If we get the same order of magnitude changes and possibly this year it will go down

in order of magnitude, but will really drive it is if DNA synthesis becomes really cheap and there has not been a lot driving that in the recent future. That would be one avenue.

Mr. {Gordon.} Okay.

The {Chairman.} Thank you, Mr. Gordon. Dr. Griffith?

Dr. {Griffith.} Thank you, Mr. Chairman. I appreciate you calling this. This is extremely interesting to me and I heard Alabama mentioned and that is my state and my district is five and I am the home of a HudsonAlpha Institute and Rick Myers and his team and I can’t tell you how nice it is to have you here. We understand how important this is, as an oncologist and certainly, as you are basic scientists and funding, as Congressman Gordon is pointing out, we need to bring our public along, as far as education is concerned. This is mysterious to them, sometimes frightening. It sometimes goes to our culture and we are not sure what we are doing with DNA and recombinant DNA.

The public needs to be brought to speed on this whole area of genomics, which they are not now and so we, in Alabama, or the HudsonAlpha Institute has put together an educational program where we have reached over 60,000 students and 2,500 educators. We have an application on the iPod for iCell and I think when we go to the public to ask for funding, I think it is important that we begin it in the

grammar schools and that someone mentioned Silicon Valley and how important it was that this is our next Silicon Valley.

In order for us to fund it and have it accepted into our culture, we need to start educating our young men and women who are in grammar school about the importance of a cell and the cellular anatomy and the things that are going on because what we are really doing, I think, is going back to basics. We are finally able to get to the basics of the cell, knowledge that was not even known when I was being trained as an oncologist. So is there, in your institutions, an educational arm for the layperson? We have started that in Alabama and it is exciting for the students and I was just wondering is that occurring in other areas as well?

Mr. {Venter.} If I may go first, that is an excellent question and I appreciate it very much.

There is probably in my entire career nothing that I have seen that gets young people excited more than the notion of combining the digital world with the biological world. I think they are our number one fans in this area. My institute, The Venter Institute, has a public education program. We have a bus that was initially paid for with NIH funds. It is a research laboratory that goes to the middle schools in the Washington Baltimore area. My understanding of education if we don’t catch students at that age, they get

lost once they are in high school. But expanding such programs, I think, would be a huge part of this, to capture this excitement and make sure we are the number one nation in this field going forward.

Dr. {Griffith.} Thank you. Yes, sir?

Mr. {Keasling.} So through our funding from the National Science Foundation for the Synthetic Biology Engineering Research Center, we actually spent a great deal of time working with K12 students to try to get them into education, to try to understand science, basic science, but also the engineering of biology. We fund part if the iGem competition that Dr. Endy talked about. We have a new program where we bring in at risk high school students, students that wouldn’t normally go to college and get them involved in synthetic biology in summer periods and we have a great record, all of them going off to college after that period.

Dr. {Griffith.} Fabulous. Thank you very much. Yield back, Mr. Chairman.

The {Chairman.} Thank you, Dr. Griffith. Mr. Markey?

Mr. {Markey.} Thank you, Mr. Chairman, very much. I have a cold so I am trying to quarantine myself down here and hopefully this will lead to the discovery of the cure for the common cold. That would be the biggest breakthrough we could

make.

Dr. Venter, I know that you want to potentially use these breakthroughs as a way of taking carbon and taking and making it not this terrible thing that is warming the planet but something that is positive. It can be used in constructive ways in our society. Could you tell us a little bit about how you dream, envision these breakthroughs leading to that possibility?

Mr. {Venter.} Thank you very much for the question. People have talked--in fact, Al Gore has talked about carbon based fuels being the problem. In my view, they are not the problem. It is the source of the carbon that is the problem. If the carbon comes from CO2 or indirectly, as Dr. Keasling has said, through sugar, we have a chance to capture back CO2 that is being produced when we take new carbon out of the ground. There is not existing biology there would be no reason to have organisms involved to do this and pump lots of hydrocarbons. So we need these new tools of modern molecular biology and synthetic biology to get cells to be much more productive, to get to the billion gallon per facility level that is required. So we think this will help take us there.

Mr. {Markey.} Chairman Waxman and I, last year, out of this committee, we moved the piece of legislation that helped to put a price on carbon and to move to its new technological

breakthroughs in this area. Do you think that that is the right direction for us to be heading in?

Mr. {Venter.} I think it is personally one of the most important aspects that Congress can do going forward. If we are successful and I expect that Dr. Keasling will be and we will be as well, we will start to have replacements for oil, which could drive the cost of oil down. If the cost of carbon doesn’t go up in a stepwise component, we will constantly drive ourselves out of business by making oil cheaper.

Mr. {Markey.} But ultimately, you do believe that we can innovate our way out of the problem as long as we give the proper incentives for these new technological breakthroughs flourish in a short period of time.

Mr. {Venter.} I am an optimist and a scientist and we have been--I think these new tools are remarkable tools. Also as a scientist though, I view we actually have to prove that so I think the promise is there. We actually have to be able to prove that potential.

Mr. {Markey.} How long would it take for you to do this kind of a thing and how much would it cost, that is to make this transformational breakthrough that turns carbon into a positive rather than a negative?

Mr. {Venter.} As we announced last summer, our program

with Exxon Mobil, they are putting up 600 million dollars for this initial stage of funding. Three hundred they are using internally for their engineering and 300 to synthetic genomics to try and develop the biology to make this possible. We are talking about facilities potentially the size of San Francisco. These have to be extremely robust things. Our optimistic estimates, it is going to be a decade before there are substantial replacement for gasoline and diesel fuel that is made from CO2 in the gas pumps.

Dr. {Fauci.} I should mention that--

Mr. {Markey.} I should mention that my time is going run out. Dr. Fauci, the notion of synthetically created DNA conjures up images of the classic science fiction movie, Bladerunner, where Harrison Ford hunts down synthetically created humans in a smog-bound Los Angeles dystopia set in 2019. Now we are not confronted with that scientific reality right now.

There is a difference between producing a synthetic microbe or bacteria in a more complex organism. But it does raise the question of who plays God and perhaps you could tell us what kind of discussions or programs you have that help to discuss the ethical ramifications of the beginning of this process that we are now walking down in this new pathway?

Dr. {Fauci.} Thank you for that question, Mr. Markey. Myself, as a scientist, my view of what I am seeing right here now is to emphasize what you yourself said. We are talking about a microbe, a bacteria with a one million base pair, not a three billion base pair. That is the first thing. The second thing is appropriately, the president himself has, in a letter of May 20 of this year, written to the Commission on Bioethics Panel and he has asked them to review this from a variety of ethical and other issues to lay some report back to him within six months as to what we feel we need to do to examine this very important question that I am sure a lot of people are going to be asking. So we are already on that. The mandate to the Commission has already been given by the president.

Mr. {Markey.} And I thank you so much for that answer, Doctor. That bioethics panel was established after an investigation I conducted of human experimentation, the government using radioactive materials on human beings and that was 1993 and I do think it is important for us to stay current and have this ongoing discussion, while at the same time recognizing that there are tremendous positive aspects to this. So much so that the Vatican actually called this a very interesting breakthrough because there are many positive aspects to the breakthroughs that Dr. Venter and the others

are making at this time. So I thank you, Mr. Chairman.

The {Chairman.} Thank you very much, Mr. Markey. The Chair would like to ask unanimous consent that a letter from the ETC Group, Friends of the Earth, and the International Center for Technology Assessment be included in the record. Without objection, that would be the order.

[The information follows:]

********** COMMITTEE INSERT **********

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The {Chairman.} All right. I want to thank you for being here and giving your presentation to us. We are at the dawn of a new age of science and the breakthroughs described today have the potential to some of the most challenging problems we face, including global warming and global pandemics, but like any new scientific breakthrough, it is important it be used with appropriate guidelines and we will continue to monitor your progress and continue our oversight and also to be available to you to help in any way to assist you as you go forward. Thank you very much for being here.

We will--without objection, we will leave the record open and members may submit written questions and have a response in writing for the record. That concludes our hearing. We stand adjourned.

[Whereupon, at 12:04 p.m., the Committee was adjourned.]