So let me talk about what this is all about, SunShot and Grand Challenges. It’s really about energizing all the capabilities we have in the United States in solar technologies. And so, then you might ask, why do we really need Grand Challenges, what is, is this some – I just want one other wire, that’s so I can tweak while I’m giving you a talk. [laughter] So, the United States is in a fierce race, we—to be the inventor, the manufacturer, the distributor of a lot of clean energy technologies; this would be very useful for our own economy, out economic growth and our energy security, and we think the Department of Energy is trying to identify the most critical grand challenges in this. Solar energy is one of them; electric and plug-in hybrid vehicles is another. There’s several of them. And the point here is that success will require more than just something you discover in a research laboratory, it goes beyond discovery, it goes beyond invention—it really goes to innovation, and innovation to me means that it gets deployed and eventually gets deployed at scale…and for that innovation, we also need innovation in technology, in business models, finance, and policy. So, the purpose of this forum is that we want to engage the stakeholders. We have a lot of them out there, that’s great. We think we’ve identified key technical and non-technical challenges and want to discuss this with you. And especially we want feedback—it’s exactly as Arun said: this is what we think, what do you guys think. And we’ll take that back with us. What about the name? Well, first, what’s the SunShot Initiative? If you look at various prices of energy, solar, coal, nuclear, gas, what we want is to bring down the price of solar significantly. We want to bring down the price of solar where it would be essentially competitive with gas at, let’s say, $4, a million BTU, which is, I think, going to be a stabilizing price. That means it’s got to come down more than twofold, two-and-a-half-fold…and we started this a little while ago, it has come down substantially…at least threefold. All right, what has happened, well, the cost of solar modules has been terrific. These are so-called learning curves where we’re plotting on the y-axis the costs of the solar module, the costs per watt, and this is the cumulative production volume, so if you increase production tenfold, it goes down by a certain fraction. You increase another tenfold, it goes down another fraction, and so on. And so this slope for crystalline silicon has been going down very nicely. There’s a very strong feed-in tariff for Germany. There was a temporary oversupply, so it went up a little bit, but the market responded, perhaps a little too well, and now the April ’12 spot market price for crystalline silicon is 83 cents a watt…and some are actually beginning to deliver 76 cents a watt. That’s an amazing story because it used to be $4 a watt about three years ago. Thin-film crystalline—thin-film cad telluride is also coming down very rapidly. It’s a very competitive world out there. And if you look at the United States PV cell and module production and shipments all around the world, when it was not a major product in 1997, we owned 42% of the shipments, and by 2011 we’re at 4%. So there is some concern, with China especially, China’s in red rising very rapidly. Now here’s a very sad, both good and sad, story. There are two ways of growing high-quality silicon. The highest quality is you take a little seed crystal on, essentially, a string, and molten silicon and you slowly draw it out, and what happens is that a single nearly perfect crystal of silicon is formed, and you can slice this boule into wafers. This is the kind of silicon that goes on satellites, where cost is not that much of an object. So this is way single-crystalline silicon is made. This is the way polysilicon is made, the last refining stage, the last solidification stage, is a very, very big oven…you have a blob of silicon in there, you then cool it, cool it slowly. The more slowly you cool it, the bigger the single-crystalline sections are, and the bigger the single-crystalline sections are, before you go to a grain boundary, the more carrier mobility you have. So the object is to get high-quality polysilicon and say, let’s let those electrons and hole flow as far as they can before they are captured, and hopefully they are captured on electrodes. Now, we in the Department of Energy funded some research beginning in 2007, BP Solar in the United States, can you take that bulk production and solidify it very, very slowly, and in fact try to get a little directional growth so it’s kind of a hybrid Czochralski method, but in this big tub where it’s really inexpensive. And amazingly they found that up to half or maybe more than half of the silicon in that big tub could be grown as single-crystal silicon, and when you take that silicon out and slice it up, and not using all the techniques of sun power, you’re getting over 20% conversion efficiency. So that’s 20% conversion efficiency with polysilicon prices. In those days, polysilicon was about 14 going to 15, and it’s now 16.5% conversion efficiency. Now, BP Solar unfortunately was getting a little scared off by the very large investments of Chinese companies, so they backed out; they sold it, the IP, to a German company, and the Chinese have taken the IP and are improving on it, and the rumor is they’re going to go into production of essentially single-crystal silicon within a year. The poor German company is not big enough to chase after the IP rights. This is a little scary. So we’re trying to figure out what to do. So, let me just, speaking about scary, remind you something that Andy Grove said. First, he said that if we abandon…you know, silicon modules are a commodity. But abandoning today’s commodity manufacturing can lock you out of tomorrow’s emerging industry. It’s a commodity, but on the flip side, it’s a very high-tech commodity. But so are, so is wheat and corn, as well. And so, he’s also famous for saying, and writing a book, “Only the Paranoid Survive: How to Exploit the Crisis Points That Challenge Every Company.” And so, this…he’s taken this from an old Hungarian saying. It’s wei ji, and it’s two characters that mean crisis, but they’re actually, alone, different characters. One character means danger. The other character is opportunity. So he knew very well this old Hungarian saying, that in every crisis lies the seed of opportunity. And so that’s where we are now. Let me talk to you about another crisis. When I was a small kid, October 1957, Sputnik placed into orbit a little globe, 84-pound, beach-ball size satellite called Sputnik, and this satellite can actually be seen when the light was right, circling over the United States. So this is a view of Sputnik taken from Earth in the United States, just shortly after nightfall, and it was really scary to the United States at the time because it meant that the Soviet German rocket scientists were better than our German rocket scientists. [laughter] So how did the nation respond? Amazingly, one of the few five-star generals in the country, President Eisenhower, didn’t respond by saying we’re going to put a lot of money into rocket scientists. He said we’re going to put a lot of money into educating a new generation of scientists and engineers because that’s the base from which you will actually get technological leadership. What an amazing thing—1957—to respond that way from a five-star general. This was followed later by a speech that Kennedy gave September 1962, let me see if I can…We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we’re willing to accept, one we are unwilling to postpone, and one we intend to win. And the others, too. All right, that was one of his famous SunShot speeches—moon shoot speeches. That’s what happens when you don’t have that much sleep. And in that, he said, we will—before the decade is out, we will put a person on the moon. We were several years behind the Soviet Union, and it really galvanized the United States. Now, what do we have today? We don’t have this imminent threat, a defense threat, but we have other threats that I think are where the stakes are higher, or at least as high, and they’re not just the United States, but they’re actually all over the world, and that is the fact that there is growing evidence that the climate is changing. This is a reinsurance company called Munich RE, and it’s totaling the natural disasters in the United States, and the natural disasters include earthquakes; that’s the little brown stuff at the bottom. But the things that I want to draw your attention to are the storms, the floods, and what are they called, climatological events like extended forest fires, which Colorado is going through this year, went through last year, I expect next year it will also go through similar things. So statistically these things are increasing. You look at the very heavy rainfalls that are occurring all over the world, this is from a very recent Nature article, and these are anomalies. If you see blue, it’s additional higher rainfall, but these are not just ordinary rainfall, these are the storms that cause dramatic flooding. So the highest single-day rainfall, the highest five-day rainfalls. And so, this is—differences from a baseline, let’s say, a decade ago. Now the scary thing about this is this is what’s been recorded, but what did the climate modelers say about this? If you take out the increase in carbon dioxide, which we strongly believe and know to be caused by humans, the climate simulations don’t give much of an increase in rainfall. So we don’t actually understand what’s going on. We’re seeing more severe storms, the climate models are not showing this, but as the computers get bigger and bigger, for some strange reason you go to a smaller and smaller pixel size, and they begin to appear. All right. But this is just to remind us, it’s not a debate as to is it happening—it’s happening, it’s a debate as to how bad it will get. And so that’s something. Heat waves—we’re going to be seeing a lot more heat waves, but let me remind you, in August 2003, there was a pretty big heat wave in Europe and 52,000 people died in Europe, including—and these are, these are advanced countries—Italy and France, 18,000, 14,000. Chicago, there were about, in 2005, I believe, about 700 people died of heat. So, this is in part why we’re doing it, but the other part, the opportunity, is we think as these prices come down, this will be a worldwide global market. And this is one of the things we are—have a target. This is our residential, this is, you know, your own home, SunShot target. Right now it costs about $5.71 to install, and so we’re looking at these things. The little yellow bar is the cost of electronics, the things that convert the DC to AC, and control those. We have grants that will make this much more robust, much less expensive, much smaller, and should be an integral part, actually, of the module. There’s another thing, what’s called the balance of systems hardware costs. These are the mounting brackets. You don’t want to penetrate the roof when you’re putting it on the roof; that will cause a lot of extra costs. So there’s so-called these hardware costs. There’s soft costs, and I’ll tell you a little bit more about the soft costs; the soft costs are things like, you know, what the municipality will charge you and make you go through. There are soft costs of, actually, the labor, of getting people to walk around the roof and things like that, and of course there’s improving the efficiency, because it’s—the efficiency goes from 16% to 20%, that’s 4% over 16%, one quarter improvement in efficiency means proportionally everything else goes down. So efficiency is very big on this because it affects everything. And then finally, we want these things—modules to be made in America, and we want to be competitive, and we want to reduce the costs. So the goal is that these costs would be $1.50 a watt on your roof. It’s very aggressive, but we’ll see if we can get there. Now, as I said before, we’re investing and helping companies and laboratories improve the efficiency. With crystalline silicon, it’s not really…it really tops out at 25%, but really, how do you get it to lower costs. With polysilicon, we just saw 16.5% today, but it’s going to probably go to 20%, very low cost. Cad telluride, we really got to get up to 17, 18, 23% to make a difference. Gallium arsenide always looked good, very high efficiency but can you make it in large swaths in a liftoff technique….a little promise here, we don’t know. But there are many, many other types of things. And then whenever I talk about PV, I’m always asked, what about concentrating solar. Well, what about it, we are very agnostic; we don’t really care which one wins. We want one of them to win, at least. And so we have a pathway to concentrated solar power—again, a waterfall diagram of all these things and how much you can decrease from 9 cents to 7 cents, from 4 cents to 2 cents, from 3 cents to 2 cents, and so on, again, to get to a target which will be comparable to gas energy—new gas energy. So those are some of the things we are looking at and trying to do. This is some work, some graphs taken from Bloomberg New Energy Finance, and I love this graph because it tells you what the cost is in that section of the country or in the world, and what the insolation is, that is, how much solar energy per year is actually hitting that place, and so if you’re in a bright sunny spot, your energy is very high, solar, and this blue line is the break-even point for residential, not utility. Rooftop solar. Utility’s down by another 30 to 40%. So if you’re in a country, well, unfortunately, Denmark doesn’t get as much sun as you’d like, but if you’re in a country, but their costs are high, Denmark, so they’re there. Hawaii is 25 cents per kilowatt-hour now, and yet, there’s not widespread deployment, so we’re wondering why. Puerto Rico, it’s 33 cents a kilowatt-hour. No reason why—so you people out there, you entrepreneurs, you business people, are you taking notes? There’s an opportunity here. Okay, so this is what the residential cost is in 2012; 2014, it goes down. By 2012, it looks like much of California, which is averaging about 15 cents a kilowatt-hour— this is without subsidy—clicks in. All right? And now utility-scale PV is 15 cents, maybe 14 cents. But this is, again, rooftop. And then finally by 2020, this is where it’s going to be; it starts to include Texas, which has very low electricity power; New Jersey, less sun, but it’s above the line. So anything above the line means it’s economically viable—you don’t have to hug trees, you just want to save money. Now, what is our goal? That’s where New Jersey is, our SunShot goal is there, 8 cents levelized cost per kilowatt-hour. And it’s, again, an ambitious goal, but if we can get to 8 cents per kilowatt-hour, then most of the United States, well, not Alaska, but you know, a lot of the United States will be there. But mostly, and I hope you’re noticing this, most of the world will be there. And that’s the thing to keep your eye on. All right, so those are predictions or hopes with some technology paths forward, but they may not come out to be true. We hope they will, but let me remind you, sometimes when new technologies emerge, other people say, no, this isn’t going to work, and I’ll give you a few quotes. The president of Michigan Savings Bank asked—was asked by Henry Ford’s lawyer Horace Rackham whether he should invest in the company. And the bank president said the horse is here to stay, but the automobile is only a novelty—a fad. So Henry Ford’s lawyer decided to ignore the advice, invested $5,000, and cashed in at $12.5 million at the turn of the century. That’s real money. All right, Alexander Graham Bell invents the telephone, gets a patent for it, chief engineer, British Post Office, says Americans have need of the telephone, but we do not. We have plenty of messenger boys. [laughter] so if there’s an incumbent technology, there’s a resistance of people who are invested in that incumbent technology to look forward. The same is said of people who have in fact invented the incumbent technology. There’s another quote from Lee De Forest, the inventor of the vacuum tube, a radio pioneer; he was asked about the prospect of television. He said, never will work, never will be economically feasible, forget it. So it even occurs with technologists. Here’s another reason why you may get naysayers, and that is the incumbents want the existing technology to stay there longer, and this is a report of ExxonMobil, it’s called the 2012 Outlook for Energy: A View to 2040. And it’s not just oil and gas, it’s all sectors of energy. And for example, it shows this nice plot of what the cost of coal will be, just the capex and the total cost at certain prices. So this is coal with no capture of carbon, but if coal goes up by a little amount, it’s sensitive to fuel. This is natural gas, again, the lowest price at the moment. This is solar PV; this is, remember, what they’re predicting into 2030, and so they’re predicting by 2030, utility-scale solar will reach an average of 18 cents per kilowatt-hour in the United States. They may be safe in this prediction; as I said, in California, it’s 14 cents today. So we can backslide a little bit and we’ll still make this. Now they’re, of course, they turn their attention on cars, and they think that conventional gasoline by 2025 or 2030 will roll over and will be picked up by what they call mild hybrids, and mild hybrids are not Prius hybrids; they’re even smaller batteries, just to get the thing started hybrids, and so this little sliver in here is plug-in hybrids or electric vehicles, and they’re predicting, here in the United States, the average new car mileage in 2010 is about 22 miles a gallon, about right, if you can consider all the loopholes. It’s supposed to be 25. But by 2040 they’re predicting the United States will be getting about 45 miles to a gallon. And what are these little bars? Those little bars are future targets that vary country to country, so somehow they put the target of the United States by 2040 to be about 38 miles to a gallon. Now we have a target of 54.5 miles to a gallon by 2025, so I’m not sure what’s happening about this, but…so maybe they’re hoping we can roll it back. And so why are the projections for plug-in hybrid and electric vehicles so modest? Well, they said that by 2030, an electric vehicle like the Nissan Leaf will cost about 20—$12,000 more than conventional vehicles. The Nissan Leaf costs $32,000, its similar-sized vehicles $20-$25,000, so they’re saying from now until 2030, we’ll slide back a little bit in battery development. All right, so, you know, sometimes naysayers have other reasons for saying no. What is the potential market for clean energy technologies? I need to remind you that, again, these are all predictions, and I have to remind you what the greatest American philosopher of the 20th century said. That’s Yogi Berra having a philosophical conversation. And he said it’s hard to make predictions, especially about the future. [laughter] Now, in the ExxonMobil report I’m a little bit stunned, because surely you can predict the present, but… [laughter] Anyway, we have barriers to deployment. There are research, development, and deployment barriers. What are we doing about it? We have, for example, new announcements, and I guess this is the announcement today that we investing up to $55 million over three years, 21 projects, to companies to develop technologies, either parts or entire technologies, that would greatly lower the cost of concentrated solar power. And this would include high-temperature receivers, dry-cooled power cycles, lower-cost collectors, you name it. And these groups are at the Tech Forum, so I encourage you to go and look at what’s being done there. There are several valleys of deaths from the time you discover something, invent something, those largely supported by government and industry, and there’s this little valley of death which we call pre-commercial. Can the invention actually be picked up by venture capitalists, by a company, others…and so this is the gray area, venture capitalists getting excited about this. There could be angel investors, things of that nature. And a much deeper valley of death is, you’ve proved that—the venture capitalists have sunk in $5 million or so, it looks like it’s good to go, but how do you get over this big valley where commercial and more standard investors will pick this up. And so in these pre-Incubator, these pre-commercial gaps, what are we doing…well, we have multiple Incubator rounds, and we’ve set off these rounds. We’re now going to rounds 6 and 7. These are SunShot Incubator rounds. This is the Soft Cost Incubator and so on. How successful have they been? Well, let’s just look at round 1 where we actually see what’s going on. These are some of the companies that have been in round 1. Not all of them will grow to be successful companies, but we hope some of them will, and some of them are still there getting investments, innovating. Let me just say that in the first round, we invested $17.5 million in that round of incubation, and then we see a follow-on private investment, and it’s $1.6, integrated $1.6 billion. So it’s highly leveraged money. And as I said, not all of it will succeed, but this is very gratifying, and we hope that—we’re seeing this in ARPA-E as well, a lot of the first round investments are growing. And in terms of dealing with the second one, much deeper, we’re starting a SUNPATH goal, again, very short two-year contract. We’re asking that companies, private sector, put in 75% cost share. We’re asking the maximum cost, the Department of Energy’s $50 million, with the idea of getting this going. We’re also looking at new financial models. Let me talk to you about a couple. There are financial, infrastructure-type banks that have worked very well in the world. In the United States, we have one, EXM and OPEC. They state, this is decades ago, the U.S. government gave them some money; it’s semi-autonomous, so they just, a bunch of smart people said go and loan this money out to stimulate, let’s say, exports or something that, for policies that we as country believe in. Loan programs have been attacked recently, and so then they have been setting their sights on OPEC. I was just talking to the head of OPEC about this, as I was actually trying to get him to come aboard the Department of Energy, and he said, well, they’ve finally decided they’re not going to kill it, because when they asked the Congressional Budget Office how much it would cost, it would cost them about $250 million a year to stop the program. It was making money. And in fact, many countries, dozens of countries around the world, if done right, you can actually stimulate investments, and it not only just goes around and around and around, it actually grows. And it really can partner with the private sector in a very effective way. And so all the charges about it…and private sector money don’t seem to be there. So this is one of the things. And another very simple idea—master limited partnerships. If you’re wealthy, you can form a partnership, you can invest in a wind farm, or invest in something, an efficiency upgrade or you name it. A master limited partnership—and with a partnership, there’s no real corporate entity, so the investors invest in this, there’s a direct investment, and then the profits go directly back to the investors. And so the IRS says, if there’s a mimimus corporate entity, only 10% or less is in there, there’s no corporate tax. You get personal income tax but not the corporate tax. Master limited partnership allows you, the public, to invest in it, so it’s not only a bunch of richer people, but the actual public or pension funds, or—well, pension funds are rich people, sort of—but individuals, like you and, well, like me, and some of you, who will say, I’ll buy a share in this or that. And so, right now it would be great if we could have master limited partnerships in renewable energy, renewable energy projects. But we can’t. The areas where you can—the only areas where we can have master limited partnerships are in gas and oil. So this would be a nice thing to at least level the playing field, because that would draw in a lot more investment. So there are opportunities like that which we think are there. Installation. Even if we gave you PV modules for free, I’m quoting myself. [laughter] Anyway, it’s my favorite author. [laughter] Even if we gave them to you for free, the residential, commercial, and utility installation costs are quite high, and in many instances they could be half, in residential they can be half, so what do we do in order to actually go—the module costs are going to go down. We don’t actually have to do much. We think the module, our target three years ago was that the module costs will be 50 cents by the end of this decade. I think we’re going to make it. [laughter] But what about the others? And so we’re now beginning to concentrate on this balance of system cost, including installation. And so, you know, the installation is pretty expensive. It’s very complicated; it’s confusing. They’re different for every city, municipality, state. There are different things to fill out. Very high permit fees. Some municipalities think this an income-enhancing venture. And so, you’ve got a lot of paperwork that translates into a lot of money. Then you have to stand in line for, to submit the application. An experience we all know about in other parts of the government, both state and local and federal. And you have to wait for an inspection. And so just to remind you of standing in line, these are individuals standing in line in front of a state department building for a visa. So instead of just email, you know, you certainly have to stand in line, I guess, to say that you’re you, but sometimes we think these lines are there to make you wait. Anyway, you can do a lot to decrease this. Let me give you—oh, this is one hypothetical city’s process. Now, this is the thing that brought down my computer. It’s their flowchart. [laughter] What I was trying to do in this flowchart is expand the flowchart, turn it into a picture, then expand it, and just turning this thing into a picture brought down the computer. This is the beginning of the flowchart of what you need to do to apply for a permit to get solar installed on your roof. That’s part 1 through 15, and that’s part 15 through 30. If the flowchart can bring down a computer, what do you think it can do to the applicant? This is a very, very scary process. This is the procedure you have to go through in a major East Coast city. Let’s compare that with Germany. You sign a contract with an installer, you register the PV system, you’ve got to register because you want to know—the system’s got to manage two-way flows. But this is one page, and it can be submitted online in 15 minutes. All right. And so, as long as the—and if the housing structure is built to code, there are no permits filed. And in many municipalities they require that there is a detailed roof inspection, and then after it is installed, another roof inspection. Okay. So what we’re doing in our Rooftop Solar Challenge is right now we count over 18,000 local jurisdictions with different PV permitting requirements, over 5,000 utilities implementing the interconnections, and we’re trying to consolidate them to just 22 teams with a minimum population of half a million, to consolidate. The solar panel in California and New Jersey are the same. All the forms are very different. And so the question is can we actually get a consolidation of this and make it much simpler, and make the application online. Let me leave you with this image. This is my second to last slide. This is someone installing solar on a rooftop. He’s—this is a good picture because he’s all tied in there, so he doesn’t fall off. Good. Now, if you think about what are the dangers of installing on a rooftop, well, you don’t want someone clomping around; that will induce a leak in your roof. But if you train people properly, you can get them to do that. Okay, another thing is you want to minimize roof penetration. That’s some of the things you can design in, and as you go to lower and lower modules, that’s going to be happening as well. But if you consider the dangers of that, versus the danger of installing a gas water heater, or recently in our home we installed a tankless water heater. The tankless water heaters, there’s no reservoir, so it’s more efficient, but it’s a much more powerful gas burner. And if you think about this, you don’t have to stand in line for a permit. A plumber comes and does it, a licensed plumber. And it doesn’t have to be inspected. And guess which one’s more dangerous? You know, a gas water heater, and a tankless water heater, you can have a leak, and you can have carbon monoxide poisoning. You can have a leak and you can have an explosion. All right? You can have a leaky roof, but that should be covered by the warranty of a solar rooftop installation. So we need to get into the framework where installing a solar rooftop is like installing a dishwasher or solar water heater, as long as you have a roof that meets code, which should have been done when you bought the house. All right, so, those are some soft costs. Let me leave you with this. There was a word on soft costs at an MIT energy conference, and I like this: unlike physics, where we can fundamentally figure out the upper limit for efficiency of solar cells, there is no such limit to bureaucracy. [laughter] There’s no such lower limit. So we in the Department of Energy are trying to help figure this out, but in the end, it’s going to be all the stakeholders, collectively, that will make this happen. The balance of systems costs are about 60, 70% of the cost now of rooftop installation. All right. So focus on that. And as the modules go down, they’re going to go down another twofold, and they’ll be 75, 80% of the cost. So this has really got to go down. So with that, I thank you for your attention, and sorry for the little screwed-up presentation, but that’s what happens when very complicated bureaucracies bring your computer down. Thank you.