R&D Pathways for the Future Energy System

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Thank you, President Farvardin, and distinguished faculty, alumni, guests and students. I'm deeply, deeply honored to be with you today, and really humbled to receive Stevens Institute of Technology's President's Medal later on. You know, to be included in the company, as Dr. Farvardin just stated, of so many inspirational innovators and leaders who have received this recognition, it's certainly gratifying to me and very, very humbling. And any acceptance within ExxonMobil, it's important to note that we do this on behalf of all of my outstanding colleagues at ExxonMobil Research and Engineering, a number that are here today, and alumni of ExxonMobil Research and Engineering, as well as ExxonMobil's 75,000 employees all across the world.

So, we're grateful for your honoring us today. And the opportunity to speak today with you is also very rewarding because without a doubt, Stevens is one of the premier research engineering and technology universities in the United States. In fact, there's a unique and very long and productive partnership that my company, ExxonMobil Research and Engineering, has with the Stevens Institute. As I did some research for this presentation, I found it very interesting that in the early part of the 19th century, the Stevens family, probably the first family of inventors in our country, really transformed the way our country worked, how we travel, and how we moved goods.

They developed an impressive array of technological innovations, things like steam boats, locomotives, railroad tracks and much, much more. In fact, Colonel John Stevens, the father of the institute's benefactor, Edwin Stevens, was even awarded one of the very first-ever patents from the U.S. Patent Office. That was way back in 1791, for a new steam boiler. Today, nearly 250 years later, graduates of this university that bears the Stevens family name are working at ExxonMobil to transform the way we work and the way we live in the 21st century.

In fact, I've had the privilege of working for, and with, a number of Stevens graduates in recent years, and I'm continually impressed by their creativity, their ingenuity and their passion for science, their passion for research, attributes and skills that were shaped by this university and its outstanding professors and programs. Let's give them a round of applause for the work they do.

This picture here is a photo of our primary research facility in Clinton, New Jersey. It's about 50 miles west of here. And we are working to unlock the solutions to the world's energy future. We have roughly 300 Ph.D.s, over 400 labs, 90 pilot plants and about 800 acres that you see here, and we continue to build on ExxonMobil's long, long history of innovation and technological advancement. Just like the Stevens family, who looked at their rapidly changing world and saw how new ideas could drive industry, and the progress of human life, we, too, see a world that needs innovation. And for us, the central question is this: How can we meet the growing needs of an expanding global population that wants to live a better quality of life, but do so in an environmentally responsible manner? At ExxonMobil, we call this the dual energy challenge, and it's a very complex task with no easy answers.

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But let's start to look at it in a little bit more detail. Consider that by the year 2040, just two decades from now, the world's population will be over 9 billion people. That's up from 7.5 billion people today. And many of these new global citizens will be living in developing countries in emerging economies. This is where people are still starving and striving for the modern conveniences that all of us take for granted every day, things like electricity for lights, air conditioning in the summer, heat for cooking and for warmth, refrigeration for food safety, fuel for transportation — the benefits we could mention and consider are practically endless.

Today, according to the International Energy Agency, more than 1 billion of that 7.5 billion people do not have access to electricity, and more than 2.5 billion people lack modern cooking fuels, and they rely on unsafe methods that are linked to close to 3 million premature deaths every year by living in indoor air pollution. That's tragic, and it's entirely preventable. Many of us rarely stop to think about how much we rely on energy each day. So, take a minute. Let's consider how we would get through our days without transportation to get to this event today, and without food, medicine, clothing and other vital goods.

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How would you do without Amazon shipping those packages every Christmas to your door? And, by gosh, what would we do without charging our iPhones every day? What a world that would be. And throughout history, it's true that access to reliable and affordable energy has played a vital role in supporting prosperity and enhanced living standards around the world. And you can see that in that chart by some of the countries mentioned there. However, at the same time, meeting growing energy demand for the modern world needs to be done in ways that reduce potential impacts on the environment, including those related to air quality and the risks of climate change.

Now, each year, ExxonMobil completes a long-range energy supply and demand forecast. We call it our outlook for energy. And that outlook for energy and several other similar studies around the world forecast that global energy demand will grow by about 25 percent over the period from the present day to 2040, and that's even with extraordinary increases in energy efficiency. It's difficult to comprehend the scale and the significance of what a significant statistic that is. In 2016, each and every day, people around the world consumed the equivalent of 280 million barrels of oil a day. Think about that number — every day, 280 million barrels of oil.

And it takes all major energy sources to meet this demand: oil, natural gas, nuclear, coal, large-scale hydro power and, of course, renewables, such as wind and solar power. And by 2040, however, the world's going to need nearly 350 million barrels of energy-equivalent products each and every day. That's 65 million more each and every day. And as our energy needs expand significantly, you can see on this graph on the right, that global CO_2 emissions are also expected to rise. But notice it's much, much less than 25 percent. The increase is expected to come entirely from developing countries that are not yet part of the OECD.

In 2004, you'll notice on this graph that CO_2 emissions from those non-OECD countries surpassed those from developed countries in North America and Europe. In the years ahead, we would expect that trend will continue, with population growth, but more importantly, people's pursuit in emerging economies to live a higher quality of life. They live that higher quality of life by using energy each day like you and I do. As you can see in these graphs, the emerging economies' pursuit for this higher quality of life has already begun. And by 2040, countries with emerging economies will account for about three-fourths of the world's CO_2 emissions. So, exactly what emissions are increasing?

There are three major areas of use, or what we call sectors, that drive emissions growth. The first sector is electricity generation. It's the single largest driver of energy demand, and ultimately, emissions. In 2040, we expect we'll account for about 40 percent of the global energy-related emissions. The second category is the industrial use of energy, accounting for a little more than 25 percent by 2040. And the final sector where we will see modest emissions growth is in transportation. That, we expect, will be driven by substantial increases in the number of passenger cars in places like China and India, but also the expansion of commercial transportation activity — that includes rail, marine, aviation and heavy-duty truck transportation.

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As I said in President Farvardin's office today, you could just see this all around you. Marine activities on the river, traffic all around, airplanes coming into the New York metro area — a great example of the energy that's there all the time. In terms of transportation, though, it's quite important to note that the light-duty transportation, or personal vehicles, makes up only about 40 percent of the demand for all transportation liquid fuels. Now, given these realities, our dual challenge is clear. We must find ways to continue to produce the vast and growing amount of energy that the world needs, while at the same time reducing CO_2 emissions across three of these high-use sectors.

And it's tremendously important to focus on all three sectors, because eliminating emissions entirely from electricity generation, which gets a lot of focus today — that won't be enough to achieve a 2° Celsius pathway. That's the objective that's laid out by the UN framework convention on climate change. We need to work on all three sectors. So, this chart helps provide some context for the projected progress of CO_2 emissions, and it's based on, again, our 2018 outlook for energy. You can see on this chart, from 1980 to 2015, efficiency improvements were our primary way that we reduced the growth in energy CO_2 emissions.

You can see how that energy efficiency came down that vertical axis. And despite the gains that we achieved in efficiency over 35 years, total emissions from energy-related sources still rose from about 18 billion tonnes in 1980 to about 33 billion tonnes in 2015. That was all due to population growth and, of course, increasing modernization in the developing world. From 2015 to 2040, with an expected doubling of energy efficiency and faster growth in renewable electricity generation, world experts predict global energy-related CO_2 emissions growth will slow and peak before 2040.

Now, this purple line illustrates a range of 2040 performance levels that reflect combinations of energy efficiency improvements, and/or de-carbonization improvements that, if reached by 2040, would indicate that we would be on a 2˚C pathway. So, even with significant progress from today to 2040, and it's important to note that the world's been making progress all along, we and several other studies forecast that we still have a significant gap to reach the potential 2˚C pathway. And you can see that gap from 2040 to the purple line.

In other words, we still need to move closer to this line on the chart, and still need to reduce the carbon content of fuels, and increase our efficiency. Note the indicator to the right-hand side of a doubling of low greenhouse gas electricity. We'll look next at the investments that are needed to achieve this.

I think you can see the magnitude of the challenge here. The table on the right shows the investment scenarios needed in the electricity generation sector to meet a total emissions reduction of 50 percent. And you can see by comparing the middle column with the right-hand column that it indicates the scale and also the change of pace needed when using just solely existing technologies.

An important area of focus also is to identify practical and cost-effective solutions to reduce emissions. These costs can vary quite substantially, as the chart of mitigation shows. And that's why it's important to identify the most practical and cost-effective solutions. We find that markets are very, very helpful. When costs are competitive, the decision for consumers to use a different kind of energy is much, much easier to make. You can see this on the graph. By shifting to natural gas from coal in power generation on the far left-hand side, that's relatively inexpensive and can deliver significant CO_2 emissions reductions.

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And we've seen that in the world, as coal plants are being replaced by gas-powered plants. Also, in the middle of that graph, you can see that on-shore wind and utility solar costs have dropped substantially. And now they are practically aligned from a cost standpoint with gas-fired power generation combined with carbon capture and storage. So, our desired way to successfully curb emissions across the three sectors I mentioned earlier, without disrupting the economic and the social progress of countries all around the world, is to develop new technologies, new technologies that can be deployed affordably at scale.

And while some of the most promising advancements aren't quite commercially viable, we are working hard to bring them from the development stage to reality, and our team is uniquely qualified to do this. That's because at ExxonMobil, we've been involved in research and development of cost-effective emissions solutions for many years. For example, we've long worked to mitigate CO_2 emissions in our own operations. We've improved our efficiency at drilling sites, in our refineries, and all across our petrochemical facilities.

Recently, we undertook a company-wide campaign and commitment to reduce our flaring and venting — that's the burning or the release of natural gas from a drilling site, usually done for safety reasons — and we've committed to reduce that by 20 percent. We are making progress. Our XTO Energy business unit has reduced energy emissions by about 9 percent since 2016. So, not quite halfway there. We've still got tons of room for improvement, and we're actively, actively working on the issues.

We also want to provide a range of solutions for our customers. That's providing clean-burning natural gas as fuel for power generation, and industrial uses as well. Chemical products, like high-strength plastics that can replace steel, wood and other infrastructure materials — these things make automobiles lighter and more fuel efficient. And we also produce high-value fuels and lubricants that reduce energy use and, of course, the resulting emissions. As a company, we're actively engaged on climate change policy.

We're trying very hard to advance the climate science to underpin sound policy, and working with a wide range of stakeholders to provide solutions. But most importantly, we are investing in research and development of several promising next-generation, lower-carbon technologies that can benefit all of the three major energy-intensive sectors I showed you previously. For example, we have an effort called process intensification. That's research that could lead to a significant reduction in the amount of energy we need to use in our refineries and our chemical plants to make the products that we do.

And we also have research into affordable, effective techniques for carbon capture that could both benefit power generation facilities and industrial facilities. And we're continuing to make good progress on next-generation biodiesel fuels for transportation. We strongly believe that our capabilities, our knowledge, our expertise and our experience are better suited to developing these new, next-generation technologies rather than repeating what other companies are already doing in wind, solar, ethanol development for the first-generation technologies.

I'll talk in more detail about each of these new second-generation technologies a little bit later, but let me just add one more slide that talks a little bit more about the background on ExxonMobil's involvement in research and development over the years. We call this slide our history of innovation, and you can see we've been a leader in developing new technologies and products that have delivered significant benefits to the world. This is the reason that I'm confident, and my peers here with me today are confident, that we can successfully tackle this dual energy challenge.

We know how to take an idea from someone's imagination, take it into the laboratory, take it into a pilot plant, and eventually scale it up to be a global business in a global marketplace. The energy industry has faced some significant challenges before, and we've always turned to new technology to solve those challenges; technology that's fueled by human innovation and is really the best solution in the long run. In fact, we, ExxonMobil, at its heart, we are a technology company.

We've been at the forefront of many technologies you see on this page that have allowed energy to be delivered in a safe, affordable and a reliable manner for many, many years. And many of the tools that we use today and the products we create were unimaginable just a few decades ago. Let's highlight some of these. In the 1940s, we developed a process to make high-octane fuels and synthetic rubber tires, which were critical components in winning World War II. In the '50s, we used then-state-of-the-art computers to simulate reservoirs more efficiently and effectively to produce more oil.

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We also produced the first synthetic catalyst to make high-octane fuels, and this was the genesis of several catalyst innovations that continue even into today. The 1960s and 1970s brought plastics and the first synthetic motor oil, called Mobil 1. We were one of the pioneers that actually explored the fundamental science that enabled the lithium ion battery, and we dropped it a few years later. What a shame. Lithium ion batteries are still the leading battery in use today. And we led the way in developing low-sulfur fuels with greater improved air quality as well.

At the turn of the century, in 2000, the Hoover Diana platform in the Gulf of Mexico achieved many world and industry firsts. It included setting a water-depth record at that time for a floating drilling and production platform, and it also used sub-sea tie-backs. We continue to this day to develop specialty plastics that can provide tougher, thinner and lighter-weight packaging films that reduce energy and reduce waste. And today's computers have allowed us to set a record for the number of processors used in modeling a reservoir, and hopefully all of you realize, because you're buying it, we now have Annual Protection Mobil 1.

These are examples of some of the breakthroughs that our internal research and development has created over the years. In short, science, engineering and research underpin everything we do and everything we've done, and our business thrives thanks mainly to the innovation and ingenuity of our people, and many of these are Stevens Institute of Technology people.

This is a slide of our R&D operations and how we will progress the technologies I mentioned earlier and that we'll cover in a little more detail. This chart is an interesting chart because it shows how our research organization is structured. We're structured around scientific capabilities rather than ExxonMobil business lines. You can see four key technical capabilities here: physics and mathematics, process engineering, materials and, of course, hydrocarbon and emerging energy. We believe these scientific capabilities are the most critical to help solve the dual energy challenge, and that's the primary focus today of our R&D work. The highly skilled, capable women and men working on these teams are supported by the most sophisticated tools our industry can buy.

That includes super-computing capabilities. We're starting to get into quantum computing capabilities, things like a helium ion microscope, and on and on and on, much, much more. We're committed to maintaining really high levels of investment in our laboratory facilities in Clinton and all around the world. And through the years, we've learned a key lesson: That's if we can get the fundamental science and the engineering right in the lab first, that'll have a direct correlation to be able to deploy and scale technology in the field, where it really counts.

But what also is very, very important is that we don't work alone. Scientific collaboration we do with more than 80 leading universities, and many other government and industry groups. That allows us to share ideas, share our insights and collaborate with some of the world's leading scientists and researchers. It's an ideal way to spur innovation, creativity, and, of course, avoid any duplication of effort. And you can see our people are pretty prolific. Last year, for example, we had papers published in over 90 peer-reviewed publications.

We also collaborate with others in our industry. Another example is that we are one of 13 leading companies involved in the Oil and Gas Climate Initiative. That's a group that's working across a number of key fronts to reduce carbon footprints.

So, as I promised, I'd like to provide you now with some more details on the R&D pathways we are working on to lower CO_2 emissions and improve efficiency across the three primary sectors of energy usage. These are the R&D pathways we are applying our unique technical capabilities and trying to innovate and produce second-generation technologies.

> **"To put it as simply as I can, we need to take the energy out of making energy."**

I'll start with our work to lower emissions at industrial facilities first. I don't think it's any secret to anyone in the room here that producing fuels and chemicals requires large, large amounts of energy. And also, complex capital-intensive infrastructure. Today, our industry primarily starts with raw material — crude oil. It contains a distribution of different hydrocarbon molecules. We then separate and convert those crude oil molecules into other molecules that are eventually treated and can be used as a finished product. Today's technology for separation is primary distillation.

We take advantage of the different boiling points of hydrocarbon molecules to separate them. Distillation includes a lot of heating up, cooling down, heating up, cooling down, sometimes under very high pressures. All of that heating up, cooling down and pressuring molecules uses a considerable amount of energy. The conversion of different types of hydrocarbons also uses high pressure and high temperatures, combined with catalysts and unique process configurations that are energy intensive. So, to lower industrial emissions, we must increase the efficiency of those basic separation and conversion processes.

To put it as simply as I can, we need to take the energy out of making energy. And that's what we're working to do. So, this slide with the figures at the bottom depicts producing natural gas as ethane — performing some chemical conversion, using novel materials and new, novel reactors where we're going to build up methane into large molecules.

Separations will still be required, and our researchers have found that by using innovative membranes that you can see on the right-hand side, or specialized filters, along with more efficient process configurations, we can lower the temperatures needed for separation, and significantly reduce the amount of energy used.

We're also studying other areas of process intensification, basically trying to improve the design of our conversion infrastructure to maximize output while also minimizing the amount of energy needed. And by studying and working with universities and adjacent industries that deploy some of these modular manufacturing solutions, we are pursuing today a very large number of current opportunities. It's important to note that separation and conversion will always be the core of our business and how we produce the fuels and the chemicals that the world needs.

But there is significant room for improvement, and our focus is on transformative solutions for our future development.

Next, carbon capture, utilization and storage. We believe carbon capture can play a very important role in helping us reduce emissions in the long term. In fact, every study that models a 2˚C pathway incorporates large-scale carbon capture as a necessary strategy. Today, we are an industry leader in carbon capture and storage. In fact, we are responsible today for about a quarter of the CO_2 that's captured and sequestered around the world.

Unfortunately, there are some key, significant barriers to widespread use. The current technologies in place today are complex processes that require a lot of additional energy. As an example, if you wanted to capture carbon for a world-scale-size large electricity generation plant, it would require about 20 percent more energy of the output of that plant to be successful. Said another way, if the power plant used its own power that it generated, it would need to be de-rated by 20 percent to capture the CO_2 emissions that it currently produces.

But what if — what if we could capture CO_2 from electricity and industrial facilities, both new facilities and existing facilities, and in the process, produce more energy while capturing those CO_2 emissions? That would really be transformative. The schematic on the bottom shows how we're using a fuel cell to concentrate CO_2 and generate a small amount of electricity through the electric chemistry in the fuel cell. Once again, our collaborations are very, very critical. We're working with companies like FuelCell Energy, as well as research institutes in the Netherlands, like the ECN, and leading universities, such as University of California at Berkeley, to develop the materials involved in unique process configurations.

In particular with fuel cell energy, we're working with them to understand the fundamentals with an eye towards longer-term, large-scale deployment. The good news here is that this process, this fuel cell process, will work both on electricity generation and on industrial CO_2 emissions. That means we've got a portfolio of options to progress our first commercial scale, where we will test the fuel cell technology in a commercial plant. And we plan to do that in the next couple of years. We're also working on other novel materials and processes to concentrate CO_2.

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And in the utilization and storage of carbon capture, it's important to find other valuable uses for carbon dioxide, since at some point, we'll be challenged to concentrate all of it and sequester it in the ground. All of these are not very simple tasks, and we still have a lot of work to do on the research front to make these ideas a reality. And we continue to look for additional ideas to add to our portfolio.

Finally, let's talk about transportation, that third sector. Now, our outlook forecasts that light-duty or personal vehicle transportation will continue to see increasing electrification. All of us have seen hybrid vehicles and electric vehicles continue to grow in popularity, and costs have come down, re-charging options have improved, and their market share, we expect, will increase accordingly. However, you heard me mention before that only about 40 percent of liquid transportation fuels go into the light-duty transportation. We will still need liquid transportation fuels for many, many decades into the future. And, again, these are commercial fuels for heavy-duty transportation. It includes trucks, railways, airplanes, marine vessels — where we will still need a liquid fuel that's portable, that's high density, and that has a lot of energy in it.

Biofuels have the potential to provide energy density required for commercial transportation, and our challenge today is to improve on these current technologies to be able to scale up biofuels to be more reliable, affordable and sustainable that can meet future demands. Today biofuels are primarily ethanol. It's largely made from food sources such as corn or sugar cane, and that limits their overall scalability. We believe that in order to achieve large scale, biofuels should not have to compete with food-sourced crops for water, for land, or for other resources.

Our work is focused primarily on next-generation biodiesel fuels that are either based from algae or from cellulosic materials, plant materials. Algae has multiple benefits here. They're fast growing, they actually thrive in brackish water, they absorb CO_2 and they're a good fit with the lipids or the fat that they produce to drop into today's commercial fuel infrastructure. And biomass from crop residue, things like stalks, leaves and husks left over from the production of corn, is also a very promising source in cellulosic biodiesel.

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Again, we're working with leading universities and companies, like Synthetic Genomics, the renewable energy work group, and Clarion, making great progress in both algae-based and cellulosic biodiesels. We're really excited about the progress being made for both of these biodiesel technologies. Fundamentals are driving our research, and this recent progress in both technologies is driving our enthusiasm. We set an aggressive target to have the technical capability to produce 10,000 barrels per day of algae biodiesel by 2025.

Being able to produce these larger quantities affordably and sustainably at scale is still likely a couple decades away. But recent results give us reason to believe that biofuels have a future in our energy mix.

So, at ExxonMobil, we don't believe that economic growth and environmental protection have to be mutually exclusive. We believe that we will need to find, produce and deliver reliable, affordable sources of energy that the world will need, and do so while producing significantly less emissions.

What it will take, however, is human ingenuity, new ideas, new ways of thinking, powered by technology, by research, by development, ideas that can transform our energy mix and ensure that people all around the world have access to the prosperity and the benefits of energy that support modern life. And it will also take significant collaboration between industry, academia and others with valuable knowledge and valuable capabilities to develop the technology solutions to the issues we face today.

So, in closing, I want to issue a dual challenge of my own to all of you that are here today. Too often we think of technology and innovation in terms like "what's that new app that I want to download to my phone?" There are more challenging technology and innovation challenges out there. These are very real, very significant challenges that are waiting to be solved by people with scientific and engineering rigor and a passion to help change the world, just as the Stevens family did so many years ago.

Our industry is hungry for these kinds of people who can think critically about the growing need for affordable and reliable energy, all forms of energy, and be creative in developing solutions of how to produce them — people who aren't afraid to roll up their sleeves, put in the hard work to find ways to meet the world's energy needs, while at the same time reducing emissions. Our team is pioneering new technologies and processes that will deliver tangible, much-needed benefits for our world and for our planet.

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And, as I said earlier, some of those individuals got their start right here. The education and the experience that you provide here at Stevens Institute that the students in the audience are fortunate to receive is vitally important to my company, to ExxonMobil, and to our entire industry and the world. If you really want to change the world as a professor, a graduate student or a student, join the effort to solve the dual energy challenge. There are billions of people around the world, as I mentioned earlier, that really need our help.

And if you have other dreams or other aspirations, by all means, reach for the stars. I wish you much success, although I'm pretty confident that you'll do great, because Stevens people have a long tradition of making a real difference no matter what their passion is. But, by the next time you see, you hear, or read a discussion about energy and climate change — that's likely to be pretty soon, the way the world works today — I challenge you to remember at least some of what I shared with you today and recognize that the energy industry understands the issues at stake, and we are committed to find solutions. Again, thank you so much, President Farvardin, and thank you to everyone here at the Stevens Institute of Technology.