**The Grand Challenges of the 21st Century**

Prepared remarks of Tom Kalil at the Information Technology and Innovation Foundation

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Good morning. Today I am going to be talking about Grand Challenges – ambitious yet achievable goals that capture the public's imagination and that require innovation and breakthroughs in science and technology to achieve.

Some historical examples of Grand Challenges are President Kennedy's call to put a man on the moon or the Human Genome Project. More recently, we have seen decentralized, bottom-up efforts as well. Jimmy Wales defined the mission of Wikipedia as giving "freely the sum of the world's knowledge to every single person on the planet in the language of their choice." Today Wikipedia has almost 20 million articles in 282 languages and 365 million readers.

I want to explore the following questions:

- What role do Grand Challenges play in President Obama's innovation strategy?
- What are the attributes of a Grand Challenge, and why are Grand Challenges important?
- What are some examples of Grand Challenges that deserve more attention?
- How could we significantly increase the number of individuals and institutions that are involved in identifying and pursuing Grand Challenges?

**The Role of Grand Challenges in President Obama's Strategy for American Innovation**

President Obama's Strategy for American Innovation has three elements: investing in the building blocks of long-term economic growth such as R&D, education, and infrastructure; creating the environment for private sector investment; and harnessing innovation to address national priorities in areas such as health, energy, and education. One component of the President's national innovation strategy calls for the pursuit of Grand Challenges, but the strategy supports many other approaches as well. For example, support for curiosity-driven research is critical, both because expanding the frontiers of human knowledge is an end in itself, and because it leads to benefits that we could never have predicted. Studying the bioluminescence of jellyfish does not sound very practical, but it led to the discovery of green fluorescent protein, a key tool in biological imaging.

A number of agencies are supporting Grand Challenges related to their missions. The Department of Energy, for example, is backing several Clean Energy Grand Challenges, including "SunShot" – an initiative to make solar energy as cheap as coal, and "EV Everywhere"

– an initiative to make electric vehicles as affordable and convenient to own as today's gasoline-powered vehicles.

USAID and its partners have launched several Grand Challenges for Development, including "Saving Lives at Birth" – designed to improve maternal and newborn health during the critical 48 hour period after birth by increasing access to primary health care for pregnant women and newborns by at least 50%, and "All Children Reading" – which seeks to dramatically increase the number of children in low-income countries who leave primary school with basic reading skills.

DARPA and NASA are supporting a study of a 100-Year Starship to understand what it would take – from an organizational, technical, sociological, and ethical perspective – to send humans to another star.

As one of many tools to address Grand Challenges, the Administration is also encouraging agencies to increase their use of incentive prizes to set and meet ambitious goals. Incentive prizes have a long history of catalyzing breakthroughs. In 1714, the British government offered a prize of £20,000 to the person who found a way to accurately determine a ship's longitude. Charles Lindbergh won the $25,000 Orteig prize for making the first nonstop flight from New York to Paris. In recent years, the use of incentive prizes for open innovation by the private sector and philanthropies has increased dramatically as companies and donors have come to understand the power of this tool.

Incentive prizes work as one tool to address Grand Challenges because they shine a spotlight on an ambitious goal without having to predict which team or approach is most likely to succeed. Incentive prizes help us reach beyond the "usual suspects" to increase the number of minds tackling a problem, bringing out-of-discipline perspectives to bear and inspiring risk-taking by offering a level playing field.

The recent Wendy Schmidt Oil Cleanup X Challenge, supported by judging assistance from the National Oceanic and Atmospheric Administration and the Department of the Interior, set out a target of doubling today's standard for oil recovery by mechanical cleanup systems. After more than 350 organizations expressed interest in competing, 10 finalist teams demonstrated their systems in 54,000 gallons of oil at an Interior Department test facility. Seven of those teams exceeded the industry's previous best oil recovery rate in testing, and the winner almost quadrupled that standard with 4,670 gallons per minute oil recovery rate at 89.5% efficiency, an astounding feat given that teams had less than 6 months to develop and refine their systems.

Another recent prize was NASA's Green Flight Challenge that called upon aviation innovators to build and demonstrate a super-fuel efficient full-scale aircraft. The cash prize purse of $1.65 million offered by NASA attracted 14 teams, which collectively invested more than $6 million. In a historic achievement, the two winning teams exceeded the performance requirements by nearly a factor of two, flying more than 200 miles on the energy equivalent of just half a gallon

of gas, all while averaging 100 mph with two people on board. NASA further leveraged taxpayer dollars, by partnering with the CAFE Foundation, which invested over $1 million in rigorous evaluation and publicity – extending the impact of the prize. The high-profile demonstration of safe, low-emission technologies may spark a new electric airplane industry.

Incentive prizes are one of several powerful tools for working towards a Grand Challenge. I will address more mechanisms for contributing to a Grand Challenge later in my remarks.

**Attributes and Benefits of Grand Challenges**

As President Kennedy observed, "By defining our goal more clearly, by making it seem more manageable and less remote, we can help all peoples to see it, to draw hope from it, and to move irresistibly towards it."

Although there is no universally accepted definition of what constitutes a Grand Challenge, I want to focus on Grand Challenges that have the following attributes.

First, they can have a major impact in domains such as health, energy, sustainability, education, economic opportunity, national security, or human exploration.

Second, they are ambitious but achievable. Proposing to end scarcity in five years is certainly ambitious, but it is not achievable. As Arthur Sulzberger put it, "I believe in an open mind, but not so open that your brains fall out."

Third, Grand Challenges are compelling and intrinsically motivating. They should capture the public's imagination. Many people should be willing to devote a good chunk of their career to the pursuit of one of these goals.

Fourth, Grand Challenges have a "Goldilocks" level of specificity and focus. "Improving the human condition" is not a Grand Challenge because it does not provide enough guidance for what to do next. One of the virtues of a goal like "landing a man on the moon and returning him safely to the earth" is that it is clear whether it has been achieved. Grand Challenges should have measurable targets for success and timing of completion. On the other hand, a Grand Challenge that is too narrowly defined may assume a particular technical solution and reduce the opportunity for new approaches.

Finally, Grand Challenges can help drive and harness innovation and advances in science and technology. I certainly do not want to argue that technology is going to solve all of our problems. But it can be a powerful tool, particularly when combined with social, financial, policy, institutional, and business model innovations.

The identification and pursuit of Grand Challenges has a number of benefits.

Grand Challenges can catalyze innovations that foster economic growth and job creation, spur the formation of multidisciplinary teams of researchers, encourage multi-sector collaborations,

bring new expertise to bear on important problems, strengthen the "social contract" between science and society, and inspire the next generation of scientists, engineers, and entrepreneurs to work on hard and important problems.

Also, as various technologies such as bio, info, and nanotechnology become more and more powerful – the question "what should we do" is arguably as or more important than "what can we do." This is not primarily a technical question, it is a question that relies on imagination, creativity, values, and our individual and shared views on how we define progress.

**What are some Grand Challenges that deserve more attention?**

Although a growing number of organizations are beginning to embrace ambitious goals, there are many Grand Challenges that deserve more attention relative to their importance.

For example, what if we could use advances in learning science and technology to dramatically improve education and training?

DARPA and the Navy are collaborating on a program called Education Dominance, whose goal is to allow military personnel to acquire a new technical skill in months, not years.

Preliminary evaluation of the program by the Institute for Defense Analysis suggests that they may have succeeded in developing a digital tutor for IT systems administration that is as effective as a personal tutor. After using the digital tutor for a few months, new Navy recruits are outperforming Navy IT experts with 5-7 years of experience on real-world trouble tickets.

If these results are confirmed, and if they can be replicated for academic subjects such as 8$^{th}$ grade math and additional technical skills that are valued by employers, this would be a game-changer.

Researchers are exploring other approaches as well, such as online courses that get better the more students use them. By instrumenting the learning environment, we can provide more rapid feedback to learners, teachers, course designers, and learning scientists. Researchers can also create a virtual learning laboratory with hundreds of thousands of participants. As opposed to having theoretical debates about the best way to teach a given subject like fractions, we can conduct many low-cost fast experiments, in the same way that Internet companies use A/B comparisons to continuously improve their services.

We also have an exciting opportunity to give every child the ability to become a Maker and to have the experience of designing and building something that they find personally meaningful to them. As information technology has evolved from the mainframe, to the personal computer, to the computer that fits in your pocket, new technologies such as 3-D printing, low cost machine tools, and open-source hardware are enabling personal fabrication. These tools and interaction with the Maker community could significantly increase the number of students who get interested in STEM.

There is a huge gap between the potential of learning science and technology and what we actually observe in the classroom and the workplace. One of the reasons for this is that we invest less than 0.2 percent of K-12 expenditures on R&D. That is why the Administration is committed to creating a DARPA for the Department of Education. And it is why we announced the creation of a League of Innovative Schools – a coalition of school districts and virtual high schools that plan to use their purchasing power to encourage learning technologies that significantly improve student performance.

**What are the elements of an "all hands on deck" approach to Grand Challenges?**

In closing, I want to offer some suggestions on what President Obama calls an "all hands on deck" approach to the identification and pursuit of Grand Challenges might look like. This is important because many of these challenges will undoubtedly require collaborations that span sectors, industries, disciplines, and boundaries.

I would like you to imagine a world in which more individuals and institutions are involved in pursuing or supporting a Grand Challenge and a world in which these challenges play a more prominent role in our culture and in our public discourse.

This summer, the Office of Science and Technology Policy will convene a White House event to celebrate and honor individuals and organizations that have embraced a Grand Challenge and to inspire more people to do so. We see important roles for many different types of organizations.

*Government agencies*: In the same way that the Department of Energy is pursuing SunShot to make solar energy cheaper than coal and DARPA is developing prosthetics that might allow a veteran that has lost his arms to play the piano again, more agencies could be explicit about setting ambitious and important Grand Challenge goals and then convening funding and private sector commitments to work towards those goals. Governments can also collaborate on international Grand Challenges – particularly as they relate to global development, global health, and global public goods.

*Philanthropists and foundations*: Philanthropists and foundations could organize some of their giving around Grand Challenges. The Gates Foundation is funding Grand Challenges in Global Health, such as vaccines that do not require refrigeration and a single crop that provides all of the nutrients needed for a healthy diet.

*Research universities:* Some universities such as Duke and USC have joined with the National Academy of Engineering to launch the Grand Challenge Scholars Program. This program enables engineering students to organize their coursework, research, service, international studies, and experiential learning around a Grand Challenge. Universities could extend these programs to interdisciplinary teams of students from all disciplines and emphasize ambitious Grand Challenges in their capital campaigns.

C*ompanies*: More companies could identify a Grand Challenge they can contribute to. IBM has driven advances in computing and AI by beating Kasporov at chess and Ken Jennings at Jeopardy. Google has recruited Sebastian Thrun, the Stanford researcher who won DARPA's Grand Challenge competition for unmanned vehicles, and is making significant investments in self-driving cars.

Additional companies and philanthropists are getting involved by sponsoring a major incentive prize. Progressive Insurance, for example, sponsored the $10 million Automotive X Prize for the teams that could build a car that gets the equivalent of 100 miles per gallon. We will hear today from Rick Valencia about how Qualcomm is sponsoring a $10 million Tricorder X Prize to develop a portable wireless device that can monitor and diagnose a broad range of health conditions.

Larger companies could also partner with start-ups that are pursuing ambitious goals by serving as early customers and providing capital, mentoring, and milestone-based payments.

*Investors*: Some venture capitalists are investing in startups that are pursuing Grand Challenges. The Founders Fund, for example, is focused on "smart people solving different science and engineering challenges," such as lowering the cost of space launch costs by a factor of ten; dramatically reducing the time, cost, and uncertainty associated with the drug development process; and machine intelligence that can replicate components of human intelligence. Flagship Ventures is investing in a startup called Essentient, which has stated that its technology could provide enough protein for everyone on the planet in an area the size of Rhode Island.

Financial innovations could also increase the extent to which institutional investors could help address Grand Challenges. Andrew Lo and his colleagues at the MIT Laboratory for Financial Engineering have developed a proposal for a $5 - $15 billion cancer mega-fund that they believe would generate attractive returns for pension funds and life insurance companies and would significantly increase the capital available to find cures and better treatments for cancer.

The field of "impact investing" is creating opportunities for investors to back firms and social enterprises that can generate both financial and social returns.

*America's storytellers:* Media companies and America's storytellers could help elevate the role that Grand Challenges and innovators play in our culture. Dean Kamen observed that in a free society, you get what you celebrate. How many Americans can name a living scientist or engineer? What could Hollywood and our creative talent to do help make engineers and entrepreneurs the rock stars of the 21st century?

We should also recognize the important role played by science fiction. There are many instances in which science fiction – from Arthur C. Clarke's communications satellites, to the Star Trek replicator, to the user interface in the Minority Report – has inspired scientists and engineers. Things that may seem like science fiction one day – like a cloak of invisibility or a tricorder –

can rapidly become science fact. That is why I am delighted that Neal Stephenson and other science fiction writers have started a project called Hieroglyph to depict future worlds in which Big Stuff Gets Done. We used to say, "I'll believe it when I see it." But increasingly it is the case that, "I'll see it when I believe it."

In conclusion, I ask you: What Grand Challenges do you believe deserve more attention? I encourage you to share your feedback and ideas with me and via email to challenges@ostp.gov. What Grand Challenges are you motivated to work towards?

Thank you.

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# WHAT IF?

## Clean Energy

Solar cells compete with coal and natural gas generation before the end of the decade

Building energy use is cut in half within a decade

Buildings and industries continuously monitor performance, diagnose problems, and summon repair crews before problems become serious

Meters provide continuous detailed information about the energy consumption of every device and provide users information only when and where it can be useful

Utilities can make as much money saving a kilowatt hour as generating a kilowatt hour

The equivalent of Saudi Arabia's oil production is replaced by biomass

Nuclear reactors are safe, affordable, and easy to site almost anywhere

Electric vehicles travel for 300 miles, and "filling up" with electrons is cheaper than gasoline at $3 a gallon

We make 10 high-volume products that are "carbon-negative" – turning carbon dioxide into a valuable raw material as opposed to pollution

Business travel miles are cut in half by the use of virtual presence technologies

Non-food crop can be used to produce liquid fuels, electricity, animal feed products, and industrial materials anywhere in the country, tailored for each local area

We can eliminate radioactive waste from nuclear power generation

Deep water wind farms on our coasts and great lakes that compete with coal and natural gas

Strong, lightweight materials now used only by NASA and the military cheap enough to use for cars, trucks, and wind machines

## Education and Training

A $100 e-reader can read a child 10,000 stories in the voice of their favorite celebrity, dramatically reducing the gap in vocabulary size between children from rich and poor households

*Thomas Kalil, prepared remarks at the Information Technology and Innovation Foundation, April 12, 2012, Washington, DC*

Every child has access to educational software as effective as a personal tutor and as engaging as the best video game

A digital tutor allows recent high school graduates to gain the skills and an industry-recognized certificate they need to increase their income by 50 -100 percent in 4 months

Individuals can find online education and training materials tailored to their exact needs quickly and easily

**Environment**

Microbes or nanotechnology lower the cost and time required to clean up waste by 50 percent

Millions of cell-phones with sensors that cost under a dollar help create a real-time "dashboard" for the planet

Industry and university researchers create green substitutes for dozens of the most toxic chemicals

All 10 million+ species on the planet are catalogued in a DNA library, enabling the developing of new products such as life-saving drugs

Green chemists can create plastics competitive at the commodity scale that require less energy to produce and, after serving their purpose, rapidly biodegrade to non-toxic materials

**Health**

Patients and healthcare providers have the technology, techniques and incentives to reduce the costs of managing major chronic diseases such as diabetes (or preventing them to begin with) by one-third

Patient information available where it's needed, in the form it's needed, wherever it's needed and safeguarded against misuse. Doctors and patients have access to automated analysis of potential mistakes such as drug interactions.

Smart anti-cancer therapeutics deliver drugs only to tumors, leaving healthy cells untouched

We can sequence the entire human genome in under an hour, delivering rapid personalized medicine

Regenerative medicine routinely replaces damaged tissues or organs – ending the agonizing wait for an organ transplant or repairing spinal cord injuries

We create therapies and vaccines for diseases in months, not years

We accelerate the availability of vaccines for AIDS, TB, and malaria by 10-20 years – diseases which kill 6 million people every year

People with prosthetic legs climb mountains and people with prosthetic arms play the piano

We inexpensively and accurately detect dozens of diseases with a breath, a saliva sample, or a drop of blood

Replacement cartilage is available and safe for treatment of osteoarthritis of knees and hips. People no longer need expensive and painful operations to replace worn joints, and older people can continue to exercise and be independent

Patients can access all of their medical records, get quick responses from providers to questions, and make their own appointments on line

Errors in patient care in hospitals have been reduced to 10% of their current rate

**Information Technology**

"Do what I mean" computing allows us to program computers and direct software agents using conversational English

Real-time speech translation allows us to talk to or chat with anyone in any language

Smart homes empower seniors to live independently for another 5-10 years

We extend Moore's Law (doubling computing power every 12-18 months) for decades to come, enabling us to put a supercomputer on a wrist-watch

Cyberspace has an "immune system" that rapidly and effectively responded to cyber-attacks, worms, and viruses

High-fidelity holographic video-conferencing dramatically reduces the need for air travel

**Manufacturing**

The US leads the world in producing batteries for electric vehicles, next generation lighting, solar cells, next generation heat pumps, blades and generators for wind machines

US firms define the state of the art in the next generation of manufacturing methods (bioprocessing, separations at room temperature, waste-free fabrication)

We reduce the time required to design, build and test manufactured products by a factor of 5, while dramatically increasing the number of product designers and entrepreneurs who make things

We put the tools to design and make just about anything (e.g. 3-D printers, TechShops, Maker Sheds, FabLabs) at the fingertips of every child

We create the foundation for a "bio-economy" that allows us to make dozens of chemicals without petroleum

Teams of workers and robots allow American companies to beat the "China price" for many manufactured products

**Nanotechnology**

Atomically precise manufacturing allows us to create materials that are stronger than steel and a fraction of the weight

**National Security**

American soldiers have dozens of "superpowers", including:

- X-ray vision and the ability to see around corners
- Spiderman's ability to climb up walls (a number of researchers have been looking at developing nanofibers that mimic the skin of a gecko)
- The ability to command dozens of robots – including flying robots the size of dragon-flies
- An exoskeleton that allows them to lift a truck
- A light-weight vest that stops armor-piercing bullets
- The ability to fight for a week without sleep
- Accelerated healing of battle-field wounds
- A cloak of invisibility
- The ability to incapacitate a large angry crowd without casualties

We can detect any IED from a distance of greater than 100 meters

Monitoring for nuclear security is so capable that the US and its partner nations can track (either cooperatively or non-cooperatively) the status of weapons-usable nuclear material and related activities at any location in the world

Our troops fight unconstrained by costly and dangerous oil supply lines, powered in the field by hyper-efficient solar cells, batteries, and fuel cells

**Small business/entrepreneurship**

Cities in all 50 states use "smart permitting" to allow entrepreneurs to start a business in a day

Students can play a multi-player game that gives them the skills they need to start their own business. Students that successfully complete the game are twice as likely to get financing and to ultimately launch a rapidly growing business.

College graduates choose to join innovative startups in greater numbers than those who go to work in finance or consulting

Startups have seamless access to government data, government-funded innovations, and government contracts

**Space**

We make Mars habitable using advanced biotechnology, self-replicating robotic factories, and an interplanetary Internet

Suborbital flight is as unremarkable as the DC/NYC shuttle and U.S. companies are regularly and reliably transporting crew into low-Earth orbit

We have the capability to detect and deflect planet-killing asteroids

We can do human missions to Mars in months instead of years

We can predict major storms and natural disasters in time to alert and move the at-risk population

Money made through utilization of near-space capabilities (long-duration, near-space platforms, satellite servicing, propellant depots, space tourism, biomedical & pharmaceutical products) exceeds launch costs by a factor of 10

We have initiated interstellar robotic exploration

**Transportation**

Self-driving cars reduce traffic fatalities by 80 percent, while freeing up our commute time for work, leisure, or a nap

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