STEPS

SCIENCE, TECHNOLOGY, ENGINEERING, AND POLICY STUDIES

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Robert Hummel, PhD
Editor-in-Chief

IN THIS ISSUE

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About *STEPS*

STEPS stands for Science, Technology and Engineering Policy Studies. *STEPS* is the technical publication of the Potomac Institute for Policy Studies, where scholarly articles of broad interest are published for the policy studies communities. We welcome original article submissions including, but not limited to: discussions of policies that either promote or impede S&T research; articles that address implications and/or consequences of S&T advances on national or international policies and governance; articles that introduce or review topics in science, technology, or engineering, including considerations of potential societal impacts and influences; and non-partisan opinion pieces concerning policies relevant to S&T, to include S&T research trends; S&T policy event highlights; editorials; letters to the editor; book reviews; and similar contributions.

The Potomac Institute for Policy Studies defines policy and policy studies as a two-way street with respect to science, technology, and engineering. Policies are necessary to advance scientific research toward achieving common good, appropriate use of human and material resources, and significant and favorable impacts on societal needs. At the same time, the creation of effective policy depends on decision makers being well-informed by science.

Societal changes arising from technological advances have often been surprises to mainstream thinking – both within technical communities and the general public. *STEPS* encourages articles that introduce a bold and innovative idea in technology development, or that discuss policy implications in response to technology developments. These articles can include more controversial "outside-the-box," thought provoking contributions intended to 1) encourage discussions concerning science, technology, and engineering developments and related policies, 2) stimulate new research and development or policy actions, and/or 3) stimulate scientist, engineers, and policymakers to support relevant activities. Articles published in *STEPS* will include contributions that consider potential advances that might otherwise be suppressed by reviewers as being too unlikely or "too far out there."

Impressum

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STEPS

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ARTICLES

VIEWS IN BRIEF

About the Potomac Institute for Policy Studies

The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science, technology, and national security issues facing our society. The Institute remains fiercely objective, owning no special allegiance to any single political party or private concern. With over nearly two decades of work on science and technology policy issues, the Potomac Institute has remained a leader in providing meaningful policy options for science and technology, national security, defense initiatives, and S&T forecasting. The Institute hosts centers to study related policy issues through research, discussions, and forums. From these discussions and forums, we develop meaningful policy options and ensure their implementation at the intersection of business and government.

These Centers include:

- Center for Revolutionary Scientific Thought, focusing on S&T futures forecasting;
- Center for Adaptation and Innovation, chaired by General Al Gray, focusing on military strategy and concept development;
- Center for Neurotechnology Studies, focusing on S&T policy related to emerging neurotechnologies;
- Center for Regulatory Science and Engineering, a resource center for regulatory policy; and
- International Center for Terrorism Studies, an internationally recognized center of expertise in the study of terrorism led by Professor Yonah Alexander.

The Potomac Institute's mission as a not-for-profit is to serve the public interest by addressing new areas in science and technology and national security policy. These centers lead discussions and develop new thinking in these areas. From this work the Potomac Institute develops policy and strategy for their government customers in national security. A core principle of the Institute is to be a "Think and Do Tank." Rather than just conduct studies that will sit on the shelf, the Institute is committed to implementing solutions.

From the CEO

Michael S. Swetnam

The Potomac Institute for Policy Studies, continues to foster *STEPS* as an important outlet for scholarly works by the Institute and our many friends in the science and technology policy community. The Institute was created as a public, non-governmental, independent replacement for the Office of Technology Assessment (OTA). We are firm advocates of the development of policy based on solid understandings of pertinent science and technology. *STEPS*' articles include historical examples of where the nation faced difficult issues of policy affected by science and technology, and then also look to the future and predict trends and directions in science and technology that will impact society, and require policy prescriptions.

While the opinion of the authors is theirs alone, *STEPS* is an excellent forum for fostering the discussions on key science, technology, and national security issues facing our society, and permitting future policymakers to gain a head start in considering the issues. The Potomac Institute, and *STEPS*, are both strictly non-partisan.

Our next president, whoever it may be, in conjunction with the next Congress, will confront many difficult issues that relate to science and technology. We know, however, that the candidates and transition teams will have questions and thoughts about policy issues that intersect with science and technology considerations. The march of technology requires that we confront and solve thorny issues with data and rational policy. From driverless vehicles, to autonomous drones, and the future of Moore's Law in microelectronics, to the deterrent capability of our nuclear stockpile, the next administration and legislature will be dealing with difficult problems requiring boldness and courage for solutions.

We welcome all of these useful and needed discussions during this political season, and seek to inform these vital debates on matters of science and technology. We are an independent voice to inform policymakers of the science and technology trends and changes throughout the world that directly impact us. At the Potomac Institute we expect to be a continuous voice for meaningful and sound policies that impact, or are impacted by, the continued developments in science and technology.

Editor's Notes

Robert Hummel, PhD

The publication,*STEPS* is becoming a premier publication for science and technology policy. For topics in Science, Technology, Engineering, and Policy Studies, our articles address timely issues with a mix of historical perspective and prescriptive policy recommendations. In this issue, *STEPS* articles are concerned with how science and technology (S&T) can impact business and government, with considerations of how those policies can improve societies and our lives by leveraging the good aspects of S&T.

Gerry Yonas returns as a *STEPS* author, with a fascinating excerpt from a forthcoming book. Yonas was the chief scientist of the US Strategic Defense Initiative in the mid-1980s. This article concerns the Reykjavik summit, where President Reagan and Chairman Gorbachev discussed the future of the Strategic Defense Initiative (also called the Star Wars project) and the possibility of nuclear disarmament. Yonas points out that an agreement could have happened, and might have even led to a world wherein the superpowers agreed to forgo stockpiles of nuclear weapons; that both the US and the Soviet Union might have embraced purely defensive postures, vice a world with mutual offensive annihilation deterring armed confrontations, based on potential technology advances such as laser weapons and missile intercepts. He explores the mystery as to why this objective did not happen, despite both sides wanting to achieve a major agreement that could lead to disarmament. We live with a legacy wherein nuclear weapons remain an important (and proliferating) part of the world's strategic peacekeeping apparatus, founded on the principles of deterrence as a defense doctrine. Yonas explains how misunderstandings and domestic agendas doomed any possibility of total disarmament. The phrase "laboratory or goodbye" refers to Gorbachev's desire to prevent his military industrial complex from pursuing space-based experiments that might bankrupt the country.

Jim Richardson's article makes the case for an Office of Science Policy, which would serve all branches of government in coordinating and promoting the use of S&T policy for the benefit of society. Carefully reviewing how we have developed a mish-mash of different agencies and policies for science and technology within the US, Richardson points out that there have been previous calls for national-level bodies to support national science and technology. He considers both the impediments, and the potential benefits by looking retrospectively at prior mega-science projects, namely the Human Genome Project, the Superconductive Supercollider, and the International Space Station.

In the article by the Potomac Institute's Microelectronics team led by Dr. Mike Fritze, the eventuality of the demise of Moore's Law is considered. The exponential growth of microelectronics density has been a major economic driver, and perhaps the most important technology trend of the past fifty years. Whereas the end of Moore's Law has been erroneously heralded for a long time, Fritze provides convincing evidence that progress is reaching, or has reached, a fundamental limit, at least with respect to density and line widths. The article points out that this will portend a major change in the market and production of microelectronics in the future. They forecast new approaches to innovation in microelectronics that could translate into new markets and applications.

This issue includes a pair of viewpoint articles, both related to potential dystopian futures where the earth is rendered largely uninhabitable. One article by Hertzler and Rench supports an enhanced NASA program to provide for an outer space lifeboat to ensure the survival of the human race; the other article by Rench reviews a series of books that supposes a possibility of long-term protected suspended animation.

The next issue of *STEPS* is already planned and a spring release is expected. I'd be glad to talk to you about contributions to future issues on relevant topics of timely interest to the science and technology policy community.

Robert Hummel, PhD
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From the CReST Blog

The Center for Revolutionary Scientific Thought (CReST) blog features timely discussions addressing key societal, national, and international science and technology issues. CReST addresses Bold Ideas, current events, and policy recommendations. The CReST Blog is one of CReST's forums for discussion of science and technology futures from both an academic and policy perspective. These blog entries are available online at: www.potomacinstituteceo.wordpress.com.

JENNIFER BUSS, PHD

Next Forms of Intelligence

Humans, as we currently know them, are no longer the most intelligent beings.

CHARLES MUELLER, PHD

A Revolutionary Future

The State of the Union and S&T impacts. Where are they?

CHARLES MUELLER, PHD

Upgrading the Right to Privacy

Our privacy laws and rules must reflect the digital information concerns of our current technological age.

THE CREST TEAM

The Right to Erase Data

The darker side of travel for our digital fingerprints and what can be done.

CREST
CENTER FOR REVOLUTIONARY SCIENTIFIC THOUGHT

STEPS Policy News

A World-Wide Framework to Foster A Prosperous Climate

2015 was the hottest year to date, and Earth's temperature continues to rise. Now, for the first time ever, 195 countries across the world have agreed to an environmental treaty known as the Paris Agreement under the United Nations Framework Convention on Climate Change. The main objective, along with maintaining sustainable development, is to hold the increase in global temperature to 1.5°C. In order to achieve this goal, we must virtually halt emitting greenhouse gasses into the air by the year 2060 according to "A Reader's Guide to the Paris Agreement" (Dec 16, 2015 *The Atlantic*). The rate of our current emissions productions has led to the critical need for finding a method of removing carbon dioxide from the air through so-called "negative emissions" technologies, noted by Knutti, et al. in "A Scientific Critique of the Two-degree Climate Change Target." (*Nature Geoscience*, 2016; 9:13-18) While negative emissions are not mentioned explicitly throughout the text of the Agreement, it is certainly a noticeable undertone. See: *https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf*.

Neuroprosthetics Successfully Meet the Posterior Parietal Cortex

In a remarkable case from May 2015, a quadriplegic man successfully played a game of tic-tac-toe utilizing neuroprosthetics- specifically, robotically programmed prosthetic arms (*Controlling a Robotic Arm with a Patient's Intentions - Caltech News May 21, 2015*). A trial led by Richard Anderson and colleagues investigated the capabilities of the posterior parietal cortex (PPC) in executing motor function. The PPC plays a pivotal role in producing planned movements and receives input from the visual, auditory, and somatosensory systems. These initial intentions are subsequently transmitted from brain to spinal cord and, finally, to the arms and legs where the motion is completed. Many previous applications of neuroprosthetics involving the use of small electrodes and brain wirings to record signals from the motor cortex proved defective, as such signals were extensively detailed and too complex. Anderson and his team have focused on simplifying the message. Using the simpler signals recorded from the PPC, Anderson anticipated patients would find the task more intuitive, thus yielding more successful motor operation. As soon as day one after surgical recovery, the patient was able to control the limb. Results bring great hope of improved quality of life for paralyzed patients. See: Richard A. Anderson, "Decoding Motor Imagery from the Posterior Parietal Cortex of a Tetraplegic Human." *Science Magazine* May 22, 2015: 906-10. *http://authors.library.caltech.edu/54866/*.

FAA Gives the OK for Unmanned Aircraft Systems

The Federal Aviation Administration (FAA) has officially announced its rules and regulations to drone registration in efforts to maintain aerial security. As Unmanned Aircraft Systems (UAS), or "drones" become increasingly popular for avid consumers and military personnel, the FAA revealed updated measures, effective December 21, 2015. For example, anyone in possession of a small UAS (the category weighing 0.55lb-55lb) is directed to register with the FAA UAS registry before they fly outdoors. Individuals who have already flown drones of this weight category must register by February 19, 2016. In a Bard College study, researchers categorized 921 recorded UAS encounters from 2013-2015 into: Sightings and Close Encounters. Sightings were defined as "a pilot... spotted a drone flying within or near the flight paths of manned aircraft though not posing an immediate threat...," and Close Encounters were occurrences "where a manned aircraft came close enough to a drone that it met the (FAA's) definition of a 'near midair collision' or close enough that there was a possible danger of collision..." The study concluded that 35.5% of the recorded cases were Close Encounters and 64.5% were Sightings. Furthermore, 90% of the recorded events showed the UAS went above 400 ft., the maximum height allotted to any UAS. Many industry officials are skeptical of the new FAA regulations, while FAA advisers assure that the actions being taken are simply to bolster national security. See: *http://dronecenter.bard.edu/files/2015/12/12-11-Drone-Sightings-and-Close-Encounters.pdf*.

As Nanotechnology Reaches Below Sea Level, Regulations Aren't so Deep

One of the most highly sought after technologies is nanotechnology. The frequently evolving nature of nanotechnology innovation has heightened questions as to whether the regulations governing nanomaterials are sufficient in determining safety, while also fostering uninhibited field growth. In November of 2015, scientists at Rice University developed a nanosubmarine with a light-reactive motor modeled after a bacteria flagellum, as opposed to more traditional propellers ("Unimolecular Submersible Nanomachines. Synthesis, Actuation, and Monitoring" Garcia-Lopez, et al. *Nano Lett* 2015;15(12):8229–8239). This development demonstrates promising insight into unique research methods, new approaches to transferring medicine, and potential advancements in locating renewable energy sources. While the Obama Administration has continuously encouraged advancements in nanotechnology, the regulatory sphere has voiced safety concerns. In an April 2015 proposed rule that would be included in the Toxic Substances Control Act, the US Environmental Protection Agency has proposed reporting requirements that include one-time reporting for new and existing individual nanoscale materials before they are manufactured or processed. See: *http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPPT-2010-0572-0001*

Cyber Readiness Index (CRI) 2.0

No country is cyber ready. It is a given that global economic growth is increasingly dependent upon the rapid adoption of information communication technology (ICT) and connecting society to the Internet. Indeed, each country's digital agenda promises to stimulate economic growth, increase efficiency, improve service delivery and capacity, drive innovation and productivity gains, and promote good governance. Yet, the availability, integrity, and resilience of this core infrastructure are in harm's way. The volume, scope, velocity, and sophistication of threats to our networked systems and infrastructures are real and growing. Data breaches, criminal activity, service disruptions, and property destruction are becoming commonplace and threaten the Internet economy. Until now, however, there has not been a comprehensive, comparative, experiential methodology to evaluate a country's maturity and commitment to securing its national cyber infrastructure and services upon which its digital future and growth depend. The Cyber Readiness Index (CRI) 2.0 provides a blueprint to objectively assess a country's cyber capacity and maturity. The CRI 2.0 was released by Melissa Hathaway and her team at the Potomac Institute for Policy Studies in November 2015. The methodology builds off of the CRI 1.0 methodology developed by Hathaway in 2013. The CRI 2.0 evaluates 125 countries' "cyber readiness" across seven essential elements: National Strategy, Incident Response, E-Crime and Law Enforcement, Information Sharing, Research and Development, Diplomacy and Trade, and finally Defense and Crisis Response. Hathaway brings over 20 years of cyber security national and international expertise to the CRI 2.0 team. Hathaway notes that "the CRI 1.0 was launched over two years ago and has influenced many countries around the world. We hope the CRI 2.0 has even broader impact." See: *http://www.potomacinstitute.org/images/CRIndex2.0.pdf*

Scientists Discover Intelligence Genes

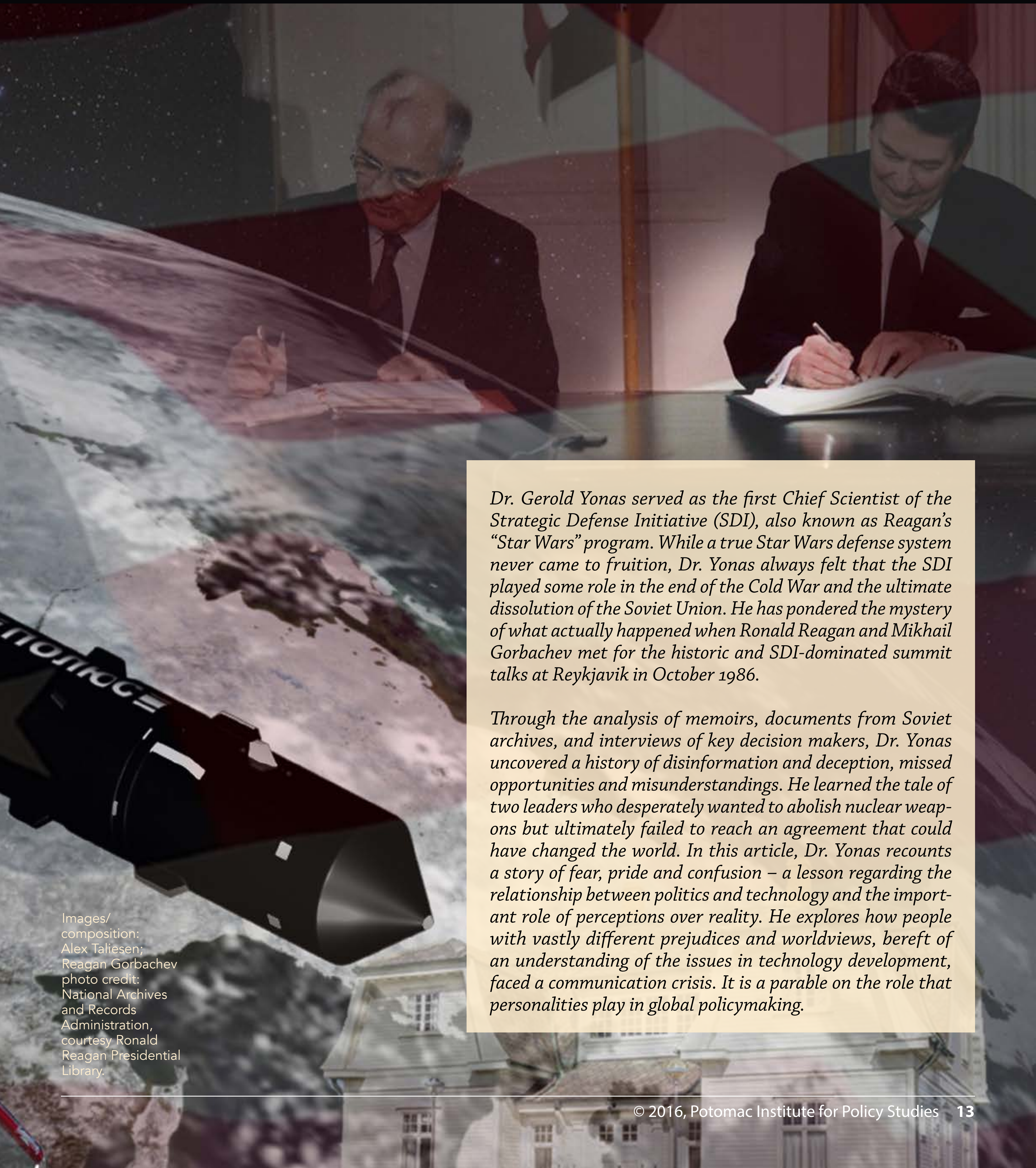
In a recent study, scientists believe they have taken encouraging steps toward mapping human intelligence systems in relation to genetic inheritance. The investigations focused on two groups of genes located in the brain that Johnson, et al. believe may have some influence from one master control system. Specifically, scientists identified two networks of genes, called M1 and M3, which are involved in regulation of other genes. According to the findings, these regions "showed replicable enrichment for common genetic variants underlying healthy human cognitive abilities." The study harnessed information from subjects' cognitive abilities in memory, attention, processing speed and reasoning combined with genetic information submitted from people with autism spectrum disorder, epilepsy, or intellectual disabilities and information from people with no similar diagnoses. Their computations revealed that the genes congruently responsible for altering the ability and intelligence of healthy people were the same genes that impaired cognitive ability and caused epilepsy when mutated in disabled patients. While there are no known cures for neurodevelopmental disorders, the new information from Johnson, et al. suggests a hopeful future in treating disorders and illnesses such as autism, epilepsy, and schizophrenia. See: *http://www.nature.com/neuro/journal/vaop/ncurrent/full/nn.4205.html*

ARTICLES

FEATURE ARTICLE

It's Laboratory or Goodbye

Gerold Yonas, PhD and Jill Gibson



Images/composition: Alex Taliesen; Reagan Gorbachev photo credit: National Archives and Records Administration, courtesy Ronald Reagan Presidential Library.

Dr. Gerold Yonas served as the first Chief Scientist of the Strategic Defense Initiative (SDI), also known as Reagan's "Star Wars" program. While a true Star Wars defense system never came to fruition, Dr. Yonas always felt that the SDI played some role in the end of the Cold War and the ultimate dissolution of the Soviet Union. He has pondered the mystery of what actually happened when Ronald Reagan and Mikhail Gorbachev met for the historic and SDI-dominated summit talks at Reykjavik in October 1986.

Through the analysis of memoirs, documents from Soviet archives, and interviews of key decision makers, Dr. Yonas uncovered a history of disinformation and deception, missed opportunities and misunderstandings. He learned the tale of two leaders who desperately wanted to abolish nuclear weapons but ultimately failed to reach an agreement that could have changed the world. In this article, Dr. Yonas recounts a story of fear, pride and confusion – a lesson regarding the relationship between politics and technology and the important role of perceptions over reality. He explores how people with vastly different prejudices and worldviews, bereft of an understanding of the issues in technology development, faced a communication crisis. It is a parable on the role that personalities play in global policymaking.

INTRODUCTION

At Reykjavik in October 1986, Reagan and Gorbachev almost agreed to abolish all nuclear weapons, but Gorbachev's fear of initiating a space race with the US, and Reagan's misguided commitment to SDI prevented what might have changed the course of history. The mystery of why they failed at a historic agreement has haunted me for decades.

The mystery I pondered for many years was focused on something Mikhail Gorbachev said to President Reagan at the Reykjavik summit meeting. He said four words that abruptly changed the course of history: "It's laboratory or goodbye." And now I think I understand.

So what really happened at Reykjavik? What role did the SDI play in the end of the Cold War and the collapse of the Soviet Union? Many historians and analysts have considered this question over the decades. None other than the "preeminent historian of the Cold War," Yale history professor, John Lewis Gaddis wrote that the SDI "may have been the most effective in ... promoting internal reform in the Soviet Union…the SDI may well have pushed them over the edge."[1] He was not alone in this theory and many well informed scholars have agreed with Gaddis that "…SDI was the straw that broke the camel's back."

Having served as the first chief scientist of the program, and from my vantage point of the SDI program that existed in 1986, I understood that we had few if any technical accomplishments to prompt a giant arms race, let alone the collapse of the Soviet Union. It seemed to me to be like trying to knock over a Sumo wrestler with a feather. When Nigel Hey interviewed me for his book, *The Star Wars Enigma* about the SDI'S role in the collapse of the Soviet Union, I was unable to clarify or substantiate Gaddis' claim. I told Hey "the real SDI story is about human behavior, bluff, fear, confusion and hope." When Hey asked me about the reported description by Robert McFarlane, Reagan's national security advisor, that SDI was "the greatest sting operation in history," I replied, "there was no sting, there was no plan, but the story unfolded anyway. It happened because the role of people – crazy, thoughtful, selfish, drunk, stupid, clever people – is to contribute unpredictably."[2]

So why did Reagan and Gorbachev consider the future of SDI so important that they could not come to an agreement? This, to me, was an enigma, particularly given what I knew about the state of the program at the time. I was not satisfied with just leaving an important part of my life as a mystery, so I set out to uncover the reasoning behind the decisions that took the world to the edge of abolishing nuclear weapons and then backed away.

I now think that Oleg Baklanov, the leader of the Soviet military industrial complex, and the fate of Polyus, the Soviet's first space based laser experiment, hold part of the key to unraveling the mystery of Reykjavik. At the same time, a clash of ideologies, not between the US and the Soviet Union, but rather between the political and technical leaders within each country, created unresolvable conflicts that led to strategic errors. But before I explore the pivotal role these factors played, I want to take a look at the events that led up to the summit.

WHAT WAS THE SDI?

Reagan's March 23, 1983 Star Wars challenge was to "make nuclear weapons impotent and obsolete." Exactly how the SDI program would protect America depended on whom you asked. The very conservative side of American politics saw SDI as a leak-proof defense, and the liberal side saw it as a dangerous but mostly rhetorical attempt to gain an upper hand in the continuing geopolitical struggle. Even the right side of the political spectrum saw the limitations of any defense. Ken Adelman, the US chief of arms control, wrote that Reagan "vastly exaggerated SDI's promise by claiming, 'our scientists are convinced [it] is practical, so much so that within a very few years we can have such a system ready to deploy.'"[3] The middle of the road was represented by James Schlesinger, former US defense secretary, who said, "The best use of SDI lies in that much maligned role of bargaining chips…the quintessential bargain chip."[4] The left could be characterized by Jimmy Carter's Secretary of Defense, Harold Brown, who published an excellent review of the SDI technical challenges, and wrote about doubts "about the vision of protecting populations from a nuclear attack by means other than deterrence."[5]

I had helped to prepare the plan for SDI. During the summer of 1983, I led the directed energy weapon panel of the Defense Technology Study Team (also known as the Fletcher Study). The study prepared a five year, $25 billion Research and Development (R&D) plan that would provide the basis for a deployment decision. In the fall of 1983, I briefed Reagan's Scowcroft

Commission on Nuclear Weapons, and Harold Brown, one of the most knowledgeable members of the panel, stated that the only credible deterrent was the belief that both societies would be destroyed in a nuclear exchange. The Scowcroft Commission's charter was to define a strategic weapon deployment that would provide a survivable retaliation against a Soviet first strike. They had doubts about the proposed silo-based MX missile, which they saw as an attractive target for the Soviet SS-18 intercontinental ballistic missile. This commission on strategic forces, which reported to the President, was critical of the President's initiative, and dead set against any sort of missile defense. They made it clear that the right approach to survivability would be to deploy many small single warhead missiles. Not only were the strategic military implications of the SDI controversial within the administration, the reality of the underlying science and technology was widely debated by both advocates and detractors.

Many directed energy weapons concepts; such as space-based chemical lasers, neutral particle beams, and ground-based electrically pumped lasers; were considered in the Fletcher Study, but they all had deficiencies needing many advances in science and technology. Much has been written about the importance – or lack of importance – of so-called "scientific breakthroughs" for ballistic missile defense, but none were as controversial as the x-ray laser. Noted physicist Edward Teller championed the argument that the key to any effective ballistic missile defense would be an effective x-ray laser.

This subject was well documented by Bill Broad, who wrote in his book *Teller's War: The Top Secret Story Behind the Star Wars Deception*, "The disintegration of the Communist bloc showed that much of its economic and military might have been a ruse. So too, the x-ray laser in many respects was a lie."[6] The most ironic aspect of this development was the Soviet view expressed in 1998 by M.A. Gareev, deputy head of the Soviet General Staff, who wrote that they were way ahead of us in the race to develop this weapon. Gareev spoke of the USSR's successful x-ray laser test during the 1970s at Semipalatinsk saying, "In this field we surpassed the Americans in many areas. However, we spent tens of times more resources on all the programs than the Americans."[7] The Soviet programs included a giant ground based laser driven by explosives as well as space based gas dynamic lasers.[8] The Soviet Polyus spacecraft, launched in 1987, would have tested components of a carbon-dioxide laser in space with an eventual goal of one million watts of power; however, this spacecraft failed to reach orbit. This was a pivotal development that I will discuss later in detail.

In the US, many had doubts about the x-ray laser, including Reagan's scientific advisor, Jay Keyworth, who in an interview in 1998 called the nuclear driven ray laser, "a pack of lies, unadulterated lies."[9] The scientific community in the labs, academia, and industry were very critical of the exaggerations and overselling from the start. Don Kerr, who was Los Alamos National Lab director at the time, described Teller's enthusiasm as being a result of his technical optimism, but warned that, "It's dangerous because in part, there are very few people in the government who can objectively participate in or observe and learn from a technical debate."[10]

As it turned out, no one was less able to understand and deal with the technical issues than Reagan and Gorbachev, but other decision-makers had a hard time grasping the technical issues. George Shultz, Reagan's secretary of state had problems early on in the program in trying to understand what was real and what was fantasy. At a briefing I gave to Shultz in 1985, I emphasized that that the program would require a long-term R&D effort, and that the outcome of the R&D program was uncertain. I left him quite unsatisfied because I was unable to offer him the technological silver bullet I think he and many others were seeking.

WHAT WERE THEY THINKING

But what were the Soviets thinking and how much did they actually know about what was happening in the US?

In 1993, two of the most highly regarded Soviet scientists who were directly involved in advising Gorbachev gave interviews about their views on the implications of the SDI on Soviet decision making concerning the Cold War, and they could not have been more clear. They claimed that SDI was of no importance in the collapse of the Soviet Union. Evgeny Velikhov, the leading scientific arms control adviser in the Soviet Union who accompanied Gorbachev to all meetings with Reagan, said, "any importance of the SDI on the collapse of the Soviet Union is a kind of a historic injustice." Roald Sagdeev, Soviet and Russian expert in plasma physics and a former director of the Space Research Institute of the USSR Academy of Sciences, simply called such a hypothesis explaining the fall of the Soviet Union, "nonsense."[11] But if the SDI was of little importance, why did Gorbachev take it so seriously? In his memoir, Sagdeev indicated that the explanation might lie within the vast Soviet defense investments, and the competition for funds within the Soviet defense ministries, and not directly dependent on our actions.[12] V. Shlykov, the department head of the Soviet military intelligence, GRU, said, "Nobody cared and nobody considered a practical response to the Star Wars program."[13]

Clearly the Soviet scientific perspective greatly influenced the decisions their leaders made. Throughout my work with the SDI, I sought to understand their viewpoint. In 1983, I concluded that the outcome of the five-year program would depend not just on our technology advances, but how the Soviets responded based on their perceptions of reality.[14]

George Shultz explained in his memoir that he really appreciated the limitations of our technology and was prepared to trade our non-existent accomplishments for some meaningful agreement. In his instructions to Reagan in preparation for the Reykjavik summit, Shultz suggested a compromise, stating that SDI could be a bargaining chip to gain cooperation on arms reductions. Shultz recognized the power the SDI held in the negotiations and advised Reagan to "give them the sleeves from our vest on SDI and make them think they got our overcoat."[15]

I was determined to understand why we did not achieve an agreement and give up "the sleeves of our vest." George Schultz not only understood the status of technology development and had a strategy for the negotiation, but also had stood by the president's side during the Reykjavik summit. In 2014, I made arrangements to meet with Shultz, and, when I asked him why we did not trade, he made it clear that Gorbachev was convinced America had already developed a successful SDI technology that could become extremely effective against their ballistic missiles.

What was driving Gorbachev to walk away from a deal that would satisfy his dreams of eliminating nuclear weapons and preventing a space arms race? I knew that the Soviet scientific community had provided substantial evidence to Gorbachev that the technical foundation of SDI was inadequate to justify the initiative, but I am not sure that scientific advice amounted to much when confronted with other more powerful goals and beliefs from the Soviet military.

The information that Gorbachev had received from his political and military advisors contradicted that of the key Soviet scientists. Instead, the information he received before the summit painted a frightening picture of American superiority.[16] Gorbachev was convinced that he had to stop not only the American SDI program, but also had to stop the arms race driven by his own military industrial complex. M.I. Gerasev, from the Soviet Institute for the USA and Canada, said, "We had plenty of zealots who greeted Reagan's SDI with open arms. They came running with comprehensive projects expecting to be showered with funds."[17] Before Gorbachev left for Reykjavik, he stated, "Our main goal now is to prevent another new stage in the arms race… drawn into an arms race that is beyond our strength. We will lose because now for us that race is already at the limit of our possibilities."[18]

"The Soviets were keenly aware that we were waging a psychological war that was just as serious as any aspect of the Cold War conflict."

Gorbachev seems to have been most strongly influenced by outrageous claims from his own military industrial complex. Evgeny Velikhov, wrote in his memoir, "Our negotiators and military experts were convinced that by 1990, the Americans would deploy space weaponry."[19] Gorbachev's military advisors misled him to believe that the US had developments including "kinetic energy nuclear weapons…creates a stream of metallic fragments of small mass …and are capable of striking targets in space, including warheads, [with] a direct hit."[20] If this were true, it would be a fantastic space weapon. Gorbachev had also been told that full-scale development of "x-ray laser weapons, directed electro-magnetic radiation weapons, and kinetic energy weapons is expected to occur in the second half of the 1990s."[21] Regardless of reality, Reagan's outrageous statement that the SDI was nearing deployment, according to Adelman, "must have caused heartburn for Gorbachev, and confirmed his worst fears."[22]

Not only had Gorbachev been told that the Soviet military industrial complex had proven that a space-based missile killer was possible, but "the US has achieved results in this area which surpass those of our country."[23] The Soviet leader had been warned "overall the Soviet Union lags approximately 4-5 years behind the US in research on creating the elements of a space-based missile defense echelon,"[24] and "Americans think that a multi-echelon missile defense system should allow at most 0.1% of the attacking missiles to get through."[25]

What was behind such wildly exaggerated claims? Was it the marketers of the Soviet military industrial complex taking advantage of the technically incompetent decision maker? Or maybe we had some hand in creating this perception?

WHAT INFLUENCED THEIR THINKING?

The Soviets were keenly aware that we were waging a psychological war that was just as serious as any aspect of the Cold War conflict. M.A. Gareev described his perception of our approach to the "non-war" mind war as including, "hostile indirect activity [that] was the extraordinary effort to undermine the Soviet Union... measures aimed at preventing the inflow of modern technologies."[26]

Project Farewell was the name of another aspect of the United States' attempt to undermine the Soviet Union. The Soviet military had been fed bogus technical intelligence from Project Farewell, a technical disinformation program engineered by Gus Weiss of the CIA.[27] There probably were many other instances of the technology-thirsty Soviets accepting our nonsense. This may have been the source of the panicky advice Gorbachev received.

Gorbachev's military advisors warned him of the need to delay the US space weapons program "to gain the time to conduct analogous work in our own country."[28] They told Gorbachev over and over again, that the US must not be allowed to test "apart from laboratory research."[29] His instructions were clear, emphatic, and repeated over and over again; the US must not test "outside of the laboratory." Gorbachev was not at all educated in science and technology, but he certainly understood and believed that it was absolutely necessary to keep the US from testing SDI technology in space.

Many in the Soviet military industrial complex saw SDI as an opportunity for funding, and Gorbachev must have been acutely aware of the rising tide of pressure to invest in space weapons. He was also aware that his own military industrial complex, led by Oleg Baklanov, was prepared to accelerate the race toward the development of space weapons.

Baklanov, born in 1932, rose from an engineer, then factory manager in the Ukraine, and received many awards including the Lenin Prize in 1982. He became leader of the Soviet space industry in the '80s and then the head of the military industrial complex under Gorbachev. Baklanov seems to have been dedicated to saving the Soviet Union from Gorbachev's well-intentioned but mismanaged Soviet reforms, and he appears to have approached this problem as a sober and linear thinking engineer would. Baklanov also had little respect for Gorbachev or his understanding of technology. He later wrote, Gorbachev "had a poor grasp of

USSR, MOSCOW. Central Committee of the CPSU Secretary Oleg Baklanov. (© ITAR-TASS Photo Agency / Alamy Stock Photo, Valentin Cheredintsev).

the subject matter ...no understanding of it, no definite ideas about the issues of defense."[30]

That belief in Gorbachev's technical incompetence was seconded many years later by Victor Mikhailov who became the head of all Soviet things nuclear as the leader of the Russian Federation of Nuclear Energy. He believed in the potential of nuclear directed energy weapons that he called the "Evil Jinn."[31] Mikhailov wrote in his memoirs that Gorbachev was in no mood to listen to his technical advisors. Instead, he wrote, "Gorbachev has to take the blame for the attempts to demolish the military industrial complex. He almost ordered that the directors of our enterprises be squashed, treating the talented scientists and organizers like bedbugs."[32]

Baklanov not only lacked respect for Gorbachev, he also viewed America's leader with contempt. He was just as convinced of Reagan's lack of technical understanding and capabilities to deal with these issues, writing, "Reagan was completely illiterate when it came to talking about problems of a scientific and technical nature. He didn't understand anything he said about SDI...a bluff and a myth." Baklanov recognized that Gorbachev used Reagan's mythical SDI to advance his own objectives, noting, "Gorbachev wanted to use the myth about the capabilities of SDI...as a pretext for getting us to surrender."[33]

Baklanov was not alone in his opinion of Reagan's scientific illiteracy. The nominal leader of the left wing, Alexander Yakovlev, Gorbachev's minister of propaganda, was in close agreement on the view of Reagan: "In Reykjavik, Reagan missed his chance to go down in history not as a clown, but as a statesman...not intelligent enough and too limited in his freedom of choice...."[34]

At the same time, as Reykjavik negotiations proceeded, in October of 1986, the Soviet Union's military industrial complex was preparing to launch the world's biggest booster, Energia from the Baikonur Cosmodrone Site in the desert of Kazakhstan. Energia would be carrying the Polyus payload, a demonstration of bits and pieces of the Soviet's first space based laser. It is ironic that our own shuttle launcher had blown up on launch in January 1986, just 10 months earlier, and the US shuttle fleet was grounded for three years. What we didn't know at the time was that the Soviets were ahead of America in the development and space deployment of a crude space weapon, which would have been the key to their ability to destroy our space assets. I am sure that they would have gone ahead with some sort of minimally effective laser weapon program, which would have in turn energized our own program, if their tests had proven successful. Ashton Carter, now the secretary of defense but then a prominent critic of SDI, speculated on a hypothetical Soviet effort. He pointed out correctly that an "ASAT attack on crucial sensors based in space is probably the cheapest and most effective offensive countermeasure."[35] A comprehensive history of their giant Terra laser program was published in the '90s that convinced me that they had the experience and desire to commit to very large investments in laser weapons had they had the political will to do so.[36]

"The world was on the edge of a fundamental change in military capabilities and nuclear weapon deployment.."

Fear of, or maybe hope for, the American SDI program was driving the ambitions of the Soviet military industrial decisions. Baklanov was expecting that SDI would compel his country to compete in an expensive arms race, and he was confident that the outcome would be favorable to the Soviet Union. He said, "Creating SDI system in space would have required enormous and ultimately worthless expenditures."[37] He wanted us to waste our money while they raced ahead with countermeasures, and he expected the most effective countermeasure would be his own anti-satellite weapons, such as those under development and to be tested on Polyus.

WHAT HAPPENED AT REYKJAVIK AND BAIKONUR?

In the midst of this conflict and confusion, in October of 1986, Gorbachev and Reagan met together at Reykjavik, struggling with decisions that could save the planet from nuclear destruction. After almost three days of back and forth arguing about SDI and arms control, the leaders had arrived at a dramatic point in the conversation that might have changed the world. The meeting was drawing to an exhausting and frustrating close and it was either make or break when Gorbachev demanded dozens of times that the SDI "be confined to research and testing to the laboratories."[38] According to Ken Adelman, "Gorbachev's insistence that SDI be confined to laboratories...was repeated constantly ...and then a stunning twenty times on Sunday afternoon. Mentioned every five minutes."[39] Gorbachev and Reagan had made it clear that they both desperately wanted to abolish nuclear weapons, but they were stuck on the issue of testing SDI outside of the laboratory.

During the last moments of the summit, Reagan stated "it would be fine with me if we eliminate all nuclear weapons," and Gorbachev enthusiastically followed with "let's eliminate them. We can eliminate them."[40] The world was on the edge of a fundamental change in military capabilities and nuclear weapon deployment. Then Reagan demanded to "continue research, testing, and development which is permitted by the treaty." Gorbachev objected. The Soviet leader said, "if development can go on outside the laboratory, and the system can go ahead in ten years.... It's laboratory or goodbye...ten years of research in the laboratories within the limits of the treaty ought to be enough for the President."[41] Apparently he was not against SDI research, but the research had to be conducted in the laboratories.

It is possible he was more worried about his own military industrial complex and their imminent breakout from their laboratory confines. This connection between the negotiations at Reykjavik and the upcoming events at Baikonur, explains the mystery of Reykjavik.

Gorbachev was at the end of his patience and desperate to clinch the deal, but he knew he could not walk away and leave the door open for Baklanov to launch an ultimately dangerous and probably ruinous space arms race, and he must have been focused on the upcoming launch of the world's biggest booster, Energia. This achievement, if successful, would create momentum in the space arms race from which there could be no turning back. This world changing agreement between the super powers was hanging on one word: LABORATORY, and Gorbachev hoped to thwart the launch and the ruinous arms race by committing to "staying in the laboratory". While Gorbachev argued with Reagan about future US space weapons, what he feared most was what was about to take place at Baikonur Cosmodrome in Kazakstan.

Shortly after the Reykjavik summit, Gorbachev and members of the Politburo flew from Moscow to Baikonur to witness the first launch of Energia. Baklanov, not to be undone, brought his team of scientists and engineers to the historic event. Ironically, they were not just there to view the historic launch of the world's biggest rocket, but to persuade Gorbachev to allow the launch to take place.

When they arrived, Energia, was ready for launch. It was fitted with the 100-ton Polyus space based laser demonstration. "This was a full scale mockup of what they called the Skif-DM orbital combat laser platform – 37 meters long and over four meters in diameter. The Energia/Buran program had been under way for 18 years at a cost of 16.5 billion rubles, and involving 1200 industrial sites."[42] Gorbachev, immediately upon his arrival, made a startling announcement. He declared to the already exhausted and frustrated launch crew that had dedicated months to preparation and then delayed for the arrival of the dignitaries, that there would be no launch. He ordered them, in classic bureaucratic style, to do more analysis and write comprehensive reports. Then to make matters worse, he preached to them about the evils of space-based weapons.[43]

Baklanov was well aware of Gorbachev's attitude, and he was prepared for this move. That evening he and his team gave Gorbachev a comprehensive briefing on the subject of rockets, space, and Energia. He undoubtedly emphasized the glory of Energia and Soviet space technology. "We created close to eighty five new materials of a higher caliber than anything else in industry and engineering... we introduced something on the order of six hundred innovations."[44] I can imagine how a technically educated person might be persuaded by such argument, but none of this should have been convincing to a social/economics expert or a diplomat who could did not care about any technical innovations. After his insistence at Reykjavik about the need to stop development and deployment of any weapons in space, how could Gorbachev then relent?

But surprisingly Gorbachev gave the go ahead for the next day. Somehow Baklanov had convinced the Soviet leader to change his mind, and abruptly reverse his conviction to stop the launch of Energia. It is possible that Gorbachev's behavior was subsequently explained by the very revealing book *Ten Years That Shook the World* by V. Boldin, Gorbachev's chief of staff, and one of his closest associates. Undoubtedly Boldin's comments, particularly his book, which he wrote behind bars after he participated in the 1991 failed coup to overthrow

Gorbachev, were driven by intense dislike or worse, but I don't think his words can be entirely ignored. In his memoir, Boldin described how Gorbachev, "for whom maneuvering had become a habit, was really taking two steps forward, three to the side, and one backward, and everyone found such conduct disconcerting... he had everybody confused." In another blistering comment Boldin said, "Gorbachev is a coward by nature."[45] Strong words from a bitter man who had turned against his boss of ten years.

But similar comments were made by Baklanov who described Gorbachev as a manipulator and schemer, writing, "Perhaps Gorbachev wanted to use the myth about the capabilities of SDI for certain purposes, such as foil for his later actions."[46] Very sour grapes, but not contradicted by the comprehensive and well-documented historical analysis of Vladislav Zubok, who wrote a most comprehensive description of the period. He quoted William Odom, who was the Director of the National Security Agency: "Gorbachev was an inveterate schemer, loquacious obfuscator, unable to anticipate the likely consequences of policy."[47] Zubok also quotes Anatoly Dobrynin, Soviet Ambassador to the US, that Gorbachev "had the emotional makeup of a gambler... was visible even in 1986 at the Reykjavik summit."[48]

So I surmise that Gorbachev could easily have changed his mind. He had the ad hoc optimism of the moment to hope things would work out, and it seems he lacked the inhibitions to be consistent with the position he had taken so forcefully at Reykjavik.

But why was Reagan so insistent that SDI was more important than his dream of abolishing nuclear weapons?

Reagan may have been acting out his part as the savior of his country and he had to fulfill his obligation to the American people to deliver the ultimate defense, like an umbrella in a rainstorm that would stop incoming nuclear warheads. Unfortunately, the reality was that even in the most optimistic outcome, that umbrella would be useless in the torrential downfall of an all-out nuclear missile attack.

Maybe Reagan's belief in fate and luck that he had demonstrated throughout his acting career[49] was not misplaced, since the start of a real Star Wars never occurred. Circumstance, incompetence, or luck played the key role in the outcome of the Energia launch, which suffered, ironically, a software glitch that probably saved both countries from a ruinous arms race.[50] Polyus went unceremoniously into the Pacific and was never seen again, and Gorbachev was saved from the inevitable US reaction and Soviet counter action.

WHAT ENDED THE COLD WAR?

The historian Pavel Podvig, after an extensive study of the comprehensive Soviet archives that appeared after the Cold War, argued convincingly that the vigorous attempt by Gorbachev to curtail SDI was really a fear of unleashing the powerful Soviet military industry complex on an uncontrolled Star Wars spending spree.[51] But if all of that is true, then what could Gorbachev have been thinking at the closing moments of the Reykjavik meeting that prevented him from realizing his goals to abolish nuclear weapons, and keep SDI within the bounds of the existing agreements? We will never know, but it could have been no more than the emotions of the moment and his sense of self-confidence. In Gorbachev's memoir, he did not admit making a single mistake. He barely mentioned strategic defense, or Reagan, although he certainly deeply believed in abolishing nuclear weapons. He said in his arms control proposal in January 1986 that to do away with all nuclear weapons was "not utopian after all ... this noble and salutary goal is reachable, given the good will of all members of the international community."[52] He never indicated that the SDI had any impact on ending the Cold War, but instead wrote, "The Cold War was brought to an end thanks to Perestroika and the new thinking." He also made it clear that the "totalitarian system had run its course morally and politically, and a prolonged and potentially deadly period in world history, in which the human race had lived under the constant threat of nuclear disaster had come to an end."[53]

Zubock described the collapse as a failure of will to save "the empire they did not believe in, and for the empire they did not profit from. Instead of fighting back, the Soviet socialist empire, perhaps the strangest empire in modern history, committed suicide."[54] Maybe this self-inflicted wound was not that dramatic, but was just a compounding of very bad management. Boldin wrote, "By 1987, virtually the entire membership of the Poliburo had been changed, only to undergo another overhaul in 1990...utterly incapable of deciding or uniting anything at all – a sure sign that the collapse of the organs of government and of the entire party was imminent."[55]

Baklanov's role in the history of the Soviet Union reached a climax on August 18, 1991, when he and three of his right wing colleagues, including Boldin, as members of the "Gang of Eight" coup plotters, showed up at Gorbachev's dacha in the Crimea, and "nicely" but forcefully asked him to step aside so they could straighten out the mess that had become the Soviet Union. The August coup collapsed in a few days and the Soviet Union soon was to see its last days. This confrontation with Gorbachev was the culmination of a conflict with Baklanov, and indeed the entire Soviet military industrial complex.

The concept that one of the largest and most powerful countries in the world committed suicide because of its moral decay and mismanaged political institutions, rather than economic collapse or even a scientific and technology competition, as many claim, is profound. It is a warning about protecting and unifying the national social and political fabric as well as its military-based national security.

All Reagan had to do was agree to keep SDI "in the laboratory" for maybe ten years, or even less. There were plenty of technical challenges to keep all of us scientists and engineers very busy. There was plenty of wiggle room in the definition of the "laboratory" and the program could have proceeded for many years in the "laboratory," without disruption. The Soviets and Americans could have worked together in a shared environment that would have been accepted by the scientists and engineers on both sides. The problem of the trusted computer hardware and software to manage a shared system of early warning and response would likely have been one of the most difficult challenges, but would also pay enormous spin-off benefits for commercial applications. Getting the diplomats and military experts to go along would have required a level of trust that in itself would have constituted a revolution in international affairs.

Ultimately, the two leaders were hobbled by their own personalities and emotions of the moment, as well as the disinformation they had been given by their advisors. The US hard liners argued with Reagan that the Congress would not support a constrained R&D program. But my experience with arms control agreements of nuclear testing is that Congress tends to increase funding for laboratory research in spite of any limitations because of internal politics. Scientists and engineers are adept at arguing that we always need a hedge of new knowledge "just in case" somebody cheats. This is the sort of a not-so-subtle yet persuasive approach that has given laboratories the leverage they need to go along with arms control agreements and continue to receive substantial funding.

> ***"The key was then – and is still – the art of empathetic communication between two very different cultures, but might have been possible between two men who were both dreamers and ideologues."***

WHAT COULD HAVE BEEN

When Reagan and Gorbachev met at Reykjavik, the two world leaders could have agreed to end the nuclear danger – or at least started on an admittedly long and arduous journey toward total nuclear abolition. Neither of them had the backing from their supporters and assistants. Both were really on their own in dealing with what had to become enormous resistance from all political persuasions. The path forward would have required a leap of creativity and vision, widespread disarmament, economic aid or possibly a jointly or multi-national operated defense R&D laboratory, and possibly even the invention and realization of a shared space-based missile defense as first envisioned by Reagan. As a minimum, they could have agreed to develop a shared early warning system that would prevent accidents or warn of rogue nation actions by requiring that any launch of a missile be reported before it occurred.

A LESSON FOR THE FUTURE

And so ends my tragic tale of two men who desperately wanted to abolish nuclear weapons but ultimately failed to reach an agreement that could have changed the world. MacFarlane said the SDI was a sting;[56] Keyworth called the directed nuclear weapons "unadulterated lies;"[57] and Baklanov called SDI a "hoax,"[58] but I suggest that, although all of these perceptions were somewhat real, they don't tell the story.

This story is a complex lesson about not just technology, but about politics, psychology, leadership, competition and control. Instead of SDI ending the Cold War, which was on its final path on its own, it stood in the way of an agreement to abolish nuclear weapons. Had we learned this lesson back in the 1980s, perhaps we could have taken remedial steps to begin to abolish nuclear weapons, and create a relationship of mutual understanding and trust that has escaped us even now. The key was then – and is still – the art of empathetic communication between two very different cultures, but might have been possible between two men who were both dreamers and ideologues.

The fallout from the momentary agreement at Reykjavik to abolish nuclear weapons was similar to that from Reagan's 1983 announcement of the Star Wars initiative to "make nuclear weapons impotent and obsolete." Both Gorbachev and Reagan shared a vision but neither had a realistic idea how to implement it, and it caught everybody, particularly the US Congress, off guard. Sam Nunn, one of the most respected arms control experts in the Senate, said "it would have been the most painfully embarrassing example of American ineptitude in this century."[59] The fight between the left and the right in both societies would have been furious, but, in my opinion, the route to an agreement was emerging and should have been seriously pursued.

The academics would have had to walk back their predictions in 1986 that "SDI has seen its last good days."[60] They would have had to get on with solving the technical challenges in a jointly managed program. The military/industry leaders who were lusting after new military programs would have found non-military challenges for application of their facilities and capabilities. The diplomats would all have been given satisfaction in continuing negotiations, and they would have found many ways to argue endlessly about the nuances of verification of agreements.

It might have taken years or decades, but maybe we could have aided what Alexander Yakovlev, Gorbachev's minister of propaganda, said in his history of the evils of Bolshevism the need for the "Russian psyche healing" process.[61] We might have avoided the resurgence of the Russian militaristic strategies and investments. It is now most likely too late, and the possibility of changing the Russian culture might be just a totally foolish concept. Maybe it was just an unrealistic dream after all. We now see that the nuclear arms race is heating up again. The Soviets have improved their ICBM capabilities as evidenced in 2015 by their test firing of the ten-warhead payload, submarine-launched Bulava missile, which has advanced countermeasures against ballistic missile defense. They even developed a decoy to "mimic all features of warhead's signature"[62] This capability is even more worrisome when we take into consideration increasing Russian emphasis on nuclear weapon use, and that Gorbachev last year warned that the world is "on the brink of a new Cold War."[63] In addition we now are witnessing a continuing threat from nuclear weapons proliferation.

My conclusion is that Reagan had a vision to abolish nuclear weapons and share the as yet non-existent SDI with Russia and eventually the world. Gorbachev had a determination to stop the dominance of his own military industrial complex that stood in the path of fundamentally changing his society. Both were driven by their own ideologies that had little useful support from their political and military advisors. Scientific advice was realistic and credible to other scientists, but irrelevant to the decision makers. Gorbachev's dilemma was the legacy of totalitarian rule on domestic psychology and the economic/technological backwardness from the lack of economic competition. Reagan's problem was the lack of a national or global acceptance of a world without nuclear weapons. They were both visionaries who never bothered to think about the details. Any compromise would still have required that the two leaders convince their own societies that cooperation would be more beneficial than continued confrontation. They almost changed the world, but missed the opportunity in the fleeting moment at Reykjavik.

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US Federal Government
(Biography of Lt Gen James A. Abrahamson, USAF), PD.

Rationalizing the National S&T Policy Mess

James Richardson, PhD

Image credit: CReST Blog.

It is important that the nation enacts sound policies, whether the issues are impacted by science and technology (S&T), or whether the policy impacts S&T development. Yet, national policymaking with respect to S&T are spread out among numerous federal, state, and private agencies and organizations. There is no one in charge, and no consensus on who speaks for which issues and at what level specific technology issues should be addressed. Even as S&T moves more quickly and becomes more complex, processes to formulate and maintain policies remain problematic. The author describes the mess that is our national S&T policy apparatus, and suggests the creation of an Office of Science Policy.

In 2003 the Potomac Institute for Policy Studies proposed a study to continue its earlier examinations of the status of selected areas of science and technology research in the US and abroad, projecting where this research might lead and how its products could affect national security. Numerous agencies and organizations sponsored the study.[1] Its overarching goal was to suggest ways to improve the quality of S&T information involved in decisions made, or directly influenced, at the "highest levels" of government.

The study's output fell into two subject matter areas, S&T trends and impacts, and implications on the processes of creating technical policy in the US. Communication of this output was accomplished through a final report,[2] briefings presented to sponsors and industry; an article for the Review of Policy Research (RPR);[3] and a presentation and published proceedings at the Policy Research for Science and Technology (PREST) conference at the University of Manchester in the UK.[4]

This article updates and illustrates by examples those portions of the study's final report that involved creating technical policy in the US. We will discuss the broader structural issues that arise whenever any science and technology topic confronts policy-making individuals and organizations. In particular, we wish to reexamine the questions:

- How are national S&T policies created currently?
- What are the general weaknesses of today's S&T policymaking?
- What are some ways to build on the strengths and mitigate the weaknesses in national policymaking and management?

For the third question, we will make the bold recommendation of forming a new national agency, and consider its potential impact through three selected case studies.

The need to continually improve our ability to create and maintain good S&T policy is crucial and should begin by clearly and factually defining the technical aspects of the issues being addressed, even as we consider their moral, ethical, social, and political aspects. This is especially vital because of the continuation of three indisputable trends: The increasing rate of breakthroughs in science, the decreasing time between these breakthroughs and their application, and the growing impact of these products of science on our lives. The first two trends may often work to our advantage, but technology can produce unfortunate as well as beneficial impacts on society. The rise of drug resistant diseases in response to overuse of antibiotics, the threat of global climate change brought on by the broad proliferation of fossil fuel technologies, and the weaponization of increasingly deadly gases are illustrative. Could current research programs, such as nanotechnology and genome research produce similar dangers? Under the best circumstances predicting tragic unintended consequences of technology is difficult, but failing to take the time to think through their possible downsides can dramatically increase the chances of things going wrong. The last trend, which involves such basic elements as national security, economics and competitiveness with foreign research, is treated more holistically in the final report of the original study and the RPR article.

Unfortunately, the reality is that too often the political content of the decision process dominates and accelerates decisions and policies. And, broad issues are often addressed in narrow terms because of political expediencies or disagreements, or simply because of inadequate technical understanding by the policy-makers. The result is that while political aspects of science-laden issues are laboriously considered, even the foundational scientific arguments are frequently ignored.

A recent confrontation between Rep. Lamar Smith, Chair of the House Committee on Science, Space and Technology, and scientists at the National Oceanic and Atmospheric Administration (NOAA) demonstrates this point. The issue is over a study published by scientists at NOAA that contradicts assertions that global temperatures have held steady for the past several years, a thesis that has encouraged skepticism of climate change by Rep. Smith and others. The difference of opinion is important since policies based on a monotonic rise in Earth's average temperature would tend to prescribe stronger preventative measures than those that assume fluctuation or pause in warming trends.

Rep. Smith has threatened to subpoena the authors of the study, while seven scientific organizations, including the Association for the Advancement of Science, have accused him of "establishing a practice of inquests." Rep. Smith has charged that the authors have used inaccurate data, prompting NOAA Administrator Kathryn Sullivan to declare, "I have not or will not allow anyone to manipulate the science or coerce the scientists who work for me."[5] Whether or not political manipulation of science is at the root of this quarrel, it is difficult to ignore the ideological undertones. This clash between the scientific and political worlds occurs too often and is just one problem in S&T policymaking that should be addressed.

HOW ARE S&T POLICIES CREATED?

Some technical policies evolve from the passage of a body of related laws, others are carefully crafted by experts in the field, and still others spring ad-hoc from various activities. Normally, formal policies reflect an overarching goal developed by either the Executive or Legislative branch, as promulgated by the relevant agency (e.g., civil service department) and often informed by academia or the private sector. The Judicial Branch is sometimes involved in S&T decision-making, usually when arbitration of legal aspects of strategy and policy is required.[6]

It is instructive to consider some of the players and issues that are part of the process of setting technical policy at the national level.

The Executive Branch. The Director of the Office of Science and Technology Policy (OSTP), sometimes granted the additional title of "Presidential Science Advisor," is the principle S&T advisor to the President. Established in 1976 by Public Law 94-282, the Director's function is to "provide the Executive Office of the President with advice on the scientific, engineering, and technological aspects of issues that require attention at the highest levels of government,"[7] thereby codifying into law prior functions of the Office of Scientific Research and Development (during WWII) and the President's Science Advisory Committee. The OSTP, as established in the 1976 law, "serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the Federal Government." OSTP's strategic goals and objectives include promoting science for "economic prosperity, public health, environmental quality, and national security." The office provides insight and guidance on subjects such as optimizing the science and technology workforce and the government's participation in the national S&T enterprise.

The Director of OSTP is also the co-chair of PCAST, the President's Council of Advisors on Science and Technology. The PCAST advises on "technology, scientific research priorities, and mathematics and science education "utilizing resources within the private sector and academia." There is also a National Science and Technology Council (NSTC), chaired by the Vice President and served by the Director of OSTP, Cabinet Secretaries, S&T-related Agency Heads, and others.

The NSTC's mission is "to prepare coordinated R&D strategies and budget recommendations to orient science and technology toward achieving national goals, which involves coordinating the parts of the Federal R&D enterprise." NSTC coordinates actions in selected areas of S&T by directing Interagency Working Groups (IWGs) to study particular issues. Some of the recent reports by the NSTC are on the National Nanotechnology Initiative (5th Assessment), Education Technology, Antibiotic Resistance, and Big Data and Privacy.

In 1991, Congress created a Critical Technologies Institute, renamed the Science and Technology Policy Institute (STPI) in 1998. The Institute is a National Science Foundation-sponsored federally funded research and development center (FFRDC). STPI's stated mission is "to help improve public policy by conducting objective, independent research and analysis on policy issues that involve science and technology." The main activity of STPI is to support OSTP, although it also supports other agencies in the Executive Branch. Despite lofty and worthwhile aspirations, OSTP and its organizations are poorly resourced and insufficiently empowered to proactively analyze and make recommendations concerning the S&T areas that need better policies.

The Legislative Branch. The Congressional Research Service (CRS) is "the public policy research arm of the United States Congress. As a legislative branch agency within the Library of Congress, CRS works exclusively and directly for Members of Congress, their Committees and staff on a confidential, nonpartisan basis."[8] The Service's output includes reports on major policy issues (approximately 700 per year), memoranda, briefings, consultations, seminars and workshops, expert testimony, and individual inquiries.

Under different names, CRS has advised Congress since 1914. Their staff of around 600 is organized into six divisions, one of which is Science and Industry. Their responsibilities for scientific topics grew when Congress eliminated the Office of Technology Assessment (OTA) in 1994.

On specific issues, the Congressional Budget Office (CBO) and the Government Accounting Office (GAO) may also provide perspectives that affect or are affected by S&T. The GAO includes an office of Technology Assessment and a chief scientist. Common to the CRS, CBO, and GAO is that their participation is by invitation only. A member of Congress must initiate an examination by one of these organizations, so their part in the process is seldom proactive and independent. Further, the service makes no recommendations to Congress and public access to (and comment on) their work is generally denied.

POLICY FOR S&T INVESTMENT

The NSTC is instrumental in establishing a national R&D budget. The committee and OMB develop research priorities and issues directives to agencies. Each department submits its budget to the OMB for separate consideration. OMB does not look at R&D consistency with national objectives before sending it on to Congress. A simplified version of the R&D budget trek from agency-to-President-to-OMB-to-Congress is shown in Figure 1.

The House Science Authorization Committee considers a large portion of the consolidated R&D budget (exempting DOD), but then it is split up into the appropriations subcommittees. There is no formal coordination among the subcommittees regarding how separate R&D programs may affect one another. The separation of the appropriations subcommittees is analogous to the way the appropriations bills are considered. Legislators do not have the opportunity to analyze the collective R&D budget before voting separately on each section.

S&T FOR POLICY

The second type of S&T policy deals with the technical content of policies that govern or guide the management of national issues or initiatives. In this case, the purpose of the technical aspect of the policy is to ensure that the scientific foundation of the policy is correct. Although S&T investment may be part of the policy, it is not its focus.

These policies occur at every level of government and society. They become impossible to fashion and defend when bad science is used, either intentionally or inadvertently, as their basis. Just one example is our

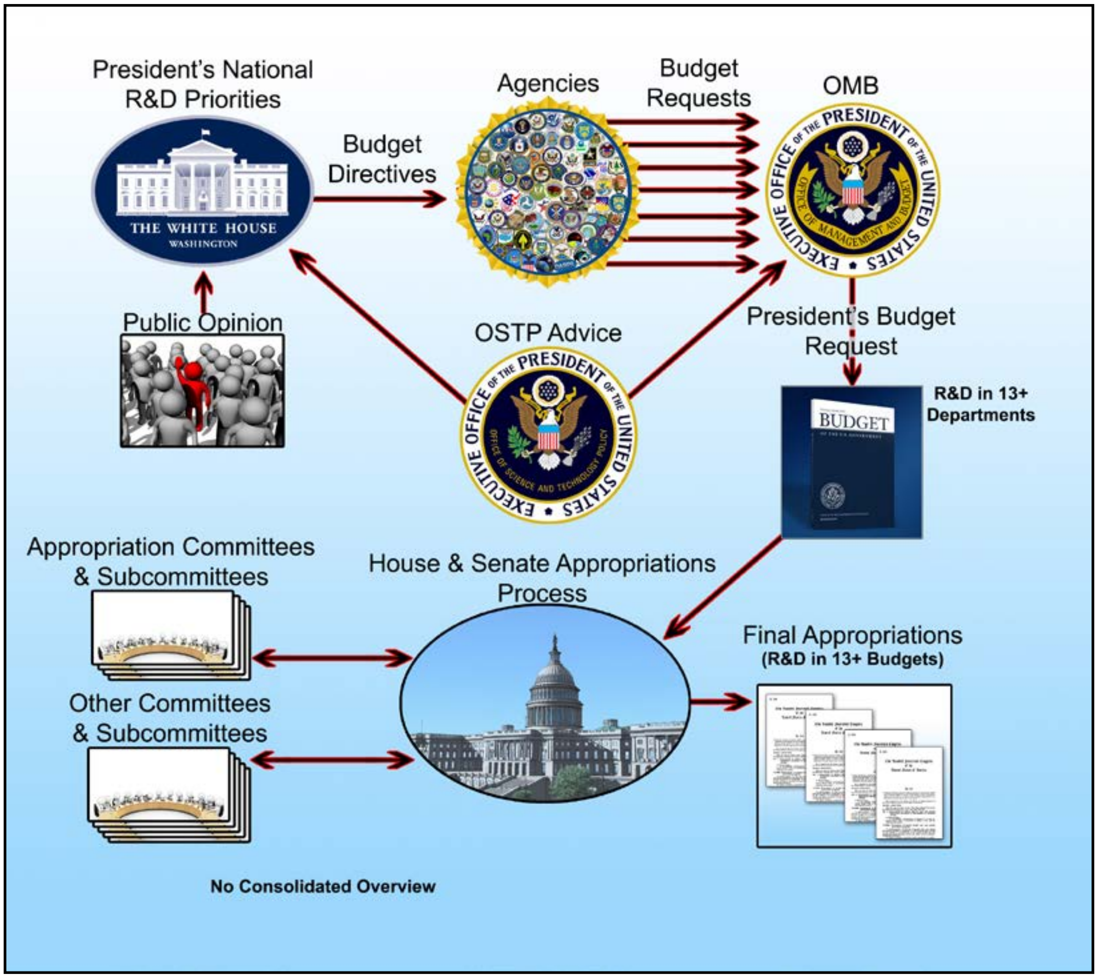

Figure 1. Agencies' R&D Budget Preparation (Image Credit: Alex Taliesen).

MOTIVATION	Subject Matter Expertise	Mechanism	S&T Performers
National security Health and other public good Political constituents General public	Government agencies and officials Associations Not for Profits Advisory panels and committees	Budget Organization Legislative Budgetary Tax Structure Law Position Political (Ad Hoc)	Government Agencies Contractors Academia Private Sector

Table 1. Influences to policies with S&T content.

difficulty in dealing with tradeoffs between immediate gratifications and future benefits, such as promoting savings over spending or husbanding our resources and ecological health for the benefit of later generations.

Many issues confronting the nation require considerable S&T expertise. A few considerations and players in this process are summarized in Table 1. Motivation to address an issue involving S&T content can arise from nearly any quarter, but it often comes from one or more of the sources listed in the first column. Subject matter experts may include government or non-government personnel and organizations, thus the need for advisory panels. The mechanism to resolve issues most often comes from the political or the budgetary community. Finally, if the issue is one of constricting or expanding the vision of a particular area of research, the effect of decisions is often visited earliest on S&T performers, often with sudden changes in direction.

ISSUES WITH TODAY'S S&T POLICYMAKING PROCESSES

This discussion of how S&T policy is created makes two main points. First, there are few explicit criteria to guide the process, which therefore tends to be driven by extraneous agendas. Second, there are too many players and organizations often episodically involved in policy-making to do it well.

The missions of the OSTP, NSTP, the PCAST, STPI, and, of course, the National Academies of Science, suggest that each of these organizations have major, and even overlapping, roles in guiding S&T policy. But, while these organizations advise the President and his staff on S&T, they don't develop detailed S&T policies that holistically support national strategies. They generally become involved in issues-of-the-day, rather than proactively addressing even larger issues that will surface tomorrow. The result is a continual game of "catch-up."

Moreover, OSTP and CRS are viewed as being subordinate to their masters, namely the Administration and Congress, respectively. There are also inevitable policy discontinuities arising from changes of Administration and Congressional make-up. Accordingly, their objectivity and ability to prioritize is often challenged.[9] Agency-level organizations, on the other hand, tend to have more credibility with both the Administration and Congress because they are reliant on both.

Too often, forces try to "bend" science and scientific advice toward their self-interest, which in many instances causes distortions. The introduction of bias is often attributed to political players, but scientists too can be tempted by self-interest – for instance, by promises of funding for their discipline.

And of course, there are honest disagreements that require adjudication. Many theories or truths in science attract controversy, even within the scientific community. Similarly, a new technology may have consequences that are socially and economically positive overall, but include facets that create opposition.

Policymaking should incorporate methods that objectively focus the process on the real character of the individual issues and goals to be pursued in their resolution. For example, many technical problems are amenable to projecting outcomes and considering benefit versus cost. Forms of risk analysis may be harnessed to determine the likelihood of harm from actions taken, or not taken. The precautionary principle provides a means to approach these kinds of unknowns with care.[10] Famously, the original cost/benefit analyses performed on nuclear power plants were extremely favorable; risk analyses were not, and those risks raised costs enormously and crippled a large nuclear component to our national power solution.

Fortunately, there is plenty of good scientific advice to aid in addressing these problems, such as the National Academies of Science (NAS). Interestingly, the NAS was founded by Abraham Lincoln. Eventually, the NAS gave rise to the NSTC. At government's call, scientists are generally willing to apply their expertise to any problem or decision. Further, a rich "information circuit" of papers and data, including most reports from advisory committees and individuals, is open and widely available through the Library of Congress.[11] The difficulty is in taking advantage of this advice and transforming it into a consistent and wise policy.

The desire to include all stakeholders and opposing views on advisory groups often presents a complication. Increasingly, Government is called upon to respond to interests whose voices are omitted from the advisory process.[12] Sometimes that opposition comes from the scientific community, for even the most fundamental "scientific truths" can be overturned by refutive observations. The noteworthy example is global climate change, where a few voices dissent from the scientific consensus of anthropomorphic climate influences.[13] Clearly, there are many options and ways of shaping and using panels to deliver cogent advice.[14] But even if successful, the advice need not be respected. For instance, recipients might not absorb the information, or it might be picked over to support separate agendas.

A special challenge in S&T policy is how to address its non-technical components (e.g., economic, ethical, or social) without drowning out the scientific details. While the constitution of an advisory body might understandably include private citizens and special interest groups to pursue a diversity of viewpoints, care must be taken to fully understand and articulate the scientific facts behind the recommended policies as well as to consider other factors.

FUTURE DIRECTIONS FOR NATIONAL S&T POLICYMAKING

How do we solve these apparent shortcomings, considering the complex technical issues involved and the nature of the layered policymaking bureaucracy that is often at war with itself? One radical approach is to introduce a new organization whose charter and manning are tailored to address them.

We will arbitrarily call this organization the Office of Science Policy (OSP). It could be an agency or a department and we propose that it should operate at the cabinet–level. The OSP must have well defined and jurisdiction-limited missions, for example to avoid duplicitous power over agency mission R&D funding. The principal mission of the Office is to recommend policy and issues that should be considered and to advise the government on the best way to maintain or update existing policies.

What would the OSP look like, where would it live, and would it be worth the expense and effort? In view of the challenges discussed above, there are several things the OSP must do well.

First, it must be able to project and proactively consider long-term S&T policy needs and coordinate the development of appropriate policies to respond to those needs. This demands an ability to organize and aggregate mountains of data, facts, and trends, and to focus thought on optional paths that guiding policies could take. The final product would be recommendations on technical policies at the national level. While other aspects of policy must be considered, the OSP's emphasis must be on S&T. Simply maintaining sufficient continuity to identify and lead national thinking on technical issues would be an important contribution.

Encouraging advice from appropriate sources, sifting through that advice interactively with the advisors, and ensuring the best ideas are aggregated and incorporated into policy is an immeasurably important task. This responsibility includes harnessing the government's in-house technical expertise, which is seldom done well, despite the good intentions of the NSTC.

Another vital mission is raising or augmenting the level of technical understanding of policymakers and the populace. This is challenged by the rate of S&T progress. Given the exponential growth in technology and capabilities, it has become a progressively more profound task to develop comprehensive technical policies. Supporting educational initiatives, such as STEM, and improving approaches to explain complex issues and policies should receive OSP's support.

The NSTC could serve as a template for the OSP. Eventually, melding the NSTC into the OSP may be desirable. However, as a civil service organization the OSP must be able to avoid the "see-saw effect" on issues disrupted by change in administrations and change in party majorities. This requires a focus on the issues at hand, rather than distractions by political issues de jour. The OSP would need to be subject to oversight by both Congress and the White House.

There are, of course, impediments to establishing a large new office or department – just consider the birth of the Department of Homeland Security. Nevertheless, as reported in the PREST conference proceedings, there have been many attempts to establish an office or Department of Science. The 1880s brought about the initial attempt at a Department of Science, when the Allison Commission proposed conjoining all scientific offices and bureaus into one national department. The laissez faire spirit of the time, however, was illustrated with Congressman Hilary Herbert saying, "Government patronage shackles that spirit of independent thought which is the life of science."[15] More recently, the period after the Vannevar Bush's report to FDR resulted in various national scientific offices (NSF, NASA, ONR, AEC, etc.). In all, there have been 60 or so attempts to combine the Federal S&T agencies reflected in bills in Congress. The President's Commission on Industrial Competitiveness of the Reagan Administration proposed consolidation of Federal S&T initiatives under a new Department of Science and Technology. Subsequently, there persisted the introduction of Bills to establish some sort of overarching department well into the mid-1990s.

So, while a Department of Science could have had benefits in the nation's R&D budgeting, policymaking, and cross-fertilization processes, it was not to be because of concerns about its affects on the missions of other federal departments. We believe these problems would be mitigated under an Office of Science Policy, which may even tend to promote agency-level science.

THREE ILLUSTRATIVE EXAMPLES

Let us consider three mega-science projects where the federal government made poor decisions. Each has non-scientific factors, such as economic or ethical aspects, but the technical and scientific forecasting were crucial to their success or failure. In the following, we extend the analysis of these case histories presented during the PREST conference by imagining how the recommended policy actions might have helped to make things better.

1. Human Genome Project.

The Human Genome Project is viewed as a supremely successful big-science national program. The program met its goals, below budget and earlier than scheduled, a tribute to good policy and management. Even so, the project was originally designed to disseminate into the public domain genetic information and deeper knowledge. But, an enthusiastic and capable private sector joined in, accelerating progress while demanding a broad swath of patents in the field (thus restricting dissemination and use of basic information). There is a need to balance the incentives to inventors and researchers against the benefits of broadly sharing results of experimentation and analysis that might lead to new breakthroughs or better products.

Would the recommendations made in this article have made the program more effective? While the federal government did an excellent job of ensuring the broad participation of stakeholders and researchers, perhaps the proactive thoughts and analysis of a policy-oriented office could have better addressed the patent issue, and could have attempted to streamline transition to applications. For example, more expert input could have anticipated the innovative way in which the private sector applied computer science matching algorithms to the problem of sequencing the genome. This expertise would have been available in several government agencies, but not necessarily in the National Institutes of Health (NIH), so this may have been an excellent opportunity to initiate an interagency task force that included better computer knowledge.

Jonathan Bailey, NHGRI.

PD: US Government.

2. Superconductivity Supercollider.

Originally planned and approved for $4.4 billion by the government, and competed throughout the US, the Superconductivity Supercollider (SSC) was designed to find the Higgs particle. The project, which would have allowed the US to maintain world leadership in high-energy physics, began construction in Texas in the late 1980s, following a feasibility study and several stages of development. The SSC was to include two 53-mile-long stacked rings and construction was to have taken eight years, but in 1995 Congress terminated the still unfinished project. This left the science exploration to the European Large Hadron Collider. The program completed over 10 miles of track, expending about $2 billion, before ceasing activity with little return on investment. Magnablend, a chemical company, now owns the site.

According to *Scientific American*, "at its end the project was already employing 2,000 people at the site or in Dallas, about 200 of whom were scientists, plus a contingent of Russian physicists employed after the end of the Cold War. Another 13,000 jobs linked to the project never materialized. About half the SSC scientists left the field of physics, according to a 1994 survey by *Science* magazine, some to become analysts in the financial industry. Many took a loss on homes sold in a sudden buyer's market."[16]

The extent to which national attention would have made a difference in this tragic waste of scientific funds depends upon how much of the blame should be placed on the policymaking stage versus poor execution. For instance, cost overruns brought the project to an estimated $11B in 1994 dollars. But the policy strategy should have included better program management by an appropriate agency, which might have solved many execution problems. The management strategy should also have more persuasively articulated the program goals to a largely disinterested public, not to mention to physicists who opposed the spending levels that precluded numerous small projects. Most notable, however, is the need for a cogent process to choose, structure and manage large programs that include both science and infrastructure.

3. International Space Station (ISS).

Another mega-science project (estimated at $160B thus far and costing an additional $3B per year) is NASA's International Space Station (ISS) program. The program was to minimize expenditures of a previous plan, "Space Station Freedom." Interestingly, the project competed against the SSC for funding. Initially, the ISS was advanced as an orbiting scientific research, with the promise of a useful platform for scientific investigation and discovery. Scientific advisors, including the National Research Council, warned that ISS's enormous cost burden could not be rationalized by the scientific value of the proposed research. In spite of this, defense for the project continued. One specific promise of the program was to enable the scientific study of humans in space. Once clear that the true goal was not scientific, focus shifted to international aspects of its value, emphasizing commercial, diplomatic, and educational goals. Since inception, Russia was a crucial partner. However, Russia's involvement declined as its economic and infrastructure problems increased. Other countries also participated, but the burden of the program increased, resulting in significant overruns for the US.

NASA/Crew of STS-132.

NASA made several attempts at commercialization and privatization of the payload and station. Industry was disinterested in the intermittent accessibility and expense of this "factory in the sky." The mutual dependence of the ISS on the Space Shuttle was difficult due to the Shuttle's carrying inefficiency. Then, after two Shuttles and crews were lost, the shifting importance of the key to success in orbital space became getting there and back, safely and affordably – not orbiting. These arguments were forwarded during that time, but had not been sufficiently considered at the national level.

If an OSP had been engaged in the process of pursuing the ISS, perhaps more attention would have been paid to the tradeoffs between science and the program plan. At any rate, the logic behind improving earth-to-orbit transport could have been escalated to the national decision levels. Again, political, rather than scientific rationale continues to drive its continuation, now extended to 2024.

CONCLUSION

Our country is the most prolific discoverer of scientific fact and provider of useful technology in history. We have investigated our universe from the outer reaches of space to the smallest of particles. And we have invented more effective ways to harness that knowledge and put it into use, from feeding exploding populations to digitally communicating with the world. But, mankind's challenges are just beginning. Resource shortages, climate change, the population explosion, and many other critical, complex, and massively interactive trends call upon our resolve to do a better job in setting and pursuing worthy goals. S&T policy must be at the center of these tasks and we must turn our national talents toward making them work.

NOTES

1. Sponsors included: Senator Jeff Bingaman, Senator Joseph Lieberman, Representative Curt Weldon, Deputy Undersecretary for Defense (Science and Technology), Air Force Office of Scientific Research, Department of the Army, Defense Advanced Research Projects Agency, National Intelligence Council, National Science Foundation, Office of Naval Research, US Coast Guard, and the Potomac Institute for Policy Studies.
2. "Shaping Science and Technology to Serve National Security (PIPS-05-02)", James Richardson, Whitney Matson, and Robert Peters, Potomac Institute for Policy Studies, 31 Jan. 2005.
3. "Innovating Science Policy: Restructuring S&T Policy for the Twenty-first Century," James Richardson, Robert Peters, and Whitney Matson, *Review of Policy Research* November 2004; 21(6): 809–828.
4. James J. Richardson, Whitney Matson, and Robert Peters, "Promoting Science and Technology to Serve National Security" In: *Science and Technology Policies for the Anti-terrorism Era*. Edited by Andrew D. James (Washington, DC: IOS Press; 2006).
5. The results of the study were published in *Science*. According to the article, "Standoff over government climate study provokes uproar by scientists," by Lisa Rein, *Washington Post*, 24 November. According to this article, the review process took 50 percent longer than the normal 109 days that is normal for the journal.
6. In the area of intellectual property rights, the Judicial Branch may have a considerable influence on S&T. For instance, patents being granted or renewed for modified pharmaceuticals and for organisms derived from genetic manipulation are being challenged on a legal basis. This represents a trade-off between placing important data in a public status where everyone can use it, or keeping it in a private domain to provide commercial motivation.
7. All quotes in this section are taken from the White House website, see: https://www.whitehouse.gov/administration/eop/ostp/about.
8. All quotes in this section are taken from the CRS Website, see: https://www.loc.gov/crsinfo.
9. See, for example, Eamon M. Kelly, "Federal Research Resources: A Process for Setting Priorities, National Science Board, October 11, 2001; Steven W. Popper, et al, "Setting Priorities and Coordinating Federal R&D Across Fields of Science: A Literature Review," Rand, April 2000; and Daniel Sarewitz, "Social Change and Science Policy," *Issues in Science and Technology Online*, June 5, 2003.
10. John D. Graham, Administrator of the Office of information and Regulatory Affairs at the Office of Management and Budget has written of various issues treated through the precautionary principle. See, "The Perils of the Precautionary Principle: Lessons from the American and European Experience," Regulatory Forum of the Heritage Foundation, October 20, 2003.
11. The NAS alone publishes over 200 books and many more reports per year.
12. Frederick Anderson makes several interesting suggestions on how government can improve the process of forming advisory panels in, "Improving Science Advice to Government," Issues, September 15, 2003.
13. If the majority/minority positions on climate change were switched, we would not even be discussing it.
14. I am not encouraging government officials to micromanage advisors. In fact, such activity would undermine one of the strengths of our nation's R&D system. Rather, the aim is to make that advice more specific and useful.
15. H.A. Herbert, Restricting the Work and Publications of the Geological Survey…, May 5, 1886, 49 Cong., I Sess, H.R. Report 2214 (Ser. 2441), 16.
16. "The Supercollider that Never Was, David Appell, *Scientific American*, Oct. 15, 2013.

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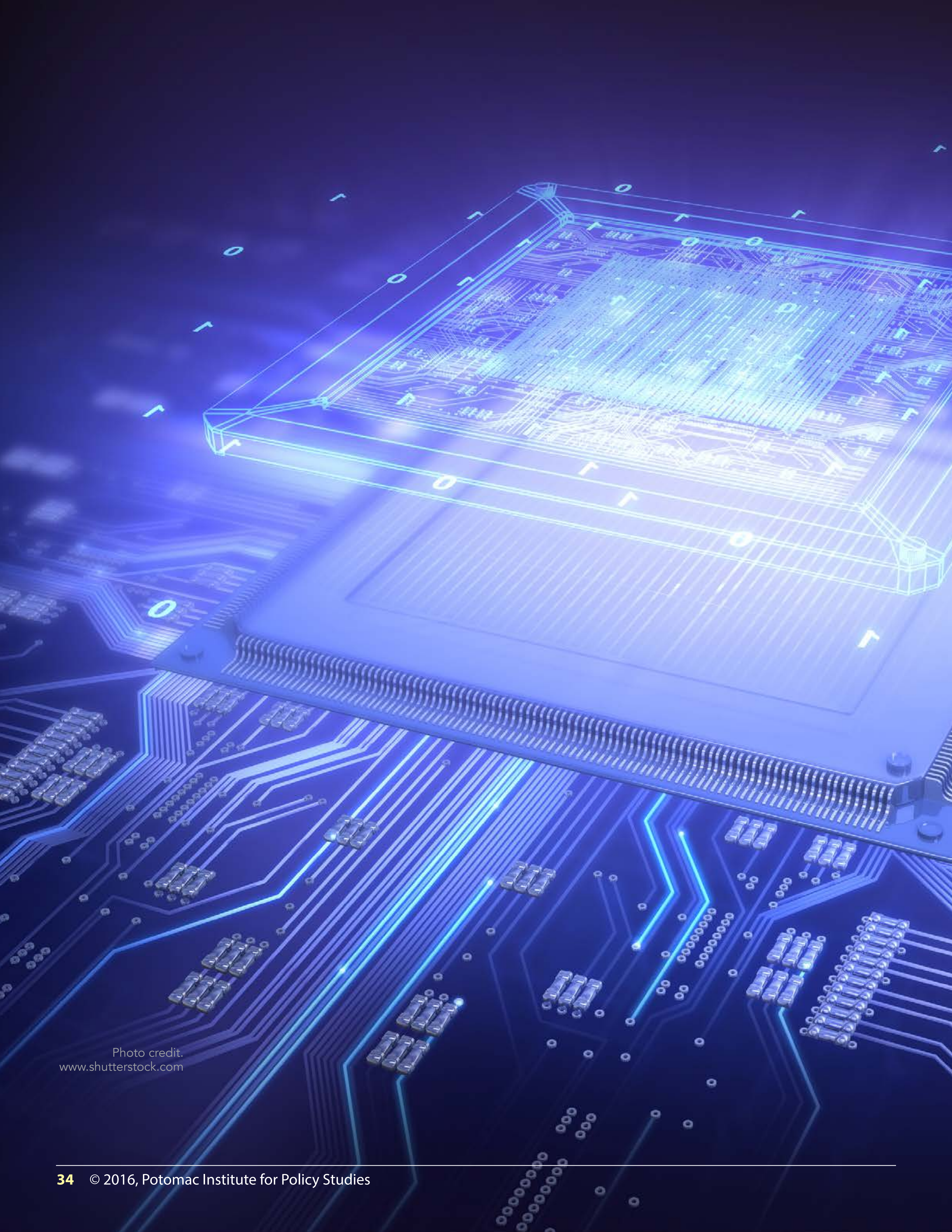
Capitol (aoc.gov), PD.



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THE DEATH *of Moore's Law*

Mike Fritze, PhD; Patrick Cheetham; Jennifer Lato; and Paul Syers, PhD

For more than 50 years, Moore's law has successfully described the steadily increasing power of microelectronics. Decades of exponential growth in transistor density has revolutionized the way humanity lives, and has generated a worldwide semiconductor industry. However, as Gordon Moore, co-founder of Intel and author of Moore's Law, once said: "no exponential is forever." Today, the imminent end of classical Moore's Law scaling represents a major turning point in the history of microelectronics. The authors explore the historic background of Moore's Law, the economic implications of its demise, and policy ideas for the US Department of Defense to adapt to this paradigm change.

THE END OF MOORE'S LAW

With over 50 years of sustained exponential scaling, the field of microelectronics has had a profound impact on society. In the 1960s, electronic chips had but a handful of components; today, a single chip contains several billion transistors. Moore's law has characterized a $336 billion worldwide semiconductor industry,[1] and has fed the development of multiple other industries. From modern GPS applications, to smart phone technology, it has revolutionized the way we live. Microelectronics has driven the historic transformation from analog to digital representation of data, and has enabled the vast expansion of data storage.

However, the heady days of exponential scaling are about to come to an end. Fundamental limits signal a major paradigm shift in microelectronics technology. These changes will be disruptive to the industries that have grown accustomed to exponential growth as described by Moore's Law. The US Department of Defense will need to adapt its policies to ensure continued technological superiority.

Moore's Law, as formulated by Gordon Moore in his 1965 paper *"Cramming More Components onto Integrated Circuits,"* is nothing more than an empirical observation that the density of components in an integrated circuit (IC) doubles every 18-24 months. According to Moore,[2]

> *...the complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years.*

In 1975, Moore updated this prediction to expect the doubling of transistors every two years. Transistor density has in fact continued to increase, doubling every 18 to 24 months since 1975, with a number of other parameters also changing in the positive direction. The result has been that devices have become faster, more reliable, efficient, and cheaper to produce. There has been much speculation as to the longevity of Moore's Law. Moore himself only expected the law to last for 10 years, but since 1965, we have seen 50 years of exponential growth.

Yet in the early 2000s, cracks began to appear. An upper limit on processor speeds appeared, due to challenges in reducing levels of power consumption (and thus increasing heat dissipation). Multi-core processors were introduced, but required parallel computing to achieve performance gains; yet typical applications, such as operating systems, cannot be perfectly parallelized because many of the steps in a program depend on the results of earlier steps. The increasing difficulties with technology feature size scaling were also reflected in higher fabrication process complexity. Advancements in photolithography, the technology required to fabricate integrated circuits, stalled at a wavelength of 193 nm. This has necessitated costly imaging "tricks" and multiple photolithographic exposures per level, slowing down the fabrication rate and adding cost.

Currently, in 2015-2016, even more serious limits have been reached. With transistor minimum feature sizes falling to 14 nanometers, the industry has reached a size regime where a countable number of atoms comprise each component within the IC, presenting difficulties in process control. The evidence that a fundamental limit has been reached is apparent in the actual cost per component. A major turning point has recently been realized as the cost per transistor on an IC has started to increase after 28nm. As shown in Figure 1, this change is the first time this has happened in the past fifty years, representing a major shift for the future.

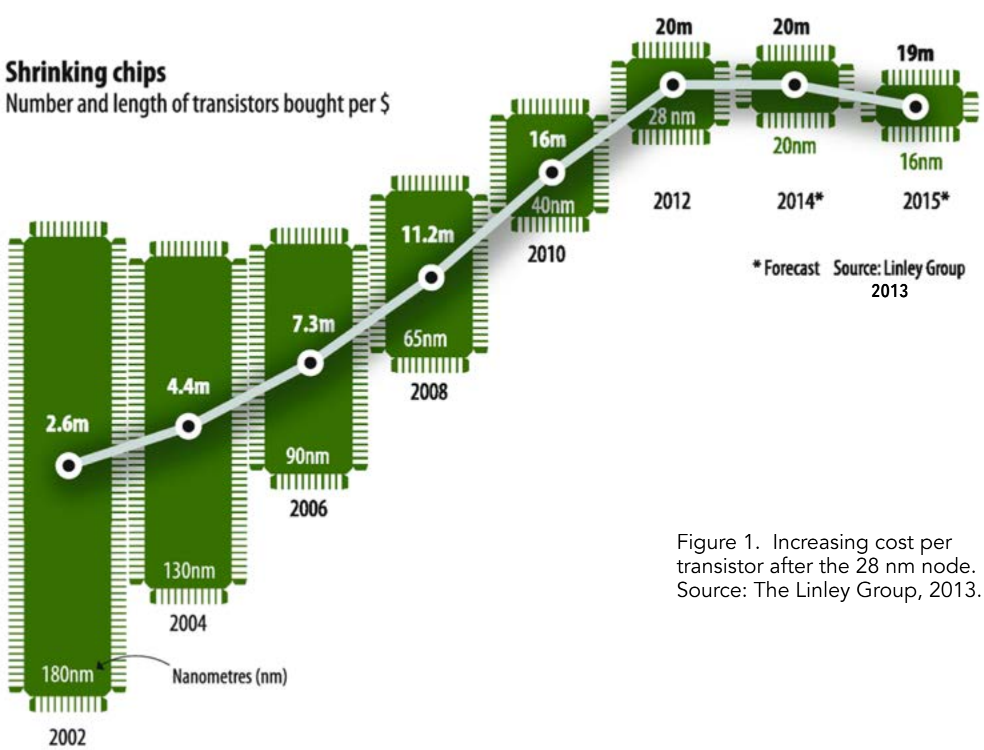

Figure 1. Increasing cost per transistor after the 28 nm node. Source: The Linley Group, 2013.

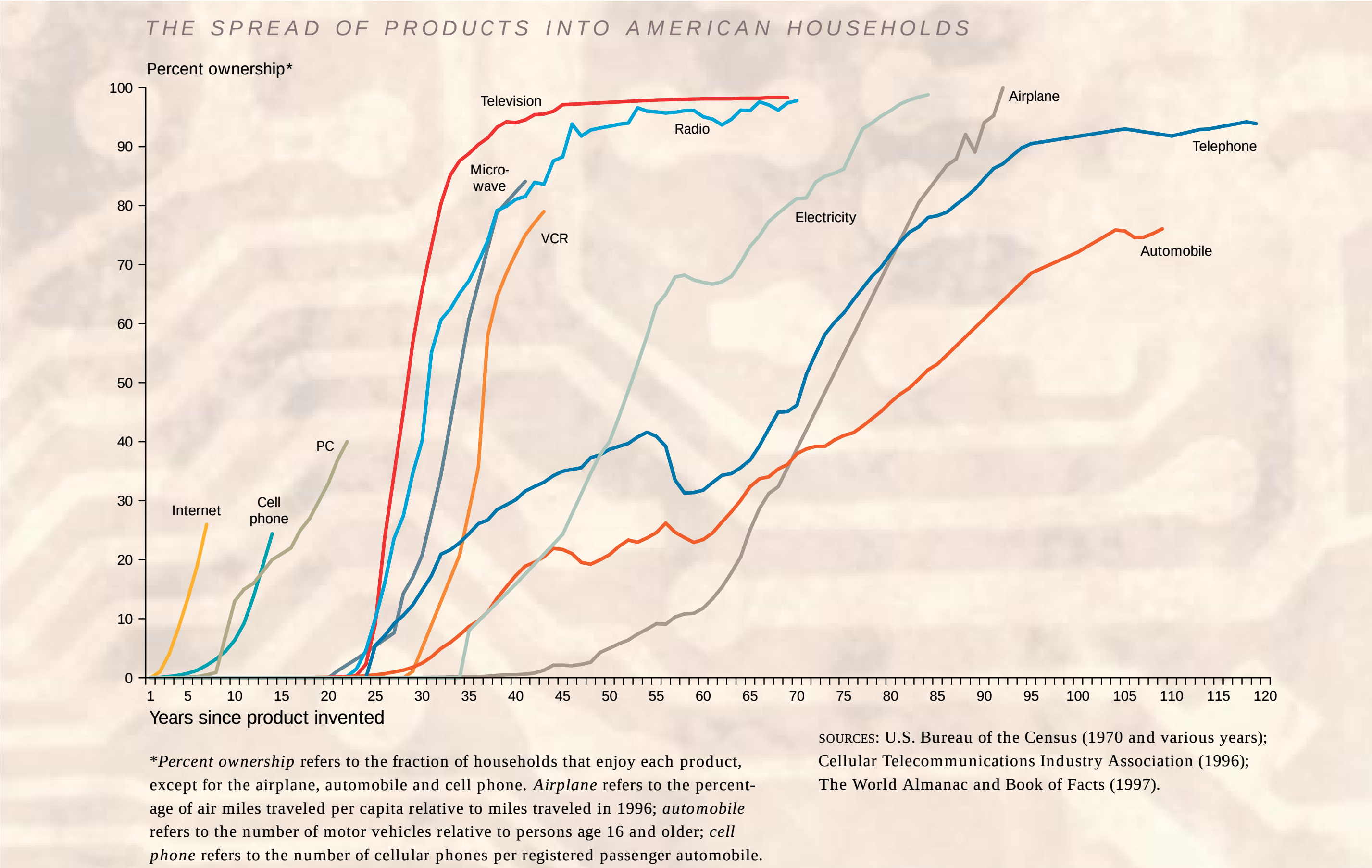

Figure 2. The spread of products into American Households. Reprinted here with permission, Federal Reserve Bank of Dallas 1996 Report, by W. Michael Cox and Richard Alm.

CONSUMER PRODUCT DOMINANCE

In the beginning, the microelectronics industry was fueled by government investments, much of it through the US Department of Defense (DoD). DoD's expenditures in equipment as well as research and development (R&D) in electronics was in the billions of dollars, increasing from $3.2 billion in 1955 to $7.8 billion in 1964 – a significant investment considering that this took place more than fifty years ago.[3] DoD spurred integrated circuit development and production in order to increase the automation, miniaturization, and reliability of defense systems. Military specific (or MIL-spec) components were also developed, with the added goal of ensuring that parts used in military systems maintained the functional capability and reliability to operate in harsh environments.[4] DoD also wanted multiple sources of chips, and so encouraged technology transfer between semiconductor firms, which indirectly grew the product diversity of the semiconductor industry.[5] Since then, DoD's influence over the semiconductor market has waned.

Semiconductors became more and more dominated by commercial applications, evidenced by the military's falling share of the US market from nearly 100% in 1962 to roughly 30% by 1968.[6] After 1970, commercial IC applications totally dominated. Microelectronics became a "commodity," feeding interchangeably many different commercial applications, as well as the military's needs. Growing consumer demand established a sizable market for increasingly sophisticated microelectronics. From the 1980s through the 1990s, a prime driver was the personal computer. From the 2000s to the present, the primary driver has been the mobile communications market, as exemplified by the cell phone. The economic "engine" of the microelectronics industry has been built on the "fuel" of very high volume consumer applications.

A potential challenge to the consumer demand trend is the "adoption curve" of new technologies, signifying how quickly they penetrate a national or worldwide market. Figure 2 shows that older technologies such as the car, telephone, and household electricity took many decades to become ubiquitous, whereas newer technologies like the TV and VCR only took a few years to saturate the global market. A seen in Figure 3, even the current cell phone market is showing evidence of saturation.

For the past few decades, Moore's Law has guaranteed the rapid obsolescence of most consumer electronic devices. Accordingly, most consumers felt compelled to replace their PCs every few years, and even faster refresh cycles for smart phones became commonplace. Rapid penetration of electronic devices throughout the entire world further propelled the microelectronics industry.

Contrastingly, DoD has been challenged by the fast lifecycles of consumer products, compared to the much slower acquisition cycles of typical military systems. Moreover, the commercial industry drove the types of ICs that were produced, with a relatively small number of "general-purpose" ICs made to meet the demands of most consumer applications. As a result, DoD had to adapt its systems to piggyback on available commercial microelectronics; military systems used expensive specialized components only when absolutely necessary.

As the consumer market grew to a global size, economies of scale could be reached by achieving very high volume production of relatively standardized ICs. Industry R&D focused on technologies to maximize volume and yield, in addition to shrinking size and increasing performance. Business boomed as consumer products were regularly upgraded by taking advantage of steadily increasing performance. Even though DoD had driven much of the early development of the technology, its demands were overshadowed by the burgeoning commercial marketplace and eventually its role was primarily limited to adapting commercially available products.

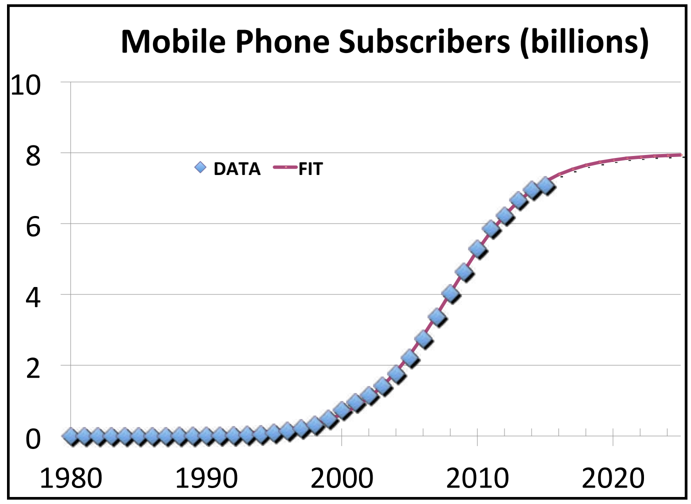

Figure 3. Adoption curve for cellphone technology. Data Source: ITU (International Telecommunication Union).

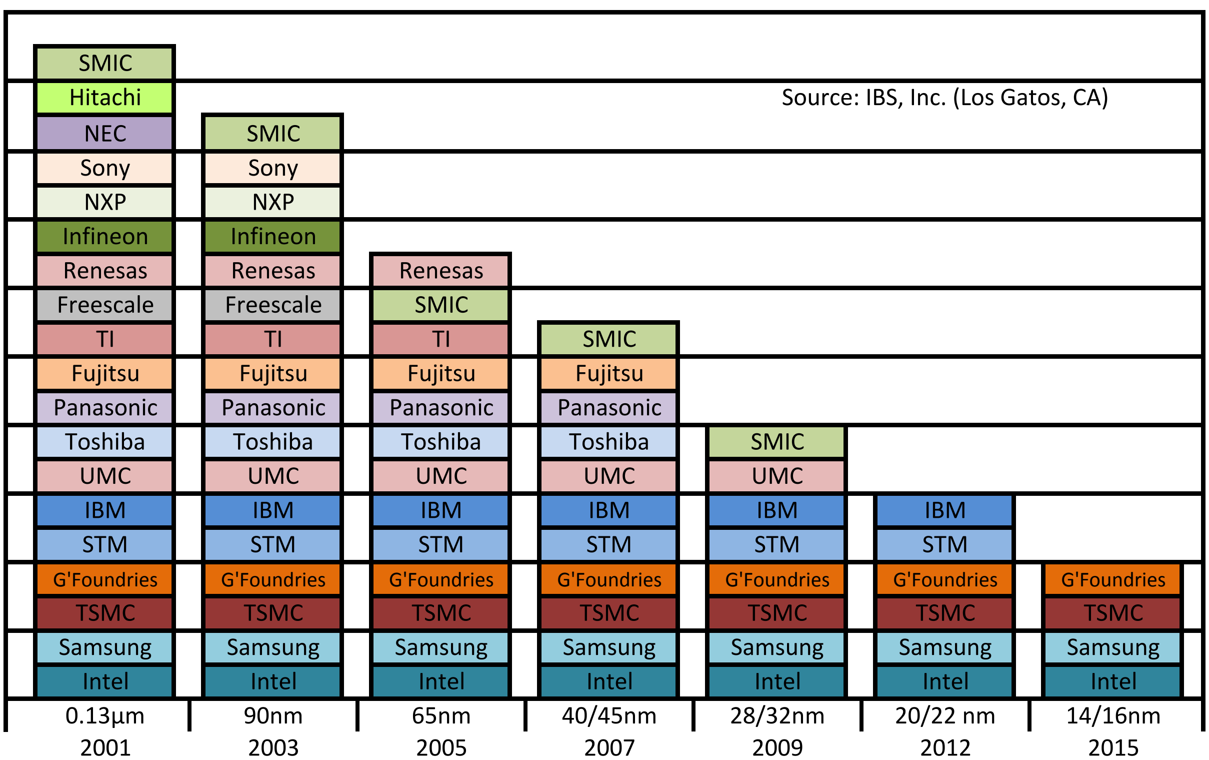

Figure 4. Dramatic Consolidation of state of the art CMOS Fabs. Source: IBS , Inc. (Los Gatos, CA).

THE ECONOMIC DRIVERS

With the demise of Moore's Law, what will fuel the microelectronics engine? How will the microelectronics industry adapt?

Already, we see changes in the way the industry operates. Recently there has been a dramatic increase in mergers and acquisitions among the larger manufacturing companies.[7] Further, as shown in Figure 4, there has been a stark decline in the number of microelectronics fabrication facilities (or fabs) capable of manufacturing state-of-the-art chips.

A new product class could create a renewed driver of the current industry model. The future highly interconnected world, known as the "Internet of Things" or IoT, will certainly require many electronics parts. However, the parts needed for IoT devices generally will not require powerful processing. They will also need to be cheap, durable, and use low power. It is not likely that this market will be enough to sustain the current microelectronics business model of high volume manufacturing of complex ICs. Without a new high volume commodity product, such as a replacment of the smart phone, the microelectronics industry will need to evolve in significantly new ways.

Without plentiful "fuel" in the form of Moore's Law coupled with high volume commodity consumer products that customers want to frequently upgrade, the microelectronics industry will lose the economies of scale required to produce complex ICs at attractive prices. Consumers will keep their technology products for longer periods, placing a greater emphasis on their reliability and sustained utility. The microelectronics inside of products will migrate from "commodity" items to "durables," like consumer appliances.

Once market saturation occurs, a technology industry typically matures to serve the unique needs of its customers. Business differentiators that offer a range of different amenities to serve unique needs are found in the aviation industry, for example,[8] as well as the automobile industry. Saturation in the microelectronics industry, if it occurs, will have major impacts on the way the business is structured. In the future of integrated circuits, a new emphasis will be put on meeting a wide variety of needs of customers via customization of features for specialized markets – and DoD will likely return as a driver of some of these markets. Thus, DoD needs to be prepared to leverage these new industry dynamics.

FUTURE DIRECTIONS

In a new world of microelectronics as durables, the key driver of innovation and performance may revert back to *military and aerospace applications*. DoD may once again be in the captain's chair, at least for their particular needs. The defense community has always been willing to pay a premium for required critical performance, but had become a sideline customer during several decades of the microelectronics "commodity" phase. In the new commercial environment for microelectronics, specialized technologies carrying a cost premium will mostly likely be driven once again by DoD's applications for the warfighter. The microelectronics research agenda could once again be driven by specialized customers, and DoD can steer development in directions that meet its needs for technical superiority in military applications.

One of the promising "Post-Moore" emerging technologies that might become important to DoD is 3-Dimensional (3D) stacking, also called 3DIC technology. 3D stacking is a promising means to achieve high performance custom ICs, without requiring a greater number of transistors in two dimensions. A schematic of this approach is shown in Figure 5. The key to 3DIC technology is the ability to integrate multiple active "tiers" into a final customized IC. Each individual tier can be implemented in a different specialized technology. Designers can combine sophisticated processors with sensor tiers, or even tiers at legacy technology levels, in such a way that as to maximize security and reliability in addition to increasing performance. At this point in time, supporting infrastructure is lacking, including robust design tools and supply chains to provide tiers and interconnects. This infrastructure will not be developed by industry in the absence of an obvious high volume commodity driver. DoD can therefore play an important role helping to develop the enabling infrastructure of 3DIC technology, reaping the custom performance benefits as well as helping seed a new US manufacturing industry.

Another enabling technology that could benefit DoD is based on the paradigm of low volume flexible fabrication. As noted earlier, commercial microelectronics rely on high volume fabrication to realize economies of scale, and as a result the available types of ICs are limited. Going forward, flexible low volume approaches will play an increasingly important role in providing customized parts for specialized applications. Such fabrication approaches are based on a different type of economic model. In this model, specialty or "custom"

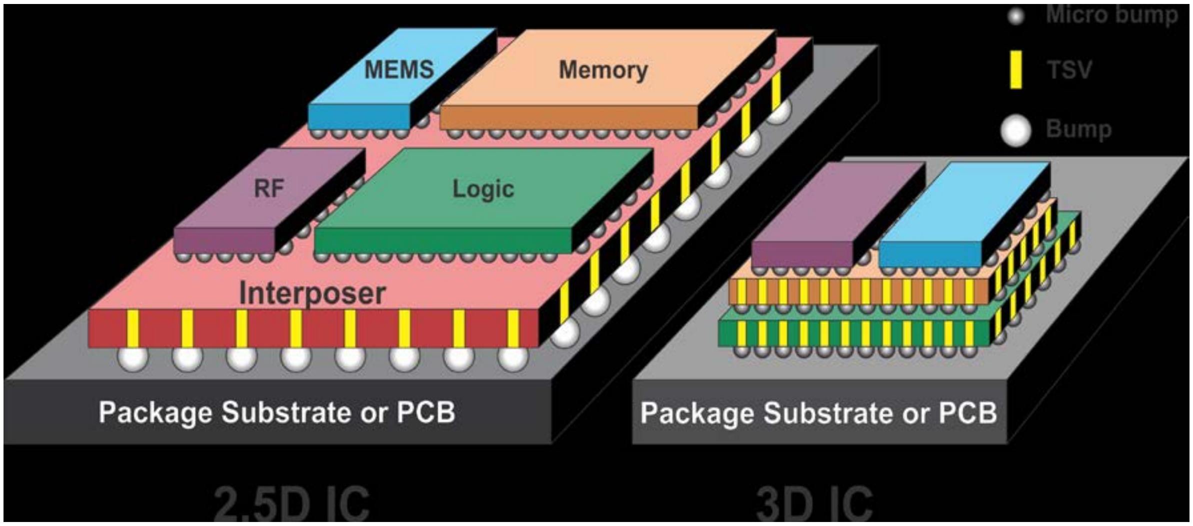

Figure 5. Two main types of 3DIC technologies. On the left is an "interposer" based solution and on the right is a 3D-stacked "multi-tier" solution featuring a higher density of vertical interconnects. Reprinted here with permission, Dr. Bob Patti of Tezzaron/Novati.

parts are the goal, and absolute lowest cost per part is not a requirement. Such an approach is already practiced in some domains where aggressive scaling is not required, such as radio-frequency and radiation-hardened parts. This new business model will need to be able to support higher cost margins than today's typical commercial manufacturing. The low volume flexible fabrication paradigm also requires alternative approaches to ensuring reliability, including more robust testing. DoD can therefore play an important role in developing the infrastructure required, such as multi E-beam Direct Write technologies. Such an investment would provide desired custom parts for the DoD as well as helping seed a new US manufacturing industry.

CONCLUSION

The impending end of Moore's Law represents much more than a technological paradigm shift. This major turning point will in fact trigger major changes in the business models of the microelectronics industry. Recent decades have been characterized by commodity consumer products like the PC and cell phone, with product generations that were refreshed rapidly as microelectronics technology advanced. As these markets saturate, a new business model is required for the industry and more emphasis will be placed on reliability and robust lifetime performance. More attention will also be placed on customized performance for smaller market segments, as opposed to a "one size fits all" generic approach. This "maturing" of the microelectronics industry will follow a progression similar to past technologies, such as cars and commercial aviation. As a result of this change, new fabrication approaches will become more important including 3DIC integration and low volume flexible fabrication concepts. The DoD can play a key role helping to develop the engineering techniques and the infrastructure for these new technologies. This will not happen automatically by industry given the business uncertainties and risks that accompany the end of Moore's law. This major paradigm change offers the DoD another opportunity to help drive microelectronics to both serve its specialized needs and seed the development of new US manufacturing industries – a role it has not been able to play for many decades.

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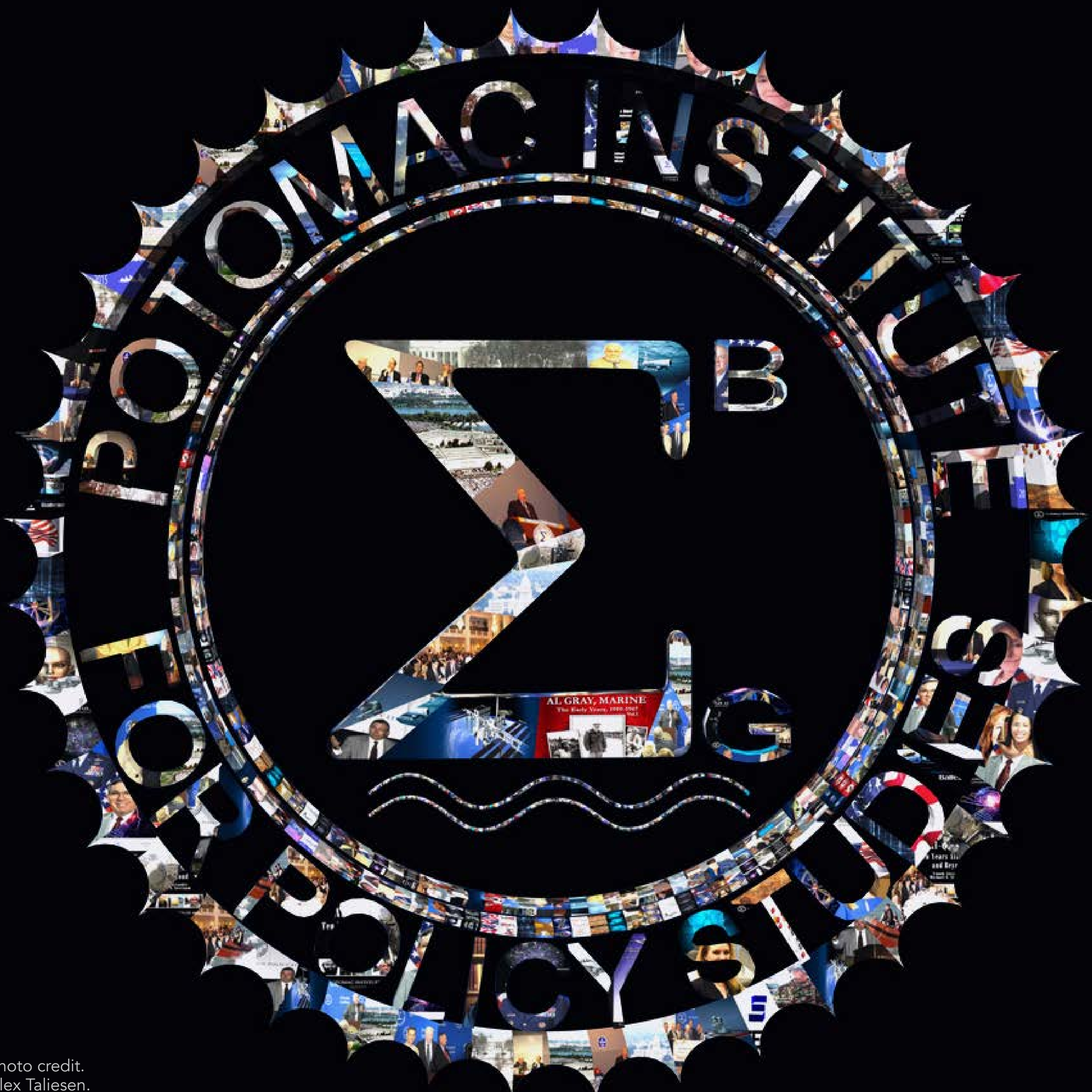
VIEWS IN BRIEF



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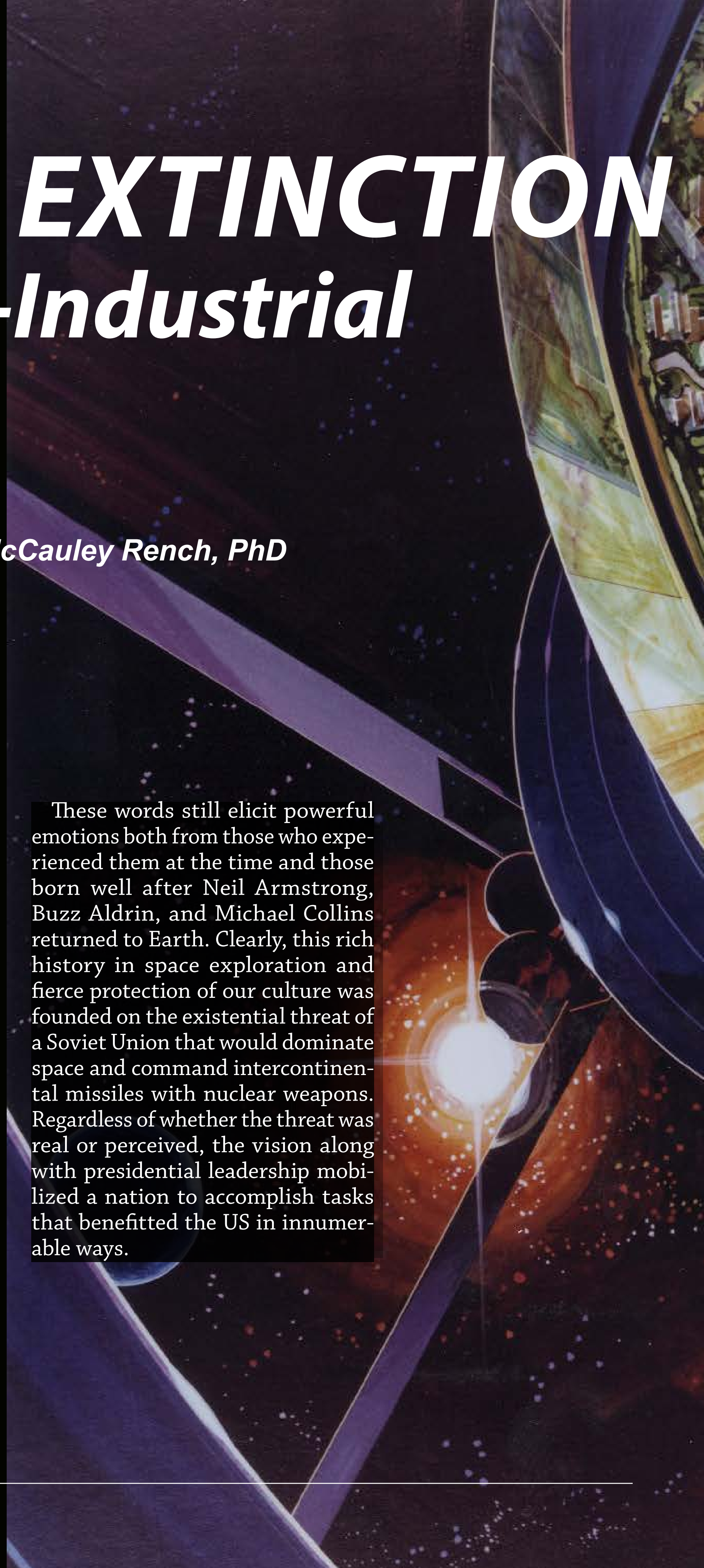
Alex Taliesen.

GLOBAL EXTINCTION or a Space-Industrial Complex

Kevin Hertzler and Rebecca McCauley Rench, PhD



During the the peak of the Apollo program, the United States government funded NASA at over 4% of the federal budget[1] as compared to the less than 0.5% of federal funding NASA receives today. The allocation of resources was possible as our country perceived a real threat from the Soviet Union and their launch of *Sputnik*. Not only did we mobilize our military and technological assets to protect our way of life, but President Kennedy energized the nation in a time of global crisis while the Cold War was threatening the world with nuclear annihilation.[2]

> *...this nation should commit itself to achieving the goal, before the decade is out, of landing a man on the moon and returning him safely to the earth.*

These words still elicit powerful emotions both from those who experienced them at the time and those born well after Neil Armstrong, Buzz Aldrin, and Michael Collins returned to Earth. Clearly, this rich history in space exploration and fierce protection of our culture was founded on the existential threat of a Soviet Union that would dominate space and command intercontinental missiles with nuclear weapons. Regardless of whether the threat was real or perceived, the vision along with presidential leadership mobilized a nation to accomplish tasks that benefitted the US in innumerable ways.

Image credit:
NASA Ames Research Center.

Yet, the bigger existential threat of annihilation of all humanity, by nuclear holocaust or natural forces, is currently considered too remote to be taken seriously. The geological record has preserved the rise and decline of many species throughout earth's history, whether their extinctions were the result of asteroid impacts, volcanic activity, solar flares, or gamma ray bursts from distant star systems. To think humanity above the historical trends of the universe is conceited and illogical. Perhaps it is time to reconsider the annihilation threat and to entertain the need for an off-Earth sustainable colony.

Humanity might not get a second chance at survival. The idea of an extinction event has long been fuel for science fiction writers, and is exemplified in the novel by Neal Stephenson entitled *Seveneves*.[3] In *Seveneves*, humanity will be wiped out on Earth within two years unless nations collaborate to put a small group of astronauts and scientists on the International Space Station in hopes they survive and repopulate the planet. Science fiction has been known to become science fact, both in ways that are beneficial to society, and in ways that have negative consequences. A study of threats and a dystopian future is also inculcated into academia, with Niklas Bostrom, the founder of the "Future of Humanity Institute," as a recognized leader. While the risk in any given year might be quite small, there is almost certainly an eventual global extinction event. With a growing population and the speed of destructive technological advancements, the annual risk of humanity's downfall may be increasing. When the inevitable is presented as a certain future, or happens before we can react, what will be humanity's last collective thought? Given our current technological prowess, perhaps the time to take action is now. During a *Wall Street Journal* All Things Digital conference,[4] Elon Musk said:

> *Either we spread Earth to other planets, or we risk going extinct. An extinction event is inevitable and we're increasingly doing ourselves in.*

World renown physicist Steven Hawking agrees and recently told a gathering at the Big Think:[5]

> *I believe that the long-term future of the human race must be in space. It will be difficult enough to avoid disaster on planet Earth in the next hundred years, let alone the next thousand, or million. The human race shouldn't have all its eggs in one basket, or on one planet. Let's hope we can avoid dropping the basket until we have spread the load.*

The timing and the nature of this event remains truly unknown. Predictions suggest an existential event may come from space or be the product of our own hand, but we will likely remain ignorant of the cause until its near arrival. What we do know is that if humanity is still inhabiting only one planet, our unique life stories will be tragically and permanently erased. Thus, we confront the realization of the likelihood of a global extinction event that we have absolutely no control over, that we currently have no defense for, and no plans to escape from. We are deluded into believing that since an extinction event is rare, it can not occur in our lifetime. Consider the attitude expressed in the Jet Propulsion Laboratory's Near Earth Object program's website[6] which states:

> *On an average of every several hundred thousand years or so, asteroids larger than a kilometer could cause global disasters … No one should be overly concerned about an Earth impact of an asteroid or comet. The threat to any one person from auto accidents, disease, other natural disasters and a variety of other problems is much higher than the threat from [Near Earth Objects] NEOs. Over long periods of time, however, the chances of the Earth being impacted are not negligible so that some form of NEO insurance is warranted. At the moment, our best insurance rests with the NEO scientists and their efforts to first find these objects and then track their motions into the future. We need to first find them, then keep an eye on them.*

However, what will our response be if we find an NEO larger than a kilometer that is on a collision course with Earth? A database is not an insurance policy and leaves open the issue of an appropriate response. Currently, our only real hope lies with mitigation strategies predicated on intercepting[7] or redirecting[8] NEO objects. The former suggests using a robotic spacecraft that is weighted or carries a nuclear explosive and the latter will redirect the NEO object with a robotic spacecraft. However, as NASA states in their "Asteroid and Comet Watch" website[9] a response requires decades of warning time if the NEO object is larger that a few hundred meters.

We needed *Sputnik* to motivate our resolve for the domination of space. The mental contrast of one day dreaming about space travel through science fiction, and then seeing it live on television in the living room, stimulated our imaginations. President Kennedy's speech inspired a nation and the decade-long pursuit that saw a surge in academic scholarship and technological advances. There are many technologies and spinoffs[10] woven into the fabric of the world culture that owe their birth to that speech and subsequent technology development.

Can we expect the development of a humanity insurance policy before a crisis begins? It might require funding of NASA at levels similar to the 1960s, when we successfully landed men on the moon. It might require the development of a space-industrial complex that could help drive future economic growth. It might require that we spread out to other planets and achieve Earth independence to stave off global human extinction, even on our watch. It does require that we take the threat, and its inevitability, seriously and devote resources to preventing our extinction.

The ancient seafarers were motivated to take risks for the sake of curiosity and the desire for exploration and resources.[11] The drive to leave the planet and set up colonies is similar: There is the allure, the curiosity, the adventure, and the insurance. It could, and should, be an international effort justified based on the purpose of planning for the preservation of humanity.

Certain plans are underway. Mars One is a nonprofit organization that promotes its plans for a Mars settlement within fifteen years.[12] Elon Musk's company SpaceX is reportedly developing plans to send large numbers of people to Mars.[13] And NASA recently released a comprehensive strategy[14] that leverages near-term space activities with a comprehensive capability development culminating in an independent human presence on Mars. The NASA plan, at a minimum, would provide a future with a sustainable presence for humanity in deep space and provide an answer to many global extinction scenarios. Some of these plans are more logistically feasible than others, but all demonstrate the ambition of a select sect of humanity interested in pursuing off-Earth colonization. This strategy is well reasoned and has the potential to save humanity as well as provide a much needed economic boost by creating a space-industrial complex with the nascent private-public partnerships[15] for mining asteroids, manufacturing propellant on the moon, creating fuel depots, and launching humans into space. The spinoff technologies would fuel real job growth as evidenced by the Apollo program of the 1960s. Rather than a short lived event to win a space race, this modern space age will be designed as a sustained effort in human space colonization. The current roadblocks preventing this strategy from moving forward are budgets, political priorities, and the changeable public interests; the exact same denouement of the moon landings over 40 years ago. An article posted on the *Washington Post* website by Joel Achenbach made the following observation:[16]

> *At the moment NASA can't even get an astronaut to the International Space Station without buying a seat on a Russian rocket. A new NASA space capsule that was conceived in 2005 likely won't be ready until 2023, according to NASA's latest estimate, and it's built for 21-day missions, not for trips to Mars.*

The same article quotes Doug Cooke, a former NASA associate administrator as saying:

> *There needs to be more of a plan for actually getting there [Mars]. You can't have a flat-line budget indefinitely and think you're going to put all of this together by 2030.*

We must support the mission of human space exploration and colonization with both our interests as well as our national budget priorities if we want any hope of surviving the inevitable existential global extinction event.

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Image credit: NASA and the NSSDCA.

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Kevin Hertzler graduated from Virginia Polytechnic Institute and State University with a degree in Aerospace and Ocean Engineering in 1974. He built his career in a variety of roles in the aerospace industry, starting as an aerospace engineer for the Office of Advanced Manned Vehicles at the Air Force Flight Test Center analyzing the aerothermodynamics of the Space Shuttle during its Operational Flight Test Program, then as a conceptual design engineer for the Lockheed Skunk Works in Burbank, CA and as a subcontracted research engineer studying electromagnetic propagation and scattering physics at the NASA Langley Research Center for the National Institute of Aerospace. Additionally, he founded an engineering consultancy, Hertzler & Associates, LLC. Kevin Hertzler can be reached at kevin.hertzler@gmail.com.

Dr. Rebecca McCauley Rench successfully defended her PhD in Geosciences and Astrobiology at the Pennsylvania State University in 2015. Her graduate work focused on the diversity and metabolic potential of cave microbial communities as they relate to early Earth analog environments and the search for life. A West Virginia native, she completed her undergraduate schooling at West Virginia University and holds a B.A. in Biology and a B.A. in Chemistry. Before starting her graduate education and after obtaining her B.A. degrees, Dr. McCauley Rench participated in disaster preparedness response as an AmeriCorps member in San Francisco. Dr. McCauley Rench is a Truman Scholar and NSF Graduate Research Fellow, as well as a Research Associate at the Potomac Institute for Policy Studies. Dr. McCauley Rench can be reached at: rmccauleyrench@potomacinstitute.org.

Book Review -

Wayward Pines: Where Paradise is Home

Rebecca McCauley Rench, PhD

Given the opportunity, is there anyone that would turn down living forever? Suspended animation has been a cornerstone of fairy tales and science fiction novels, albeit the two genres utilize long-term sleep in hugely disparate ways. Fairy tales, such as Snow White, tend to use it as a means of saving a beloved character or helping them see the error of their ways, while science fiction focuses on the use of non-magical suspended animation to make interstellar space travel possible, or for purposes of preserving the human race. In the movie *Star Trek II: The Wrath of Khan*, suspended animation is used to both travel through space and preserve a race of genetically modified super-humans.

Image credit: ForestWander Nature Photography.

Now, a recent trilogy of books by Blake Crouch: "Pines," "Wayward," and "The Last Town," explores the use of suspended animation to put humanity on a lifeboat and survive the demise of the human species. While many lifeboat scenarios involve expanding the human race into outer space and colonizing another planet or retreating to the depths of Earth in a bunker, the "Wayward Pines" trilogy places the survivors in small town America. As with other science fiction works,[1] the trilogy makes us consider the viability of suspended animation.

The science of suspended animation is indeed moving from science fiction to science-fact with recent discoveries of fish[2] that can enter a natural state of suspended animation, and with a developing commercial marketplace that promises to wake you when treatments are available for whatever ails you. As of last year, doctors at the UPMC Presbyterian Hospital in Pittsburgh started a trial to put trauma victims into a state of emergency preservation and resuscitation.[3] The concept involves a few hours of suspended animation, and has some degree of proven success in dogs[4] and pigs.[5] This method is on a short enough timescale that the body is not being preserved, but rather slowed to a metabolic crawl and obviates a discussion on preventing memory loss and identity. However, should the technique be extended, how long could a person remain in this state and awaken with the same identity? In 1999, a woman was trapped under the ice for 80 minutes and recovered, although she still suffers from nerve damage.[6] We are still researching how memories are stored and what the differences between long-term and short-term memory is physically in the brain. While we know pigs retain memories after being cryogenically preserved after an hour,[7] whether cryopreservation would destroy memories is an area of research that will not be fully tested until we can put animals into suspended animation for longer periods of time. There are many arguments against chemical preservation suggesting that it is unlikely to maintain the identity-encoding areas of the brain.[8]

Nonetheless, suspended animation in all its forms is old news for Mother Nature and the variety of life on our planet. Microorganisms have been able to survive in salt crystals for 250 million years and still remain able to grow and reproduce[9], while seed spores have been able to grow thousands of years after they were spawned.[10] The African lungfish mentioned above can hibernate with no intake of food or water for up to five years and is an excellent example of long-term hibernation in multicellular, multisystem species.[11] Some speculate that life on Earth is derived from cross-cosmos seeding by organisms from other celestial systems, suspended in transit through space and is an easy way out in discussing the origin of life on Earth. It leaves open the question, however, of how life evolves from abiotic processes.

If the time spent in a suspended state could be extended, we could potentially use suspended animation technologies for a variety of purposes, such as lengthening our own lives when dying of a presently incurable disease, helping humans sleep through a catastrophe, or traveling to other portions of the cosmos in the blink of an eye. The real question future explorers must ask themselves is whether they trust the caretaker, be it human or machine, to make sure they wake up on the other side.

The "Wayward Pines" trilogy uniquely postulates human suspended animation over thousands of years. If possible, we could consider the lifeboat scenario for a set of volunteers and thus provide some insurance against the potential of a near-term catastrophe. In Crouch's books, you are taken on a journey to explore the nature of humanity and consider what parts of it are worth saving. The key to our species' survival lies with a few hundred humans awoken after a long period of suspended animation. The books further consider issues of governance and control, as well as the innate human desires for freedom and travel. While many of the concepts are extreme and take the characters down logical yet unbelievable paths, the inner reflection is worthy of deeper consideration.

In 2016, we do not have the expertise or technology to achieve the level of suspended animation reflected in the "Wayward Pines" trilogy. However, what the next decade holds remains unknown. Should the long-term suspended animation technology become available, even with a modicum of confidence, humankind will need to confront the conundrum of the ethics of a suspended population for the purposes of self-preservation. Given mankind's thirst for adventure and strong desire for continuation, it is almost inevitable that a set of volunteers would accede to this form of future-only time travel.

Image credit:
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Dr. Rebecca McCauley Rench successfully defended her PhD in Geosciences and Astrobiology at the Pennsylvania State University in 2015. Her graduate work focused on the diversity and metabolic potential of cave microbial communities as they relate to early Earth analog environments and the search for life. A West Virginia native, she completed her undergraduate schooling at West Virginia University and holds a B.A. in Biology and a B.A. in Chemistry. Before starting her graduate education and after obtaining her B.A. degrees, Dr. McCauley Rench participated in disaster preparedness response as an AmeriCorps member in San Francisco. Dr. McCauley Rench is a Truman Scholar and NSF Graduate Research Fellow, as well as a Research Associate at the Potomac Institute for Policy Studies. Dr. McCauley Rench can be reached at: rmccauleyrench@potomacinstitute.org.

Featured Authors

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Robert Hummel, PhD

STEPS, Editor-in-Chief

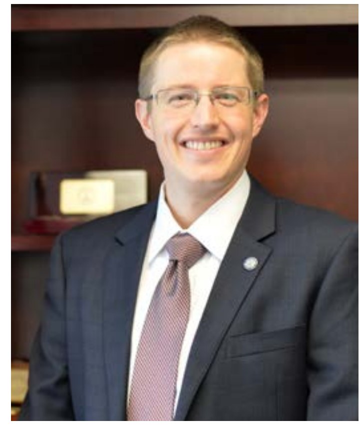
Dr. Robert Hummel serves as the Chief Scientist of the Potomac Institute for Policy Studies in the Science and Technology Policy Division and is a member of the Center for Revolutionary Scientific Thought. He is the author of the recent Potomac Institute book on "Alternative Futures for Corrosion and Degradation Research," and is also serving customers in DARPA and OSD. He is the principle author of the Institute's forthcoming book on machine intelligence. Prior to joining the Potomac Institute, he served as a program manager at DARPA for nearly nine years, managing and initiating projects in information exploitation, computer science, and sensor design. Prior to joining DARPA, he was a tenured faculty member at NYU's Courant Institute of Mathematical Sciences in the Computer Science Department, where he did research in computer vision and artificial intelligence. Dr. Hummel's PhD is from the University of Minnesota in mathematics, and he holds a B.A. from the University of Chicago, also in mathematics. Dr. Hummel can be reached at: rhummel@potomacinstitute.org.

Kathy Goodson, PhD

STEPS, Associate Editor

Dr. Kathy Goodson is the Director of Communications at the Potomac Institute for Policy Studies. Dr. Goodson leads outreach and communications components of a joint Potomac Institute and Office of Corrosion Policy and Oversight effort. Prior to joining the Potomac Institute, Dr. Goodson was an Assistant Professor of Biological and Physical Sciences at the College of Southern Maryland. She completed her studies for a doctorate in biochemistry from the University of Maryland, College Park, Department of Chemistry & Biochemistry in 2012. Her dissertation research focused on spectroscopic determination of protein-DNA complex conformations using organic dye molecules. Her areas of graduate research study included biochemistry, physical chemistry, biophysical chemistry, and molecular biology. Dr. Goodson received her B.S. in Chemistry from Virginia State University. Dr. Goodson is a member of the American Chemical Society and the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE). Dr. Goodson can be reached at: kgoodson@potomacinstitute.org.

Patrick Cheetham



Patrick Cheetham is a Research Associate at the Potomac Institute for Policy Studies at the Center for Adaptation and Innovation. He served as a fellow in the Center for Revolutionary Scientific Thought from 2012 to 2014. Currently, he is providing research and analytical support to policy development projects for the Department of Defense. Patrick has worked on national security strategy and technology policy issues with customers in the Office of the Secretary of Defense, the US Marine Corps, the Defense Advanced Research Projects Agency, the Office of Naval Research, and the Defense Research and Engineering Enterprise. Mr. Cheetham joined the Potomac Institute's International Center for Terrorism Studies (ICTS) in August 2010. He held the position of Research Coordinator at the ICTS, coordinated research for the book Al-Qa'ida Ten Years After 9/11 and Beyond, and assisted on a number of counterterrorism reports. Patrick served as Assistant Editor for NATO's journal, Partnership for Peace Review, and coordinated over thirty foreign policy and national security-related seminars. Before joining the Potomac Institute, Mr. Cheetham was the Assistant Director and Foreign Teacher for an English program in Fuyang, China. Patrick also served as a Senior Clerk at the University of California, Los Angeles (UCLA) School of Law. He received a B.A. from UCLA in Political Science, a M.A. in Security Studies from Georgetown University, and speaks some Mandarin Chinese. Patrick is a founder and member of Business Uniting with Government for Security. Patrick can be reached at: pcheetham@potomacinstitute.org.

Mike Fritze, PhD

Dr. Fritze joined the Potomac Institute for Policy Studies in April of 2015 as a Senior Fellow. He leads PIPS efforts in the area of US Government Microelectronics policy with a current focus on Trusted electronics issues. He also contributes his experience to helping Roadmap US Government Microelectronics R&D efforts for the future. He currently performs strategic planning for DMEA and develops projects related to USG microelectronics issues. Dr. Fritze was the Director of the Disruptive Electronics Division at the USC Information Sciences Institute (2010-2015). He also held a Research Professor appointment in the USC Ming Hsieh Department of Electrical Engineering (Electrophysics). His research interests at ISI included Trusted Electronics, CMOS Reliability & Robustness, Low power 3DIC enabled electronics and Rad-hard electronics. He was a Program Manager at the DARPA Microsystems Technology Office (MTO) from 2006-2010. Prior to joining DARPA, Dr. Fritze was a staff member from 1995-2006 at MIT Lincoln Laboratory in Lexington, Massachusetts, where he worked on fully-depleted silicon on insulator (FDSOI) technology development with an emphasis on novel devices. Dr. Fritze received a PhD in Physics from Brown University in 1994, working in the area of compound semiconductor quantum well physics. He received a B.S. in Physics in 1984 from Lehigh University. Dr. Fritze is an elected member of Tau Beta Pi and Sigma Xi. He is a recipient of the Office of the Secretary of Defense Medal for Exceptional Public Service awarded in 2010. He is a Senior Member of the IEEE and is active on the program committees of the GOMAC and IEEE S3S conferences. Dr. Fritze has published over 75 papers and articles in professional journals and holds several US Patents. Dr. Fritze can be reached at: mfritze@potomacinstitute.org.

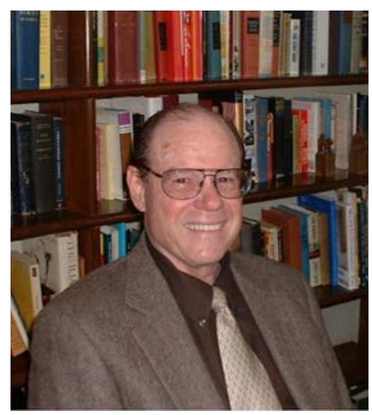
Jill Gibson

Jill Gibson chairs the Honors Program and Matney Mass Media Program at Amarillo College. Winner of Amarillo College's highest teaching award, the John F. Mead Faculty Excellence Award, she has spent the past 20 years in higher education both as an administrator and faculty member. Prior to her career in education, Gibson worked as a television anchor, reporter and producer. Her areas of expertise also include technical writing, public speaking and presentation, video production, desktop publishing, public relations, business communication and team management. Gibson holds a master's degree in journalism from Northwestern University and a bachelor's in English and drama from Stanford University. Ms. Gibson can be reached at: triggibson@gmail.com.

Jennifer Lato

Jennifer Lato is a Research Assistant in the S&T Policy Division at the Potomac Institute for Policy Studies. Jennifer first joined the Institute in 2013, and provides analytic and research support for the Corrosion Policy and Oversight (CPO) and Defense Microelectronics Activity (DMEA). Jennifer also provides editorial assistance for Potomac Institute publications, such as *U.S. Health Policy: An Insider's Perspective* (2014). She has a B.A.in History and Spanish from SUNY Geneseo, and a M.A. in International Affairs from the George Washington University, Elliott School of International Affairs. Prior to joining the Potomac Institute, Jennifer worked in the Department of Treasury's Office of Financial Assets Control, where she assisted sanctions investigators as part of an executive order to combat transnational criminal entities. Additionally, Jennifer held a short-term post at the Bureau of Intelligence of Research (INR) at the State Department. In this position, Jennifer coordinated the review of strategic signals intelligence requirements with INR analysts. Ms. Lato can be reached at: jlato@potomacinstitute.org.

James Richardson, PhD

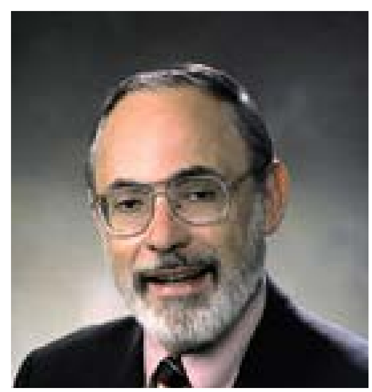


Dr. Richardson has held many positions in research, development and engineering in government, academia and the private sector. He is a former Deputy Director for Research, Development, and Engineering for the US Army Missile Command, Director of the Land Systems Office at the DARPA, Scientific Advisor for the Conventional Forces in Europe Treaty in Vienna, Austria, and Vice President for Research and Chief Scientist at Potomac Institute for Policy Studies, where he is currently a Senior Fellow. Dr. Richardson can be reached at: jabrichardson@verizon.net.

Paul Syers, PhD

Dr. Paul Syers is a Research Associate at the Potomac Institute, joining in September 2015. His current interests focus on hardware trust and policies related to the research and development of materials. For example, he is a member of the Regulatory Science and Engineering Center, which is currently looking at regulations on corrosion. He is also a Fellow of the Center for Revolutionary Scientific Thought (CReST). Dr. Syers received his PhD in Physics from the University of Maryland, having researched methods for improving the material quality of topological insulators. He has also received an M. Phil. from the University of Cambridge for research on high temperature superconductors, and spent some time in Germany researching wear and tear on commercial train tracks. Prior to that, Paul received a B.S. in Physics from Emory University. Dr. Syers can be reached at: psyers@potomacinstitute.org.

Gerold Yonas, PhD



Dr. Gerold Yonas joined the Mind Research Network in 2009, as the director of neurosystems engineering. In his current work, he is dedicated to creating the new fields of neurosystems engineering that links advances in neuroscience with systems engineering through interdisciplinary teams that focus on the development of solutions to complex system problems. Previously, Yonas worked at the Sandia National Laboratories, where he served as vice president of Systems, Science and Technology, and later became Sandia's principal scientist and initiated Sandia's Advanced Concepts Group. Yonas served as the acting deputy director and chief scientist during the implementation of the Strategic Defense Initiative. He is a Fellow of the American Physical Society and a Fellow of the American Institute of Aeronautics and Astronautics. He has received numerous honors including the US Air Force Medal for Meritorious Civilian Service and the Secretary of Defense Medal for Outstanding Public Service. Yonas serves on several defense boards and is senior fellow and member of Board of Regents at the Potomac institute for Policy Studies. He has also taught as an adjunct professor in the Department of Electrical and Computer Engineering at the University of New Mexico and has published extensively in the fields of intense particle beams, inertial confinement fusion, strategic defense technologies, technology transfer, and "wicked engineering." Yonas received his PhD in engineering science and physics at the California Institute of Technology. Dr. Yonas can be reached at: gyonas@aol.com.

Policy Statement from the Potomac Institute

(reprinted from the CReST Blog, January 28, 2016: https://potomacinstituteceo.wordpress.com).

THE RIGHT TO ERASE DATA

The Internet has become a platform of societal intercourse: an information repository, communication tool, commercial-space, and a location for self-brand promotion. Yet unlike in the past, information on societal intercourse is no longer ephemeral, the digital ones and zeros produced from these interactions are permanent, creating a digital fingerprint of each individual user in cyberspace. On their own, personalized bits of data are not particularly useful, and only appear to provide relatively esoteric indicators of a particular individual. Big data analytics, however, correlates flows of data and provides insights derived from behavior science. This information generated about individuals allows corporations and government entities to predict and model human behavior.

Personal big data can be a societal boon, helping to facilitate healthier living, smarter cities, and increasing web simplification through personalization. However there is a darker underbelly to the accumulation of this information. Personal data (clicks, keystrokes, purchases, etc.) are being used to create hundreds of inaccessible consumer scores, ranking individuals on the basis of their perceived health risk, lists of occupational merit, and potential propensity to commit fraud. Moreover, *as recent leaks of celebrity photos illustrate*, Internet privacy is no longer a guarantee (FBI, Apple investigate nude photo leak targeting Jennifer Lawrence, others, Alan Duke, *CNN*, Tue Sept 2, 2014). Information that is meant to remain in the private sphere is slowly leaking into the public sphere, challenging previously conceived notions of civil liberty. In order to curb the tide of cyber intrusions, the individual right to erase data must be enacted.

The European Court of Justice ruled in 2014 that citizens had the "*right to be forgotten*" – they ruled in favor of citizen right's to privacy. As January 27 was *Data Privacy Day*, perhaps it is time for the US to stand up and create their own variant of this law, a uniquely American law that allows American citizens the right to erase data – the right to ensure their privacy.

CREST PROPOSED LANGUAGE:

> *"Any person has the right to erase personal data that they identify as a breach of their privacy. Data erasure may be requested to and arbitrated by the search engine that publishes the data online. If erasure is justified then the search engine must erase any links or copies of that personal data in a timely manner. The search engine is responsible for the removal of authorized 3rd party publication of said data."*

Image credit:
Alex Taliesen.

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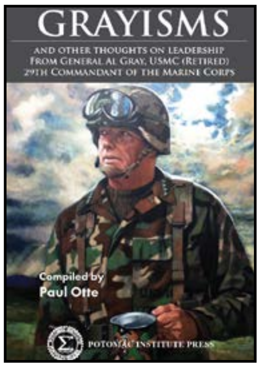

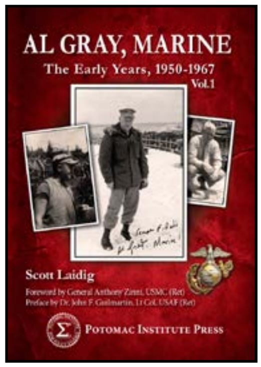

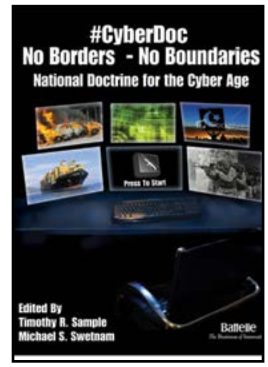

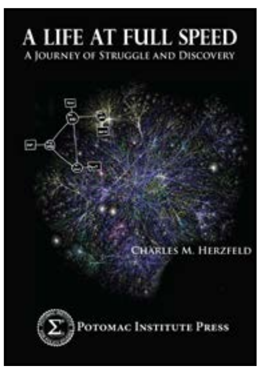

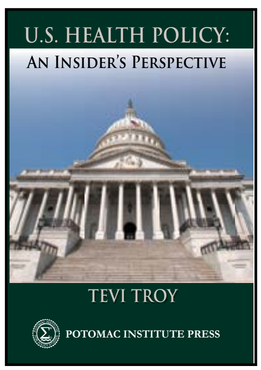

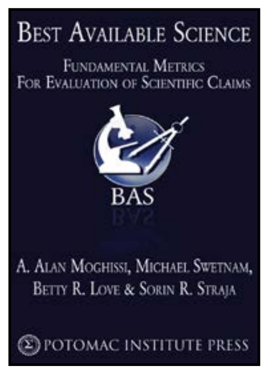

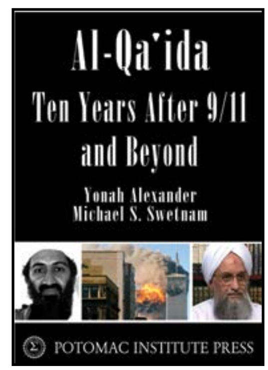

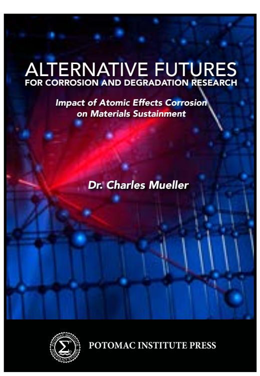

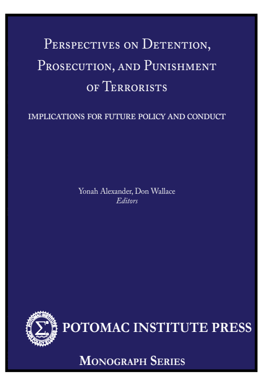

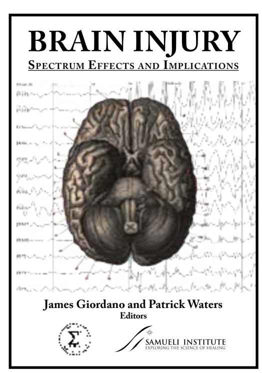

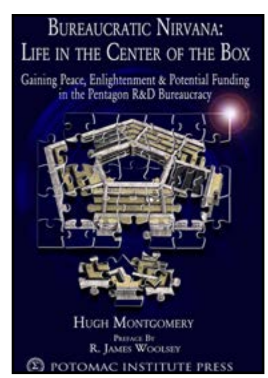

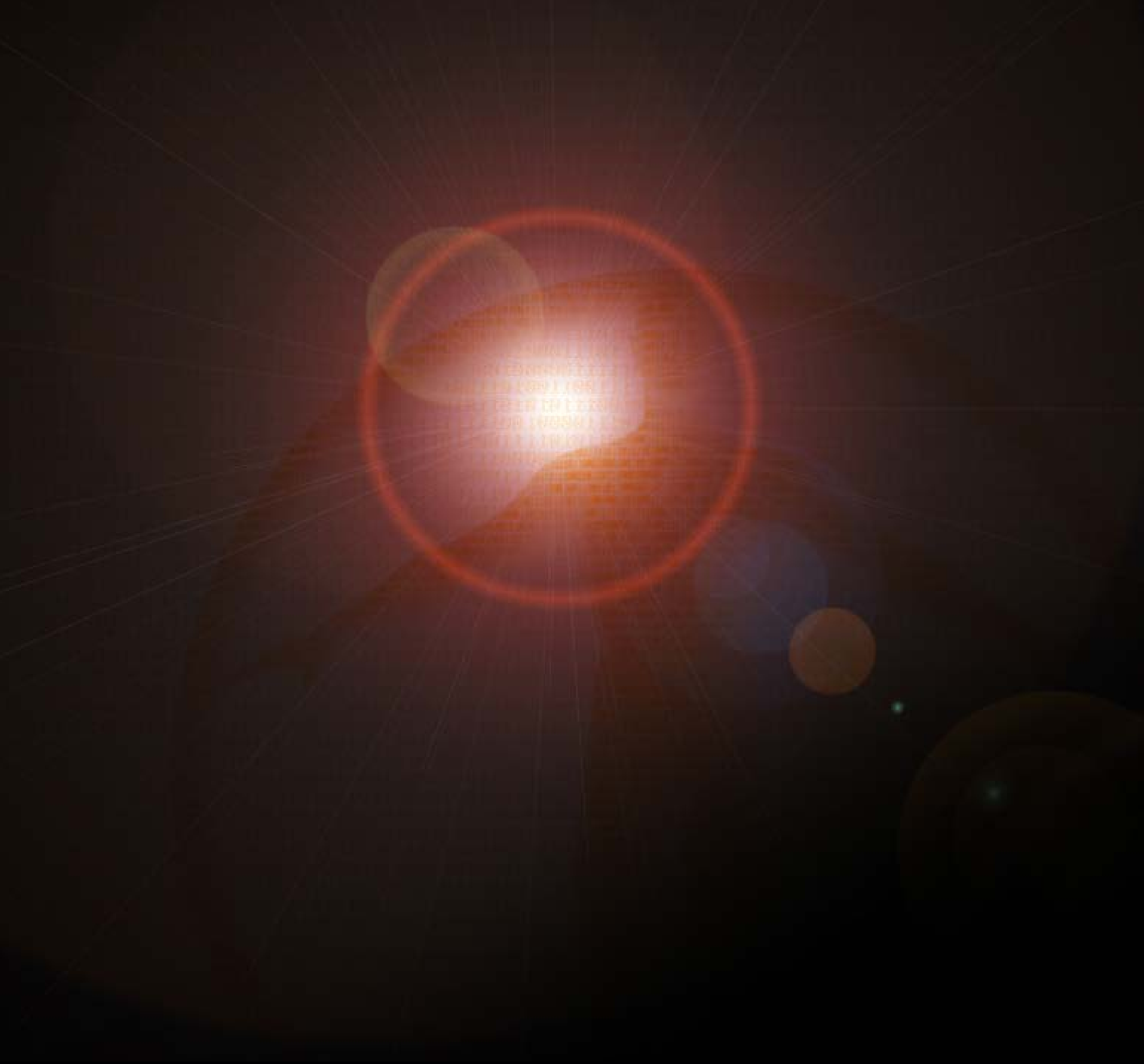

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