



CONFERENCE REPORT

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Disruptive Civil Technologies

**Six Technologies With Potential Impacts on
US Interests Out to 2025**

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NONGOVERNMENTAL EXPERTS TO GAIN KNOWLEDGE AND INSIGHT AND TO SHARPEN
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Six Technologies with Potential Impacts on US Interests out to 2025

Biogerontechnology

Energy Storage Materials

Biofuels and Bio-Based Chemicals

Clean Coal Technologies

Service Robotics

The Internet of Things

The National Intelligence Council sponsors workshops and research with nongovernmental experts to gain knowledge and insight and to sharpen debate on critical issues. The views expressed in this report do not reflect official US Government positions.

Prepared by SRI Consulting Business Intelligence under the auspices of the National Intelligence Council. Questions and comments regarding this report should be directed to the National Intelligence Officer for Science and Technology on (703) 482-6811.

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Scope Note: To support the development of the National Intelligence Council’s Global Trends 2025, SRI Consulting Business Intelligence (SRIC-BI) was asked to identify six potentially disruptive civil or dual use technologies that could emerge in the coming fifteen years (2025). A disruptive technology is defined as a technology with the potential to causes a noticeable – even if temporary – *degradation or enhancement* in one of the elements of US national power (geopolitical, military, economic, or social cohesion).

The six disruptive technologies were identified through a process carried out by technology analysts from SRIC-BI’s headquarters in Menlo Park, California, and its European office in Croydon, England.

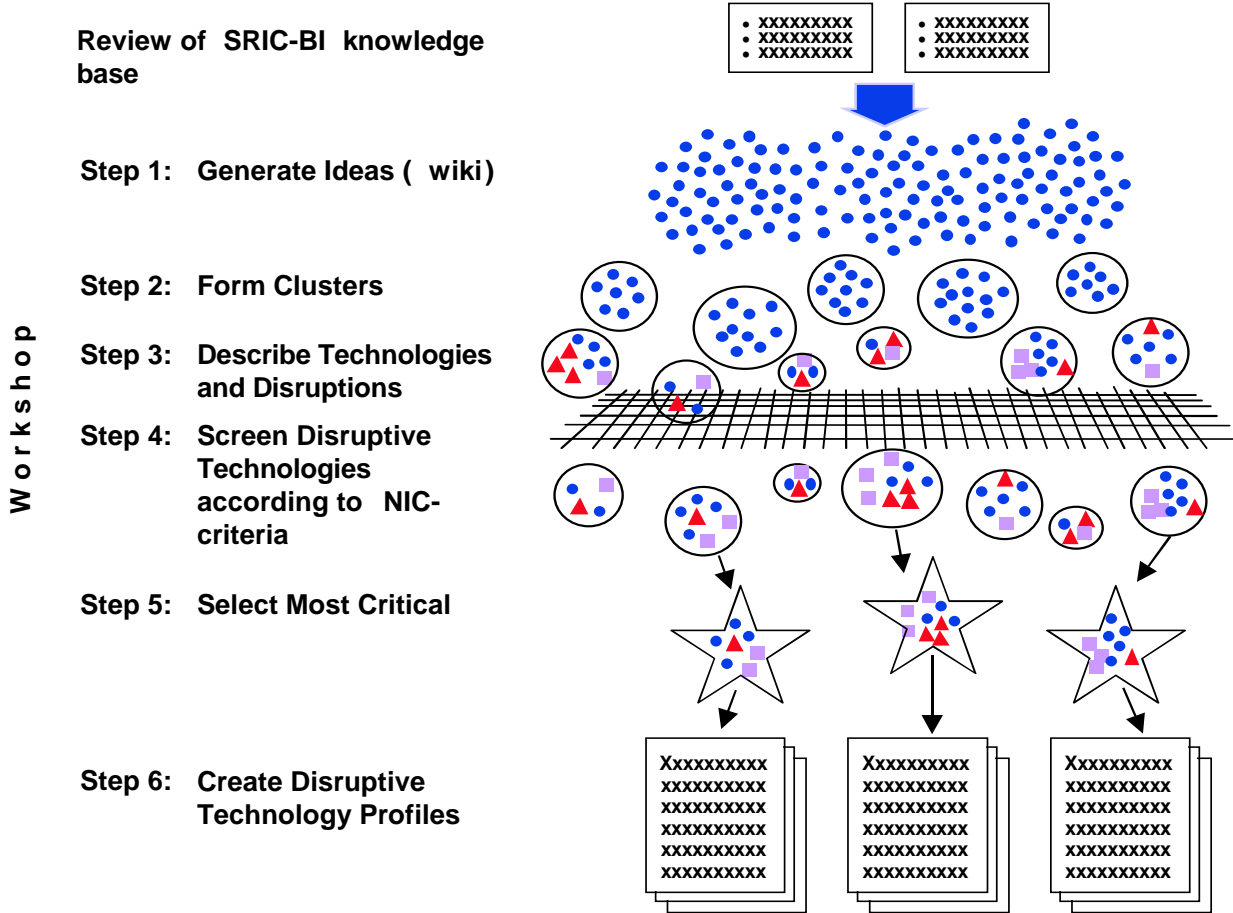
These analysts are continuously monitoring technology, business, and social environments for two long-term continuous research programs:

- The SRI Scan™ program identifies and assesses possible futures by gaining early awareness of signals and patterns of change before they become conventional wisdom.
- The SRI Explorer program identifies and develops an understanding of how and why technologies develop. The program also evaluates the commercial development parameters and uncertainties behind technology commercialization.

Through a process of online discussions, clustering, development of technology descriptors, screening, and prioritizing, SRIC-BI Explorer and Scan™ analysts down-selected from 102 potentially disruptive technologies. They identified the following six technologies as most likely to enhance or degrade US national power out to 2025:

Biogerontechnology
Energy Storage Materials
Biofuels and Bio-Based Chemicals
Clean Coal Technologies
Service Robotics
The Internet of Things.

PROCESS FOR SELECTION OF DISRUPTIVE TECHNOLOGIES



Source: SRI Consulting Business Intelligence.

Executive Summary: *Six civil technologies offer the potential to enhance or degrade US power over the next fifteen years according to National Intelligence Council (NIC) sponsored contractor research. These include biogerontechnology,¹ energy storage technology, biofuels and bio-based chemical technology, clean coal technology, service robotic technology, and information technology devoted to increased connectivity of people and things.*

Biogerontechnology offers the means to accomplish control over and improvement in the human condition, and promises improvements in lifespan. The advancement of the science and technology underlying the biological aging process has the potential to not only extend the average natural lifespan, but also to simultaneously postpone many if not all of the costly and disabling conditions that humans experience in later life, thereby creating a longevity dividend that will be economic, social and medical in nature.

- The disruptive potential comes in the form of new treatment modalities, shifts in the cost, and resulting allocation and use of health care resources.
- *Nations will be challenged as a result of changing demographic structures, new psychologies, activity patterns of aging yet healthy citizens, and the resulting requirement to formulate new national economic and social policies.*

Energy Storage technologies have the potential to disrupt the way energy is stored and distributed for use in transportation and portable devices.

These technologies include battery materials, ultracapacitors, and hydrogen storage materials (particularly for fuel cells). Within these components both synergy and competitive tension exists.

- *The biggest level of disruption that could occur, both in economic terms and in terms of global socio-economic structure, would be the potential for one of these technologies (or a combination) to lead to a paradigm shift away from fossil fuels.*

Biofuels and bio-based chemicals production technologies have the only potential near-term capability to provide alternatives to conventional gasoline and diesel-fuel and petrochemical feedstocks. Crop-based biofuels are already in wide use, work in today's vehicles, and require no major investments in infrastructure for their use. Biofuels also help to address global-warming concerns by reducing net greenhouse gas (GHG) emissions from vehicles. The rate of technology advancement will be strongly influenced by the regulatory environment and the need to address feedstock constraints and reduce costs.

¹ Biogerontechnology is technology related to the biological aging processes.

- The United States and a growing number of other countries have already begun a transition toward biofuels that could ultimately have far-reaching impacts on world energy markets. ***A large-scale move to energy-efficient biofuels could increase US energy security and ease international competition for world oil supplies and reserves.***
- Conversely, if the United States does not develop a strong bio-based economy, the country would become increasingly dependent upon less-than-friendly countries for a critical energy resource.

Clean coal technologies and an array of related technologies offer the potential to improve electrical generation efficiency, lower emissions of harmful pollutants, and provide fuels and chemical feedstocks from available coal resources. The development of clean coal technologies is gaining momentum in coal rich nations, which include major economic and scientific powers, but it is not certain to succeed.

- ***Failure to successfully develop clean coal technology in an environment where there is high expectation of success will result in environmental damage with major adverse economic impacts.***
- Conversely, a successful accelerated and rapid deployment of clean coal technology could pose a major challenge to other (predominantly oil) energy markets; the resulting geopolitical instability could also be a major challenge to US interests.

Robots have the potential to replace humans in a variety of applications with far-reaching implications. Robotics and enabling technologies have already advanced to the stage where single-application robots and related systems (including autonomous vehicles) are being implemented in a wide range of civil and defense applications. Although a great deal of development is still required in terms of *intelligence* for robots, many of the building blocks for potentially disruptive robot systems are either already in place, or will be by 2025, including hardware (e.g. sensors, actuators, and power systems) and software (e.g. robot platforms).

- The use of unmanned systems for terrorist activities could emerge because the availability of commercial civil robot platforms will increase significantly.
- Unmanned military systems with a much greater level of autonomy and closely related/synergistic technologies (e.g. human augmentation systems) could enhance the performance of soldiers.
- ***The development and implementation of robots for elder-care applications, and the development of human-augmentation technologies, mean that robots could be working alongside humans in looking after and rehabilitating people. A change in domestic and social responsibilities and a change in domestic employment***

requirements could adversely affect lower income service-oriented workers.

By 2025 Internet nodes may reside in everyday things—food packages, furniture, paper documents, and more. Today’s developments point to future opportunities and risks that will arise when people can remotely control, locate, and monitor even the most mundane devices and articles.

Popular demand combined with technology advances could drive widespread diffusion of an Internet of Things (IoT) that could, like the present Internet, contribute invaluablely to economic development and military capability.

- *Streamlining—or revolutionizing—supply chains and logistics could slash costs, increase efficiencies, and reduce dependence on human labor. Ability to fuse sensor data from many distributed objects could deter crime and asymmetric warfare.* Ubiquitous positioning technology could locate missing and stolen goods.
- *However, to the extent that everyday objects become information-security risks, the IoT could distribute those risks far more widely than the Internet has to date.*
- Massively parallel sensor fusion may undermine social cohesion if it proves to be fundamentally incompatible with Fourth-Amendment guarantees against unreasonable search.

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² Appendices are available on the accompanying compact disc (CD).

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Discussion

Biogerontechnology

Why is Biogerontechnology Potentially Disruptive?

Since the start of the twentieth century, when the average natural lifespan in the United States was 47 years of age, gains in life expectancy have been impressive thanks to a combination of medical interventions, lifestyle choices, and behavior modifications. In 2005, the average human life expectancy in the United States was 78 years, with life expectancy for women approximately five years longer than for men. The US Census Bureau estimates that life expectancy will increase by another six years by 2050. Biogerontechnology, which offers the means to accomplish control over and improvement in the human condition, promises even greater longevity gains. The advancement of the science and technology underlying the biological aging process has the potential to not only extend the average natural lifespan forecasts but also to simultaneously postpone many if not all of the costly and disabling conditions that humans experience in later life, thereby creating a longevity dividend that will be economic, social and medical in nature. The disruptive potential will also come in the form of new treatment modalities, and shifts in the cost, allocation and use of health care resources. Nations will be challenged as a result of the changing demographic structures and new psychologies, behaviors and activity patterns of aging yet healthy citizens and the concomitant need to formulate new national economic and social policies.

Potential Impacts of Biogerontechnology on US National Power

Geopolitical: Biogerontechnology will influence policy making and business decisions related to international finance and macroeconomics which will lead to changes in global investment cycles as well as investment flows and economic ties between nations. With health care spending accounting for 16% of GDP in the United States (closer to 9% in other OECD countries), the opportunity to reduce that share of spending through biogerontechnology will allow the US government to transfer resources to other areas of the economy and prioritize capital investments that could change the course of national economic development. The same goes for many other countries. Nation states may also see a healthy aging population as a labor resource that can be leveraged to assure economic competitiveness in global markets. An aging and healthy population in the United States that remains economically productive can therefore contribute towards national economic output and productivity. The ability to maintain a stable stock of domestic labor may also affect the competitive dynamics and economics of global labor markets and traditional migration patterns.

Economic: If breakthroughs enabled through biogerontechnology were to extend lifespan and compress morbidity, the costly life stage of frailty and disability that is so common with today's aging populations could be postponed and experienced during a shorter duration of time before death. This, together with a delay in the age at which people may enter age-entitlement and public health care programs, would create significant economic savings for the US system. The organization, practice, financing and delivery of health care could change dramatically in the United States as well as many other industrialized countries. Biogerontechnology, however, is likely to displace some of the more conventional gerontology approaches to caring for and providing for the elderly. As a result, labor markets might be affected as demand for health services declines. Labor markets could also be affected by the fact older people may

seek to remain employed longer. As a global business leader, the US may be at the forefront of innovation and new opportunities in businesses, such as financial products and services that will seek to capitalize on the longevity boom and risk factor.

Military: Some technologies inherent in the extension of lifespan and healthspan could find important applications in a military context primarily those implicated in delaying the onset of biological aging. This would lead to knowledge retention among older personnel as they seek to delay retirement from service. The opportunity to prevent the onset of certain debilitating diseases could lead to significant savings to the military's health system, which would allow resources to be deployed to other strategic areas that are more likely to result in aiding the military might of the United States.

Cultural: Inequitable market access to biogerontechnologies that offer life-enhancing benefits may create different life expectancy cohorts according to race, income, socioeconomic status, or geography, for example, in the United States. Biogerontechnology could also lead to intergenerational conflicts between younger and older cohorts and lead to social unrest as investment and employment cycles are disrupted and affect economic values associated with labor and other capital. New cultural norms may be established due to changing psychology and behaviors among older people, which could also lead to dramatic lifestyle changes. Uncertainties may emerge as lifestyles converge with and influence technology and market trends in other business sectors as diverse as energy, communications, and finance. Lifestyle behaviors may also lead to the emergence of new health profiles for populations and disease threats and health risks may change as unexpected behaviors emerge due to biogerontechnology.

Future Scenarios and Potential Impacts on the United States

The key uncertainties in the biogerontechnology field tend to fall along two major axes:

- The science-and-technology–commercialization continuum
- The formulation of global policy and funding support levels.

The key uncertainty along the science-and-technology–commercialization continuum is the extent to which advances in scientific knowledge and technical capabilities occur and the degree of the resulting technical risks and knowledge gaps). Nations will either move toward a more complete level of understanding and enhanced capabilities or toward an environment of many weak links and unorthodox risks that limit progress towards market applications.

The global policy and funding environment will be strongly influenced by the degree and rate of progress in scientific and technical capability. The level of public interest and support for longevity science as well as government's ability to balance that with commercial interests will also temper the policy and funding environment.

On the basis of the two axes of uncertainty, four distinct scenarios seem plausible: one that is unruly and negative (“Rebel Science”), one that is conservative, having some breakthroughs but that fall short of the full potential of the technology (“Animal Magic”), and two that have strong levels of public support but with varying degrees of scientific and technology capabilities (“Dorian Gray” and “Forever Young”). We describe each of the scenarios briefly and detail the opportunities

and threats in the two scenarios that highlight the extremes in possibilities for how the future could play out until 2025.

Table 1
BIOGERONTECHNOLOGY: FUTURE SCENARIOS

		Science and Technology Commercialization Continuum	
		Weak Links and Risks	New Science World
Global Policy and Funding	Limited Scientific and Technical Rationale	Rebel Science	Animal Magic
	Strong Support And Public Demand	Dorian Gray	Forever Young

Source: SRI Consulting Business Intelligence.

Scenario 1: Animal Magic

In “Animal Magic” the promise of biogerontechnology is ushered in but only in research involving animal models. Scientists are in disagreement as to the exact mechanisms for how these research results could be reproduced in humans. Despite this disagreement and the fact that there has been no reproducibility of the animal research results in any human studies, researchers remain emboldened that the critical breakthrough in humans is near. Policy makers and the public are growing increasingly skeptical the longer the impasse continues. Other fields of biomedical research that seek to affect aging and the decline in health have borne many more breakthroughs in clinical potential, and gain greater attention and interest from the public and policy makers.

Scenario 2: Dorian Gray

In “Dorian Gray” all is good on the public face of science but less so within the research field on account of limited progress in advancing biogerontechnology. Both the public and policy makers want to believe in a dream and urge scientists to forge ahead. But scientists feel pressured to take risks and make unorthodox decisions in their research, which leads to some risky research and unexpected outcomes. Spin sells the public and policy makers a sense of progress. The US and other governments continue to pour significant amounts of funding into research but with little to show for it. Yet a sense of optimism in the future remains. Governments support and the public pursues interim strategies, such as caloric restriction, to slow down aging while awaiting breakthroughs in biogerontechnology.

Scenario 3: Rebel Science

In “Rebel Science” biogerontechnology fails to realize its full potential and advance to a level that scientists had once anticipated. Scientists, however, remain confident that it is only a matter of time before the critical breakthroughs, which push biogerontechnology to the next level, emerge. The global policy and funding environment remains unconvinced and is cool to heed calls from scientists for further funding. Scientists seek to compensate for the lack of funding from public

sources through tapping wealthy individuals and technology philanthropists. But desperation and a lack of accountability and formal oversight forces researchers into some unorthodox situations. The US government is forced to introduce tough legislation governing research activities, which drives much of the ongoing research underground or offshore. The biomedical industry sees little incentive to invest heavily in the field because of the growing restrictions. Experimentation on humans is unregulated, fails to follow standard ethical guidelines, and clinical applications that emerge often go unreported such that any knowledge learned is not shared and used to advance knowledge in the field.

- *Potential opportunities.* Governance issues loom large. The United States is well positioned to assume a leadership role in the international science and technology community to establish guidelines and frameworks governing ethical practices in biogerontechnological research. Domestically, the United States could pursue and prioritize or earmark available funding for alternative areas of biomedical research that offer the greatest opportunity to delay the onset and impact of diseases associated with aging.
- *Potential threats.* The United States is alarmed by the degree to which international markets and scientific research remain unregulated. Private money and venture philanthropy pose a significant challenge to the regulated practice of biogerontechnology research and adherence to the ethics of biomedical research. Despite international efforts to restrict or ban research activities, these research initiatives are always sure of finding a safe haven where authorities are willing to turn a blind eye.

Scenario 4: Forever Young

In “Forever Young” the breakthroughs that scientists envisioned for treating aging as a medical condition have come to pass. The US academic biomedical research community benefits greatly from the research and innovation and the resulting technology transfer to the private sector results in considerable entrepreneurial activity that drives a new era of technology-led economic activity to boost national economic growth. Governments talk of the longevity dividend that will stem from the clinical applications and convene international meetings to discuss the challenges in applying and managing biogerontechnology in society in a controlled and responsible manner. The implications of advances in biogerontechnology will extend beyond medicine and health care. The benefits of healthier and more active lifespans will allow people to remain in the labor force and work longer and to enjoy more active lifestyles. As a result, consumer spending and savings patterns adjust to reflect changing lifestyle interests. Actuaries would need to make ongoing upward adjustments to reflect expanding lifespans. The implications of longevity risk would start to feed into policy making and business decisions as finance and economic strategies adjust accordingly. Government and private pensions would need to guarantee sufficient resources to manage the costs of extended life spans, while retirement assets would see a more gradual drawing down as aging investors live longer. There is a sense of optimism, hope, and possibility in many global societies that permeates beyond the field of biogerontechnology and feeds into other areas of the economy and society.

- *Potential opportunities.* The uptick in investment levels in commercialization activities around biogerontechnology research pushes the US government into action. Key policy initiatives deal with legal frameworks for intellectual property protection, regulatory frameworks governing human clinical safety and evaluation, and consumer education campaigns regarding the

responsible use of biogerontechnology. US companies are quick to make the strategic investments in enabling technologies and market infrastructures.

- *Potential threats.* This scenario could have very significant social and political impacts for which many policy makers are unprepared. For example, the United States is simply unprepared for the ideological and cultural backlash against biogerontechnology, which leads to many tensions and divisions within society. The United States and other countries are left to grapple with the economic burden that results from unintended consequences of covering payment for access to medical technologies that guarantee a longer-living and healthier life, and resort to creating policies that ration or restrict access to biogerontechnologies on the basis of an individual's willingness to pay.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward biogerontechnology development, include:

- Scientific evidence that both confirms and disconfirms the current aging theories,
- Global public research funding levels and trends for biogerontechnology research,
- The establishment of non-US centers of biogerontechnology research excellence,
- Successful early models for scientific research and technology commercialization,
- The size and nature of biogerontechnology investments worldwide,
- Position statements about the ethics and practices of biogerontechnology research,
- Consistency in regulatory frameworks governing research and commercialization, and
- The influence of scientific research and applications on public opinion.

Energy Storage Materials

Why Are Energy Storage Materials Potentially Disruptive?

The term *Energy Storage Materials* encompasses a wide range of materials and techniques for storing energy, each with varying levels of potential disruption. This profile focuses on three such energy storage materials groups—battery materials, ultracapacitors and hydrogen storage materials (particularly for fuel cells). They have in common the potential to disrupt the way energy is stored and distributed in two main industry sectors, transportation and portable devices. Within these energy storage materials groups, both synergy and competitive tension exists. In some manifestations of their potential disruptions the technologies will work in parallel; in others they will compete with each other.

The biggest level of disruption that could occur, both in economic terms and in terms of global socio-economic structure, would be the potential for one of these technologies (or a combination) to lead to a paradigm shift away from fossil fuels. In this context, one potential scenario is based on a move to a hydrogen economy. Such a move will largely depend on the ability to generate hydrogen from a non-petroleum source. It might also be important for hydrogen generated from natural gas or coal. Such a move will be very dramatic if the source of the hydrogen is water that has been split by a non-fossil source of electricity, including nuclear, solar, wind, or other alternatives.

Potential Impacts of Energy Storage Materials on US National Power

Depending on the path of the future scenario, energy storage materials could have a substantial impact on the four elements of national power:

Geopolitical: Energy storage materials could have a profound impact on the geopolitical balance of power. Some forecasters predict that oil has already or soon will reach its production peak, just as many countries, such as China and India, are beginning to expand their economies and place more demand on oil resources. Cheap reliable sources of alternative energy storage could reduce the demand for oil, particularly for transportation, though other primary sources of energy (specifically, electricity) will be necessary to supply the energy to recharge batteries, provide the charge for ultracapacitors, or generate hydrogen. Reduced oil demand would insulate the United States from its dependency on foreign sources of oil. On the hand, nations reliant on petroleum as a major source of revenue would find that they would have to transition their economies, or risk a substantial reduction in living standards. Such a situation could destabilize some already fragile regions.

Economic: A transition to a hydrogen economy, and to greater use of other energy storage materials, would provide a large opportunity in the production of fuel cells and fuel cell vehicles, hydrogen generation and storage infrastructure, advanced batteries and ultracapacitor production and materials. From a transportation perspective, gasoline retailers would have to transition their infrastructure to provide onsite generation and storage of hydrogen, creating a demand for local high-voltage electricity substations. Any move away from hybrids to full electric vehicles would be detrimental to manufacturers of internal combustion engines. Assuming these new sources of power are as cheap to the US end user (be they auto manufacturers or consumers), then the transition should be economically positive at a national level, due to the

reduction in demand for overseas oil (and assuming increased electricity requirements are from indigenous sources).

Military: The military has a substantial demand for offsite and portable power. Increases in energy density anticipated through this disruptive technology would provide greater autonomy of operation for field devices, and might enable remote sensors to have a greater lifetime. The high bursts of power provided by ultracapacitors can provide new weapon capabilities.

Cultural: Assuming an ample supply of energy, social cohesion is little impacted by the precise type of energy source. That situation is changing at the fringes as some small numbers of consumers choose to purchase higher cost green energy supplies, and certainly a transition to any new energy technology that would have less environmental impact would be in tune with consumer concerns. A move to a hydrogen economy could impact social cohesion as a result of any positive economic benefit that a reduced reliance on oil provided, in the form of new jobs. Ultimately, the largest impact on social cohesion would accrue if a hydrogen economy (supported by other forms of primary electricity generation) was able to mitigate against the impact of a future world with dwindling oil reserves.

Future Scenarios and Potential Impacts on the United States

The key uncertainties in the energy storage materials technology field tend to fall along two major axes:

- Developments in basic materials science.
- Choices in terms of global national energy policy.

The key uncertainty in materials science is the extent to which progress is made in a wide variety of materials required for new advanced batteries, ultracapacitors and for efficiently storing hydrogen.

The axis for global national energy policy reflects the choices (and needs) to push alternative fuels, or to continue and further develop fossil fuels.

On the basis of the two axes of uncertainty, four distinct scenarios seem plausible, including one that is dark and negative (“Running on Empty”), one that is conservative, having small technology breakthroughs (“Competitive Conservatism”), and two that have different types of huge technology breakthroughs (“Super Clean” and “Hydrogen Economy”). We describe each of these scenarios briefly and detail the opportunities and threats in the two scenarios that reflect similar energy policies but at the extremes of technological progress.

Table 2

ENERGY STORAGE MATERIALS: FUTURE SCENARIOS

		Energy Storage Materials Science Development	
		Evolution	Revolution
Global National Energy Policy Choices	Extension of Fossil Fuel Sources	Running on Empty	Super Clean
	Widespread Political Choice to Switch to Alternatives	Competitive Conservation	Hydrogen Economy

Source: SRI Consulting Business Intelligence.

Scenario 1: Running on Empty

In “Running on Empty” no breakthroughs occur in solving fundamental problems in energy technologies. Globally, countries are forced to rely on fossil fuels and either elect not to install large amounts of nuclear power or fail to do so fast enough. At some point, depending on the balance between dwindling reserves and expansion, particularly in Asia, economies will begin to stagnate as the price of oil increases. The population declines as it ages, countries periodically go to war over energy resources, and conservation is forced on consumers by lack of availability.

Scenario 2: Super Clean

In “Super Clean” technological breakthroughs in clean coal, clean oil, clean oil sands, carbon sequestration, and biofuels that do not compete with agriculture and food production result in a high-growth global economy that continues to be fueled by fossil fuels for at least 200 years. Switching to a hydrogen economy is not necessary and none of the hydrogen generation and storage technologies are required. Battery and ultracapacitor energy storage technologies are sufficient and part of the clean fossil fuel economy, transferring and storing energy efficiently from power-generating units to transportation and portable devices. Energy is available for environmental clean up, water purification, and infrastructure repair.

Scenario 3: Competitive Conservation

In “Competitive Conservation” lots of small, evolutionary advances in technology enable a sustainable and active economy, based on conservation of energy. Governments around the world compete with each other to make enlightened choices in policy to reduce waste of energy (such as by regulation, promoting low-energy consumption in lighting, green buildings, agriculture, personal transportation, and IT infrastructure) creating economic activity in the changeover. Imports of energy-guzzling products are banned, forcing reluctant countries to switch also—or lose competitiveness. Solar energy and wind power are marginally efficient and installed everywhere, creating millions of new jobs in installation and services around the world. Population growth levels off to sustainable levels, declining in some countries. People become conscious of their carbon footprint and seek to conserve energy. New businesses form around conservation. Hydrogen storage devices do not achieve the DOE goals, but are sufficient (4 or 5 % by weight) for hydrogen generated by solar and wind power to be stored in large, central facilities for end uses

such as fleet vehicles and backup power for telecommunications and computer data centers. Energy storage technologies see marginal improvements and are able to ease the energy demand on all energy-consuming products in small ways that add up to enough to be meaningful. Portable electronic devices, wearables, and implants are partially charged by energy harvesting, ultracapacitors, and improved batteries.

- *Potential opportunities.* The United States already leads in many or most of these “conservation” technologies and has a business economy that can adjust rapidly. In terms of application, the European Union is quickly moving in this direction, faster than the United States is, but US activities can easily catch up and regain the initiative. Opportunities lie in creating the leading-edge technologies and working with China, India, and Russia to help them install US energy conservation technologies that allow them to sustain growth and to head off potential future geo-political conflict. US industry gains financially from this leadership and US leadership and prestige is maintained worldwide.
- *Potential threats.* Failure of US policymaking could leave the United States at a severe disadvantage in this scenario. The EU has the policy lead now and is gaining jobs and experience in these conservation technologies, which could carry over into leadership in selling products and services to the rapidly developing countries in Eastern Europe, Asia, and Latin America. Furthermore, as the United States fails to adapt regulatory and economic policies to encourage conservation, it remains dependent on expensive forms of energy, including imported oil and puts US companies at an economic disadvantage from a cost perspective. More companies will seek to move to low-energy-cost countries, leaving the United States behind. Although this scenario is relatively peaceful, in terms of global conflict, loss of US prestige and economic power will lead to internal and external conflicts and bickering. The United States could become the “Argentina of the 21st Century,” declining relatively quickly from its world top spot in per-capital GDP (as Argentina was in 1905) to a “former wealthy nation” status.

Scenario 4: Hydrogen Economy

In “Hydrogen Economy” big breakthroughs occur in cheap hydrogen generation, cheap, lightweight, and dense hydrogen storage, and fast and easy hydrogen dispensing technologies. Solar, wind, clean fossil fuel, biofuel, and even nuclear technologies could be a part of the hydrogen-generation infrastructure. Fuel cell transportation (cars, trains, ships, planes, and niche applications, including lift trucks and robots), infrastructure backup power, and fuel cell-powered portable electronic devices abound globally. Energy is a virtually infinite resource, available to any country, leading to an explosion of devices, solving of global water shortage problems, improvements in health in developing countries, an increase in global travel, and an expansion of space exploration programs.

- *Potential opportunities.* The United States already is a leader in many of the hydrogen storage technologies and could continue to be the source of technological breakthroughs. Even where it is not the first to gain a breakthrough, US industry and individuals will gain from the new technologies if a rapid build-out of the hydrogen infrastructure takes place, coupled with environmental regulation and incentives that help industry and individuals to adopt new products.
- *Potential threats.* European countries are ahead in much of the hydrogen infrastructure prototype programs and up to speed in energy storage technologies. Canada and other countries are also pushing hard on fuel cells and alternative hydrogen-generation technologies. They

could gain advantage as breakthroughs occur in introducing those technologies into the fast-growth BRIC (Brazil, Russia, India, China) countries, leaving the United States at an economic disadvantage.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward energy storage materials development, include:

- The natural availability and the price of oil. Gradual declines in availability and increases in prices would increase the decisions to support alternatives; new giant field discoveries might delay policy decisions to support alternatives,
- Improvements in performance and cost of materials relevant to ultracapacitors, batteries and hydrogen storage,
- Energy technology choices in BRIC and the European Union. Look for competition for petroleum, reliance on coal, decision to go nuclear, successful investments to compete in alternatives, especially solar, wind, and biofuels,
- Global sales volumes of portable electronic devices, including cell phones, PDAs, music players, and wearable medical devices,
- Trials, production, and sales volumes of hybrids, fuel cell vehicles and ultracapacitor-powered vehicles,
- Investment and development of nuclear energy and alternative energy technologies, particularly solar, wind, and biofuels, and
- Investment in energy storage materials and commercial successes by type of material.

Biofuels and Bio-Based Chemicals

Why are Biofuels and Bio-Based Chemicals Potentially Disruptive?

US Department of Energy (DOE) projections indicate that world petroleum demand is set to increase by 42% between 2004 and 2030, primarily in the transportation sector. Oil-importing regions—including the United States, Europe, Japan, and China—are becoming increasingly dependent upon crude-oil supplies from key OPEC countries, but the future reliability of these supplies is uncertain. Biofuels and bio-based chemicals production technologies represent the only near-term alternatives to conventional gasoline, diesel-fuel, and petrochemical feedstocks. Crop-based biofuels are already in wide use, work in today's vehicles, and require no major investments in infrastructure for their use (unlike alternatives such as hydrogen). Biofuels also help to address global-warming concerns by reducing net greenhouse gas (GHG) emissions from vehicles (on a fuel life-cycle basis). The United States and a growing number of other countries have already begun a transition toward biofuels that could ultimately have far-reaching impacts on world energy markets. Success will depend on the development of new bio-based technologies that can efficiently convert nonfood biomass resources to fuels and chemical products on a very large scale.

Potential Impacts of Biofuels and Bio-Based Chemicals on US National Power

- Geopolitical:** A large-scale move to energy-efficient biofuels could increase US energy security and ease international competition for world oil supplies and reserves. Conversely, if the United States does not develop a strong bio-based economy, the country would become increasingly dependent upon less-than-friendly OPEC countries for a critical energy resource. The need for a transition could become essential before 2025. Many analysts believe that worldwide production of conventional crude oil will reach a peak in this time frame, which could precipitate a major oil crisis and cause oil prices to reach \$100 per barrel or higher. A broader move to biofuels may also be geopolitically essential for governments to satisfy international and national commitments to reduce greenhouse gas emissions.
- Military:** The development of a significant biofuels and bio-based chemicals economy in the United States could reduce the likelihood of US involvement in future military conflicts related to access to dwindling world-oil supplies. The military itself may increasingly rely on future biofuels that are custom designed for higher performance than today's military fuels.
- Economic:** Global markets for biofuels are already growing rapidly in many countries. Global manufacturing and sales reached \$20.5 billion in 2006 and are projected to grow to \$80 billion by 2016. Biofuels can also provide an economic hedge against higher oil prices as well as increase certainty of supply (especially for production from domestic biomass resources) in the event of future oil-supply disruptions. Reducing oil imports would help improve the US trade balance. It could become extremely important for the United States to lead in biofuels technologies in the event that an oil crisis occurs related to peak oil production or other factors. An oil-supply crisis would likely force a rapid transition to alternative energy sources, and if the United States fails to develop a significant bio-based economy, it could fall behind other regions of the world economically. A risk is that the United States could make a huge investment in biofuels but fail to address potentially cheaper solutions to reduce petroleum use, such as requiring vehicles with significantly higher fuel efficiency.

Cultural: A major commitment to biofuels could improve social cohesiveness and be a source of national pride if, for example, the impacts of global warming become serious. A strong bio-based economy could also provide significant rural economic-development opportunities, especially if a broad base of citizens helps to make the new economy a reality. On the downside, if increasing demand for agricultural biomass to make biofuels results in significantly higher food prices or negatively affects resources such as land and water supplies and land ownership, a major move to biofuels could increase social discontent.

Future Scenarios and Potential Impacts on the United States

Key uncertainties that relate to biofuels technology and implementation tend to fall along two major axes:

- The policy and funding environment
- The rate of technology advancement for enhanced capabilities and lower biofuels costs.

The key uncertainty in the policy and regulatory environment is the degree of commitment to promote a biofuels economy, which will be strongly influenced by the level of concern about issues such as energy security, global warming, and crude-oil prices.

The rate of technology advancement will be strongly influenced by the regulatory environment and the need to address feedstock constraints and reduce costs.

Four scenarios are possible on the basis of those axes. We concentrate on the two extreme scenarios—”Stalled” and “Biofuels in the Fast Lane”—that highlight the spectrum of possibilities for how the future could play out through the year 2025. These are disruptive in different ways and we describe these scenarios in some detail and identify the opportunities and threats for each. We briefly describe the other two scenarios, “Supported Growth” and “Economic Biofuels,” which have more intermediate impacts.

**Table 3
BIOFUELS AND BIO-BASED CHEMICALS: FUTURE SCENARIOS**

		Rate of Technology Advancement	
		Incremental	Rapid
Policy and Funding	Lack of Support	Stalled	Economic Biofuels
	Strong Commitment	Supported Growth	Biofuels in the Fast Lane

Source: SRI Consulting Business Intelligence.

Scenario 1: Supported Growth

In “Supported Growth” advances in biofuels technology have been slow and most production still relies on relatively expensive food crops for feedstock. Some biofuels markets have seen

significant growth, however, where governments have continued to mandate their use and provide subsidies to help make biofuels cost-competitive with conventional fossil fuels. A number of industrialized and developing countries that have the economic and/or land resources to make a major dent in dependence on imported crude oil have been willing to make a large public commitment to biofuels.

Scenario 2: Economic Biofuels

In “Economic Biofuels” the private sector is the main driver of a steadily growing biofuels sector. Technology breakthroughs have led to the manufacture of large-scale second- and third-generation biofuels, such as those based on high-growth algae, that are increasingly cost-competitive. Many governments nurtured the early growth but gradually cut biofuels subsidies as markets became self-sustaining. The largest biofuels markets emerge in areas with ready access to biomass resources from wastes and energy crops optimized for biofuels production.

Scenario 3: Stalled

In “Stalled” the vision of a vibrant biofuels economy does not materialize. The United States and some other governments decide that large biofuels subsidies are not the best use of public monies and begin to scale back ambitious biofuels targets. Investment tax credits for blending biofuels into gasoline and diesel at low concentrations remain in place, supported by vociferous corn- and soy-grower lobbies. But the US government quietly drops ambitious policy targets for the large-scale use of biofuels to replace gasoline. Crude-oil prices remain relatively high—in the \$50-to-\$75-per-barrel range—but environmentally conscious consumers prefer to purchase high fuel-efficiency hybrid and electric vehicles rather than flex-fuel vehicles—especially because the availability of E-85 fueling stations remains quite limited. Although governments worldwide (including the US government) agree to take real action to reduce greenhouse gas emissions, the use of biofuels is not a preferred path. Instead, the United States focuses on reducing greenhouse gas emissions in the electricity-generation sector (through cleaner coal technologies and more nuclear power) and mandates higher efficiency standards for vehicles, buildings, and appliances. Much of the disenchantment with biofuels is that, despite significant public and private R&D funding through the early 2010s, second-generation technologies do not advance sufficiently to make cellulosic ethanol and other new biofuels and bio-based chemicals close to being cost competitive with petroleum-based fuels. Reliance on crop-based biofuels has led to sustained higher prices for a range of food products, resulting in a backlash against biofuels by the general public. By 2025, biofuels represent just 5% of the US transportation fuel pool, only slightly more than the 2% level in 2006.

- *Potential opportunities.* The United States could continue R&D to improve biomass feedstocks and biofuels with no need to take on the risk of rushing new technologies into production before they are viable. The United States could take a more market-based approach to energy issues and still improve its international reputation by taking alternative actions to address global warming. To supplement limited food crop availability for biofuels, the United States could import lower-cost biofuels from countries such as Brazil and new suppliers.
- *Potential threats.* The United States could fall behind other regions, notably the European Union, which is likely to maintain a stronger commitment to developing advanced biofuels, and China, which needs advanced biofuels to help meet rapidly increasing demand for transportation fuels. The United States would have less room to maneuver to address periodic crude-oil-supply disruptions and future upward trends in oil prices, as supplies of

nonconventional energy supplies eventually dwindle. This would be especially true if US vehicle-efficiency standards are not aggressive enough. The United States would remain dependent upon less-than-friendly OPEC oil-producing countries for key energy supplies.

Scenario 4: Biofuels in the Fast Lane

In “Biofuels in the Fast Lane” the US government confronts an increasingly energy-constrained world that requires new, cleaner, safer, and more secure energy solutions. As conventional crude-oil production declines, prices spike to \$100/barrel and even higher. At the same time, physical impacts of global warming—especially more severe weather patterns and collapsing fish populations—demand drastic steps to reduce GHG emissions. Supported by public opinion, the US government commits to a “Brazil model” of widespread biofuel use and helps to fund new commercial-scale plants and a flexible fuel infrastructure. By 2020, biorefineries processing lignocellulosic waste feedstocks are becoming common throughout the country. Technology breakthroughs have significantly lowered the cost of converting agricultural wastes, and cellulosic ethanol is now very cost competitive with high-priced conventional gasoline. Ethanol-fueled hybrid vehicles are in great demand. Newer synthetic “designer fuels” offer even higher performance and are in wide use in jet-fuel blends. Commodity and specialty chemicals and bioplastics also increasingly are derived from renewable feedstocks, and producers benefit from more energy-efficient manufacturing and environmentally friendlier products. By 2025, US petroleum fuel demand is more than 35 percent below 2007 levels, surpassing the ambitious government goal set in 2007 to displace 30 percent of gasoline use with biofuels by 2030.

- *Potential opportunities.* The United States has the opportunity to take the lead in developing low-net-carbon advanced biotechnologies and other processes to produce second- and third-generation biofuels and bio-based chemicals. In spite of oil price shocks and tight supplies, the US economy could benefit from increasing oil independence and increasing entrepreneurial activity, especially in rural areas. The United States could also gain political influence by working cooperatively with countries such as China that are also making a major transition away from petroleum-based fuels. New synthetic fuels with improved performance could be useful for the military.
- *Potential threats.* The United States may not be able to move fast enough to enable a major biofuels economy fully by 2025. A new oil crisis could cause a severe economic recession and cash-strapped governments and citizens may not be able to afford the new plant capacity, infrastructure upgrades, and vehicles necessary to enable high-concentration cellulosic-ethanol fuels. With a major push to produce biofuels, the US government and US oil companies may lose leverage to obtain necessary oil supplies from OPEC countries, at the expense of countries such as China and India.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward biofuels and bio-based chemicals technology, include:

- The timing and nature of biofuels promotion policies in the United States and other regions (e.g. quotas, subsidies, specific support for domestic or low-emission fuels),
- The timing and nature of global warming policies in the United States and internationally (e.g. carbon taxes, post-Kyoto Protocol carbon reduction agreements),
- The level of continuing R&D support from the Department of Energy and Department of Agriculture for the development and commercialization of advanced biofuels technologies
- Crude oil prices and supply,
- Cost and efficiency improvements in biofuels conversion processes,
- The influence of food-versus fuel debates and public opinion on the availability of feedstocks such as corn and the spread of biofuels (especially in the near term),
- Improvements in feedstock yield and supply resulting from breeding and genetic modification of plants for very high growth or high biofuels yields,
- Fuel efficiency gains in vehicles and the spread of alternative vehicle technologies such as hybrid electric, electric, and fuel cell vehicles,
- Development of an E85 ethanol fuel infrastructure (fueling stations and flex-fuel vehicles) to enable widespread use of high-ethanol-concentration fuels, and
- International trade in biofuels from low-cost suppliers in Brazil, the Caribbean, Southeast Asia, and other locations.

Clean Coal Technologies

Why is Clean Coal Technology Potentially Disruptive?

Clean coal technologies would permit coal to function in a carbon constrained regulatory environment. The development of clean coal technologies is gaining momentum in coal rich nations, which include major economic and scientific powers, but it is not certain to succeed.

At least two sets of circumstances could indicate that either the development or the failure to develop clean coal technology would be disruptive to US interests. If the United States—and the world in general—has a high expectation that clean coal technology will allow the continued or expanded use of coal as an energy source and this technology cannot be matured, the resulting environmental and economic impact could be a major challenge to US interests. Conversely, a successful accelerated and rapid deployment of clean coal technology could pose a major challenge to other (predominately oil) energy markets; the resulting geopolitical instability could also be a major challenge to US interests.

The Energy Information Administration expects world energy demand to rise 57% between 2004 and 2030. Nations are looking toward tightening energy supplies amid growing concerns about the potentially catastrophic consequences of climate change because of anthropogenic greenhouse gas (GHG) emissions. Three of the largest and fastest-growing energy consumers, the United States, China, and India, along with Russia possess the four largest recoverable coal reserves, representing 67% of known global reserves. Expanded coal production could extend nonrenewable carbon-based energy systems for one or even two centuries. Coal also emits more carbon dioxide (and other pollutants) per unit energy recovered than do other fossil fuels like oil or natural gas, making coal one of the least environment-friendly energy options today. The technical or commercial success of technologies that enable these coal reserves to remain a viable source of energy while becoming more environmentally friendly may be very desirable to the United States, but success is by no means certain. The possible opportunities afforded by having clean coal technologies make a US failure to develop this technology disruptive to US interests³.

Clean coal technologies include an array of related technologies to improve efficiency, lower emissions of harmful pollutants, and provide fuels and chemical feedstocks from available resources. The most disruptive clean-coal technology comes at the end of the coal cycle, carbon capture and sequestration (CCS); the most developed technologies, like gasification, come earlier in the cycle. CO₂ emissions from power generation are the leading domestic contributor to greenhouse gas accumulation in the atmosphere. Sulfur, particle, and NO_x emissions from coal-driven power plants are lower than ever before, but coal power generates more carbon dioxide per unit energy than all other major power sources. True clean-coal power depends on the effectiveness of CCS; from an environmental perspective, coal derived energy is only truly *clean* with CCS. Successfully developed clean coal (with CCS) would allow the United States (or any coal-rich nation) to rely safely on an abundant domestic energy resource. However, application of successful CCS is by no means certain to occur before 2025.

Potential Impacts of Clean Coal Technologies on US National Power

³ An additional possibility is that foreign governments or multinational firms would develop the technology. In such a case, it would be advantageous to the United States to insist on the use of such technology by US utilities and energy providers. Although this may increase the cost of using the new technology, we assess that to be a minor burden overall to the US economy. We do not believe there would be a foreign interest in denying or withholding the technology when the market for it would be substantial.

- Geopolitical:** Extending the usefulness of coal reserves would lessen dependence on foreign oil sources, ease pressure on energy reserves, and give renewable energy sources more time to develop into significant contributors to the domestic energy profile. Oil-rich nations will lose some geopolitical influence without the world's largest economy as a beholden consumer. Alternatively, without developing domestic energy sources, the United States may find itself continuously dependent on unstable and often unfriendly nations for a vital and increasingly scarce energy resource.
- Military:** Reliance on foreign oil from unstable regions of the world has required military intervention in the past and will likely do so again if the global energy landscape and geopolitical situation remain unchanged. The United States, Russia, China, and other growing world powers could avoid military engagements to protect global oil energy reserves by extending the usefulness of their expansive coal reserves.
- Economic:** A convergence of public interest, technological development, and the promise of environmental policy changes has dramatically increased growth in clean energy technologies. Additionally, expanding domestic energy sources to lessen (or eliminate) the energy trade deficit will remove stress on the US economy. Clean coal also provides a reserve strategy in case developments in renewable fuels do not come to fruition. Alternatively, the economic consequences of global warming may be much higher than the incremental costs of clean-coal systems or the economic cost and burden of implementing clean coal technology may degrade US and global economic performance.
- Cultural:** Clean coal may offer a near- to midterm pathway toward lessening the rift between the industrial sector and citizens concerned about global warming. Carbon capture and sequestration is the most important component toward this end. Economic growth coupled with responsible environmental stewardship will add cohesion and a sense of pride to a population that views these two areas as incompatible. Successful development and deployment of clean coal technologies would globally enhance the United States' technical reputation.

Future Scenarios and Potential Impacts on the United States

Key uncertainties affecting the successful integration of clean-coal technologies can fit along two major axes:

- What will be the driving policy and funding environment, economic growth or climate/environmental protection?
- What will be the rate of technological advancement for clean coal technologies, rapid or incremental?

The uncertainty of the policy and funding environment is strongly influenced by concerns about issues including climate change, economic development, energy security, and natural gas and crude oil prices relative to coal.

Although the rate of technology advancement will have some dependence on supportive policies and funding levels, it will also depend on the success or failure of other non- or minimally carbon-contributing energy sources, including nuclear, biofuels, solar, and wind.

Although four scenarios are possible with these axes, we concentrate on the two that perhaps present the most immediate challenges for the United States (“Leave it in the Ground” and “King Coal”). These are disruptive but for different reasons and we detail the opportunities and threats for each of these scenarios. We also briefly describe the other two scenarios: The case of high economic emphasis and incremental clean coal technology development (“Wealth Not Health”) would ultimately lead to an environmental disaster. The scenario with policy and funding driven by environmental concerns and rapid development of clean coal technologies (“Act Now”) would not be as disruptive as clean coal technology matures at such a rate to minimize any adverse economic impact.

**Table 4
CLEAN-COAL TECHNOLOGIES: FUTURE SCENARIOS**

		Rate of Technology Advancement	
		Incremental	Rapid
Policy and Funding	Grow the Economy!	Wealth Not Health	King Coal
	Protect the Climate!	Leave it in the Ground	Act Now

Source: SRI Consulting Business Intelligence.

Scenario 1: Wealth Not Health

In “Wealth Not Health” power derived from coal generates more CO₂ per unit energy than any other major source of energy. The bulk of the scientific community believes that the effect of uncontrolled expansion of GHG emission will eventually alter the Earth’s climate resulting in unprecedented economic and environmental damage (see “Leave it in the Ground”). Another urgent concern is that coal power plants emit mercury, sulfur oxides, nitrogen oxides, and particulate matter along with other pollutants at rates intolerable to public safety. As seen in the case of TXU Energy in 2007, many US communities will not readily support expansion of coal power without a paradigm shifting achievement in emissions control technology.

Scenario 2: Act Now

The main impacts of this scenario will be the oil and natural gas industry facing new competition, and the geopolitical shift in attention from oil-rich countries (see “King Coal”). The remainder of the United States and much of the world economy will enjoy the benefits of a relatively seamless transition to operating on clean energy.

Scenario 3: Leave it in the Ground

In “Leave it in the Ground” the hope of clean coal technologies does not materialize but regulations aimed at stemming GHG emissions place severe limitations on the coal industry. Carbon capture and sequestration in deep saline formations proves to be impractical at the scale necessary for reaching the DOE’s goal of sequestering 90% of carbon emissions from a coal power plant. Investment in biofuels, solar, next-generation nuclear, wind, and tidal energy result in carbon-free energy alternatives that are cost-competitive with conventional coal under the carbon-penalizing regulatory regime. Regulations never go to the extreme of shutting down plants, but permitting and building new coal plants proves too costly to justify to investors. Integrated gasification combined cycle (IGCC) facilities turn out to be useful for producing hydrogen gas, but still cost too much to operate as power plants with unreliable gas turbines, resulting in too much equipment downtime. Coal to liquid transportation fuels prove to be too carbon intensive and are outmoded by the availability of inexpensive biofuels from domestically grown nonfood crops. The role of coal in the US energy landscape declines (from about half of all US electricity generation in 2007) as more alternative energy sources come online and more outdated coal power plants reach the end of their life cycle and are mothballed. Coal producing states including Wyoming, Kentucky, West Virginia, and Pennsylvania face economic downturns as domestic energy dollars shift to other areas of the country, that benefit from the growing renewable energy market (Silicon Valley, coastal and farming states). China and India, having agreed, under pressure, to the stemming of their GHG emissions are now faced with severe economic challenges. The regime in Beijing is threatened. GHGs continue to grow as the planned retrofit of coal plants built in China and the United States through 2015 now are impractical. Although the growth of clean non-coal technologies has been impressive, it also has not been sufficient, and by 2020 it is obvious a quick, massive, and costly transition to nuclear power will be required to protect the climate. The US and global economies are stressed by the need for such massive recapitalization in the midst of coping with an ever increasing hostile climate environment.

- *Potential opportunities.* The United States can profit from exporting non-coal clean-energy products and technologies. Developing nations not subject to restrictions on carbon emissions may also seek to buy US coal. The United States could serve as an energy exporter and benefit from countries that do not yet have access to noncarbon alternatives. Research in clean coal may continue in an attempt to salvage US coal use and as an opportunity for technology developers and coal producers to sustain coal exports as developing countries adopt low-carbon standards. Although not useful for fuel purposes, CTL may still offer economic advantages over oil-based petrochemicals in an unstable oil market.
- *Potential threats.* If China and India refuse to adopt low-carbon standards, they will retain an even greater cost advantage in manufacturing over low-carbon states than they do today. As both countries develop and reach increased standards of living for their very large populations, dramatically increasing energy generation from outdated means would accelerate the buildup of atmospheric greenhouse gases. Researchers predict that unchecked accumulation of GHG will lead to more frequent and intense extreme weather events, which can cause extensive economic and social damage. The expanded use of nuclear power raises increased risks for nuclear proliferation and the spread of nuclear weapons. High US reliance upon nuclear power removes all moral legitimacy for opposing the development of nuclear power by other states.

Scenario 4: King Coal

In “King Coal,” rapid economic growth in the 2008-2015 timeframe has caused CO₂ emissions to increase significantly but has also provided private funds (from profits) to develop clean coal technologies. Success with CCS has been particularly impressive. New coal power plants are constructed between 2008 and 2015 without carbon capture and sequestration capabilities, but with the ability to retrofit. By 2020 retrofits can be done at minimal costs. Driven by rapid economic growth, oil prices have been very high, and other clean coal technologies (coal to liquid and coal to gas [CTG]) are developed as competitive alternatives to oil. Breakthroughs in clean coal technology, occurring around 2020, are followed by regulations requiring their implementation. Energy security becomes a US mantra, and CTL and CTG development accelerates. The start-up costs and regulatory hurdles prove too much for investors who have been interested in new nuclear capacity as an alternative to coal. Solar panels cover an increasing number of US rooftops, thanks to technology and manufacturing advances and government subsidies. Wind power also advances although it is limited to certain wind-rich geographic regions because of opposition from wildlife and coastline-preservation groups. But combined solar and wind power doesn’t exceed 10% of US electricity generation by 2025. Coal use has grown to account for nearly two-thirds of US electricity generation, and hydrogen (from natural gas and coal via IGCC) and coal-based diesel provide a significant and growing percentage of transportation fuels. After 2020 oil markets plummet. Major oil exporters face severe economic challenges as their single commodity economies collapse. Despite the resulting internal and regional instabilities, the United States, with energy independence, shows little interest in engaging with the ensuing problems. China and India readily accept the clean coal technology. Russia has wisely saved oil revenues from the previous rise in oil prices and has diversified its economy. Because coal resources are finite, development continues with other non-coal clean energy technologies.

As the coal industry moves forward beyond 2025 with near elimination of environmental concerns from newly built coal plants, significant long-term potential exists for sustained, clean, domestic energy supplies.

- *Potential opportunities.* The United States, China, and India benefit from expanded use of domestic energy supplies. They see a long-term means for using their coal reserves and could benefit from technology sharing arrangements in clean coal. The United States could also profit from exporting coal and eventually clean-coal products and technologies. The United States could serve as an energy exporter and benefit from countries that do not yet have access to noncarbon alternatives.
- *Potential threats.* Without leadership from the United States in GHG emission reduction through development of clean coal technologies, China and India will most certainly continue to prioritize economic growth over environmental concerns, which would maintain the environmental risk posed in the “Leave it in the Ground” scenario. Additionally, although extensive known coal reserves exist in the United States, many are difficult to recover. This difficulty may result in a “peak coal” effect that even with development of clean coal technologies sees a time when all easily recoverable coal is consumed. The United States would still require alternative energy sources to remain independent. Russia, with the second-largest known reserves, could find itself in an increasingly influential role as an even more important energy supplier than it is today. Regional and local instabilities coupled with a US disinterest in engagement with them may allow new ideologies and threats to fester out of control. The rich (coal countries) get richer and the poor (non-coal countries) take the double

hits from changing climate and a difficulty in economically competing with the giants, the United States, China, Russia, and India.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward clean coal technology development, include:

- Global demand for energy,
- Development of other carbon- and non-carbon-based alternative energy sources and their economic viability (for example: bio-fuels, solar energy, wind),
- The price of oil in comparison with that of alternative energy,
- US government policy regulating the emission of greenhouse gases, increasing energy efficiency, and investing in and subsidizing alternative and renewable energy sources, and
- Successful sequestration of CO₂ through energetically and economically viable means.

Service Robotics

Why Are Service Robotics Potentially Disruptive?

Robotics and its enabling technologies have already advanced to the stage where single-application robots and related systems (including autonomous vehicles) are being implemented in a wide range of civil and defense applications. Although a great deal of development is still required in terms of *intelligence* for robots, effective artificial intelligence (AI) and behavioral algorithms, many of the building blocks for disruptive robot systems are either already in place, or will be by 2025. These include hardware (e.g. sensors, actuators, and power systems) and software (e.g. robot platforms). Key disruptive applications of service robotics will include uses in domestic and defense settings. In addition, robotics technology has the potential to diffuse into other application areas, for example, human augmentation and autonomous vehicles.

Potential Impacts of Service Robotics on US National Power

Robots are designed to replace humans in a variety of applications, with each application having potentially far-reaching implications. Although truly intelligent robots are unlikely to emerge by 2025 (the key barrier being AI), robotics technology still has the potential to impact the four elements of national power:

- Geopolitical:** Robotics is unlikely to transform geopolitics unless a massive advance in AI technologies occurs. However, the use of unmanned systems for terrorist activities could emerge by 2025 because the availability of simple robot platforms will increase significantly.
- Economic:** The global market for nonindustrial robotics could reach \$15 billion by 2015. While it will be an important new industry, it is unlikely to significantly impede or aid the economic development of the United States.
- Military:** Of all the four elements of national power, robotics is likely to have the greatest impact on the military element. Many robots and similar unmanned systems are already being implemented, although their capabilities are still limited. By 2025, unmanned systems with a much greater level of autonomy will have been implemented, and closely related/synergistic technologies (e.g. human augmentation systems) will extend the performance of soldiers significantly. The United States is likely to remain the world leader in this area.
- Cultural:** Robotics could influence a number of key areas of life that affect social cohesion. The development and implementation of robots for elder-care applications, and the development of human-augmentation technologies, mean that robots could be working alongside humans in looking after and rehabilitating people by 2025 (particularly in Japan and South Korea). However, over-reliance on automated devices such as domestic robots could increase obesity levels. A change in domestic and social responsibilities and a change in domestic employment requirements could affect lower income service-oriented workers.

The opportunity exists for the United States (and US companies) to continue to be a world leader in robotics technologies, particularly for defense and domestic applications. The opportunity also exists for the United States and its allies to lead in the implementation of military robots and associated technologies. In addition, US researchers must continue to press ahead with research relating to AI and human-robot interaction, to avoid falling behind Japan and South Korea. Chinese

players will compete effectively with U.S., South Korean, European, and (most notably) Japanese companies in domestic and leisure robots by 2025—China is also developing military robots.

Future Scenarios and Potential Impacts on the United States

The key uncertainties associated with the future of robotics technologies can be demonstrated using two major axes:

- Technology advancement
- Global interest and funding.

The key uncertainty along the technology advancement axis comprises the technical risks and knowledge gaps that will either move toward useful robots with commercial applications or toward an environment of many weak links with no discernable products. Artificial intelligence in robots is the key differentiator.

The global interest and funding axis will be influenced by technical progress. Governments and industry players will either be fully supportive and enthusiastic about robotics, or be cautious, perhaps removing funding and cutting R&D programs.

Using these axes, four scenarios—”Niche Products,” “Loss of Patience,” “Quasi-Autonomy,” and the “Autonomous World”—can highlight how the future could play out through 2025. We describe each of these scenarios briefly and detail the opportunities and threats in the two scenarios that reflect the extremes of technological and commercial progress. These axes and scenarios are highlighted in Table 5.

Table 5
SERVICE ROBOTICS: FUTURE SCENARIOS

		Technology Advancement	
		Weak Links	Positive Shifts
Interest and Funding	Weakening of Government and Industrial Interest	Niche Products	Lost Patience
	Support, Funding, and Regulation	Quasi-Autonomy	Autonomous World

Source: SRI Consulting Business Intelligence.

Scenario 1: Lost Patience

Although major developments occur in several major enabling technologies, notably in terms of AI, through 2025, these developments occur too late to generate enough enthusiasm among key robotics stakeholders. Instead of commercialization of robots *per se*, advances in enabling technologies are often quickly transferred to other products and services, especially vehicles and consumer electronics. The lack of an integrated approach limits the overall impact of some significant advances in robotics technology, and low-cost manufacturing is unrealistic. Although

some autonomous robots do see use in some applications (notably for defense applications), robots are still too expensive for many application areas. In general, the structure of the robotics industry remains fairly static.

Scenario 2: Quasi-Autonomy

In “Quasi-Autonomy” we see only steady progress in key enabling technologies relating to robotics. In particular, the development of advanced computing technologies and cognitive-robotics R&D does not enable a major shift in intelligent robotics. Nevertheless, advances in other (some would say, less crucial) technologies occur, and simple robot systems start to become extremely popular in home applications. This commercial success drives interest in funding robotics R&D, and key players start to roll out affordable robots. International standards are developed, and some consolidation occurs in the nonindustrial robotics industry. Technology-transfer into other applications continues, and assisted vehicles become almost omnipresent.

Scenario 3: Niche Products

In “Niche Products” predicted advances in robotics and its myriad enabling technologies never emerge. In particular, R&D relating to artificial intelligence and cognitive science does not move fast enough. Although some progress is made, any small breakthroughs are offset by the discovery of new problems and barriers to progress. Research relating to AI becomes nebulous. The lack of progress in robotics is not helped by progress in consumer electronics, connected homes, and home automation. People do not need robots to help them. Robotics continues to struggle to find enough viable applications to sustain a growing industry. Interest in funding robotics R&D lowers, and key players follow Sony’s lead and abandon advanced robotics R&D. International standards are not developed. Some consolidation occurs in the nonindustrial robotics industry, but in general the structure of the industry remains static, with key players producing specific defense-, domestic-, transport- and leisure-related products. Low-cost manufacturing becomes the key to continued growth.

- *Potential opportunities.* The United States is well positioned to assume a leadership role in the development of robots for niche applications, especially military robots, and its players continue to lead in this area. While funding is cut for some high-level R&D activities, funding becomes concentrated around the development of key strategic technologies, such as UCVs and wearable robotics. This expertise leads to the United States having a clear advantage over many of its enemies in conflicts of many different types. By 2020, the number of US soldiers killed in combat has been reduced significantly by the adoption of unmanned systems.
- *Potential threats.* Although the United States continues to be a world leader in defense robotics, robotics technology in general has not moved on enough for this strategic advantage to be critical. Although the United States is well positioned to defeat many types of threat via the use of unmanned systems (especially guerilla tactics), other countries also start to adopt unmanned systems to bolster their forces and catch up. Problems emerge in other application areas. iRobot faces such competition from both legitimate and counterfeit competitors in China that it sells its domestic-robotics business in 2015. The lack of support for advanced R&D means that key US centers of excellence and leaders of robotics R&D (Carnegie Mellon and MIT) have a significantly reduced profile.

Scenario 4: Autonomous World

In “Autonomous World” several large advances occur in key enabling technologies relating to robotics. In particular, the development of advanced computing technologies and the successful completion of initial cognitive-robotics R&D enables a paradigm shift in intelligent robotics. Although advanced intelligent robots are still too expensive for most people to afford, robots are starting to be used for some key applications. In Japan, many robots are used to look after elderly people, and robots perform many difficult or repetitive jobs. In addition, these advances have resulted in a great deal of technology-transfer into other applications. By 2020, even a simple leisure robot can help with some small tasks around the home (such as home security and tidying up). Crucially, robots have become a “must have” item for many people and a successful consumer-robotics industry emerges. In addition, other technologies benefit from this progress, autonomous vehicles become commonplace.

- *Potential opportunities.* With key developments and breakthroughs in robotics occurring at their universities and thus holding the core patents to the commercialization of some research, the United States and Japan remain in the driver’s seat of the subsequent commercialization activity—with Europe and South Korea following close behind. The US academic research community benefits greatly from follow-on research. The resulting technology transfer to the private sector results in considerable entrepreneurial activity that provides a new era of technology-led economic activity to boost the economy. US companies continue to invest in robotics and associated technologies, and global standards for robot implementation emerge. The US military meets and exceeds its targets (set in the mid 2000s) for the implementation of unmanned systems. Robots can replace human workers in a number of skilled manufacturing roles, boosting the competitiveness of U.S.-based manufacturing (also the case in Japan) in general.
- *Potential threats.* This scenario could have some economic and demographic impacts that policy makers are unprepared for. With robots having the ability to replace humans in skilled roles, unemployment becomes more of a problem as manual labor starts to become outdated. The increasing competitiveness of completely automated manufacturing in Japan and the United States triggered a slowdown in the growth of manufacturing in China, and the specter of economic collapse hangs over the region. In the United States, homes and cars have significantly increased in complexity due to all the automation, countering reductions in the power consumption of individual devices and also affecting recycling efforts. Extensive automation has not helped solve the problem of obesity; indeed many commentators argue it is a major contributor to obesity. In addition, the implementation of advanced robots for security applications (including micro robots and UAVs) leads to social tensions and disruption in some countries.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward service robotics technology development, include:

- The size and nature of robotics investments in the United States,

- Players involved in robotics R&D. Watch for either another key player to follow Sony's lead and abandons robotics altogether, or for a new player to follow Microsoft and invest heavily in robotics,
- Global levels of funding for robotics research, in particular, whether investment continues to rise or is cut,
- Toy becomes tool. The point when a toy robot has the ability to perform a useful task within the home (for example, retrieving an object for the user),
- The establishment of centers of excellence in robotics research outside the United States and models for research and commercialization,
- The completion of initial (international) research programs for the development of cognitive robots,
- The development of noninvasive brain-machine interfaces,
- The launch of Chinese designed and built robots for domestic, service-sector, and defense applications,
- Development of unmanned vehicles with sliding autonomy for both civil and defense applications, and
- The development and implementation of national and international standards for service, domestic, and military robots.

The Internet of Things

Why is the Internet of Things Potentially Disruptive?

Individuals, businesses, and governments are unprepared for a possible future when Internet nodes reside in such everyday things as food packages, furniture, paper documents, and more. Today's developments point to future opportunities and risks that will arise when people can remotely control, locate, and monitor everyday things. Popular demand combined with technology advances could drive widespread diffusion of an Internet of Things (IoT) that could, like the present Internet, contribute invaluable to our economy. But to the extent that everyday objects become information-security risks, the IoT could distribute those risks far more widely than the Internet has to date.

Potential Impacts of the Internet of Things on US National Power

If the United States executes wisely, the IoT could work to the long-term advantage of the domestic economy and to the US military. Streamlining—or revolutionizing—supply chains and logistics could slash costs, increase efficiencies, and reduce dependence on human labor. Ability to fuse sensor data from many distributed objects could deter crime and asymmetric warfare. Ubiquitous positioning technology could locate missing and stolen goods. On the other hand, we may be unable to deny access to networks of sensors and remotely-controlled objects by enemies of the United States, criminals, and mischief makers. Foreign manufacturers could become both the single-source and single-point-of-failure for mission-critical Internet-enabled things. Manufacturers could also become vectors for delivering everyday objects containing malicious software that causes havoc in everyday life. An open market for aggregated sensor data could serve the interests of commerce and security no less than it helps criminals and spies identify vulnerable targets. Thus, massively parallel sensor fusion may undermine social cohesion if it proves to be fundamentally incompatible with Fourth-Amendment guarantees against unreasonable search. By 2025, social critics may even charge that Asia's dominance of the manufacturing of things—and the objects that make up the Internet of Things—has funded the remilitarization of Asia, fueled simmering intra-Asian rivalries, and reduced US influence over the course of geopolitical events.

Future Scenarios and Potential Impacts on the United States

When considering the spectrum of possibilities for the state of the IoT in 2025, the key uncertainties span a number of unresolved issues that fall along two major axes:

- The timing of developments (slow versus fast)
- The depth of penetration (niches versus ubiquity).

In terms of timing, just as the Internet and mobile telephony grew rapidly after their incubation periods, the IoT could emerge relatively rapidly if, on balance, the preponderance of conditions yields favorable policies, technological progress, and business collaboration. Or the IoT could arise more slowly if, on balance, conditions are less favorable in these dimensions.

In terms of depth of penetration, just as the Internet and mobile telephony penetrated deeply into the fabric of developed nations, the IoT could pervade everyday life if, on balance, the preponderance of conditions yields an enthusiastic public that uses its pocketbook to express strong market demand. Alternatively, if those demand signals do not materialize—for example if the public perceives costs, disadvantages, and risks that outweigh perceived benefits—then the IoT may remain limited to industrial, commercial, and government niches. Yet even those niches could include benefits and harms that would significantly affect the United States.

On the basis of these two axes of uncertainty, four scenarios highlight the spectrum of possibilities for how the future could play out until 2025. Whether fast and widespread, or slow and niche-driven, the emergence of the IoT has the potential to affect US interests. We focus on the opportunities and threats that the two extreme scenarios present to the United States: Important risks and advantages will arise even in the “Connected Niches” scenario, which represents moderately-paced opportunistic developments of IoT technology. At the other extreme, “Ambient Interaction” highlights the implications of a rapid and deep penetration of information-communications technology into everyday objects—a scenario that is sufficiently plausible that its dramatic risks and advantages deserve consideration. We also describe briefly “Fast Burn” and “Slowly But Surely,” which represent the middle ground among the four scenarios.

Table 6
THE INTERNET OF THINGS: FUTURE SCENARIOS

		Depth of Penetration	
		Vertical Applications	Widespread
Timing of Developments	Expedited	Fast Burn	Ambient Interaction
	Evolutionary	Connected Niches	Slowly But Surely

Source: SRI Consulting Business Intelligence.

Scenario 1: Fast Burn

In “Fast Burn” the IoT develops rapidly but in a limited fashion, and fails to sustain its momentum. Although impacts become quite significant in particular application areas (industrial automation, health care, and security), the IoT doesn’t fulfill the promise of becoming pervasive (and thus is of limited importance to everyday lifestyles, business operations, and the conduct of government). Ubiquitous positioning technology never materializes as military concerns about the risks of terrorists gaining access to improved geolocation combine with inadequate local-government funding for emergency-service positioning. In this scenario, IoT technology confers similar risks and benefits to US interests to those experienced in “Connected Niches,” but neither the risks nor the benefits to US interests inherent in “Ambient Interaction.”

Scenario 2: Slowly But Surely

In “Slowly But Surely” the IoT becomes pervasive, but not until 2035 or so. Outcomes are somewhat similar to those of “Ambient Interaction,” but there are substantial differences. The relatively slow development of the technology gives businesses and governments time to assimilate developments, allaying the most disruptive risks. Many risks remain, but the sheer complexity of technology in 2035 makes the IoT less accessible to hacking by mischief-makers. Nevertheless, the most motivated malefactors and enemies of the United States can exploit the IoT in ways that are similar to those experienced in “Ambient Interaction,” and benefits to US interests do not materialize as dramatically as they do in “Ambient Interaction.”

SRI Consulting Business Intelligence

Scenario 3: Connected Niches

In “Connected Niches” the IoT evolves along application pathways that promise rapid payback and that can overcome resistance and indifference. Demand is commensurate with evolutionary but not revolutionary cost reductions, moderate technology progress that leaves some problems largely unsolved. Industries show reluctance to fully collaborate. Policies express at best a benign neglect for the potential advantages and, at worst, discriminate against innovation in favor of grandfathered interests. Even in 2025, positioning technology remains limited to outdoor use and many individual items lack RFID tags. Nevertheless, innovations encourage adoption of connected everyday objects and sensor networks in security, logistics, healthcare, document management, inventory management, fleet management, industrial automation, and robotics. In short, connected everyday devices are common in workplaces and military operations but not in households. Similarly, sensor networks mainly reside in workplaces and public places. Connected everyday objects and sensor networks deliver significant value to the economy and significant efficiencies to military organizations but also introduce significant vulnerabilities as new pathways for exploitation become available to mischief makers, criminals, and enemies of the United States. As niches grow, some interconnect, introducing unexpected interactions—some synergistic, others counterproductive.

- *Potential opportunities.* The United States gains short-term economic advantages by adopting technologies that streamline commercial logistics and industrial automation, the combined effect of which lowers costs and boosts corporate profits. When retailers choose to keep RFID at the pallet level, technology suppliers aggressively seek and find alternative growth pathways via vertical-market opportunities. Airports and other public-transit hubs become venues for large-scale sensor networks that support the missions of private-security and public-safety agencies. For recognizing patterns of behavior indicating ill intent, software helps but does not reduce the need for human observers and analysts. Similarly, the IoT deters theft and helps locate missing goods, albeit indoor location is limited to perimeter-secured environments. Many hospitals and long-term care facilities become high-tech havens, resulting in significantly improved qualities of care. Two key niches—fleet management and document management—provide growth pathways for the IoT that confer decisive advantages over traditional approaches. Government and commercial operators of vehicle fleets find substantial value in advanced vehicle diagnostics and prognostics, enabling maintenance as-needed rather than on a schedule, concurrently yielding both reduced costs and increased reliability. Also, as solution prices fall, by 2020 paper documents and publications as well as electronic substitutes for paper—e-books, smartcards, and other devices—commonly contain RFID tags, enabling automation of many formerly tedious and time-consuming processes.
- *Potential risks.* The IoT’s advantages to the US economy are moderated by trade imbalances that favor the adding of value to everyday things by overseas manufacturers. First responders have poorer geolocation capability than terrorists (who use real-time kinematic and/or satellite-based augmentation solutions that are far less expensive to a small cell of individuals than to large public safety agencies). The IoT’s contributions to physical security come at the cost of a high rate of false positive and false negative detections, so that while people consider that the cost-benefit balance is favorable, it is only marginally so; thus, depth of support is shallow. Similarly, while the IoT proves to be a boon for healthcare overall, some hospitals and long-term care facilities reduce costs by trading away the “care” in healthcare in favor of surveillance and restrictive access-control policies. While the IoT is decisively beneficial for vehicle maintenance and document management, serious risks and unavoidable annoyances accompany even these

applications. A host of risks accompany people's overconfidence in technical solutions, often at the neglect of common sense.

Scenario 4: Ambient Interaction

In "Ambient Interaction" the IoT arises rapidly and pervasively, favored by technology progress, business collaboration, and innovation-friendly policies. Strong demand arises across several major sectors of the economy, as technological wizardry combined with creative business developments stimulate people's appetites for killer applications that reduce labor and tedium, confer peace of mind, and blur the lines between work, play, and commerce. Connected everyday objects and sensor networks are common in workplaces, public places, and households. By 2017, walk-through checkout procedures are the norm for retailing, and nationwide positioning technology is in place, including indoors. Strategic initiatives have ensured that the United States enjoys long-term economic and military advantages. Nevertheless, great risks accompany great benefits as pervasive computing introduces equally pervasive vulnerabilities. Just as the Internet aggravated the risks of cyberwarfare, spam, identity theft, and denial-of-service attacks, connected everyday objects become targets for malicious software that causes everyday devices to fail or spy. Sensor networks become channels for unauthorized surveillance by mischief makers, criminals, and enemies of the United States.

- *Potential opportunities.* Geopolitical advantages arise as the United States uses sensor networks to foil terrorists and asymmetrical warriors. The US military gains long-term advantage by quickly streamlining operations and adopting strategic initiatives for continuous innovation, specifically for the purpose of sustaining that advantage. The United States also gains long-term economic advantages by embracing technologies (notably, item-level RFID and indoor location) that concurrently streamline commercial logistics and add value to physical products, the combined effect of which stimulates GDP. In fact, the pervasive IoT enables logistics to undergo a revolution rather than merely streamlining. By 2025, robotic supply chains are common and considered more secure and less prone to human tampering than traditional shipping and receiving. At ports, containers report their contents to heavy equipment, which routes goods to trucks automatically; at distribution points, pallets and forklifts similarly communicate and route goods which arrive in stores largely untouched by human hands. RFIDs in individual food packages drive popular adoption of RFID readers in cell phones that provide an indication of food origins and provenance. Makers of other packaged goods leverage the universality of RFID readers in cell phones. A combination of useful advice and marketing gimmicks yields a remarkable mix of "advertainment" and social benefits, such as cell phones that double as displays for multilingual user manuals and recycling instructions. Individuals enthusiastically adopt objects having embedded positioning capability, dramatically reducing the incidence of misplaced and stolen goods.
- *Potential risks.* The incidental risks mentioned in the Connected Niches scenario (above) threaten to multiply by an order of magnitude. As the United States increases its reliance on the IoT, supply disruptions will yield operational disruptions. Asia's role as single-source manufacturing center establishes a single point of failure for mission-critical materiel when new vehicles arrive on US shores "contaminated" by malware. Terrorists can exploit sensor networks, whose encryption technology threatens to lag far behind the cracking capabilities of East- and North-European teenagers equipped with massively-multicore laptop computers. The same corporate and government misunderstanding of security issues that yielded email-propagated viruses and spam-generating "zombie" computers could end up providing the means

for criminals and mischief makers to exploit connected everyday objects through lax security systems.

Signposts to Monitor

Scenarios exist because of the uncertainty that is inherent with any view of the future. Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge and monitoring various signposts that would indicate the direction and pace with which any field of uncertainty (in this case, relative to enabling the disruptive potential of a technology to US interests) is advancing. Key variables, which, if positive, would indicate environments that are supportive toward development of the Internet of Things, include:

- The size and nature of demand for expedited logistics in commerce and military organizations,
- The effectiveness of initial waves of IoT technology in reducing costs, thereby creating conditions for diffusion into vertical application areas including civilian government operations, law enforcement, healthcare, and document management,
- The ability of devices located indoors to receive geolocation signals, possibly, distributing such signals by leveraging available infrastructures (cell towers, broadcasters, and other means),
- Closely related technological advances in miniaturization and energy-efficient electronics, including reduced-power microcomputers and communications methods, energy-harvesting transducers, and improved microbatteries,
- Efficient use of spectrum, including cost-effective solutions for wide-area communications at duty cycles that are much smaller (e.g., the equivalent of a few minutes per month) than those of cell phones (averaging many minutes per day), and
- Advances in software that act on behalf of people, and software that effectively fuses (“makes sense of”) sensor information from disparate sources.

Abbreviations

The following abbreviations are used in this Report:

AI	artificial intelligence
BRIC	Brazil, Russia, India, and China
BTL	biomass-to-liquids
CCS	carbon capture and sequestration
cm	centimeter
CNT	carbon nanotube
CTG	coal to gas
CTL	coal to liquids
DARPA	Defense Advanced Research Projects Agency
DNA	deoxyribonucleic acid
DOE	Department of Energy (United States)
EDLC	electrochemical double layer capacitor
EU	European Union
EV	electric vehicle
FCC	Federal Communications Commission (United States)
FCS	Future Combat Systems
FFV	flex-fuel vehicles
g	gram
GDP	gross domestic product
GHG	greenhouse gas
GHz	gigahertz
GIS	geographic information system
GPS	global positioning system
HEV	hybrid electric vehicle
ID	identification
IFR	International Federation of Robotics
IGCC	integrated gasification combined cycle
IOT	Internet of things
IPR	intellectual property rights
IT	information technology
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
LAN	local area network
LMP	lithium-metal polymer
m	meter
MIT	Massachusetts Institute of Technology
MOF	metal-organic framework
NASCAR	National Association for Stock Car Auto Racing
NDGPS	Nationwide Differential Global Positioning System
NETL	National Energy Technology Laboratory (U.S.)
NHTSA	National Highway Traffic Safety Administration (United States)
OECD	Organization for Economic Cooperation and Development

PC	pulverized-coal
PC	personal computer
PDA	portable digital assistant
PDO	1,3-propanediol
PLA	polylactic acid
R&D	research and development
RF	radio frequency
RFID	radio-frequency identification
SWNT	single-walled CNT
tpd	tons per day
TUI	tangible user interface
UAV	unmanned aerial vehicle
UCV	unmanned combat vehicle
UGV	unmanned ground vehicle
UHF	ultra-high frequency
USPTO	United States Patent and Trademark Office
UWB	ultrawideband
V	volt
Wh	Watt hour
wt	weight

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CONFERENCE REPORT

DISRUPTIVE CIVIL TECHNOLOGIES

SIX TECHNOLOGIES WITH POTENTIAL IMPACTS ON
US INTERESTS OUT TO 2025