Foresight for Societal Impact: Technology Applications and Capacity Development

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This briefing describes a foresight method used by RAND to identify plausible 2020 technology applications and how it might be used to identify capacity development needs so that those technology applications most beneficial to resolving important societal problems and issues might achieve widespread sustainable implementation.

Methodology Based on RAND 2020 Technology Foresight Study

- **Global technology trends and applications**
  - **Social, political, economic, environmental, personal, regional, international impacts**
- **Broad spectrum of outlooks, testimonies, foresights**
  - **Range of future possibilities—not single prediction or scenario**
  - **Regional needs and country capacities to acquire and implement technology applications**
- ***Available* at:**
  - **www.rand.org/pubs/monographs/MG475 (Executive Summary)**
  - **www.rand.org/pubs/technical_reports/TR303 (Full Report)**

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This study sought to identify the likely global technology trends and applications through 2020 and their major social, political, economic, environmental, personal, regional, and international impacts. We wanted not only to examine the progress made with respect to prior trends (and to look for new trends) but also to use the description of potential *applications* to help convey to the nonscientist the potential kinds of effects and their implications that are likely from the trends we discuss.

First, we conducted several parallel analyses of the state of globally important technology trends and how they are being built into specific applications. In this analysis, we reviewed major S&T journals and magazines, assessing the viability of projected technology trends based on the degree to which real progress is being made in R&D laboratories, the degree of interest and investments in these trends, and our expert judgments of the overall likelihood of the applications having a significant impact on major global demand sectors and policy drivers.

Next, we connected technology trends to regional problems and issues identified by regional experts (i.e., the "So what?" test). This analysis assessed which technology applications will be important in which regions of the world based on regional needs, investments, political and cultural drivers, natural resources, and other factors. Several RAND regional and country experts reviewed the TAs identified. They suggested, based on their knowledge and experience, which ones best addressed important regional or national problems and issues, and which ones were more or less likely to match the needs and characteristics of each region or country. Interviews with these regional experts formed the initial basis for the discussions.

Finally, we considered the effects of global variations in S&T capacity and the drivers and barriers that determine the environment in which technology developments are applied and implemented. For a representative group of technology applications that our foresight analyses suggested could have broad societal impact by 2020, we then evaluated the relative potential for their implementation and its possible effects in important policy areas such as economic development, public and individual health, resource use and the environment, defense, public safety and homeland security, governance, and social structure.

Outline

- **Foresight Methodology Description**
- **2020 Technology Applications**
- **Assessment of Technology Applications**
- **The Role of Foresight**
- **Drivers, Barriers, and Country Capacities**
- **From Foresight to Capacity Development**

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We first describe our methodology for technology foresight, then highlight some important 2020 technology applications that emerged from our analysis. We then describe our method of assessing these technology applications, including a rough net assessment that used metrics for societal impact, technical feasibility, implementation feasibility, and global diffusion. After a brief discussion of the role of foresight in technology implementation for beneficial societal impact, we review our foresight study's results on capacity of representative countries around the world to acquire 2020 technology applications, and the drivers and barriers to their widespread sustainable implementation. Finally, we make some brief remarks about how technology foresight can identify capacity needs to enhance drivers and reduce barriers for implementation of technology applications to address societal problems and issues.

An Application-Oriented Foresight Methodology

- **Focus on applications, not technologies**
  - **Applications provide functions for users**
  - **For example, cheap solar energy rather than organic photovoltaics**
- **Evaluate societal impact if implemented**
  - **What does it improve or enable?**
  - **What performance level is needed?**
- **Evaluate technical feasibility**
  - **Is it plausible based on the literature and according to domain experts?**
  - **Will there be a commercial product by 2020?**

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The focus in our methodology is on what technologies can provide for users, not the technologies themselves. Thus we identify technology applications, e.g., cheap solar energy regardless of how it is supplied. Organic photovoltaics might be one possible materials option for the collectors. We then ask what the technology application will improve or enable, and what performance level is need to actually achieve that result for the user. Then we evaluate technical feasibility not in terms of proof of principle or laboratory demonstrations, but rather in terms of whether or not there could be a commercial product by 2020. Our basic sources of data for these determinations are the technical and popular literature and the views of domain experts.

An Application-Oriented Foresight Methodology (continued)

- **Evaluate implementation feasibility**
  - **How large is the market?**
  - **Does the technology application raise significant public-policy issues?**
- **Is global diffusion likely?**
  - **Will this technology application appeal to global markets?**
  - **Is it restricted by industry, country, region, or societal characteristics?**

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We evaluate the implementation feasibility of technology applications in terms of two different criteria. First is the size of the potential market. We did not have the resources to do market studies for all of the technology applications, so we made a rough estimate of market size as large, medium, or niche. The second criterion is whether or not the technology application raises significant public-policy issues, e.g., privacy concerns for radio frequency identification (RFID) technologies or the public-policy issues associated with technologies based on genetic modification or screening.

We address global diffusion by asking if the technology application would have global appeal, or if it might be restricted in some manner, e.g., limited to a specific industry or country, or lacking in appeal to certain social groups, regions, or countries.

Identification of Technology Applications

- **White papers by domain experts**
  - **Status today, potential by 2020, applications and implications**
  - **Separate papers on biotechnology, nanotechnology, materials technology , information technology**
  - **Documented with extensive references to the technical and popular literature**
- **Technology applications collected from the white papers, subjected to detailed review based on available data and literature**

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We identified technology applications principally through a set of white papers that we commissioned by domain experts in biotechnology, nanotechnology, materials technology, and information and communications technology. Each of these white papers were published as appendices in our in-depth analyses report (TR-303). They looked at today's state of technology, potential improvements or new areas by 2020, and plausible applications and their implementations. These papers contain extensive references to the literature, including review articles and opinion pieces on these subjects.

The project team collected technology applications from these white papers, added some based on additional literature reviews and expertise, and then reviewed and evaluated these technology applications according to the criteria described on the previous slides.

Technology Applications Found Highlight an Interdisciplinary Global Technology Revolution Affecting All Aspects of Life

- **Biotechnology**
  - **Identify, understand, manipulate, improve, and control living organisms (including ourselves)**
  - **Nanosensing and nanomaterials**
    - ***Drug delivery, tissue engineering, implants and prostheses***
- **Information availability and utility**
  - **Continue to profoundly affect the world in all these dimensions:**
    - ***Data interfaces, wireless, multifunctional devices (cameras, RFID)***
- **Smart materials, nanotechnology**
  - **Integration of function with structure**
    - ***Fabrics, fibers, membranes, power***
  - **Continued miniaturization and increased functionality**
    - ***Sensors, networks, tracking***

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The technology of 2020 will continue to integrate developments from multiple scientific disciplines in a “convergence” that will have profound effects on society.

Recent advances in our ability to manipulate and modify living systems have enabled dramatic improvements in health monitoring, disease control, and therapeutic and prosthetic options, and they have even given rise to the possibilities of designed organisms.

The increasing availability of information and the growth of communication networks have been major factors in the globalization of the 20th century. Our foresight study of information and communications technology focused on the integrated development over the next 15 years of semiconductor materials processing and fabrication, mathematical algorithms, MEMS, nanoelectromechanical systems (NEMS), smart materials, and biomaterials and biomedical devices, including data interfaces and wireless multifunctional devices for both commercial and health care applications.

Materials and nanotechnology continue to expand their enabling impacts on concept and design through materials selection, fabrication, and processing to achieve the properties and, ultimately, the performance required for a product. This multidisciplinary field has grown over the past few decades through integration of physics, chemistry, metallurgy, ceramics, polymer science, and, most recently, biology to become a rich source of technological advancement. Smart materials, for example, integrates function and structure to provide more than a simple materials substrated. Continued miniaturization and increased functionality are having impacts in sensors, networking, and tracking.

Some Biotechnology Trends and Applications to 2020

- **Many different bioassays on a sample at once**
  - **Rapid analyte identification from very little material**
    - **Medical diagnoses and forensic evaluations**
- **Personalized medicine, based on large databases of patient information and disease states**
  - **Rapid and parallel gene sequencing**
- **Development of genetically modified (GM) insects**
  - **Pests that produce sterile offspring or that do not carry or transmit disease pathogens**
- **Targeted drug delivery to organs or tumors**
  - **Molecular recognition**

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Recent advances in our ability to manipulate and modify living systems have enabled dramatic improvements in health monitoring, disease control, and therapeutic and prosthetic options, and they have even given rise to the possibilities of designed organisms. The reaction to these developments has varied widely throughout the world, with some countries and regions opting for slower development because of ethical issues and concerns about environmental risks, while other countries and regions have embarked on a faster development path. However, the global flow of information, people, and resources that is characteristic of the early 21st century has weakened the power of states to impede technology development, as evidenced, for example, by the adoption of GM crops in Asia and the emergence of substantial private-sector support for research in areas such as stem cells and cloning. Thus, we suggest that by 2020, the listed applications of biotechnology will be technically feasible.

Some Nanotechnology Trends and Applications to 2020

- **New families of chemical and biological sensors**
  - **Miniaturized, highly sensitive and selective**
  - **Individually worn sensors, especially for military and emergency personnel**
- **Capability for widespread human and environmental surveillance and monitoring**
- **Improvements in battery power management and capacity**
- **Wearable personal medical monitoring devices**
  - **Data recording and communications capability**
- **Functional nanostructures for**
  - **Controlled drug delivery**
  - **Improved performance of implants and prosthetic devices**

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Nanotechnology, which for the purposes of this report is taken to mean R&D in nanometer scale science and related technologies, is a burgeoning field worldwide. Most working definitions of nanoscience and nanotechnologies define the nanoscale in the size range of 1 to 100 nanometers.

Taking into account the rapid advances, the strong U.S. and international research efforts, the commercial interest, and the importance of the societal impacts, our foresight suggests that the listed applications of nanotechnologies will be feasible by 2020.

Some Materials Trends and Applications to 2020

- **Fabrics that incorporate power sources, electronics, and optical fibers**
- **Clothes that respond to external stimuli**
  - **Temperature changes**
  - **Presence of specific substances**
- **Nanostructured coatings and composite materials**
  - **Greatly enhanced strength, toughness, wear resistance, corrosion resistance, biocidal capabilities**
- **Water purification and decontamination systems**
  - **Nanostructured, activated membranes and filters**

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Materials engineering involves concept and design through materials selection, fabrication, and processing to achieve the properties and, ultimately, the performance required for a product. This multidisciplinary field has grown over the past few decades through integration of physics, chemistry, metallurgy, ceramics, polymer science, and, most recently, biology to become a rich source of technological advancement. Indeed, advanced materials are enablers of many of the applications listed earlier under biotechnology and nanotechnology. Biomaterials have played a key role in the success of medical devices and drug delivery systems and are addressing current research challenges in tissue engineering, implants and prostheses, as well as diagnostic and therapeutic applications. Nanomaterials including nanoparticles, carbon nanotubes, semiconductor or metallic nanowires, composites with one component at the nanoscale, and fabricated or self-assembled nanostructures are integral components of every one of the applications listed on the previous slide under nanotechnology.

Based on the continued developments in materials science and engineering and manufacturing, our foresight suggests that the listed applications may be feasible by 2020.

Some Information and Communications Technology Trends and Applications to 2020

- **Wireless Internet available worldwide to middle and upper classes**
  - **Including developing countries and rural areas**
- **Wearable computers**
  - **Control medical devices, appliances, entertainment systems**
- **Massive personal databases (hopefully with robust security)**
  - **History and log of information viewed or processed**
  - **Medical records and genomic information**
- **Radio-frequency identification (RFID) tags**
  - **Track commercial goods, consumer buying patterns, and even individual movement—security, targeted advertising**

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The increasing availability of information and the growth of communication networks have been major factors in the globalization of the 20th century. The Institute of Electrical and Electronics Engineers (IEEE) recently sought the opinions of 40 leading technology developers concerning the most important technology of the past 40 years and the most important technology of the coming decade. The vast majority of the responses to the former question included the integrated circuit, the computer, or the Internet, and many of the answers to the latter included either the Internet or wireless communication, with several respondents noting the likely impact of biology and a few mentioning nanotechnology. Our foresight study of information and communications technology focused on the integrated development over the next 15 years of semiconductor materials processing and fabrication, mathematical algorithms, MEMS, nanoelectromechanical systems (NEMS), smart materials, and biomaterials and biomedical devices, suggesting that the listed applications may be feasible by 2020.

An Assessment Scheme for Technology Applications

- ***Metric 1 (Simple counting: 0 to 12)***
  - **How many societal sectors will it impact?**
    - **Food, Water, Land, Population, Governance, Social Structure, Energy, Health, Economic Development, Education, Defense/Conflict, Environment/Pollution**
- ***Metric 2 (Scale from -2 to +2)***
  - **Will there be a commercial product by 2020?**
- ***Metric 3 (Scale from -2 to +2)***
  - **What is the market size?**
  - **Will it raise significant public policy issues?**
- ***Metric 4 (Binary scale, 0 or 1)***
  - **Will diffusion be global?**

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Our assessment scheme for technology applications uses four different metrics:

1. Societal Impact – this metric was a simple count of how many of the 12 societal sectors listed above could be impacted by the technology application if it were implemented.
2. Technical Feasibility – this metric was defined by the likelihood (based on the current status and difficulties facing development and commercialization, as judged from the literature and expert opinion) of a commercial product by 2020. Its values ranged from +2 for highly likely to -2 for highly unlikely, including 0 for uncertain.
3. Implementation Feasibility – this metric was defined by market size and whether or not there were significant public-policy issues. Its values were +2 for large market, +1 for medium market, -1 if large or medium market and public-policy issues, and -2 for niche market.
4. Global Diffusion – this metric was set at +1 if diffusion would be global and 0 if diffusion would be moderated, i.e., restricted by industry, country, region, social group, etc.

Assessment Based on Sum of Metrics Yielded "Top 16" of 56 Technology Applications for 2020

1. **Cheap solar energy**
2. **Rural wireless Communications**
3. **Ubiquitous info access**
4. **Genetically modified crops**
5. **Rapid bioassays**
6. **Filters and catalysts**
7. **Targeted drug delivery**
8. **Cheap, autonomous housing**
9. **Green manufacturing**
10. **Ubiquitous RFID**
11. **Hybrid vehicles**
12. **Pervasive sensors**
13. **Tissue engineering**
14. **Improved diagnostic and surgical methods**
15. **Wearable computers**
16. **Quantum cryptography**

+ Internet (*for purposes of comparison*)

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Of the 56 technology applications that emerged in our review and analysis of the technical foresights (described in the appendices of our in-depth analyses report), the following "top 16," based on this net assessment index, formed a representative group that allowed evaluation of worldwide variation in technology implementation and its relevance to significant societal problems and issues.

1. Cheap solar energy
2. Rural wireless communications
3. Communication devices for ubiquitous information access anywhere, anytime
4. Genetically modified (GM) crops
5. Rapid bioassays
6. Filters and catalysts for water purification and decontamination;
7. Targeted drug delivery
8. Cheap autonomous housing
9. Green manufacturing
10. Ubiquitous RFID tagging of commercial products and individuals
11. Hybrid vehicles
12. Pervasive sensors
13. Tissue engineering
14. Improved diagnostic and surgical methods
15. Wearable computers
16. Quantum cryptography.

These applications are defined on the following page.

Cheap solar energy: Solar energy systems inexpensive enough to be widely available to developing and undeveloped countries, as well as economically disadvantaged populations.

Rural wireless communications: Widely available telephone and Internet connectivity without a wired network infrastructure.

Communication devices for ubiquitous information access: Communication and storage devices—both wired and wireless—that provide agile access to information sources anywhere, anytime. Operating seamlessly across communication and data storage protocols, these devices will have growing capabilities to store not only text, but also meta-text with layered contextual information, images, voice, music, video, and movies.

Genetically modified (GM) crops: Genetically engineered foods with improved nutritional value (e.g., through added vitamins and micronutrients), increased production (e.g., by tailoring crops to local conditions), and reduced pesticide use (e.g., by increasing resistance to pests).

Rapid bioassays: Tests that can be performed quickly, and sometimes simultaneously, to verify the presence or absence of specific biological substances.

Filters and catalysts: Techniques and devices to effectively and reliably filter, purify, and decontaminate water locally using unskilled labor.

Targeted drug delivery: Drug therapies that preferentially attack specific tumors or pathogens without harming healthy tissues and cells.

Cheap autonomous housing: Self-sufficient and affordable housing that provides shelter adaptable to local conditions, as well as energy for heating, cooling, and cooking.

Green manufacturing: Redesigned manufacturing processes that either eliminate or greatly reduce waste streams and the need to use toxic materials.

Ubiquitous radio frequency identification (RFID) tagging of commercial products and individuals: Widespread use of RFID tags to track retail products from manufacture through sale and beyond, as well as individuals and their movements.

Hybrid vehicles: Automobiles available to the mass market with power systems that combine internal combustion and other power sources while recovering energy during braking.

Pervasive sensors: Presence of sensors in most public areas and networks of sensor data to accomplish real-time surveillance.

Tissue engineering: The design and engineering of living tissue for implantation and

replacement.

Improved diagnostic and surgical methods: Technologies that improve the precision of diagnoses and greatly increase the accuracy and efficacy of surgical procedures, while reducing invasiveness and recovery time.

Wearable computers: Computational devices embedded in clothing or in other wearable items such as handbags, purses, or jewelry.

Quantum cryptography: Quantum mechanical methods that encode information for secure transfer.

Example 1 – Cheap Solar Energy (for rural applications, NOT connected to a power grid)

- **Impact on societal sectors (10 out of 12)**
  - **Energy, environment/pollution (alternative to fossil fuels)**
  - **Food, water, land (via power for agriculture)**
  - **Health (via food and water in rural areas)**
  - **Education and economic development (via rural electrification)**
  - **Governance and social structure (via empowerment of rural communities)**

- **Technical feasibility (+1 out of +2)**
  - **Main barriers to product development are efficiency and manufacturing cost and both are being addressed by 3rd-generation solar systems (e.g., plastic roll-to-roll manufacturing)**

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This slide describes the rationale for the assignment of metric values for the technology application, Cheap Solar Energy. We note that this technology application refers to solar energy for distributed or rural applications. Our foresight did not suggest that solar energy systems would be cost-competitive with conventional electricity in areas with a reliable power grid.

Example 1 – Cheap Solar Energy (continued)

- **Implementation feasibility (+1 out of +2)**
  - **Medium-sized market (local electricity, NOT the full electricity market)**
  - **No significant public-policy issues**
- **Global diffusion (0)**
  - **Diffusion will be moderated, because of difficulty of penetrating market with existing power grid and availability of conventional fuels**

Net Assessment = 10 +1 + 1 +0 = 12

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This slide describes the rationale for the assignment of metric values for the technology application, Cheap Solar Energy. We note that this technology application refers to solar energy for distributed or rural applications. Our foresight did not suggest that solar energy systems would be cost-competitive with conventional electricity in areas with a reliable power grid.

Example 2 – Rural Wireless Communications

- **Impact on societal sectors (7 out of 12)**
  - **Economic development** **(via connectivity)**
  - **Governance and social structure** **(via empowerment of rural communities)**
  - **Education and health** **(via distance learning and access to medical information and services)**
  - **Environment** **(via monitoring and control of resources and pollution)**
  - **Defense** **(via impeding tracking and surveillance)**
- **Technical feasibility (+2 out of +2)**
  - **Already replacing landlines in many areas**

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This slide describes the rationale for the assignment of metric values for the technology application, Rural Wireless Communications. We note that this technology application includes all methods of connection to telephone and Internet, i.e., local networks, satellite, etc.

Example 2 – Rural Wireless Communications (continued)

- **Implementation feasibility (+2 out of +2)**
  - **Large market, as evidenced by the current rate of growth of wireless communications worldwide**
  - **No significant public policy issues**
- **Global diffusion (1)**
  - **This technology application is not moderated, and will diffuse globally**

Net Assessment = 7 +2 + 2 +1 = 12

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This slide describes the rationale for the assignment of metric values for the technology application, Rural Wireless Communications. We note that this technology application includes all methods of connection to telephone and Internet, i.e., local networks, satellite, etc.

Example 3 – Filters and Catalysts for Water Purification

- **Impact on societal sectors (7 out of 12)**
  - **Water, food, land, economic development (via cleaning waste water, making currently unfit water sources usable, and enabling agriculture)**
  - **Conflict (via reducing water scarcity)**
  - **Environment and health (via reduced waste and improved hygiene)**

- **Technical feasibility (+1 out of +2)**
  - **Nanotechnology advances make it likely that by 2020 we will have the ability to control pore size and functionality to selectively separate and act against chemicals and biological pathogens**

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This slide describes the rationale for the assignment of metric values for the technology application, Filters and Catalysts for Water Purification. We note a principal feature of this technology application—it can be performed locally and does not require skilled labor.

Example 3 – Filters and Catalysts for Water Purification (continued)

- **Implementation feasibility (+1 out of +2)**
  - **Medium-sized market (local availability of clean water) that could grow as technology matures**
  - **No significant public policy issues**
- **Global diffusion (0)**
  - **Moderated, because it will initially apply only to areas where water quality or availability is a major issue**

Net Assessment = 7 +1 +1 +0 = 9

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This slide describes the rationale for the assignment of metric values for the technology application, Filters and Catalysts for Water Purification. We note a principal feature of this technology application—it can be performed locally and does not require skilled labor.

Technical and Implementation Feasibility of Illustrative Technology Applications for 2020

	Implementation Feasibility			
Technical Feasibility	***Niche market only*** ***(– –)***	***May satisfy a need for a medium or large market, but raises significant public policy issues*** ***(–)***	***Satisfies a strong need for a medium market and raises no significant public policy issues*** ***(+)***	***Satisfies a strong need for a large market and raises no significant public policy issues*** ***(+ +)***
Highly Feasible (+ +)	• CBRN Sensors on ERT (2,G)	• Genetic Screening (2,G) • **GM Crops (8,M)** • **Pervasive Sensors (4,G)**	• **Targeted Drug Delivery (5,M)** • **Ubiquitous Information Access (6,M)** • **Ubiquitous RFID Tagging (4,G)**	• **Hybrid Vehicles (2,G)** • Internet [for purposes of comparison] (7,G) • **Rapid Bioassays (4,G)** • **Rural Wireless Comms (7,G)**
Feasible (+)	• GM Animals for R&D (2,M) • Unconventional Transport (5,M)	• Implants for Tracking and ID (3,M) • Xenotransplantation (1,M)	• **Cheap Solar Energy (10,M)** • Drug Development from Screening (2,M) • **Filters and Catalysts (7,M)** • **Green Manufacturing (6,M)** • Monitoring and Control for Disease Management (2,M) • Smart Systems (1,M) • **Tissue Engineering (4,M)**	• **Improved Diagnostic and Surgical Methods (2,G)** • **Quantum Cryptography (2,G)**
Uncertain (U)	• Commercial UAVs (6,M) • High-Tech Terrorism (3,M) • Military Nanotechnologies (2,G) • Military Robotics (2,G)	• Biometrics as sole ID (3,M) • CBRN Sensor Network in Cities (4,M) • Gene Therapy (2,G) • GM Insects (5,M) • Hospital Robotics (2,M) • Secure Video Monitoring (3,M) • Therapies based on Stem Cell R&D (5,M)	• Enhanced Medical Recovery (3,M) • Immunotherapy (2,M) • Improved Treatments from Data Analysis (2,M) • Smart Textiles (4,M) • **Wearable Computers (5,M)**	• Electronic Transactions (2,G) • Hands-free Computer Interface (2,G) • *In-silico* drug R&D (2,G) • Resistant Textiles (2,G) • Secure Data Transfer (2,M)
Unlikely (–)	• Memory-Enhancing Drugs (3,M) • Robotic Scientist (1,M) • Super Soldiers (2,M)	• Chip Implants for Brain (4,M)	• Drugs Tailored to Genetics (2,M)	• **Cheap Autonomous Housing (6,G)** • Print-to-Order-Books (2,G)
Highly Unlikely (– –)	• Proxy-bot (3,M) • Quantum Computers (3,M)	• Genetic Selection of Offspring (2,M)	• Artificial Muscles and Tissue (2,M)	• Hydrogen Vehicles (2,G)

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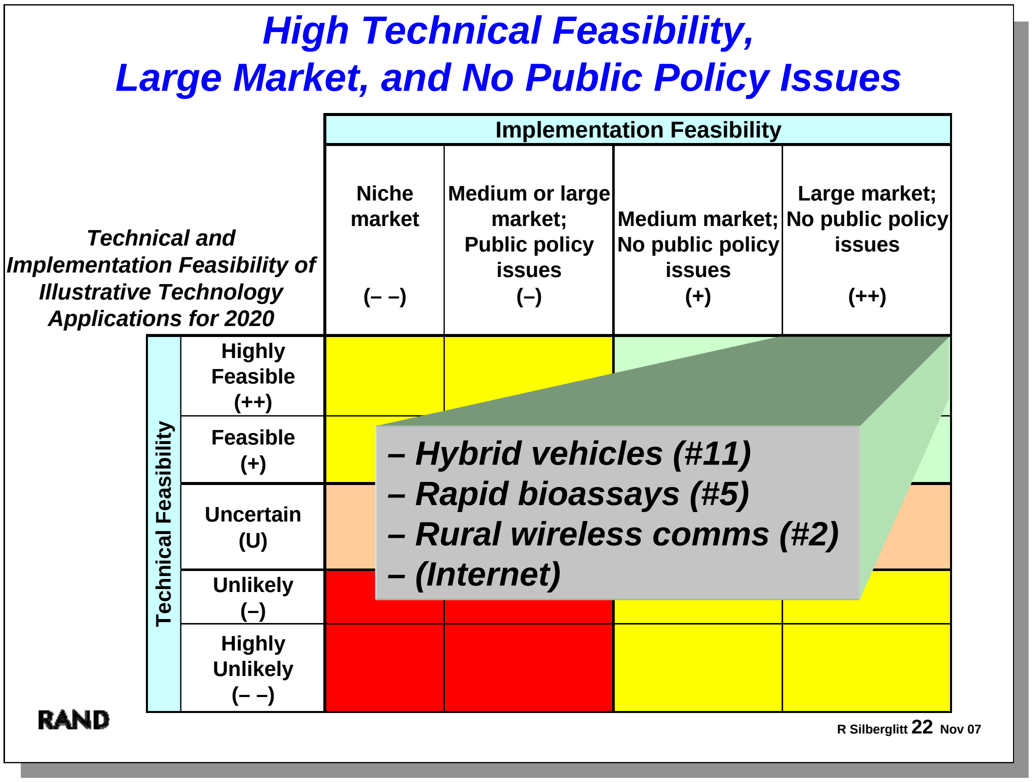
The illustrative technology applications (TAs) we identified vary significantly in assessed technical feasibility and implementation feasibility by 2020. Here we show the range of this variation on a matrix of 2020 technical feasibility versus 2020 implementation feasibility for all 56 technology applications. The metrics are as described on a previous slide.

In the parentheses, *G* indicates global diffusion and *M* indicates *moderated* diffusion. We then showed the net assessment value for the application.

The applications in **bold** are the ones with the highest net assessment score (i.e., the ones in the “top 16” by net assessment).



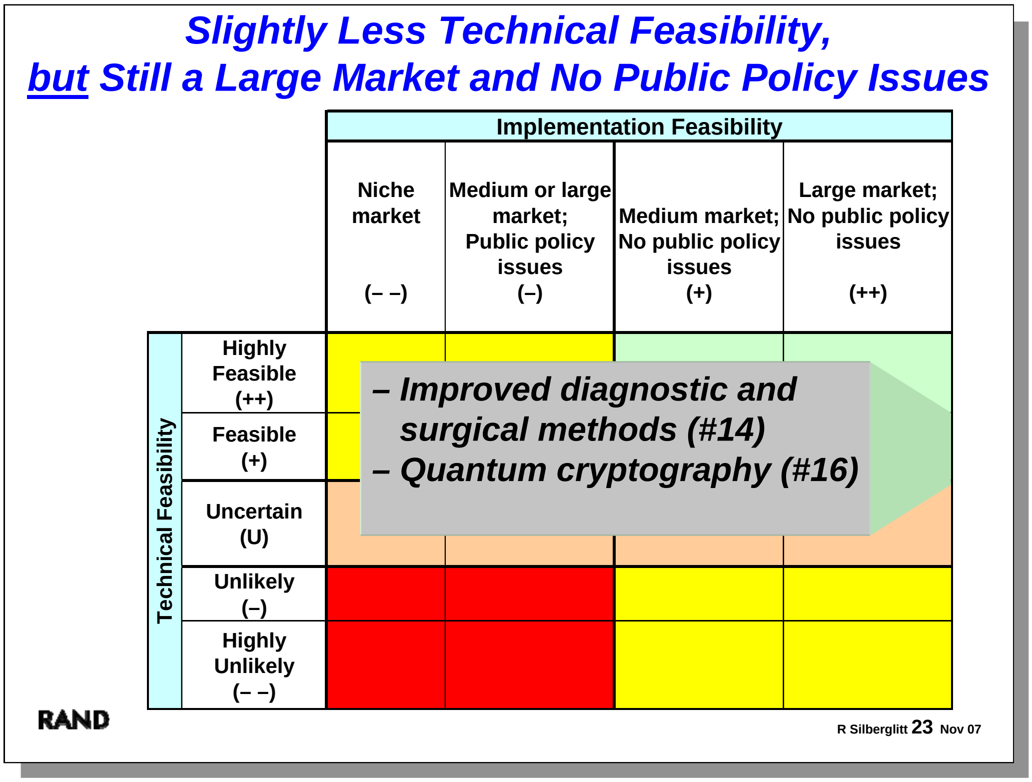
These are the technology applications with the highest technical and implementation feasibilities.

Hybrid Vehicles *(#11 in the net assessment)*: Automobiles available to the mass auto market with power systems that combine internal combustion with other power sources.

Rapid Bioassays *(#5 in the net assessment)*: The capability to rapidly perform tests to verify the presence or absence of specific biological substances and to perform multiple tests simultaneously.

Rural Connection to Telephones and the Internet Using Wireless Communications *(#2 in the net assessment):* Widely available telephone and Internet connectivity without wired network infrastructure.

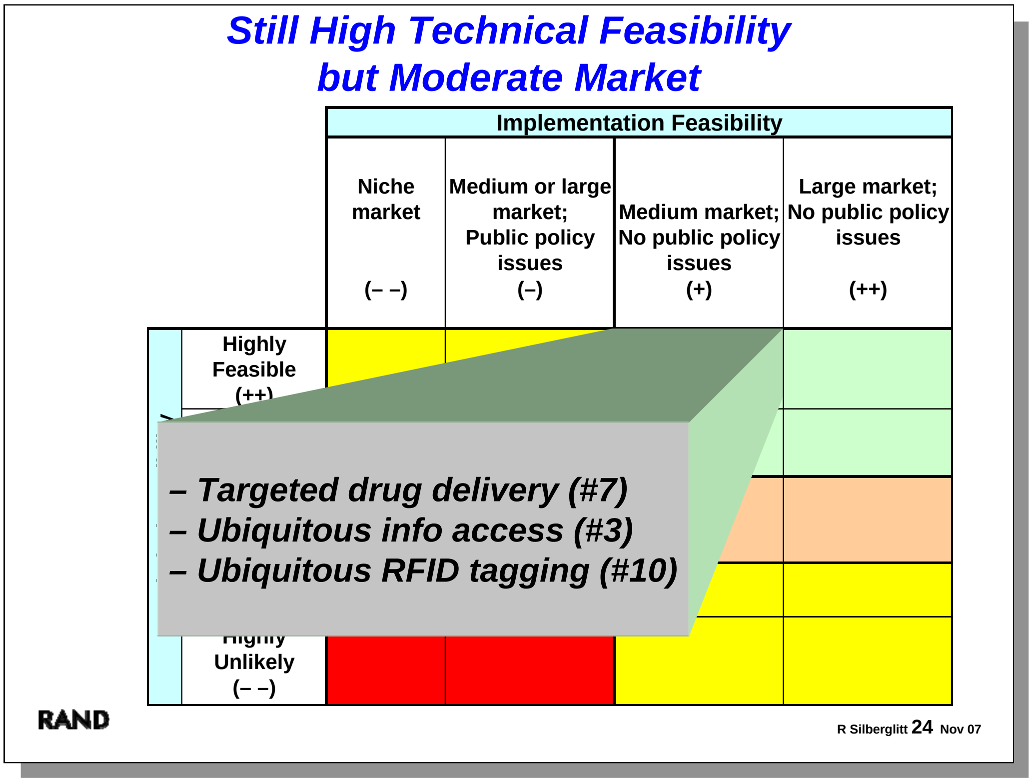
For comparison, this element of the matrix is where the ***Internet*** falls.



In a notch down technically, these are the technology applications that are still feasible technically but still have some progress to be made.

Improved Diagnostic and Surgical Methods *(#14 in the net assessment)*: Use of technologies to improve the precision of diagnoses and greatly increase the accuracy and efficacy of surgical procedures, while reducing invasiveness and recovery time.

Quantum Cryptography *(#16 in the net assessment)*: The use of quantum mechanical methods to encode information for secure transfer.

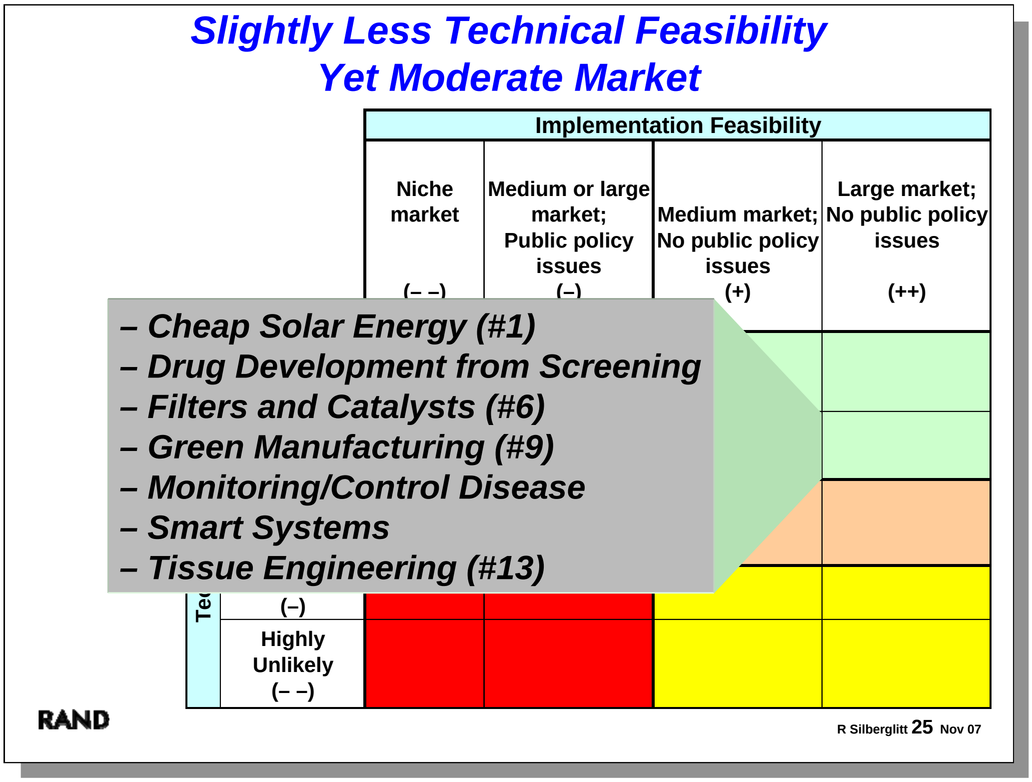


In a notch down on implementation feasibility, these are the technology applications with the highest technical feasibility but show some moderation in implementation feasibility market size.

Targeted Drug Delivery for Tumor and Pathogen Location and Destruction *(#7 in the net assessment)*: The capability to design and implement drug therapies that preferentially attack specific tumors or pathogens, without harming healthy tissues and cells.

Communication Devices for Ubiquitous Information Access Anywhere, Anytime *(#3 in the net assessment)*: Communication and storage devices that provide agile access to information sources anywhere and anytime—operating seamlessly across communication and data storage protocols. Devices may be either wired or wireless and will have increasing local data storage cache capabilities for not only text but for meta-text with layered contextual information, images, voice, music, video, and movies.

Ubiquitous Radio Frequency Identification (RFID) Tagging of Commercial Products and Individuals *(#10 in the net assessment)*: Widespread use of RFID tags for tracking retail products from manufacture through sale and beyond, as well as the tracking of individuals and their movements.



In a notch down in both feasibilities, these are the technology applications with moderated market but more technical progress that needs to be made.

Cheap Solar Energy Collection, Conversion, and Storage *(#1 in the net assessment):* Solar energy systems cheap enough to be widely available to developing and undeveloped countries and economically disadvantaged populations.

Drug Development from Screening: Design and screening of molecules for drug development based on computational analysis of drug-related data.

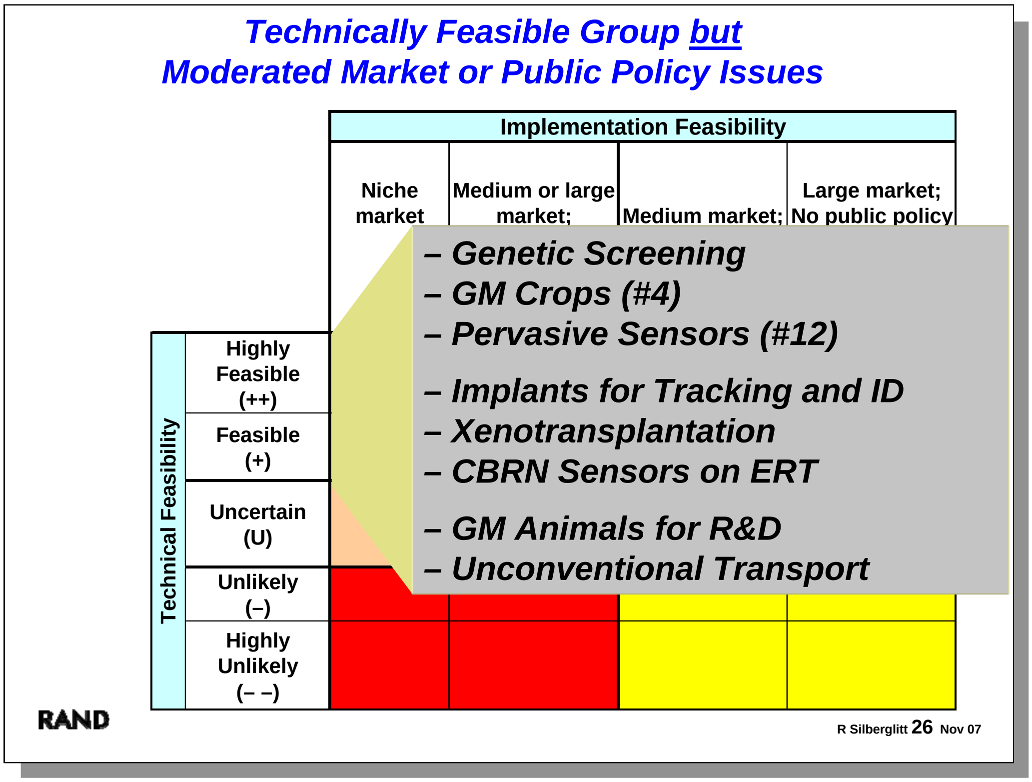
Filters and Catalysts to Enable Water Purification and Decontamination *(#6 in the net assessment)*: The capability to filter, purify, and decontaminate water with great efficacy and high reliability locally using unskilled labor.

Green Manufacturing *(#9 in the net assessment)*: Redesigned manufacturing processes that either eliminate or greatly reduce waste streams and the use of toxic materials.

Monitoring and Control for Disease Management: Widespread use of personal monitoring and on-demand drug delivery devices to control common diseases or medical conditions such as diabetes, epilepsy, hypertension, and elevated cholesterol.

Smart Systems: Systems that respond to external stimuli or instructions—for example, buildings and roads that adjust properties based on environment, kitchens that cook with wireless instructions.

Tissue Engineering *(#13 in the net assessment)*: The design and engineering of living tissue for implantation and replacement.



These are the applications in the four boxes on the upper left: technically feasible, but with significant implementation feasibility issues (either in market size or due to policy issues).

Genetic Screening: Capability to determine, by screening ,whether an individual is more or less susceptible to specific diseases.

Genetically Modified Crops *(#4 in the net assessment)*: The capability to genetically modify crops to improve the nutritional value of food (e.g., by adding vitamins and micronutrients), increase production (e.g., by tailoring crops to local conditions), and reduce pesticide use (e.g., by increasing pest resistance).

Pervasive Sensors *(#12 in the net assessment)*: Presence of sensors in most public areas and the ability to network sensor data to accomplish real-time surveillance.

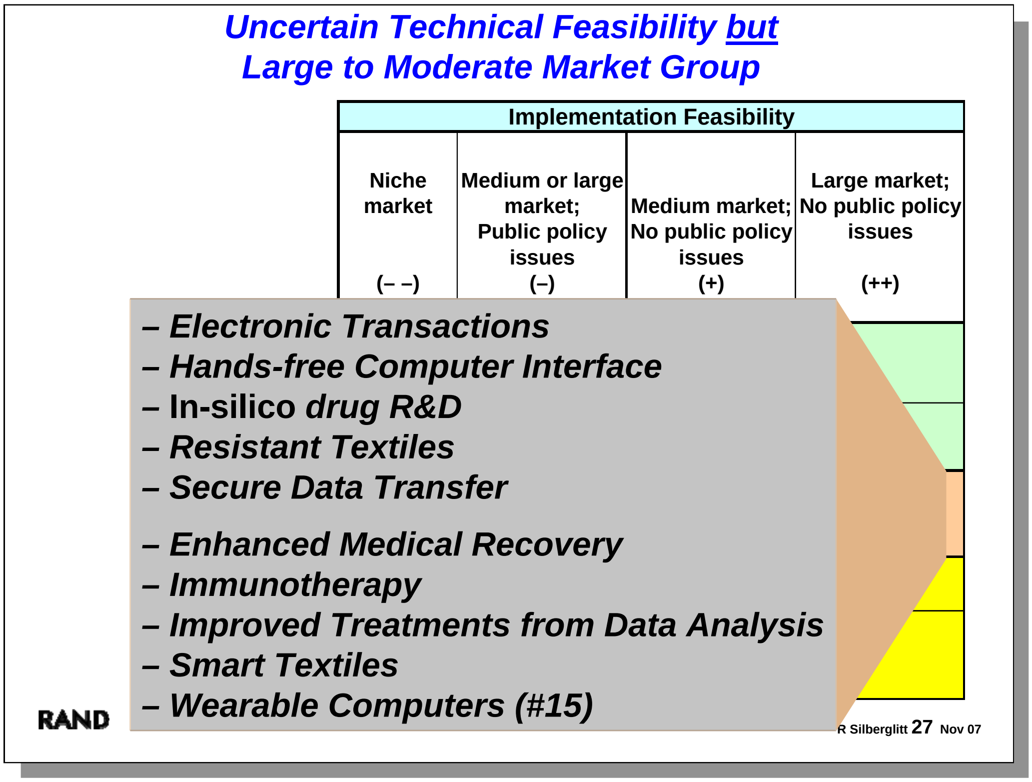
Implants for Tracking and Identification: Widespread use of human implants that either emit or receive a signal that can be used for tracking and identification.

Xenotransplantation: Transplantation of animal organs or tissues into humans.

CBRN Sensors on Emergency Response Technicians (ERTs): Widespread integration of chemical, biological, radiological, nuclear (CBRN) sensors into clothing or equipment used by emergency responders such as paramedics, firefighters, police officers, and hazmat crews.

Genetically Modified Animals for Research and Development (R&D): Animals whose genetic makeup has been specifically altered to serve as laboratory models for use in human disease research and development.

Unconventional Transport: Ultra-fuel-efficient means of transport through, for example, miniature cars or Segway-type vehicles.



These are the applications in the two boxes on the middle right: technically uncertain but with good implementation feasibility.

Electronic Transactions: Widespread and exclusive use of anonymous digital credentials and electronic cash.

Hands-Free Computer Interface: The ability, e.g., via wearable computers, eyeglass lenses with video monitors, light beams scanned to the retina, and voice recognition, to process information and transmit and receive messages, while keeping hands free for other tasks.

In Silico ***Drug Research and Development***: Drug discovery and development using computer modeling and simulation instead of laboratory research and clinical testing.

Resistant Textiles: Widespread availability of textiles that are engineered to prevent adherence of contaminants.

Secure Data Transfer: Widely accepted and routinely implemented means for removal of identity information, to allow secure transfer of personal data.

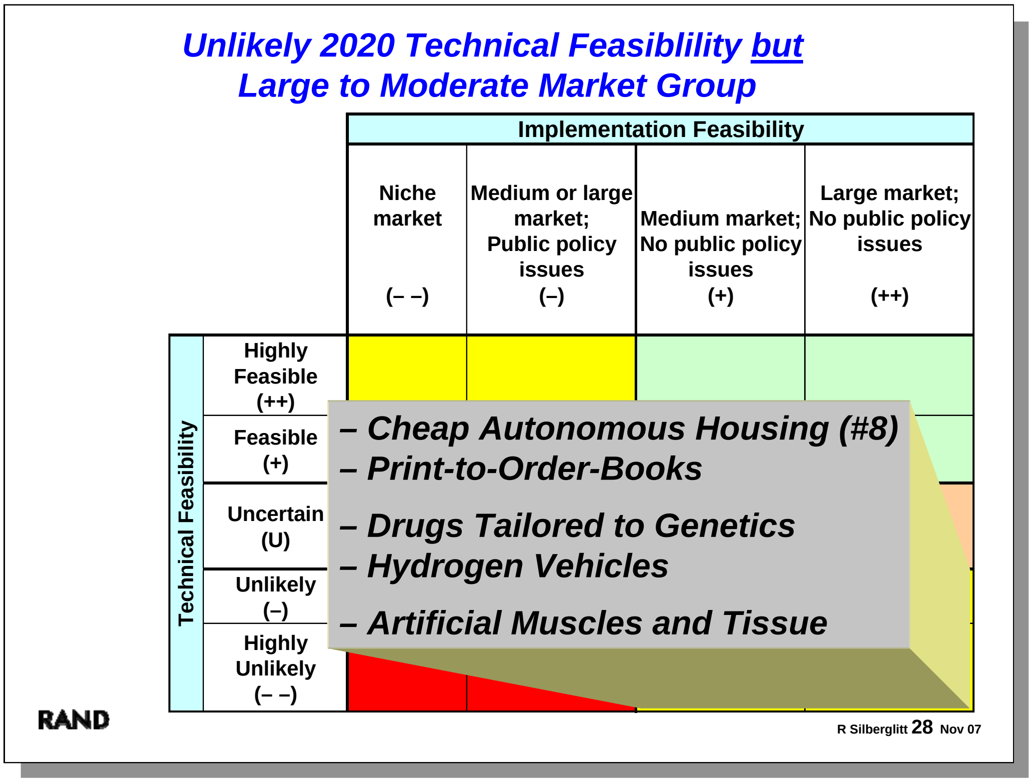
Enhanced Medical Recovery: Use of advanced prosthetic devices (e.g., an auditory imager for the blind or devices that interact directly with the nervous system) to enhance physical or mental abilities after injury, illness, or stroke.

Immunotherapy: Use of a patient's own immune cells to attack and destroy harmful substances in the body, such as tumors or microorganisms.

Improved Treatments from Data Analysis: Development of improved medical treatments based on analysis of large standardized sets of data on individual patients and disease states.

Smart Textiles: Widespread availability of textiles that incorporate sensors and electronic processing, together with a means of actuation or communication to an actuator.

Wearable Computers *(#15 in the net assessment)*: Computational devices embedded in clothing or other wearable items such as handbags, purses, or jewelry.



These are the applications in the four boxes on the lower right: technically unlikely but with good implementation feasibility.

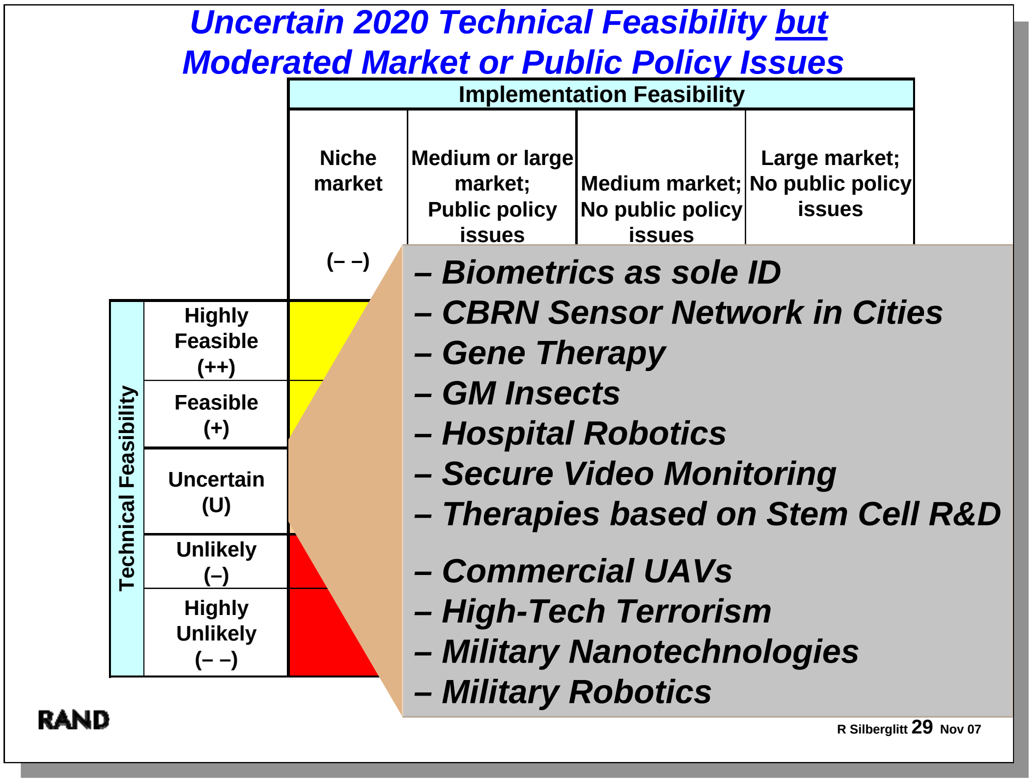
Cheap Autonomous Housing *(#8 in the net assessment)*: Locally self-sufficient and affordable housing that provides shelter adaptable to local conditions, as well as energy for heating and cooling, and cooking.

Print-to-Order Books: Publishing of individual books in response to specific orders only, with fast turnaround delivery.

Drugs Tailored to Genetics: Accelerated drug discovery and design tailored to genetic makeup.

Hydrogen Vehicles: Transportation systems that use hydrogen as a fuel.

Artificial Muscles and Tissues: Design and manufacture of fully functional muscles and other tissues, using molecular-level design and fabrication tools.



These are the applications in the two boxes on the middle left: technically uncertain and poor implementation feasibility.

Biometrics as Sole Personal Identification: Biometric data (e.g., fingerprint, face recognition, hand geometry, iris) as sole requirement on all identification documents, such as passports and driver's licenses.

Chemical, Biological, Radiological, Nuclear (CBRN) Sensor Networks in Cities: Widespread implementation of networks of CBRN sensors in major cities to provide advance warning of public safety and health dangers from accident, attack, or natural sources.

Gene Therapy: Therapies based on manipulation or alteration of the patient's genetic material.

Genetically Modified (GM) Insects: Genetic modification of pests so that, for example, they produce sterile offspring or do not carry specific pathogens.

Hospital Robotics: Widespread use of robotic tools to reduce stress and improve performance of hospital workers (but not to replace them).

Secure Video Monitoring: Capability to "lock" video surveillance images to allow viewing only after authorization (e.g., with a warrant).

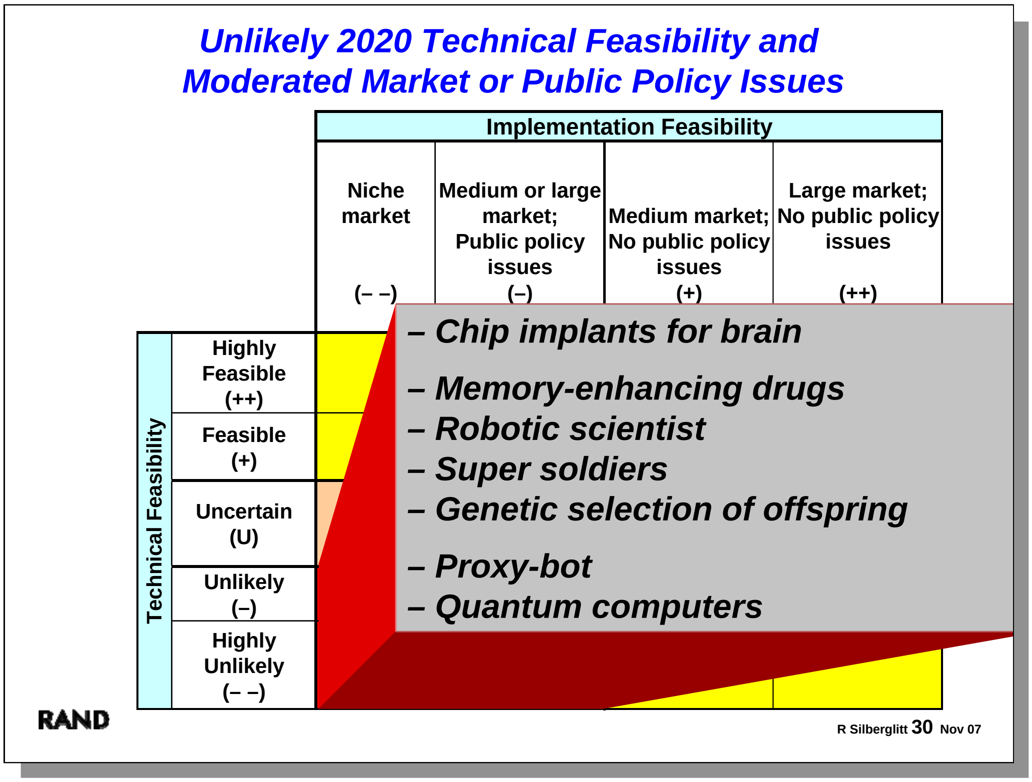
Therapies Based on Stem Cell Research and Development (R&D): Development of new medical treatments or drugs using results obtained through stem cell R&D.

Commercial Unmanned Aerial Vehicles (UAVs): Commercial availability of remote-controlled, pilot-less aircraft with onboard sensors and specialized equipment.

High-Tech Terrorism: Terrorism that attacks societal vulnerabilities arising from technological advances or that uses new weapons developed via technological advances.

Military Nanotechnologies: Use of nanotechnologies in ways that could potentially change the nature of warfare—for example, high-impact covert weapons or delivery of miniature payloads over large distances.

Military Robotics: Use of robotic systems in military engagements.



These are the least feasible applications in the four boxes on the lower left: technically uncertain and poor implementation feasibility.

Chip Implants for the Brain: Implantable computer chips that link directly to brain activity.

Memory-Enhancing Drugs: Drugs that strengthen memory or remove selected memories.

Robotic Scientist: Robots that can perform self-defined experiments—for example, to test hypotheses on large data sets.

"Super Soldiers": Soldiers with greatly enhanced capabilities—for example, strength, endurance, or enhanced senses.

Genetic Selection of Offspring: Capability of parents to select the genetic makeup of their children.

Proxy Bot: A robot with human-like features and movements that could serve as a personal proxy.

Quantum Computers: Digital computers that use quantum mechanical information to define the bits on which computation is based.

Implementation of Technology Applications is Influenced by Several Drivers and Barriers

- ***a.*** **Cost/Financing**
- ***b.*** **Laws/Policies**
- ***c.*** **Social Values, Public Opinions, Politics**
- ***d.*** **Infrastructure**
- ***e.*** **Privacy Concerns**
- ***f.*** **Resource Use and Environmental Health**
- ***g.*** **Investment in R&D**
- ***h.*** **Education and Literacy**
- ***i.*** **Population and Demographics**
- ***j.*** **Governance and Stability**

Capacity development should be aimed at strengthening drivers and reducing barriers

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The S&T capacity that enables a country to acquire a technology application is only one of several factors determining whether that country will be able to implement it. The *drivers* facilitating innovation and the *barriers* hindering it also have a decisive influence on the ability to *implement* technology applications (i.e., to put the applications in place and get significant gains from them across the country). These assessments involve things such as whom an application will benefit and whether a country can sustain its use over time. Drivers and barriers involve the same dimensions: A dimension that is a driver in one context may be a barrier in another. For example, financing, when available, would be a driver, but financing, when lacking, is a barrier. A high level of literacy among a nation's citizens would be a driver, but if literacy were low, it would form a barrier. And in certain cases, a dimension that is a barrier can simultaneously be a driver when only partial progress in that dimension has been made or when conflicting issues in the dimension are present. For example, education in the United States is a driver, but there are also concerns about problems in math and science education in the United States. Also, environmental concerns may dampen some S&T applications in China while promoting environmentally friendly applications such as green manufacturing and hybrid vehicles.

The slide lists the major drivers and barriers that countries may face through 2020. These are defined on the following page.

a. ***Cost and financing***: The cost of acquiring the technology application and of building the physical infrastructure and human capital to introduce and sustain its use; mechanisms and resources available to access the needed funds; and the costs of those funds.

b. ***Laws and policies***: Legislation and policies that either promote, discourage, or prohibit the use of a particular technology application.

c. ***Social values, public opinion, and politics***: Religious beliefs, cultural customs, and social mores that affect how a technology application is perceived within a society; compatibility of a new application with dominant public opinions; the politics and economics underlying debates about an application.

d. ***Infrastructure***: Physical infrastructure at a consistent threshold of quality that can be maintained, upgraded, and expanded over time.

e. ***Privacy concerns***: Social values toward privacy in a country; personal preferences about the availability and use of personal data that arise from an individual's ideological inclinations and experience with the privacy issue.

f. ***Use of resources and environmental health***: Availability and accessibility of natural resources; concerns about pollution and its impact on humans; social attitudes and politics about conservation and preserving land and wildlife.

g. ***R&D investment***: Funding to educate and train scientists, engineers, and technicians; build research laboratories, computer networks, and other facilities; conduct scientific research and develop new technologies; transfer technologies to commercial applications; and enter technology applications into the marketplace.

h. ***Education and literacy***: Levels of general education and literacy adequate to make a population comfortable with technology and able to interface with it; availability of sufficiently high-quality postsecondary education and training in the sciences to stock a workforce comfortable with developing, using, and maintaining technology applications.

i. ***Population and demographics***: Overall size, average age, and growth rate of the population; relative size of different age groups within a population.

j. ***Governance and political stability***: Degree of effectiveness or corruption within all levels of government; influence of governance and stability on the business environment and economic performance; level of internal strife and violence, as well as external aggression; number and type of security threats.

How Foresight Can Help

- With a given *time horizon*, foresight can identify
  - Plausible technology applications and their potential societal impact
  - For technology applications with beneficial societal impact
    - Technical feasibility and possible actions to increase it
    - Implementation feasibility and possible actions to increase it
  - Drivers, barriers, and capacity development needs to strengthen drivers and reduce barriers

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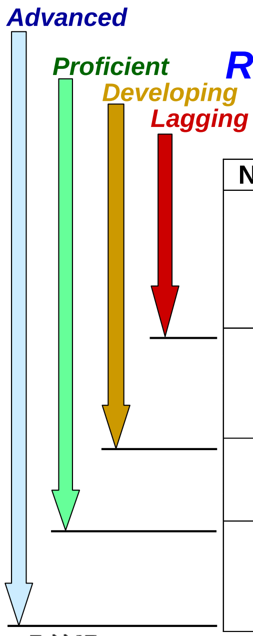
Foresight can be helpful for enabling the implementation of technology applications with beneficial societal impact by identifying such technology applications, evaluating their technical and implementation feasibility, as well as the drivers and barriers to sustained widespread implementation. Foresight can also provide the information needed to define the capacity development needs to strengthen drivers and reduce barriers to implementation.

In Our 2020 Study, We Rated Countries Based on their Capability to Acquire Representative Technology Applications



Needed Capability	Technology Applications
Low	Cheap solar energy
	Rural wireless communications
	Genetically modified (GM) crops
	Filters and catalysts
	Cheap autonomous housing
Medium	Rapid bioassays
	Green manufacturing
	Ubiquitous RFID tagging
	Hybrid vehicles
High	Targeted drug delivery
	Improved diagnostic and surgical methods
	Quantum cryptography
Very High	Ubiquitous information access
	Tissue engineering
	Pervasive sensors
	Wearable computers

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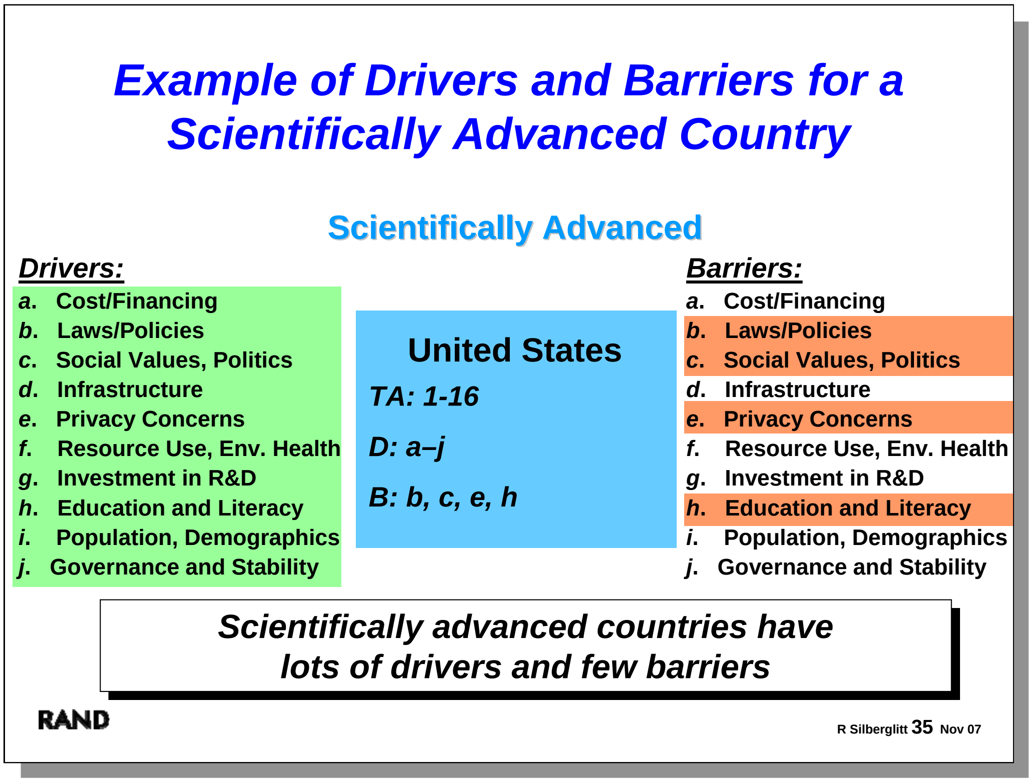
In our 2020 study, we rated a group of 16 representative countries as scientifically *advanced*, *proficient*, *developing*, or *lagging* based on the level of S&T capability they possess. This can be seen graphically in the example of these sixteen technology applications.



Individual analysis of the 200-plus nation-states of the world was beyond the resources and time available for our study. However, we selected for analysis 29 countries that we believe are representative of the most important international variations in capacity to acquire and implement technology applications. These countries were selected to reflect diversity in physical size, natural conditions, and location (e.g., large vs. small, tropical vs. temperate, land-locked vs. island); population size and demographics (e.g., high vs. low birthrate, rapidly aging societies vs. youthful ones); level of economic development and types of economy (e.g., developed vs. developing; market capitalist vs. controlled economies); types of government (e.g., competitive liberal democracies vs. authoritarian regimes); and S&T capacity levels (e.g., scientifically advanced vs. scientifically lagging). While these criteria are not independent of each other, they together represent the principal geographical, social, economic, political, and scientific characteristics of international variation. Within each region of the world, we identified several candidate countries. We then reviewed this initial country list to eliminate highly similar countries within a region. Countries across regions were then compared with each other to remove those that might be represented by others.

Scientifically advanced countries have the institutional, human, and physical capacity necessary to acquire all top 16 technology applications (*TAs*). They also have lots of drivers (*D*) and few barriers (*B*) to S&T implementation. The United States is an example of such a country. Here we show the drivers and barriers for the United States.

Example of Drivers and Barriers for a Scientifically Proficient Country

Scientifically Proficient

Drivers:

- *a.* Cost/Financing
- *b.* Laws/Policies
- *c.* Social Values, Politics
- *d.* Infrastructure
- *e.* Privacy Concerns
- *f.* Resource Use, Env. Health
- *g.* Investment in R&D
- *h.* Education and Literacy
- *i.* Population, Demographics
- *j.* Governance and Stability

China

TA: 1, 2, 4–11, 14, 16

D: b, c, f–j

B: a–d, g, h, j

Barriers:

- *a.* Cost/Financing
- *b.* Laws/Policies
- *c.* Social Values, Politics
- *d.* Infrastructure
- *e.* Privacy Concerns
- *f.* Resource Use, Env. Health
- *g.* Investment in R&D
- *h.* Education and Literacy
- *i.* Population, Demographics
- *j.* Governance and Stability

Scientifically proficient countries have similar numbers of drivers and barriers

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Scientifically proficient countries have the institutional, human, and physical capacity necessary to acquire 12 of the 16 technology applications (*TAs*). They tend to have similar numbers of drivers (*D*) and barriers (*B*) to S&T implementation. China is an example of such a country with these drivers and barriers.

Example of Drivers and Barriers for a Scientifically Developing Country

Scientifically Developing

Drivers:

a. Cost/Financing
b. Laws/Policies
c. Social Values, Politics
d. Infrastructure
e. Privacy Concerns
f. Resource Use, Env. Health
g. Investment in R&D
h. Education and Literacy
i. Population, Demographics
j. Governance and Stability

Brazil

TA: 1, 2, 4–6, 8–11

D: b, c, f, i

B: a–d, g, h, j

Barriers:

a. Cost/Financing
b. Laws/Policies
c. Social Values, Politics
d. Infrastructure
e. Privacy Concerns
f. Resource Use, Env. Health
g. Investment in R&D
h. Education and Literacy
i. Population, Demographics
j. Governance and Stability

Scientifically developing countries have some drivers but many barriers

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Scientifically developing countries have the institutional, human, and physical capacity necessary to acquire 8–9 of the 16 technology applications (*TAs*). They tend to have some drivers (*D*) but many barriers (*B*) to S&T implementation. Brazil is an example of such a country with these drivers and barriers.

Example of Drivers and Barriers for a Scientifically Lagging Country

Scientifically Lagging

Drivers:

a. Cost/Financing
b. Laws/Policies
c. Social Values, Politics
d. Infrastructure
e. Privacy Concerns
f. Resource Use, Env. Health
g. Investment in R&D
h. Education and Literacy
i. Population, Demographics
j. Governance and Stability

Kenya

TA: 1, 2, 4, 6, 8

D: f, i

B: a–d, g, h, j

Barriers:

a. Cost/Financing
b. Laws/Policies
c. Social Values, Politics
d. Infrastructure
e. Privacy Concerns
f. Resource Use, Env. Health
g. Investment in R&D
h. Education and Literacy
i. Population, Demographics
j. Governance and Stability

Scientifically lagging countries are dominated by barriers with few drivers

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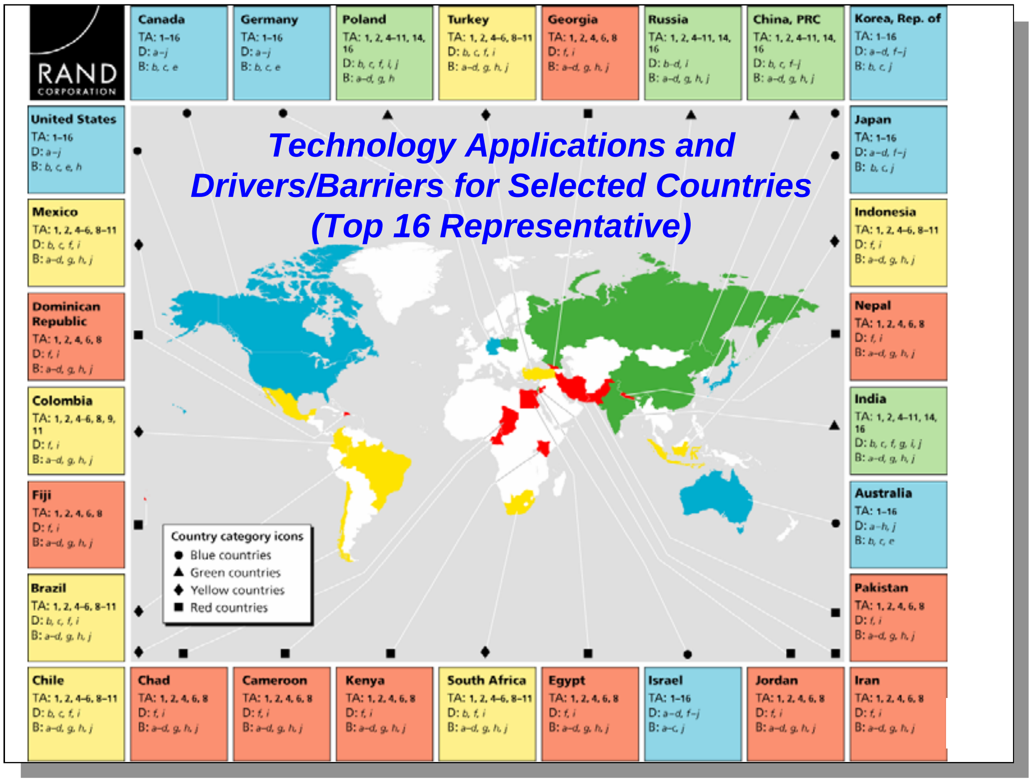
Finally, ***scientifically lagging*** countries have the institutional, human, and physical capacity necessary to acquire only five of the 16 technology applications (*TA*s). They tend to be dominated by barriers (*B*) and have few drivers (*D*) and to S&T implementation. Kenya is an example of such a country with these drivers and barriers.



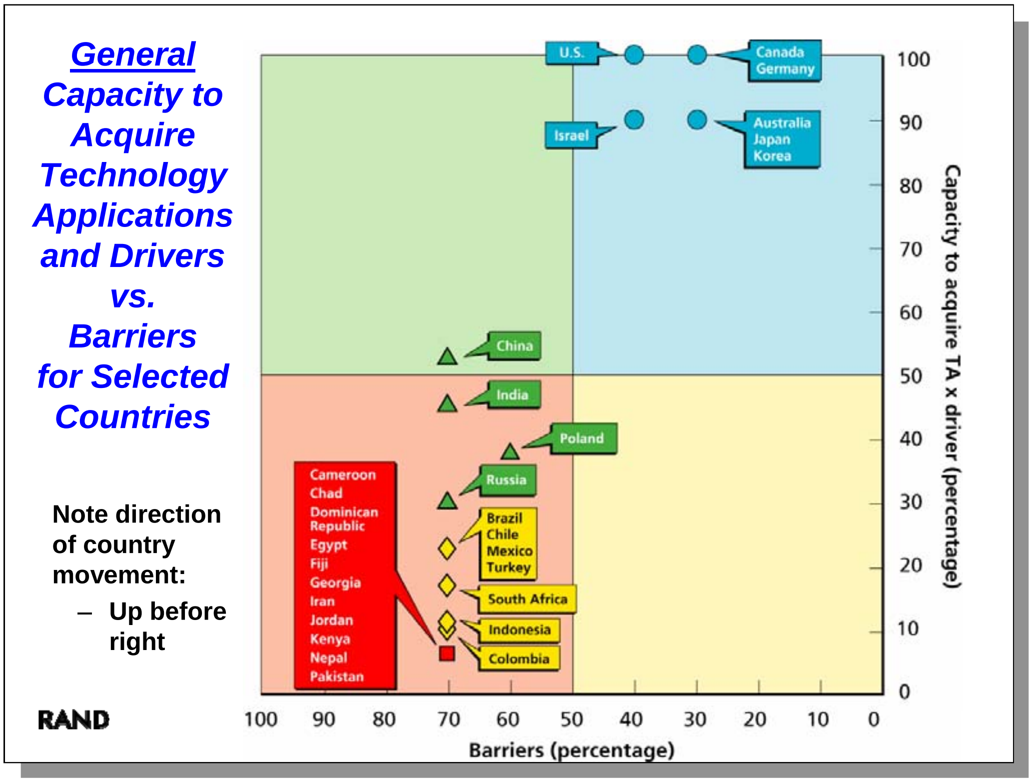
Here we map all 29 representative countries with their S&T capacity ratings, drivers, and barriers.

Seven of the 29 countries we compared will be *scientifically advanced* through 2020. They will almost certainly have the S&T capacity to acquire all 16 of the top technology applications by 2020. The United States and Canada in North America, Germany in Western Europe, and South Korea and Japan in Asia fall into this category. In Oceania, Australia takes its place on this list, as does Israel in the Middle East. These countries are in blue boxes in Figure 1.

Four of the 29 countries will be *scientifically proficient* through 2020. They will very likely have the necessary S&T capacity through 2020 to acquire 12 of the top 16 technology applications. China and India in Asia, Poland in Eastern Europe and Russia represent this group. They are shown in green boxes.

Seven of the 29 countries will be *scientifically developing* through 2020. They will have sufficient S&T capacity through 2020 to acquire eight or nine of the top 16 applications. From South America, Chile, Brazil, and Colombia fall into this group. Mexico in North America, Turkey in Europe, Indonesia in Asia, and South Africa in Africa are also included. These seven countries are shown in yellow boxes.

Eleven of the 29 countries will be *scientifically lagging* through 2020. They will have only enough S&T capacity to acquire five of the applications through 2020. Fiji in Oceania; the Dominican Republic in the Caribbean; Georgia in Europe; Nepal and Pakistan in Asia; Egypt, Iran, and Jordan in North Africa and the Middle East; and Kenya, Cameroon, and Chad in Africa are in this group. These countries are shown in red boxes.



To analyze a country's capacity to *implement* technology applications (TAs), we considered three factors: (1) capacity to *acquire*, defined as the percentage of the "top 16" TAs listed for that country; (2) the percentage of ten *drivers* for implementation applicable to that country; and (3) the percentage of ten *barriers* to implementation applicable to that country.

This plot shows the position of each of the 29 representative countries. Here the y-axis is the product of factors 1 and 2—that is, the capacity to acquire *scaled* by the percentage of drivers—and the x-axis is factor 3. Both axes are shown as percentages.

Countries are represented in the colors and icons that we established for them in the map based on their capacity to acquire the top 16 technology applications. Note that this plot provides a first-order assessment of the capacity to implement TAs, in that we applied equal weighting to all TAs, drivers, and barriers, although we recognize that specific TAs, drivers, and barriers might be more significant in particular countries.

The upper right-hand quadrant (shaded in blue) represents countries for which implementation of TAs is strongly driven by a high level of S&T capacity and the presence of many drivers and few barriers. The upper left-hand quadrant (shaded in green) represents countries for which implementation of TAs is strongly driven by a high level of S&T capacity and the presence of many drivers, but for which many barriers are simultaneously present. The lower right-hand quadrant (shaded in yellow) represents countries for which implementation of TAs is not supported by a high level of S&T capacity and for which the number of both drivers and barriers is small. The lower left-hand quadrant (shaded in red) represents countries for which implementation of TAs is not supported by a high level of S&T capacity, and the number of barriers exceeds the number of drivers.

In Addition to General S&T Capabilities for Top 16, We Examined Capabilities for Applications to Seven Policy Areas

– **Rural economic development**
– **Economic growth and international commerce**
– **Public health**
– **Individual health**
– **Resource use and environmental health**
– **Military**
– **Homeland security and public safety**
– **Governance and social structure**

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Applications are created in reaction to most established or perceived needs of society and are implemented to address specific problems and issues. We identified the following present-day needs, which we believe are likely to continue in the future to be fundamental to the well-being of societies across the globe:

- Promote rural economic development
- Promote economic growth and international commerce
- Improve public health
- Improve individual health
- Reduce resource use and improve environmental health
- Strengthen the military and warfighters of the future
- Strengthen homeland security and public safety
- Influence governance and social structure.

Technology Applications for Some of These Policy Areas Are Easier to Implement than Others

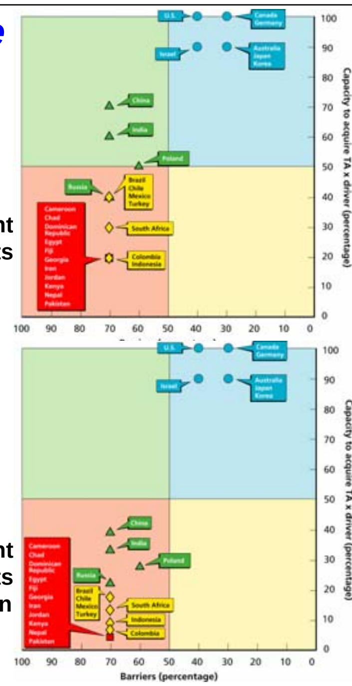
- **<u>Easier</u> to implement:**
  - **Rural economic development**
  - **Public health** ***(less capacity needed than for improving individual health)***
  - **Resource use and environmental health**
  - **Individual health**

slight shifts up

- **Require <u>same</u> as for overall S&T capacity to implement:**
  - **Military**
  - **Homeland security and public safety**

- **<u>Harder</u> to implement:**
  - **Economic growth and international commerce**
  - **Governance and social structure**

slight shifts down



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This leads to slight positional shifts up or down in the quad charts

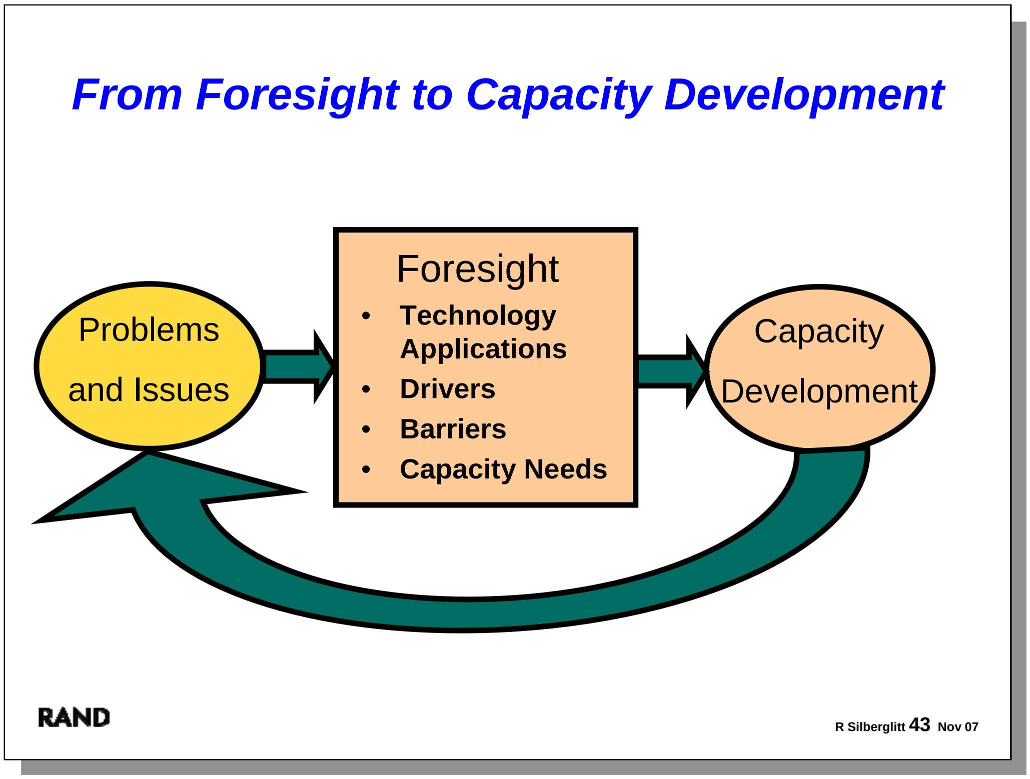
Using the list of 56 illustrative technology applications, we determined which are applicable to each of these seven policy areas. For each of the 29 countries we examined their capacity to address these problems and issues with these technology applications, taking into account their capacity to acquire, drivers, and barriers.

Here we summarize the relative positions of the countries on the quad chart for each policy area relative to the general quad chart shown earlier for the countries' overall S&T capacity.

For rural economic development, public health, and resource use and improved environmental health, the three lower groups tended to shift up. For individual health, the two lowest groups moved up.

For military and homeland security and public safety, the countries remained in approximately the same position.

For economic growth and international commerce and governance and social structure, the three lower groups all shifted down.



In summary, technology foresight can be a positive force when it is driven by the problems and issues facing society. In this case, foresight can identify technology applications that can address these issues to provide societal benefits. It can also identify the drivers for and barriers to successful widespread sustainable implementation of these technology applications, as well as the capacity needs to strengthen the drivers and reduce the barriers. This information can be used as a guide by government, industry, and academia to develop the necessary human, technical, physical, and institutional capacities that will eventually address the issues and solve or mitigate the problems. In this briefing we have presented a method for technology foresight aimed at such outcomes. This method was used in RAND's foresight study, *The Global Technology Revolution 2020*.

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This slide acknowledges several RAND researchers who either contributed to this briefing, or to RAND's 2020 technology foresight. The latter group are co-authors of TR303.