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Building a Sustainable Future:
Rethinking the Role of Technology Innovation in an Increasingly Interdependent, Complex and Resource-constrained World

A report from the World Economic Forum Global Agenda Council on Emerging Technologies

With the average lifetime of a company on the Fortune 500 estimated to be less than 30 years, the impact of technology on business has never been greater. At the same time, businesses are under increasing pressure to be sustainable.

The revolution in Internet technologies that spawned Google and Facebook is only the beginning of a period of massive and accelerating change. Emerging technologies in the life sciences, materials and computing are combining and sparking an unprecedented array of novel and potentially game-changing technology innovations (see below).

This rapid pace of change is leading to an increased competitive threat to established businesses, while offering the potential for newcomers to blindside incumbents. But it also offers businesses new opportunities to leverage global trends from energy security to availability of fresh water.

In today's globalized world, businesses cannot afford to ignore the opportunities and challenges presented by emerging technologies. Technological innovation is increasingly required to meet the goals of sustainable industry and to address pressing global issues. Yet the successful development and use of emerging technologies is fraught with difficulty – requiring businesses to learn new ways of integrating technology innovation into their plans.

This white paper looks at how we develop and use technology within an increasingly complex and interconnected society, and how we can translate this into developing timely, cost effective and acceptable solutions to pressing global challenges.

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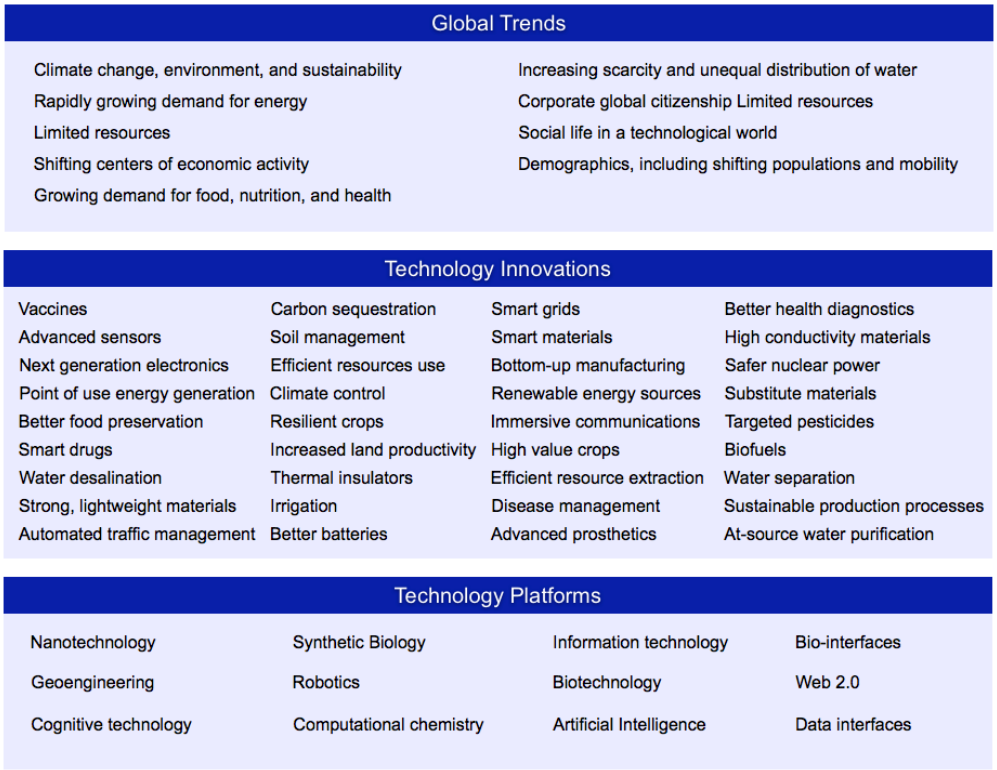

Executive Summary

For thousands of years, humanity has progressed on the back of technology innovation. Yet for all our inventiveness, we stand at a crisis point in human history. In today's complex, interconnected and resource-constrained world, we can no longer rely on business as usual to overcome emerging issues. Unless we rethink the role of technology innovation in the global economy, we will be powerless to ensure a sustainable future in the face of escalating global challenges.

Sustainable progress is more dependent than ever on technology-based solutions. Climate change, energy demands, dwindling resources, water, food, disease – all are poised to become defining issues over the next 50 years. In each case, the prognosis does not look good on a global scale, unless we can learn to harness technology in new ways.

Now, perhaps more than at any time in history, we need the tools that science and technology provide as we build a sustainable future. Yet our ability to foster effective technology-based solutions to emerging issues is far from certain. Under the triple drivers of globalization, unsustainable resource demands and increasing environmental impacts, it is clear that we can no longer rely on 20th century technology approaches to deliver 21st century technology solutions.

In 2009, the World Economic Forum identified nine global trends to stimulate discussion on innovation among its constituents. Ranging from climate change to corporate global citizenship, these trends map out some of the most significant challenges we face as a global society. In each case, there is an expectation that technology innovation will play a significant role in the solutions.

Yet there is a growing gap between the generation of new knowledge and our ability to use it effectively. We know how to innovate – as emerging technology platforms like nanotechnology synthetic biology and information technology clearly show; but we are poor at using innovations where they are most needed. This is a gap that is widened by the disparity between economies that are predominantly driving technology innovation and those that are most in need of what it can deliver.

If a sustainable future is to be built on the effective development and use of technology innovation, we need new and integrative thinking, ideas and solutions to bridge this gap. As such, there are seven specific challenges that need to be addressed:

Raising awareness: New initiatives and mechanisms are needed to ensure the challenges and opportunities presented by technology innovation are clear to decision-makers in government and industry. New insight is needed into how integrated approaches to technology innovation can support sustainable and resilient solutions to contemporary challenges. Greater awareness of the process of

translating technology innovation to sustainable technology solutions needs to be fostered among decision-makers, decision-influencers and others.

Providing intelligence: Trustworthy sources of intelligence on emerging technologies – and the opportunities and challenges they raise – are needed. They should provide insight into emerging opportunities and challenges associated with technology innovation, and should equip decision-makers with timely and relevant information to make informed decisions on emerging technologies in the context of building a sustainable future.

Building partnerships: New initiatives are needed that connect groups grappling with contemporary challenges with those able to provide insight into technology-based solutions. At the same time, collaborative and multifaceted approaches need to be encouraged when addressing pressing problems. These should facilitate integrated approaches to emerging issues that are responsive to social, economic and political factors as well as purely technical ones. And they should address tensions between economies that are driving technology innovation and those that are most in need of the solutions.

Engaging with stakeholders: Mechanisms are needed to ensure that all stakeholders have a seat at the table to make informed decisions on the development and deployment of technology-based solutions to emerging issues. The utility of building constituencies around contemporary challenges and potential solutions should be explored.

Revisiting the economics of innovation: Investment hurdles to developing promising new technologies and taking them to market should be addressed. New business and investment models should support early development of socially relevant technologies and facilitate the translation of promising technology innovation to economically and socially feasible solutions.

Re-examining the technology pipeline: A clearer understanding is needed of how investment in science and technology can lead to relevant and sustainable technology-based solutions. More effective mechanisms would maximize the emergence of technologies that address critical challenges. In particular, the role of government investment in research and development, how it is informed by stakeholder perspectives and expertise and how it integrates with industry-based initiatives need to be re-examined. “Nudging strategies” that enhance the likelihood of economically and socially relevant technology innovations emerging from the technology pipeline should also be explored.

Rethinking global technology governance: The limitations of global governance structures in ensuring the development of safe, successful and just technology innovations should be evaluated and solutions to overcoming current and future limitations explored. In particular, new thinking is needed on how global governance mechanisms can be made increasingly proactive and adaptive, enabling them to cope with rapidly developing technologies. New approaches to inclusive and responsive governance in response to changing geographical, political and social circumstances should be investigated.

The Deepwater Horizon oil spill in the Gulf of Mexico provided a sobering reminder of what can go wrong when we trust in technology without investing sufficiently in the future. But devastating as this disaster has been, it is only one small example of the challenges we will face as a global society as resources become scarcer, demands become greater and our technological reach threatens to exceed the ability to handle it effectively.

As emerging technologies become more powerful and the global climate within which they are developed more complex, a radical redesign is needed to ensure decision-makers and decision-influencers alike are equipped to make the best use of technology innovation as they strive to build a sustainable future in the face of today’s unprecedented challenges.

Building a Sustainable Future in a Technology-dependent World

For thousands of years, humanity developed on the back of technology innovation. Through our inventiveness, we have thrown off the shackles of evolution and forged our own destiny. The process has not been a smooth one – disease, pollution and modern warfare are just some of the less attractive by-products of innovation. Nevertheless, most people would agree that society as a whole is better off today because of technology innovation.

Yet for all our inventiveness, we stand at a crisis point in human history. In today’s complex, interconnected and resource-constrained world, we can no longer rely on business as usual to overcome emerging risks and to support a sustainable future. The last 100 years have seen the human race significantly altering the planet; from loss of biodiversity to climate change.

For the past 30 years we have been able to measure our impact on the Earth and are beginning to be able to predict the long-term implications of our actions. But unless we rethink the role of technology innovation in the global economy, we will be powerless to change the course the future seems to be taking and ensure a sustainable future in the face of escalating global challenges.

Our relationship with technology is a fragile one. As the Deepwater Horizon spill reminds us, technology can be a risky business. Here, we witnessed the consequences of a technology that behaved unpredictably, and a failure to sufficiently anticipate additional technologies and approaches that could have helped to more effectively minimize the impact of the spill.

Although the primary systems deployed in this case were designed to handle a variety of low-probability failure modes, greater technology foresight and appreciation of risk may have led to solutions that could have helped to avert or mitigate much of the environmental, human and economic impacts resulting from disaster.[1] As so much in today's globalized world depends on increasingly sophisticated technological applications, this incident can be seen as just one example of the challenges we face if we do not rethink how we invest in and use technology innovation within society.

Today's world is more crowded, complex, interdependent and resource-constrained than at any point in human history. It is a world where economic and social resilience and sustainable growth are more dependent than ever on technology-based solutions; and yet the potential consequences of technology missteps are greatly magnified.

Climate change, energy demands, dwindling resources, water, food, disease – all are poised to become defining issues over the next 50 years. In each case, the prognosis does not look good on a global scale unless we can learn to harness the power of technology in new ways. We are, in effect, walking a 21st century technology innovation tightrope. Society is irrevocably committed to building a sustainable future on technology innovation, but the stakes are high and time is short.

Solutions to global problems cannot be simply imagined as they are needed. Technologies take time to develop and we need to start thinking about possible solutions well before problems occur. If we can learn to use technology innovation effectively in today's rapidly shifting global landscape, we hold the key to building a sustainable future. But if we get it wrong, the consequences could be catastrophic.

Over the next 40 years, global population is projected to hit 9 billion[2], quality of life expectations will continue to rise, access to food[3] and water[4] will come under increasing threat, natural resources will become ever-more scarce and the implications of local actions on a worldwide stage will become significantly more pronounced.[5] And despite increasing global interconnectivity, these challenges are in danger of being exacerbated by the divide between richer and poorer economies. Without robust technology-based solutions that are integrated with social, economic and political action, sustainable development under these conditions will be beyond our grasp.

Yet technology innovation is not without its own risks. The cost of innovation in human lives and environmental impact has been immense across the centuries. Asbestos, DDT, Chernobyl and Bhopal are just some of the more recent reminders of how dangerous technology can be if not handled appropriately. But devastating as these and other examples have been, society has become adept at absorbing the human, environmental and economic costs of technology errors.

However, this is a luxury we will no longer have in a future where the rate of innovation is increasing, the demands being placed on technology are rising and the consequences of mistakes are potentially

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[1] Three months after the Deepwater Horizon rig blew out on 20 April 2010, the US House of Representatives passed measures to develop new technologies for deepwater drilling and cleaning up oil spills. According to Representative Lynn Woolsey (Democrat, California), "We heard time and again the technology they were using was inadequate." Bloomberg News, http://www.bloomberg.com/news/2010-07-21/house-passes-bills-to-spur-new-technology-for-drilling-cleaning-up-spills.html. Accessed 7/27/10

[2] UN estimates indicate that by 2050, global population will have reached between 8 and 11 billion people. http://esa.un.org/unpd/wpp2008/fig_1.htm. Accessed 27 July 2010

[3] A July 2010 special edition of the journal *Nature* addresses the question of what role science has to play in securing food for the future. (Nature, vol. 466, issue 7306, 29 July 2010). The challenge of feeding 9 billion people by 2050 is possible according to an accompanying editorial, but only through new research into "everything from high-tech seeds to low-tech farming practices."

[4] In January 2008 at the World Economic Forum in Switzerland, United Nations Secretary General Ban Ki-Moon urged business and political leaders that the looming crisis over water shortages should be at the top of the global agenda in an effort to prevent conflicts over the growing scarcity of freshwater supplies. Nature vol. 452 p 285, 20 March 2008.

[5] For instance, China currently produces 95% of the world's rare earth metals, and controls mining rights to 17 rare earth elements essential to the manufacture of high tech products ranging from iPods to military weapons. As new technologies depend increasingly on scarce and esoteric materials, control over access to these materials – together with the search for viable substitutes - will become increasingly important factors in ensuring sustainable technology innovation. Source: The Telegraph, 2 June 2010 http://www.telegraph.co.uk/finance/china-business/7797015/China-tightens-stranglehold-on-rare-earth-minerals.html. Accessed 7/27/10.

devastating. Instead, if a sustainable future is to be supported by technologies that solve more problems than they create, we need to rethink the process of technology innovation; embedding it within social, economic and political processes, and providing decision-makers with the tools and “intelligence” to make informed and strategic choices.

Without a doubt, technology innovation is a messy process – the chances of getting the right technology in the right place at the right time can seem as likely as winning the lottery. But if we want to build a sustainable future, we need to take greater control over this messy process and “up the odds” of delivering technologies that fit the problems we need to address, rather than merely those that we can address. And as the events in the Gulf of Mexico remind us, science and technology can only provide timely and effective solutions if there is early and strategic investment in their development and use.

But strategic investment in technology innovation is only the starting point. As the world becomes increasingly interconnected, upstream development will need to take far more account of the social, economic and political realities into which new technologies are developed. This will mean making the radical transition from technology innovation being somebody else’s business to something that is everybody’s business.

Technology Innovation Is Everybody’s Business

For close to 10,000 years, science and technology have been at the heart of economic growth and social prosperity. From the agricultural revolution to the information revolution, advances in society have been underpinned by new discoveries and their innovative use in new products and processes. Modern society was enabled by the invention of agriculture, freeing people from a hunter-gatherer existence and allowing the development of stable communities that supported further social and technological innovation.

The invention of the Spinning Jenny 250 years ago vastly increased the speed with which cotton could be turned into yarn, revolutionizing the textile industry and helping usher in the industrial revolution. The discovery of penicillin in the early 1900s allowed previously fatal infections to be treated, opening the door to modern surgical procedures. In the mid-20th century, the invention and subsequent development of the transistor initiated a technology revolution that is still driving economic and social growth. More recently, innovations in global communication, social networking and information processing have begun to empower global communities in ways unimaginable a few years ago.

Yet the continued effectiveness of science and technology as engines of economic and social growth is not guaranteed. The global economic and social landscape is evolving rapidly and, as it does, the rules governing how we use science and technology are changing. A growing global population coupled with a widespread desire for a first-world quality of life is placing unprecedented demands on resources around the world.

Humanity’s actions are becoming uniquely intertwined in environmental reactions, redefining our relationship with the planet on which we live and depend. Modern communications are making a mockery of geographical and institutional boundaries that have endured for hundreds and even thousands of years. This emerging landscape places new demands on technology innovation; but it also demands radical changes in how technology innovation is nurtured and implemented if it is to underpin a sustainable future.

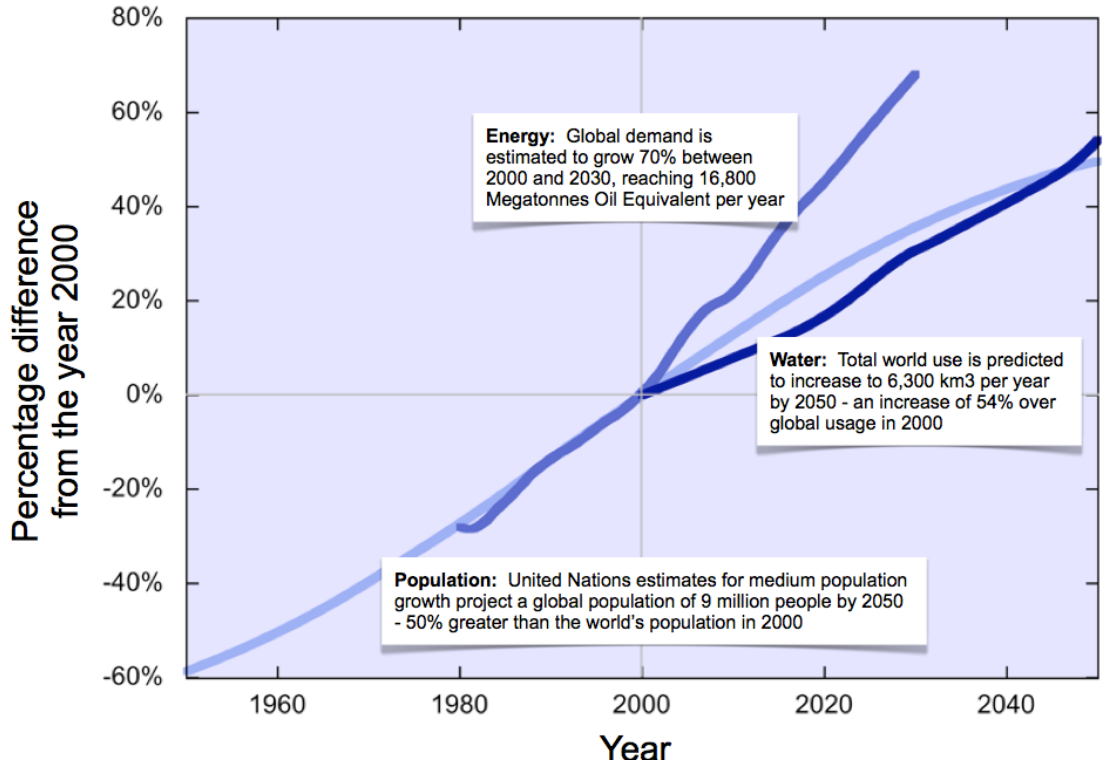


Figure 1: Global Trends in Population, Energy Demand and Water Use
Population: United Nations (http://esa.un.org/unpd/wpp2008/, accessed 27 July 2010). Energy: International Energy Agency (http://www.worldenergyoutlook.org/2009.asp, accessed 27 July 2010). Water: Organization for Economic Cooperation and Development (http://www.oecd.org/document/20/0,3343,en_21571361_43893445_44353044_1_1_1_1,00.html, accessed 27 July 2010).

Recent attempts to introduce genetically modified foods into commerce in Europe provide a sobering lesson in how easy it is to mishandle technology innovation. Despite little evidence to the contrary, apparent concerns over health and environmental impacts severely retarded the implementation of a technology that could improve millions of lives.

Yet these concerns were grounded in part in a backlash against corporate control that cut consumers out of the decision-making process. Through a socially savvy media, people and governments were galvanized to say no to "frankenfoods" – not because of the science and technology *per se*, but because of the way they were handled.

Missteps over the development of genetically modified foods are a prominent case among many where the trajectory of a technology has been dictated more by social concerns than by scientific evidence. It is increasingly clear that top-down decision-making is not sufficient on its own to ensure the successful development of socially and economically relevant technologies.

With modern peer-to-peer global communications, virtual groups can be informed about, motivated by and empowered to take action on emerging issues before institutional decision-makers are even aware there is an issue to respond to. We now live in a world where an incident in China or the Middle East can influence attitudes and actions in regions as distant as Europe and the Americas in a matter of minutes through media like YouTube and Twitter.

At the same time, technology innovation is no longer dominated by a top-down approach. We are in the midst of a shift from innovation occurring as a result of a directed programme at large institutions like Bell Labs, Bayer or IBM to a world where a college student can create Facebook, Do-It-Yourself biotechnology has a growing following,[1] and work that used to require a lab full of people and equipment can now be done on a laptop.

[1] A growing number of individuals and groups are setting up biotechnology facilities in their garages, basements and kitchens, and learning to experiment with advanced genetic manipulation. Using equipment bought over the Internet and mail-order DNA-sequences, the "DIY biotechnology" movement (sometimes referred to as Garage Biology) is enabling talented amateurs to experiment with advanced technologies outside conventional channels. See Alper J. 2009. Biotech in the basement. Nature Biotechnology 27: 1077-1078; Madrigal, A. 2010. DIY Biotechnologists Go Looking for a Bigger Garage. The Atlantic, 14 July 2010. http://www.theatlantic.com/science/archive/2010/07/diy-biotechnologists-go-looking-for-a-bigger-garage/59701/. Accessed 7/27/10

With this shift, it is easier for technologies to be deployed before most governments are aware of their potential. The constant war against synthetic drugs and legal highs is a case in point: as soon as a government legislates against one substance, a chemist can move a hydrogen atom and create a new one that slips through the oversight net. As technologies like nanotechnology, computational chemistry and synthetic biology continue to mature, top-down oversight will become increasingly difficult to implement.

Ensuring that technology innovation serves the emerging challenges facing global society will depend on far more than understanding evolving social dynamics. Under the triple drivers of globalization, unsustainable resource demands and increasing environmental impacts, a full recalibration of technology's role in addressing global economic, political and social challenges is needed.

Providing people with access to healthy food and clean water; managing climate change and its impacts; treating disease; generating and using energy wisely; working with diminishing natural resources; coping with pollution – over the next 50 years, global challenges in these and similar areas will reach unprecedented levels. Without rapid and targeted advances in science and technology, humanity will be unable to face them without paying an unacceptable price. We need the tools that science and technology provide to build a sustainable future.

Many of these tools are waiting in the wings. Emerging areas such as nanotechnology, synthetic biology, information technology, robotics, neuroscience and others are paving the way for socially and economically important technology innovations. Yet there is a gaping chasm between the knowledge being generated and the understanding of how to use it most effectively. This chasm is widened by the disparity between the economies that are predominantly driving technology innovation and those that are most in need of what it can deliver.

As new technologies emerge, it is clear that we can no longer rely on 20th century policies to deliver 21st century solutions. Neither can we assume that emerging technologies – which often take decades to mature – will provide just-in-time solutions to just-identified problems. Rather, we need to rethink how society can continue to reap the benefits of technology innovation without suffering the consequences of missed opportunities and mishandled interventions.

Past policies have relied on upstream investment in exploratory science to deliver downstream technologies. It is a model that has worked well in the past, but is looking increasingly flimsy in today's interconnected world. More significantly, it is a model that absolves decision-makers of taking a hands-on approach to science and technology – it reinforces the attitude that technology innovation is somebody else's business, and the myth that technology "just happens".

But for technology innovation to be effective in today's world, decision-makers at all levels – from policy-makers to consumers – need a firmer grasp of how science and technology work. They need the knowledge, understanding and tools to foster timely and relevant technology innovation, and to most effectively exploit this innovation. In effect, as conventional top-down approaches to technology innovation become increasingly ineffective, technology innovation needs to become everybody's business.

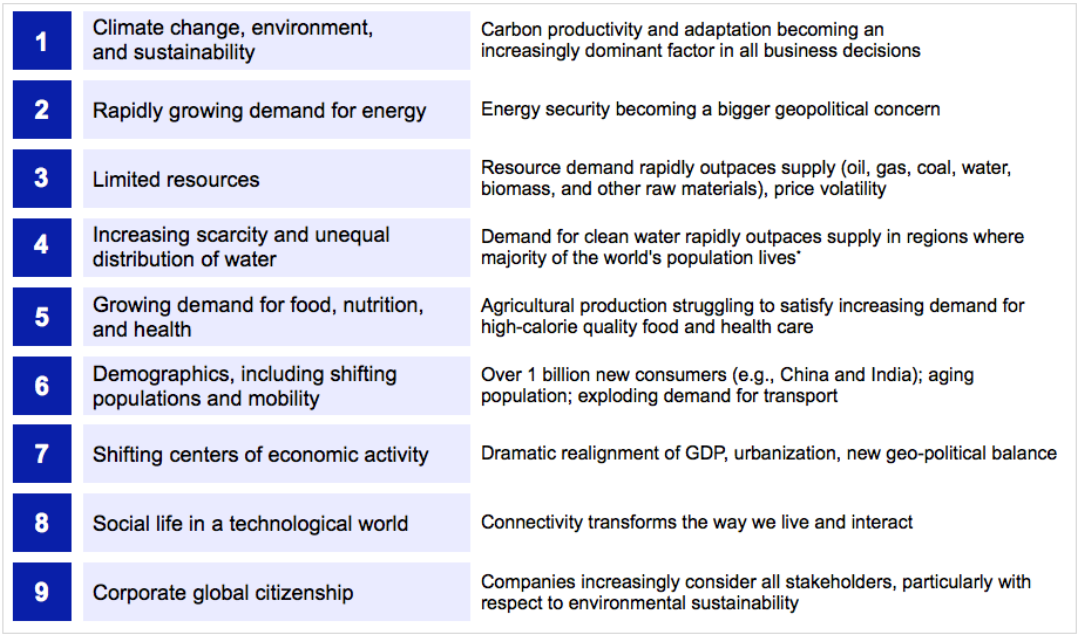
The Cost of Inaction

Without new thinking on technology intervention, the future looks bleak. Unless the role of technology in the global economy is reconsidered, we risk becoming powerless to feed a growing population, combat climate change, meet energy demands and adapt to dwindling natural resources. The consequences could be disastrous – increased pollution, poorer living conditions, power struggles over limited resources, greater disease incidence and an erosion of personal rights – leading to a vicious circle of social and economic decline.[1]

This is an extreme scenario, and is only one of many possible futures. But it underlines the reality that we cannot afford *not* to take technology innovation seriously. Failing to change the way that we develop and use science and technology – or deciding to hold back on technology innovation – is potentially more risky than a radical rethink in the long run. Over the next 50 years, the world will face an increasing number of global challenges and, for many of them, technology innovation will play a key role in underpinning the effectiveness and resilience of the solutions developed.

[1] Godfray *et al*. for example, argue that, in the face of growing global demands for food, we need a revolution in the social and natural sciences concerned with food production – not simply to maximize productivity, but to optimize it across a far more complex landscape of production, environmental and social justice outcomes. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. 2010. Food Security: The Challenge of Feeding 9 Billion People. Science 327(5967): 812-818.

In 2009, the World Economic Forum identified nine global trends to stimulate discussion on innovation needs (Figure 2). These trends – which range from climate change to corporate global citizenship – provide a useful framework for exploring how technology innovation might support a sustainable future in the light of developing challenges. But they also contain an implicit message – fail to act strategically on nurturing and implementing responsive technology-based solutions, and we risk being overwhelmed by the adverse consequences of these trends. In effect, inaction is not an option in building a sustainable future.



1	Climate change, environment, and sustainability	Carbon productivity and adaptation becoming an increasingly dominant factor in all business decisions
2	Rapidly growing demand for energy	Energy security becoming a bigger geopolitical concern
3	Limited resources	Resource demand rapidly outpaces supply (oil, gas, coal, water, biomass, and other raw materials), price volatility
4	Increasing scarcity and unequal distribution of water	Demand for clean water rapidly outpaces supply in regions where majority of the world's population lives*
5	Growing demand for food, nutrition, and health	Agricultural production struggling to satisfy increasing demand for high-calorie quality food and health care
6	Demographics, including shifting populations and mobility	Over 1 billion new consumers (e.g., China and India); aging population; exploding demand for transport
7	Shifting centers of economic activity	Dramatic realignment of GDP, urbanization, new geo-political balance
8	Social life in a technological world	Connectivity transforms the way we live and interact
9	Corporate global citizenship	Companies increasingly consider all stakeholders, particularly with respect to environmental sustainability

Figure 2: Nine global trends identified within the World Economic Forum that will drive the need for technology innovation-based solutions

These nine trends touch on the impacts of technology innovation on resource scarcity, increasing global demands on water and food supplies, changing demographics, shifting centres of economic activity and moves towards a more interconnected global society. They are trends that will have a profound impact on the lives of future generations. In each case, they are trends where present-day actions will have a strong influence on how they unfold and are managed in the future. None of the trends are primarily focused on science and technology. Yet in each case, technology innovation holds part of the key to overcoming the challenges they represent. In this context, they beg the question: is the existing technology innovation pipeline sufficiently robust to provide technology-based solutions as and when they are needed?

At a first glance, this question might appear superfluous – we are currently living in an innovation-rich world after all. Global trends show steady increases in published research and new patents (Figures 3 and 4). New technology platforms like nanotechnology, synthetic biology and robotics are grabbing the attention of investors, innovators and policy-makers. And hardly a week goes by without an announcement of a new “technological breakthrough”.

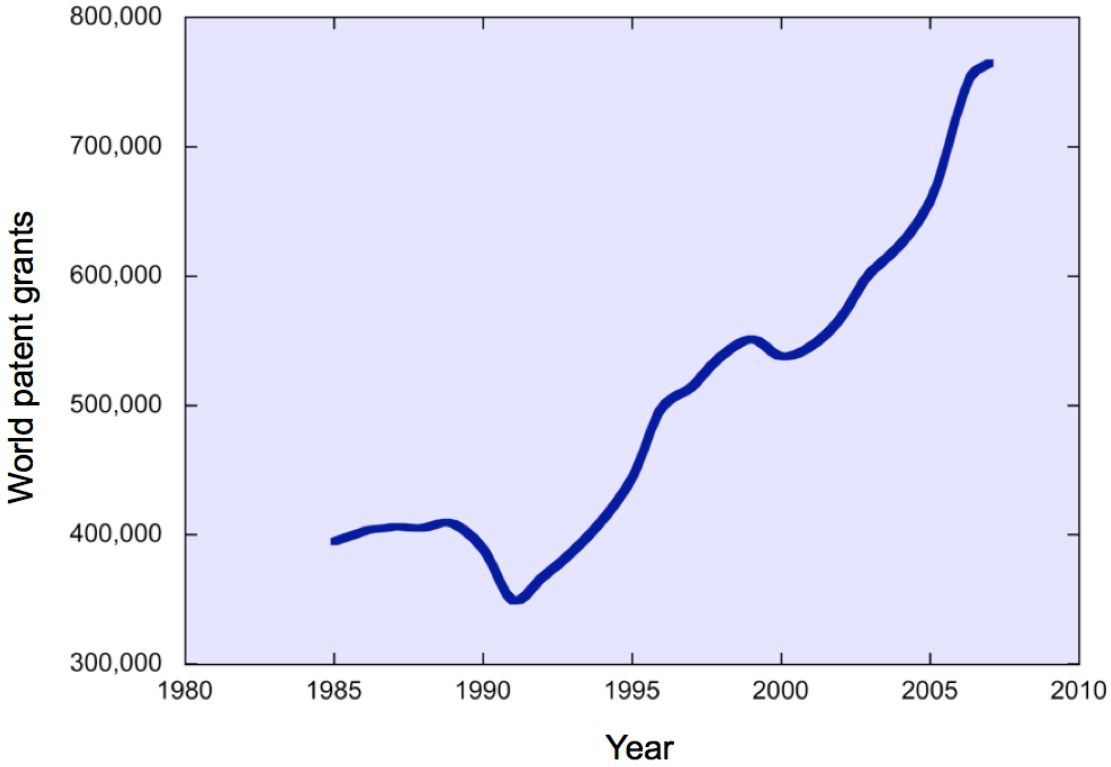


Figure 3: World Patent Grants, 1985- 2007
Source: World Intellectual Property Organization. http://www.wipo.int/ipstats/en/statistics/patents/, accessed 7/27/10

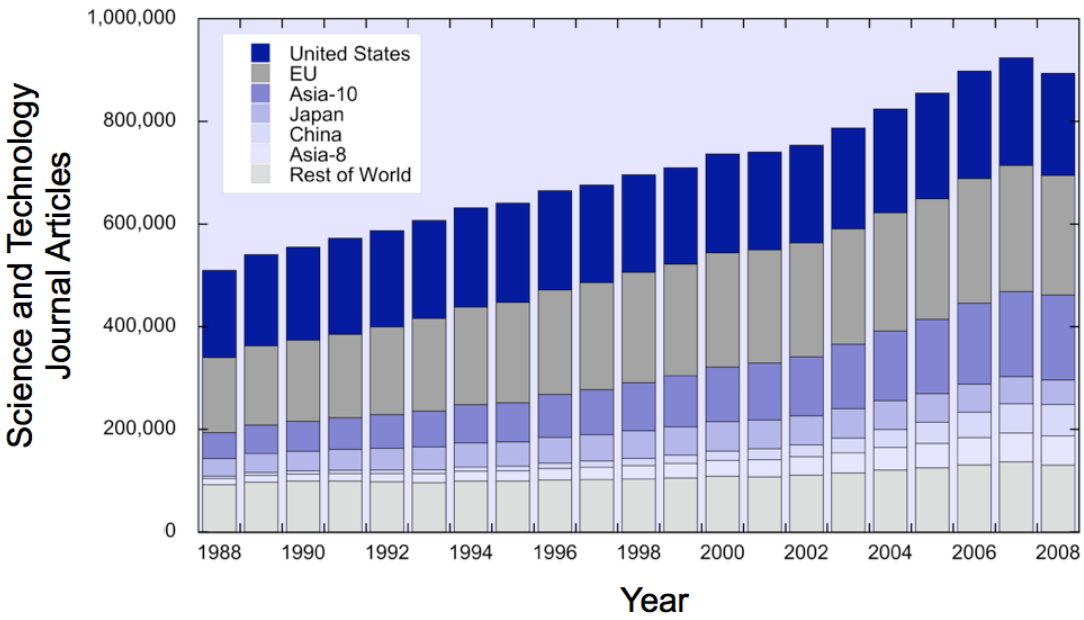


Figure 4: Trends in Worldwide Publication of Science and Technology Journal Articles, 1988-2007
Source: Science and Engineering Indicators 2010, National Science Foundation.
http://www.nsf.gov/statistics/seind10/start.htm. Accessed 7/27/10

Yet there is a real danger that we will become complacent by focusing on the problems emerging technologies *can* solve, rather than on the problems we *need* them to solve. The current technology innovation pipeline is geared to generating solutions in search of a problem. Sometimes there is a match; often there is not. This leads to the risk of orphaned challenges – global challenges that remain poorly addressed simply because the technology pipeline has not delivered a matching solution.

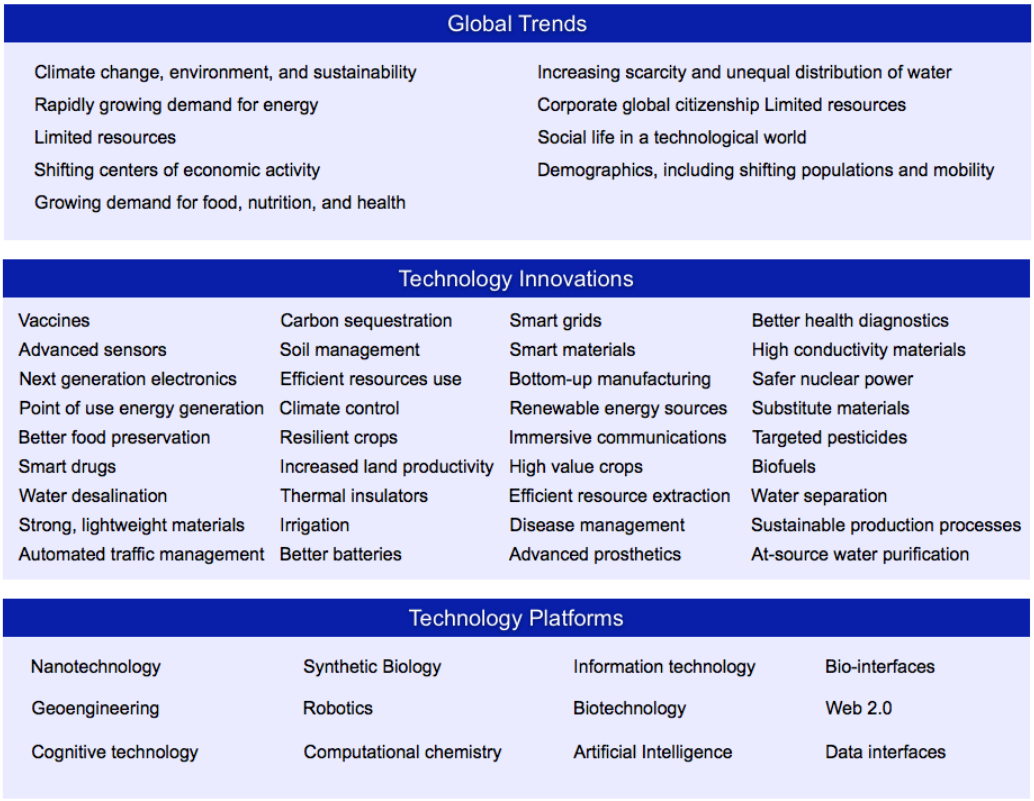


Figure 5: Technology Platforms are Linked to Global Trends through Technology Innovation
This list is not inclusive, but is indicative of current technology platforms being developed and potential technology innovations that would help address the nine global trends identified in Figure 2.

Without a doubt, the unprecedented inventiveness of today's global society provides the potential to realize technology-based approaches to addressing the nine trends in Figure 2. There is increasing global investment in technology platforms such as nanotechnology, synthetic biology, geo-engineering and information technology. These provide a foundation for new technologies to emerge, as well as new applications of existing technologies. Within these platforms and at the synergistic intersections between them, scientists, engineers and technologists are empowered to generate new knowledge and explore innovative new ways of using it. The result is a vast array of potential technology innovations.

But the emphasis here is on *potential*. Figure 5 illustrates a possible progression from technology platforms through technology innovations to solutions that address the impacts of global trends. The illustration is indicative rather than inclusive and does not show the complex but necessary feedback that occurs between challenges, platform development and innovation. Nevertheless, it illustrates how the technology pipeline might operate to deliver timely and relevant solutions to global issues.

Yet these are just *possibilities*, not *probabilities*. Without strategic investment in technology platforms, and informed nurturing of potential innovations into practical solutions, many of the technology innovations highlighted here will remain mere possibilities. This is at the crux of the challenge we face as we look to the future: how do we ensure that investment in technology innovation leads to innovations that we need to build a sustainable future, rather than simply innovations that someone can convince us we want?

The potential inherent in rapidly accelerating technology innovation is immense. But this potential is easily matched by the magnitude and unprecedented nature of the challenges we face as a global society. Together, these put us on the cusp of a new era, where sustainable development will depend on new and integrative ways of navigating the opportunities and risks presented by technology innovation in an interconnected world.

Looking to the Future

Looking to the future, we will need to think in new ways about how we use technology innovation to our advantage. We need to rethink how we develop sustainable technologies so future generations can build on advances being made now. As technologies become increasingly complex, this need for

"technology ratchets"[1] will become ever-more important if progress made by one generation is going to be sustainable in the next. And with growing pressures on global resources, an increasingly interdependent world and a burgeoning population, we have no choice but to develop new technology-based solutions.

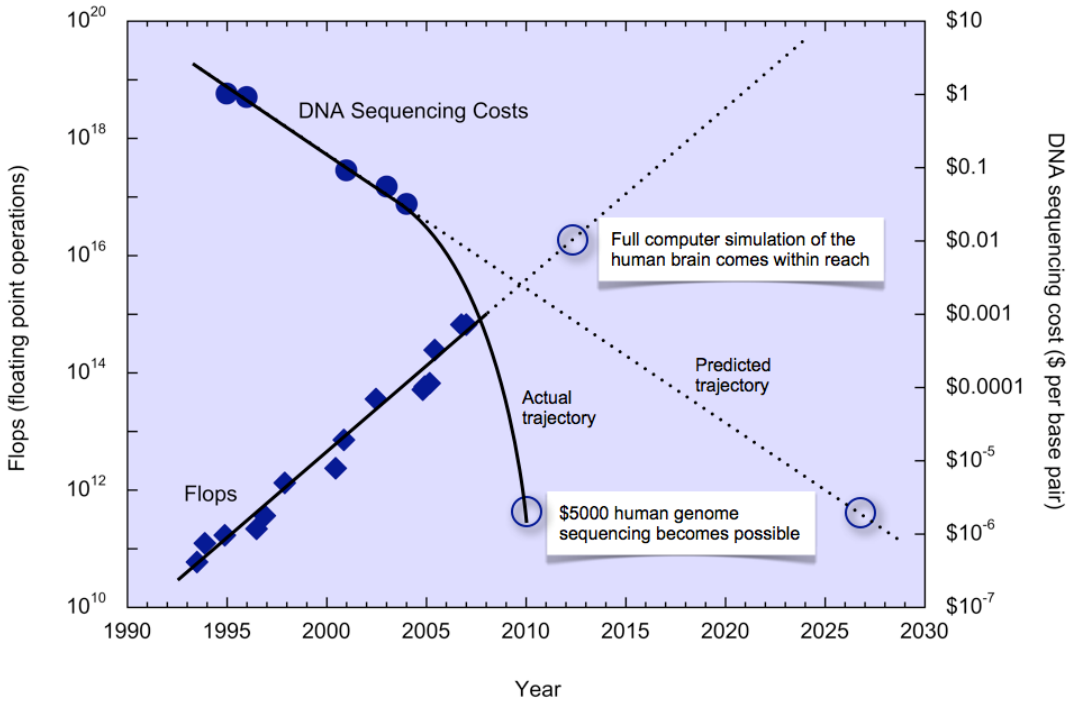


Figure 6: Our Increasing Ability to Generate and Handle Vast Amounts of Data Is Indicative of the Rate at which Technology Innovation Is Accelerating
The two trends shown here – increases in computer processing power and decreases in DNA sequencing costs – illustrate exponential growth in our ability to decode genetic data, and process digital data. While the trends predict significant technological change over the next 20 years, there is evidence that technology innovation is progressing even faster than expected: The US$ 5,000 human genome was achieved by the Complete Genomics in 2009 – nearly 20 years earlier than predicted. Data source: http://www.singularity.com/charts/. Accessed 27 July 2010.

The way forward is far from clear though. The challenges to integrating technology innovation into a sustainable future are different now compared to 10 years ago, and radically different from the challenges faced 50 years ago, when many of today's institutions and philosophies that govern science and technology innovation were being developed.

For over 200 years, the rate of technology innovation has been inexorably accelerating. Two hundred years ago, society was exploiting – and learning to live with the cost of – the industrial revolution. Fifty years ago, the synthetic chemistry revolution was in full swing. Thirty years ago, solid-state electronics revolutionized the way we handle information. Twenty years ago, the Internet began to emerge from a convenient information-sharing platform into an essential and ubiquitous part of the fabric of modern society.

In the past few years, technologies enabling unprecedented control over how matter is engineered at the level of atoms and molecules have come to the fore. In the near future, the rate of technology innovation and exploitation will become so rapid that multiple technological "revolutions" will come and go in the space of a generation.

Yet the rate at which we are learning to reap the benefits and manage the consequences of new and emerging technologies is not keeping pace with technology innovation. Over the past 10 years, nanotechnology has provided a test case for how adept we are at fostering responsible innovation.[2] Based on enhancing conventional technologies and developing unique new technologies through

[1] Technology ratchets enable technology development to move forward without slippage – much as a mechanical ratchet allows movement in only one direction. They include building effective education systems, enabling open access to information, fostering skills-transfer, and supporting greater cultural integration of science and technology.
[2] For example, see Owen R, Baxter D, Maynard T, Depledge M. 2009. Beyond Regulation: Risk Pricing and Responsible Innovation. Environmental Science & Technology 43(18): 6902-6906.

engineering matter at the nanometer scale, there has been an explosion in research and investment in nanotechnology worldwide.[1]

Touted by some as the next industrial revolution and projected to underpin or enhance products with a market value between US$1 trillion and US$ 3 trillion over the next few years, there has been tremendous interest in exploiting this new technology platform. At the same time, there has been early and sustained attention paid to the broader safety and societal issues raised by adopting unique new nanoscale science-based technologies.[2]

Governments and businesses have begun to address potential safety concerns in parallel with the development of nanotechnology, and there has been a growing international effort to address potential human health and environmental impacts of the products of nanotechnology as they begin to enter the market.[3]

On the surface it would seem that, with the development of nanotechnology, we have successfully transitioned to a new paradigm of responsible innovation. Yet despite the best of intentions, materials and products are still entering the marketplace before a clear understanding of the risks has been developed; manufacturers, regulators and consumers remain confused and uninformed over potential risks and possible ways to avoid them; and strategies for developing safe, successful and acceptable long-term nanotechnology-based solutions to global issues remain elusive.[4]

In effect, while nanotechnology has highlighted where we need to be as a global society if we are to develop and use technology innovation effectively, it has also revealed how far we still need to go to get things right.

In the meantime, new technology platforms are emerging. The recent announcement of the first living organism to be based completely on DNA synthesized in the laboratory[5] demonstrated the profound potential of synthetic biology – the emerging technology of designing DNA sequences on a computer and "downloading" them into living organisms.

Geo-engineering is another technology platform that has been grabbing headlines. The idea that human intervention could counter the effects of global warming – and that unilateral action leading to global impacts is economically plausible – is gaining ground; as are concerns over the environmental, social and political ramifications of such interventions.[6]

And the convergence between different technology platforms is opening up new synergistic possibilities that defy easy categorization. Yet these platforms and the technology innovations they are spawning come at a time when – as nanotechnology has shown – there is a rapidly widening gap between emerging technologies and the national and global social, political and oversight frameworks necessary to ensure their effective development.

If a sustainable future is to be built on the effective development and use of technology innovation, it is essential that innovative new approaches be found to bridge this gap. This will require rethinking the process of technology innovation and the interplay between science and technology. But it will also require new thinking on how informed decisions are made on technology innovation, how new partnerships can be forged between innovators, implementers and users, and how stakeholders can be actively involved in building a resilient technology-based future in an increasingly interconnected world.

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[1] PCAST. 2010. Report to the President and Congress on the Third Assessment of the National nanotechnology Initiative. Washington DC: President's Council of Advisors on Science and Technology.

[2] In 2004, the Royal Society of London and the Royal Academy of Engineering published a seminal report on nanotechnologies, which underlined the need to ensure the safe development and use of these innovative new technologies (RS/RAE. 2004. Nanoscience and nanotechnologies: Opportunities and uncertainties. London, UK: The Royal Society and The Royal Academy of Engineering.). This report has underpinned a growing effort internationally to support early research into developing nanotechnology-enabled products as safely as possible.

[3] For example, in 2007 the Organization for Economic Cooperation and Development Working Party on Manufactured Nanomaterials launched its Sponsorship Program for the Testing of Manufactured Nanomaterials. Under the Program, 17 economies, regions and organizations are collaborating together to test the safety of 14 commercially available manufactured nanomaterials. http://www.oecd.org/document/47/0,3343,en_2649_37015404_41197295_1_1_1_1,00.html, accessed 7/27/10.

[4] In 2009, the US National Academies published a damning critique of the US Government's research strategy to address engineered nanomaterial health, safety and environmental impacts. National Academies. 2009. Review of the federal strategy for nanotechnology-related environmental, health, and safety research. Washington DC: The National Academies Press.

[5] Gibson DG, Glass JI, Lartigue C, Noskov VN, Chuang R-Y, Algire MA, et al. 2010. Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome. Science 329(5987): 52-56.

[6] For instance, see: Royal Society. 2009. Geo-engineering the climate. Science, governance and uncertainty. London.

A Framework for Underpinning a Sustainable Future

Throwing technology at problems and hoping that some of it will arrive in the right place and stick, is a crude and ineffective approach – and one that will not provide solutions to contemporary issues in a timely and effective manner. Nor, as we have discussed, can technology innovation be simply left to find its own meandering way towards solving major global problems. Yet low awareness of the opportunities and challenges presented by emerging technologies among global decision-makers means that international organizations and governments are ill equipped to make the best use of our combined global science and technology base.

There are seven challenges in particular that need to be addressed if progress is to be made towards underpinning a sustainable future through technology innovation:

Raising awareness: New initiatives and mechanisms are needed to ensure the challenges and opportunities presented by technology innovation are clear to decision-makers in government and industry. New insight is needed into how integrated approaches to technology innovation can support sustainable and resilient solutions to contemporary challenges. And greater awareness needs to be fostered among decision-makers, decision-influencers and others of the process of translating technology innovation to sustainable technology-solutions.

Providing intelligence: Trustworthy sources of intelligence on emerging technologies, and the opportunities and challenges they raise, are needed. These should provide insight into emerging opportunities and challenges associated with technology innovation. And they should equip decision-makers with timely and relevant information to make informed decisions on emerging technologies in the context of building a sustainable future.

Building partnerships: New initiatives are needed that connect groups grappling with contemporary challenges with those able to provide insight into technology-based solutions. At the same time, collaborative and multifaceted approaches need to be encouraged when addressing pressing problems. These should facilitate integrated approaches to emerging issues that are responsive to social, economic and political factors as well as purely technical ones. They should address tensions between economies that are driving technology innovation and those that are most in need of the solutions this innovation leads to.

Engaging with stakeholders: Mechanisms are needed to ensure all stakeholders have a seat at the table in developing technology-based solutions to contemporary challenges. The utility of building constituencies around contemporary challenges and potential solutions should be explored. And stakeholders at all levels should be empowered to make informed decisions on the development and deployment of technology-based solutions to emerging issues.

Revisiting the economics of innovation: Investment hurdles to developing promising new technologies and taking them to market should be addressed. New business and investment models should be explored that support early development of socially relevant technologies. These should facilitate the translation of promising technology innovation to economically and socially feasible solutions.

Re-examining the technology pipeline: A clearer understanding is needed of how investment in science and technology can lead to relevant and sustainable technology-based solutions. More effective mechanisms are needed to maximize the emergence of technologies that address critical challenges. In particular, the role of government investment in research and development, how it is informed by stakeholder perspectives and expertise and how it integrates with industry-based initiatives need to be re-examined. “Nudging strategies” should also be explored that enhance the likelihood of economically and socially relevant technology innovations emerging from the technology pipeline.

Rethinking global technology governance: The limitations of global governance structures in ensuring the development of safe, successful and just technology innovations should be evaluated, and solutions to overcoming current and future limitations explored. In particular, new thinking is needed on how global governance mechanisms can be made increasingly proactive and adaptive, enabling them to cope with rapidly developing technologies. New approaches to inclusive and responsive governance in response to changing geographical, political and social circumstances should be investigated.

Next Steps

Building a sustainable future is not primarily about technology innovation. But without a radical rethink of how we develop and use technology within an increasingly complex and interconnected society, we are unlikely to develop timely, effective and acceptable solutions to pressing challenges.

The World Economic Forum Global Agenda Council on Emerging Technologies is dedicated to exploring hurdles and solutions to making technology innovation work for society. By working closely with partners through the World Economic Forum and within industry, government, academia and civil society, the Council aims to help ensure that technology innovation serves the common good.

The Deepwater Horizon oil spill disaster in the Gulf of Mexico provided a sobering reminder of what can go wrong where we trust in technology without investing sufficiently in the future. But devastating as this disaster has been, it is only one small example of the challenges we will face as a global society as resources become scarcer, demands become greater and our technological reach threatens to exceed our ability to handle it effectively.

As emerging technologies become more powerful and the global climate within which they are developed more complex, society will face ever-greater challenges. The question is whether we can adapt quickly enough to take advantage of the opportunities that science and technology promise, or whether we will be blocked at every turn by outmoded and obstructive ways of doing business.