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The Future is History

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The future has arrived - and it's here to stay

Technologies that only a few years ago were fodder for futurists are now a reality. They hold the promise of profound advancements in medicine, economic development and environmental stewardship. But they may also bring significant policy challenges.

This brief highlights 10 of today's most cutting-edge technological advancements and outlines potential policy implications.

1 Faster, Cheaper Medicine through Synthetic Biology

"The lack of access to essential medicines in developing countries is one of the most pressing global health issues. Tackling this could save millions of lives every year."
[*UK Department of International Development, 2004*]

Advances in synthetic biology – reprogramming or building of cells – may make the problem of access to essential medicines a thing of the past. Already in 2008, researchers at the University of California turned a yeast cell into an anti-malaria medicine factory, producing medicine much cheaper and faster than the usual method of extracting the drug from wormwood plants (Interlandi, 2008). The same researchers have also reprogrammed E. coli bacteria to produce medicines such as taxol, an anticancer drug, and prostratin, a potential anti-HIV drug (Bower, 2005). And synthetic biology offers the prospect of producing better drugs. Herceptin, for example, has been found to reduce the reoccurrence of breast cancer, significantly improving chances of survival (Komarova et al., 2011).

Potential Policy Implications

While the potential benefits of synthetic biology are remarkable, the technology could also be used to produce personalized bioweapons and reprogrammed super-viruses that could pose grave threats to human health.

The standardization of methods and DNA parts has allowed synthetic biology methods to become simple and relatively easy to recreate, allowing anyone to alter and manipulate biology for good or ill.

2 Organs-on-demand with 3D Printing

"More than 4,000 Canadians are waiting for an organ transplant to save their lives. Last year, only 1,803 transplants were performed. Many patients remain on waiting lists. Unfortunately, 195 Canadians died while waiting for an organ transplant." [*Canadian Society of Transplantation, 2013*]

1. The authors wish to thank Marc Saner (Associate Professor, Faculty of Arts and Director, ISSP) for helpful suggestions and advice.

The advent of 3D printing could resolve some of the most pressing problems facing organ donation – such as availability and rejection by the patient's body. Instead of spitting out ink, organ "printers" spit out a living cell mixture ('bio-ink'), layer by layer, to form human tissue. Since the organs would be printed with a patient's own cells, they would not be rejected by the patient's body. And success in actually printing usable human organs looks promising. Bioengineers at Cornell University have already printed experimental knee cartilage, heart valves and bone implants (Thompson, 2012). Researchers at the **Wake Forest School of Medicine** have partnered with the Armed Forces Institute for Regenerative Medicine on a project to print skin cells onto burn wounds (Thompson, 2012). And Australian firm **Invetech** has created a printer that is able to grow arteries (Quick, 2009).

Potential Policy Implications

Printing organs has the potential to be a major new industry. Governments will be challenged to support the industry while considering ethical implications and regulating it effectively.

The approval of 'printed' organs in one jurisdiction could put pressure on other jurisdictions to follow suit.

3 Geoengineering the Climate

"Climate change is taking place before our eyes and will continue to do so as a result of the concentrations of greenhouse gases in the atmosphere, which have risen constantly and again reached new records".
[*Michel Jarraud, head of the World Meteorological Organization, 2012*]

Geoengineering involves "the deliberate large-scale manipulation of an environmental process that affects the earth's climate, in an attempt to counteract the effects of global warming" (Oxford English Dictionary), and some researchers believe it could be an effective tool in combatting climate change. While most of the research in this area has been purely theoretical – and a recent US Government Accountability Office study found geoengineering technologies to be "currently immature, many with potentially negative consequences" (2011) – in 2012 an indirect (and controversial) geoengineering experiment took place off the coast of British Columbia (Hume, 2012). Conducted by the **Haida Salmon Research Corporation,** the experiment dumped large quantities of iron into the ocean to increase plankton growth primarily in an attempt to increase dwindling salmon populations, but also to sequester carbon dioxide from the atmosphere (Biello, 2012b). Whether the project is able to bury any carbon at sea is still undetermined, but many scientists are sceptical. Other geoengineering proposals include reflecting sunlight from the earth through various methods (e.g., painting roofs a pale colour, whitening clouds with sea-spray or spreading aerosols in the atmosphere) and blasting a dust cloud off an asteroid to shade the earth.

Potential Policy Implications

Geoengineering will likely become more controversial as research continues and more experiments are proposed.

The **Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity adopted Decision X/33**, which would restrict the type of geoengineering projects that could be conducted.[2] However, stakeholders criticize the decision for not going far enough and opposition to geoengineering remains strong among some groups (e.g., the **ETC Group**, based in Ottawa).

4 Really Smart Cars

"Behind every steering wheel lurks driver stress. It creeps up when motorists are stuck in start-

2. The decision states that "no climate-related geoengineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting and in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment".

stop traffic, or being tailgated, or having to brake hard to avoid a crash, or seeing motorists who don't follow the rules, or dealing with detours or inconsiderate parking or…" [*British Columbia Ministry of Transportation and Infrastructure, 2012*]

Stressed behind the wheel? Then let the car do the driving. Google is developing a self-driving car that has already travelled 480,000 kilometres without an accident, and the company hopes its driverless cars will be commercially available within five years (Casey, 2013). In 2011 lawmakers in Nevada passed the first law in the US permitting the testing of driverless cars on streets and highways; in 2012 Google received the first license to test the cars (Ryan, 2012). Researchers at the University of Oxford are currently developing an apparatus, which could eventually cost as little as $150 (US), that can be fitted to any car to give it self-driving capabilities (Clayton, 2013). And researchers at Canada's McMaster University are currently developing software for self-driving cars (Cheney, 2012).

Potential Policy Implications

Autonomous vehicles could make roads much safer by removing the possibility of human error. They could also provide a convenient means of transportation for the elderly or other people who are unable to drive.

Liability could be unclear. If an autonomous car got into an accident, who would be at fault: the owner or the manufacturer?

5 Third Generation Biofuels

"Growth, prosperity and rising population will inevitably push up energy needs over the coming decades. But we cannot continue to rely on insecure and environmentally unsustainable uses of energy." [*Maria van der Hoeven, Executive Director, International Energy Agency, 2011*]

Biofuels generated through synthetic biology techniques – "3rd generation biofuels" – have the potential to provide clean and abundant energy. The US Department of Energy's **Joint Bioenergy Institute** has tripled the production of biodiesel from glucose through synthetic biology techniques (Yarris, 2012). Researchers at **Bio Architecture Lab, Inc.** and the University of Washington have genetically engineered E. coli to convert seaweed into ethanol – an advancement which could resolve a host of problems associated with biofuel production, such as land use and the 'fuel vs. food' debate (Biello, 2012). And **Synthetic Genomics**, the firm led by biotech pioneer Craig Venter and which announced the creation of the "first self-replicating synthetic cell" in 2010, aims to use synthetic biology to make biofuels from algae (Biello, 2011).

Potential Policy Implications

This potentially transformative industry could come with mixed benefits to Canada (and other oil-producing nations) if demand for oil is significantly reduced.

6 The Rise of the Super-soldier

"The soldier is the Army. No army is better than its soldiers." [*George S. Patton, Jr., 1947*]

If the soldier is the Army, then an army equipped with super-soldiers would surely be a superior force. And the super-soldiers are coming. **Lockheed Martin** has developed exoskeletons that could enable soldiers to carry up to 90 kilograms at a top speed of 16 km/h (Bland, 2009). The US National Intelligence Council predicts exoskeletons with brain-machine interfaces by 2030, and researchers hope to develop "mutant" soldiers through various biomodifications, including injections of anti-stress chemicals, electroshock-style treatments to boost thinking and gene therapy to improve speed, intelligence, memory and the ability to work under stress (Axe, 2012).

Potential Policy Implications

Policymakers could be faced with ethical and legal issues concerning enhanced soldiers, e.g., whether soldiers should have to consent to be bio-enhanced or the possibility that enhanced soldiers could count as weapons in violation of international humanitarian law (Lin, 2013).

Exoskeletons could provide benefits outside of military applications, such as providing support for people with physical disabilities. **Argo Medical Technologies** has already sold its ReWalk exoskeleton to patients who have lost the use of their legs (Black, 2013).

7 Storing 'Big Data' in DNA

"In the next five years, we'll generate more data as humankind than we generated in the previous 5,000 years." [*Eron Kelly, general manager of product marketing, Microsoft, 2012*]

Storing data in DNA offers the prospect of resolving an issue at the heart of the information society – where to keep all the information. Researchers George Church and Ed Regis of Harvard University have already stored 70 million copies of their book Regenesis in DNA – that's more than three times the total number of copies for the next 200 most popular books in the world combined (Paramaguru, 2012). And researchers in the United Kingdom recently reported that they've encoded Shakespeare's sonnets and Martin Luther King Jr.'s 'I have a dream' speech into DNA (Service, 2013). While DNA is able to hold incredibly large amounts of information for incredibly long periods of time – conceivably tens of thousands of years (indyposted, 2013) – the high cost of this technology limits its utility.

Potential policy implications

The easier it becomes to store massive amounts of data, the more issues will arise relating to the security of big data systems as well as the retrieval and ownership of information.

8 Solving Deep Problems with 'Deep Learning' Artificial Intelligence

"Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain." [*Alan Turing, pioneer of artificial intelligence, 1950*]

Recent advances in computer science are producing machines that can actually learn. Researchers at Google have designed a software-based neural network that taught itself to recognize digital images of cats (Markoff, 2012b). A student team led by University of Toronto computer scientist Geoffrey E. Hinton recently developed deep learning software so impressive that it won top prize in a contest sponsored by pharmaceutical giant **Merck**. The students designed software that scanned a data set containing the chemical structure of thousands of molecules and determined which molecule would most likely be an effective drug agent – and they designed this software with little knowledge of how molecules actually behave (Markoff, 2012).

Potential Policy Implications

"Learning" computers could help humans do their jobs better and increase productivity – but there is also the risk that they could displace human workers. In the long term, as AI technology further develops, there could be calls to recognize 'thinking' machines as persons, worthy of the same rights as anybody else.

9 Materials-on-demand with 3D (and 4D) Printing

"Tea, Earl Grey, hot." [*Jean-Luc Picard, Captain of the Starship Enterprise, ordering a drink from his "replicator"*]

While recent advances in 3D printing don`t yet amount to Star Trek's food-materializing "replicators", they are ground breaking nonetheless. Currently, 3D printers create plastics, metals and other materials, but researchers at Cornell University are working on printing meals and food (Hadhazy, 2013). GE hopes to use 3D printing to make jet parts (LaMonica, 2013). The forefront of 3D printing is to print both at a much smaller (e.g., **nanoprinting**) and larger scale (e.g., **houses**), and more quickly. And 4D printing would allow objects to adapt to environments and assemble themselves – MIT has developed structures that form shapes when put in water, with the ultimate goal being objects that can actually self-assemble (Walton, 2013).

Potential Policy Implications

3D (and 4D) printing technologies could be profoundly transformative – **perhaps as important as the steam engine, computer or Internet.**

As 3D printing becomes mainstream, intellectual property issues may arise surrounding the sharing of digital files for printing objects (Thompson, 2012).

10 Pop a Pill and Become a Better Person

"It is a man's own mind, not his enemy or foe, that lures him to evil ways." [*Hindu Prince Gautama Siddhartha, founder of Buddhism, 563-483 B.C.*]

While the Buddha's words may forever hold true, advances in modern medicine may provide a person with the moral boost his or her mind has often needed. Research suggests that the common hormone oxytocin may increase marital fidelity, trust and communication (Tandos, 2012). One researcher from the University of Bristol suggests that mood altering drugs could be administered to curb illegal behaviour (Hill, 2011). And some drugs could even make us smarter. There is evidence that provigil (also called modafinil) enhances alertness, concentration and energy, although it is only approved for treatment of narcolepsy (Harris et. al., 2012). Other so-called "neuroenhancers" include ampakines, which in a 2007 study of 16 elderly volunteers was shown to improve short-term memory, and donepezil, which in one study was found to improve the performance of pilots in flight simulators and, in another study of 30 young adult males, verbal and visual episodic memory (Talbot, 2009).

Potential Policy Implications

Various ethical questions may confront policymakers, such as whether taking cognitive enhancers would result in an unfair advantage at work or school, and whether criminals should be given mood enhancers to curb violent tendencies.

PH4-138/2013E-PDF
978-1-100-22287-5

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