‘Water Futures + 1’

Water, Energy, and Agriculture to 2035

Stantec

Foreward by Gord Johnston
and David A Smith

Contents

Foreword 4

#1. Climate, security and the Anthropocene era 13

#2. Megacities: complexity, risk and creativity 21

#3. Distributed, networked infrastructures 25

#4. Systems integrators and white space 31

In brief: The secret world of invention 35

#5. Digital intelligence 37

In brief: General purpose learning machines: AI summer? 41

#6. Desalination, brine mining and resource efficiency 43

#7. Precision agriculture: opening the door to water security? 47

#8. Nanotechnology: small worlds, big disruption? 51

In brief: Securitizing water? 54

Epilogue 55

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Foreword

Water futures twelve months on: ***'Water Futures + 1'***

One year ago Stantec published Water Futures: Water, Energy & Agriculture to 2035. Formed of eight essays, its purpose was to develop fresh thinking – exploring the critical uncertainties, challenges, and opportunities for global water security and the water industry.

In recognition of World Water Day (2018), we revisit this work to see if the foresights and scenarios raised in the book are becoming more present in observations seen in the communities where we live, and/or in the impacts we are experiencing at a global level. World Water Day's 'Nature for Water' theme, and our Water Futures work, both seek to explore the tremendous opportunities presented when nature-based solutions work symbiotically with built infrastructure.

The Interdependency of Water, Energy, & Agriculture

Water Futures examines the interdependency of water within the global ecosystem – particularly its relationships with energy and food production – and the threats and opportunities this presents.

Most human activity is impacted by water as a resource. With too little water, or at times too much, uncertainties regarding its availability is one of the biggest risks to global security and creating a stable and sustainable future for the world.

We live in an age where human influence is having a profound effect on the planet's environment and climate – described as the Anthropocene era. To date, human influence has been seen as having a largely negative impact - our consumption and reliance on fossil fuels, greenhouse gas emissions, and other pollutants contributing to global warming and climate change. In a different way, we now have the opportunity (and imperative) to shape the planetary ecosystem for the better.

Making these changes will require new foresight, leadership, and creativity to drive how we act as a global community – in our attitudes, behaviours, and fundamentally our consumption of precious resources.

With the nexus of water, energy, food, and climate change being one of the overarching dynamics that will shape our world in the coming decades, Water Futures examines the uncertainties and opportunities across eight interconnected themes:

#1 Climate, security, and the Anthropocene era

#2 Megacities

#3 Distributed, networked infrastructures

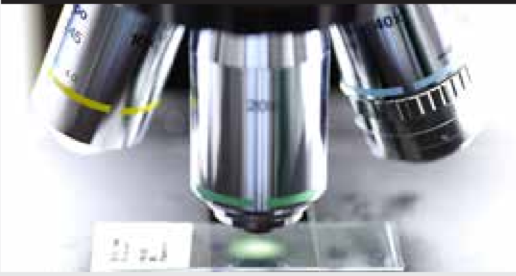
#4 Systems integrators

#5 Digital intelligence

#6 Desalination

#7 Precision agriculture

#8 Nanotechnology



Previously, Stantec commissioned Peter Kingsley, an expert in agenda-setting foresight and innovation, to collaborate in the development of fresh thinking about the future of the water industry and to write a series of essays exploring the critical uncertainties, challenges and opportunities that lie ahead. Since we first published Water Futures in 2017, much has happened to reinforce and confirm the importance of the eight interconnected themes.

#1 Climate, security and the Anthropocene era

Climate disruption continues to have an increasingly significant impact, as demonstrated by the multiple hurricanes that devastated parts of the Caribbean, the possible 'Day Zero' scenario where Cape Town's water supply is turned off due to successive droughts, and the recent extreme cold weather event in Europe at the beginning of March 2018.

Scientists continue to debate the hypothesis known as "warm Arctic, cold continents" as the polar vortex becomes less stable – drawing in more warm air and expelling more cold fronts. Longer term, Robert Rohde, lead scientist of Berkeley Earth (a non-profit organisation dedicated to climate science), expects more variation – "As we rapidly warm the Arctic, we can expect that future years will bring us even more examples of unprecedented weather."

Challenges exist but we have seen tipping points in several regions over the last 12 months where renewable energy generation uptake has, at times, been greater than conventional sources. The head of the International Energy Association's Renewable Energy Division noted recently, "The limiting factor [to clean energy growth] is no longer cost…it's system integration." Whether any action taken will be enough to turnaround or halt climate change is one of the greatest uncertainties we face, but global collaboration is needed if we are to act coherently and strategically to deliver the change needed.

#2 Megacities

Cities as a focal point for more resilient and resource efficient communities continues to gather momentum.

The Rockefeller Foundation recognized this need and launched the 100 Resilient Cities (100RC) initiative to help enable such transformation. 100RC is dedicated to helping cities around the world become more resilient to physical, social, and economic challenges. They promote a framework of seven key qualities that resilient cities should demonstrate.

Cities in the 100RC network are provided with the resources and expertise necessary to sustain their strategy and access innovative solution providers and lessons learned through a wider network of support from other cities. Approaches like 100RC are vital, as cities around the world continue to face challenges, such as water security, sprawl, and knock-on cropland impacts, alongside fragile infrastructure and funding challenges.

#3 Distributed, networked infrastructures

Rethinking how scarce resources are being consumed, or how efficient every-day services are provided, is a growing priority for communities. How a vision of distributed, highly integrated and resource efficient water, energy, and agricultural systems might be delivered is a key challenge for regional and utility leadership.

Decentralization of water, energy, and agriculture to create distributed networks and increase the viability of localized, resource efficient, partially self-sufficient communities is becoming increasingly possible.

In December 2017, the world's largest lithium ion battery (100-megawatt) began dispensing power into an electricity grid in South Australia. South Australia has been crippled by electricity problems in recent times. Elon Musk, of Tesla, offered to help. He promised to install the world's biggest battery, and that if the battery was not built within 100 days, the state would receive it for free. Tesla finished the battery in 60 days. Similar and lower key success stories are evident worldwide, with micro-solar and micro-grid management developments gaining traction during the year.

#4 System integrators

There is a world of difference between the interdependence that emerges over time and that of integration by design. Advances in one sector can offer unique opportunities for effective design-led integration and innovation in another.

Since large-scale flooding in China in 2012, flood prevention has rocketed up the state agenda. The Sponge City initiative was launched in 2015 with 16 'model sponge cities', before being extended to 30, including Shanghai. Additional innovations have emerged from the planning of green infrastructure, including more sustainable design and relief for China's water-starved regions by managing stored rainwater.

Another example in the last 12 months is the 'Living with Water' initiative in the City of Hull in the UK. Facilitated by Yorkshire Water, it is rallying the local community, council, and local businesses around Hull to solve similar problems with flooding. Working collaboratively, these stakeholders are trying to work out different ways of solving flooding by using 'blue/green' infrastructure. It's a community approach to solving the problem rather than just a water company approach or council-led approach.

We see similar examples around the globe of system integration and multi-stakeholder collaboration, often with a 'Nature for Water' focus – be it watershed management and drinking water supply, forests enhancing climate change resilience, wetlands and wastewater management, or river fisheries and food security.

As this concept of systems integration, ecosystem, and engineering design develops, we can expect large-scale invention between water, energy, and agriculture.

#5 Digital intelligence

Digital technology and application advances continue to gather pace in the digital age, complex systems are increasingly coming under the control of predictive analytics and automated systems. This will be necessary to radically improve efficiency, drive performance, and meet the affordability challenges of services in the future.

The simplest way of viewing the rapidly evolving digital landscape is starting with the scale of devices generating vast 'clouds' of data about the dynamics, behaviour patterns, and conditions in the real world. This can take the form of specific sensors out in the field (i.e. a smart meter or water quality sensor at a water treatment works) or the most pervasive of all – the mobile phone.

With ever increasing digital technology advances in sensors, interconnectivity, and computing power we are seeing more and more opportunity to utilise complex modelling and simulations with real-time predictive analytics. Digitally connected infrastructure systems are starting to enable truly resilient solutions with new forms of decision support, operational efficiency, and customer services.

#6 Desalination

Desalination and brine mining may be a partial solution to the otherwise intractable problem of producing increased amounts of fresh water to meet fast rising demand. A variety of integrated and sensor-driven membrane and other technologies continue to emerge, which may lead to smaller, mobile plants that can be delivered more economically and quicker than the 10- to 15-year cycle typical of large scale installations.

There are projects underway that provide solar powered desalination units to communities separated from utility grids. In 2017, the Center for Nanotechnology Enabled Water Treatment (NEWT) in the United States launched a "nanophotonics-enabled solar membrane distillation" technology and commented, "Direct solar desalination could be a game changer for some of the estimated 1 billion people who lack access to clean drinking water. This off-grid technology is capable of providing sufficient clean water for family use in a compact footprint, and it can be scaled up to provide water for larger communities." While desalination advances offer game changing solutions over the longer-term, we also see current desalination technologies at the intersection of water, energy, food, and climate change. For example, in Cape Town, South Africa a temporary fast-tracked desalination plant is part of mitigation efforts as the city seeks to minimise the risks of acute water shortages.

#7 Precision agriculture

Technology providers are becoming increasingly attuned to how farmers work and how they can help improve yields. Barriers of entry into farming technology are reducing, as cloud computing, connectivity, and digital tools become increasingly affordable and accessible. For example, aerial images from satellites or drones, weather forecasts, and soil sensors are making it possible to manage crop growth in real-time. These technologies are helping farmers apply the right fertilizer and optimally irrigate their farms – reducing the demand on potentially scarce resources.

Whist it is still early to evaluate the impacts of this digitalization of farming systems, the emergence of available and affordable digital technology opens vast untapped potential for farmers, investors, and entrepreneurs to improve efficiency of food production and water consumption. Worldwide, numerous 'home-grown rural start-ups' are taking the best of big data and analytical thinking and applying the principles in rural farming communities.

#8 Nanotechnology

Major corporations, utilities, high-tech start-ups, and universities are already active in some of the most potentially transformative applications of nanotechnology for water, with investment and patent activities accelerating in the sector.

Exploring its application in water treatment, 2017 saw a group of researchers creating a graphene-based sieve capable of removing salt from seawater. While it is currently difficult to manufacture graphene-based filters on an industrial scale, scientists have solved some of the challenges by using a chemical derivative called graphene oxide. Previous work had shown that graphene oxide membranes became slightly swollen when immersed in water, allowing smaller salts to flow through the pores along with water molecules. Placing walls made of epoxy resin on either side of the graphene oxide membrane was sufficient to stop the expansion.

With this and similar breakthroughs, nanotechnology is getting closer to fulfilling its potential of utilising 'small worlds' to create 'big-disruption'.

The eight essays on these key 'high impact, high uncertainty' themes are still very pertinent today. We are therefore republishing these essays under the banner ***'Water Futures + 1'.***

Scenarios are embedded throughout the essays, essentially raising two questions.

The first is 'what might happen?' The second, critically, is about strategic options in the here and now: 'what might we do?'

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High impact, high uncertainty threads

Possible futures

#1 Climate, security, and the Anthropocen era

#2 Megacities

#3 Distributed, networked infrastructures

#4 Systems integrators

We can see these high impact high uncertainty threads as eight intertwined narratives. They are not trends, which tend to be seen as linear, but components in the larger system of systems. In scenario terms, each one is a high impact, high uncertainty axis, or in other terms, a fundamental system variable.

#5 Digital intelligence

#6 Desalination

#7 Precision agriculture

#8 Nanotechnology

CHAPTER 1

Climate, security, and the Anthropocene era

We may save the planet from extreme climate, but in the transition to 2035, will we see the end of political and economic security?

Power over nature?

Heatwaves. Drought. Extreme precipitation. Floods. Rising sea levels. Storm surges. Arctic meltdown. Failing Greenland ice-shelves. Collapse in biodiversity. Ocean acidification and declining fisheries. Crop failures.

Some of the language describing the risks to natural ecosystems and the biosphere is as apocalyptic as it is varied, reflecting both the growing scientific evidence and the negative imagination that has long pervaded environmental politics.

If we see natural ecosystems as the foundation on which civilization depends, then the language describing the next level – the human systems vulnerable to the potential dangerous consequences of climate change – is no less extreme. Political instability and failed states. Mass migration. Starvation. Water wars. Financial market meltdowns. Uninhabitable coastal regions. Forced, rather than managed, retreat.

There are strong arguments in favour of exploring the extreme scenarios that this language suggests.

On one axis of uncertainty, the natural climate may enter dangerous territory quickly, or at the other extreme, evolve slowly in a relatively benign way. Recent record increases in global temperatures and the breach of the symbolic CO_2 concentration level of 400 parts per million add to evidence of the direction of travel.

On a second axis, at one extreme, human systems may be characterized by synchronized, systemic, linked failures. At the other, visionary leadership emerges that drives positive, systemic innovation–growth, prosperity, stability, and security–creating a pathway to a sustainable world.

However we ultimately frame the complexities, uncertainties, and possible futures of a world shaped by climate change, the dominant and emerging narratives are a good place to start.

Paris 2015: a turning point?

Prior to the Paris 2015 summit, the dominant climate narratives were fatalistic. The response of the international community to climate change was seen as both a political and market failure. The scientific consensus pointed to the dangers of worlds two to five degrees above pre-industrial levels.

A transition to a carbon free, renewables-centric energy system and sustainable world was seen as difficult at best, impossible at worst. If we see political action in terms of emotion, fear prevailed over hope.[1] Yet beneath the surface was a growing recognition that the consequences of inaction, and the need for coordinated inter-governmental action, was critical.

There is no doubt that Paris 2015 was a watershed, delivering a universal, hopeful narrative that will drive change, regardless of the detail of the commitments.

It might be summarized as follows:

→ **The package of political, economic, financial, institutional, and technological actions bringing an end to the fossil fuel era and transforming resource efficiency, thus enabling us to take control of the natural ecosystem to create a 2 or even a 1.5 degree world, securing transition to a sustainable environment, and keeping us out of the 2 to 5 degree danger zone.**

The Paris Agreement came into force in 2016. Even so, hidden uncertainties about this narrative remain.

The first is the assumption that nature can be controlled and further action can be taken as circumstances change – one of the key provisions of the Paris Agreement. By taking concerted action, warming can be slowed.

The second is closely related: that maintaining global temperature increases two degrees centigrade above preindustrial levels will lead to a secure environment.

The third goes further: that we cannot only create a low carbon world and take control of nature over the next two or three decades, but also overcome the fact that warming is already stored in the atmosphere.[2] We can reverse the impacts. We can, in the language of some academics, deliver negative emissions. The planet can be cooled.

The fourth is about real world politics and cultural change: that, in the face of these challenges, we can maintain political, economic, and social security while transitioning, in an orderly way, to a sustainable world. To some, these are critical arguments in a world of increasing complexity, non-linear systems and interdependence. To others, they are the politics of hope and confidence.

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1. For an analysis of the importance of emotion in political decision-making, see *The Geopolitics of Emotion*, by Dominic Moisi

2. The IPPC AR5 puts the point simply: "Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of warming increases."

The Anthropocene era emerges

From another perspective, the optimistic narratives are intertwined with variations of the Anthropocene argument, broadly defined as an era in which human influence has begun to have a profound impact on the planet's environment and climate.

'The Anthropocene' introduced to the wider public by Nobel laureate Paul Crutzen in 2002 is set to become mainstream. The International Geological Congress accepted recommendations to make the term official in 2016. The positive argument is that we are entering a new phase of the Anthropocene[3] where we may begin to develop the power to deliberately control and manipulate the planetary environment, transforming not just natural ecological systems, but also geopolitics and the economy.

The question is whether the outcome of all human actions, in sum, will influence natural ecosystems. If so, when, and will we fail to adapt in the transition, as political, social, and economic turmoil overwhelms global security.

After all, shocks may emerge before a dangerous climate disrupts the environment. Can the international community, individual countries, cities, and industries withstand and adapt to disruptive change – whatever possible future climate scenario emerges? This may become the ultimate test of human resilience.

The critical implication, not yet well recognized, is that if we can act on global natural ecosystems, then many decisions become highly politicized, raising issues about the talent and capabilities of international leadership, institutions, and local communities. The emerging picture is of a single, global, socio-political, and ecological environment in which both systemic failure and systemic innovation can spread rapidly.[4]

To put this in a more specific context, there are three critical narratives at the nexus of climate, water, energy, and agriculture: technology, economic security, and political stability. Each one hides complex interdependencies and uncertainties, together with fundamental questions of speed and timing, scale, and possible impact. Politics stands above all.

Technology: hype, reality, and secret worlds

The optimistic technological narrative – that dependence on fossil fuels can be cut, fast, particularly through investment in radical innovation – has become pervasive. The supporting evidence of this fundamental shift in perspective includes the fact that power-related investment in renewables has overtaken fossil fuels for the first time. Fund managers are looking beyond the short-term. In the run up to the Paris summit, 400 investors, with US$25trillion in participating funds behind them, signed the Global Investor Statement on Climate Change.

3. There is debate about when the Anthropocene began, but most academics argue that 'The Great Acceleration', starting around 1950, marked the beginning of a transformation of global ecological and social systems, driven by human activity. The argument is we are now seeing the emergence of a new phase.

4. Homer-Dixon et al December 2015 explores synchronous, systemic failure, but not systemic innovation.

Fellgate Surface Water Management Scheme, Tyneside, United Kingdom.

A partnership-approach with significant community involvement leads to an award-winning solution to persistent flooding problems.

Since then, leading asset managers, such as Blackrock, have advised clients to take climate into account in their investment decisions and many new specialist funds have been established.

At the same time, investor activists are exerting more pressure on the major oil companies, which is particularly important because financial market sentiment can turn quickly as alternative, imagined futures begin to crystallize in people's minds and drive strategic decisions, long before the events themselves.

Similarly, a wide variety of businesses, regions, cities, and financial institutions have signalled a sea-change, for example the RE100 corporations aiming for 100% renewable energy.[5] In some ways most emblematic of the post-oil messages came from the automotive industry, which committed in Paris 2015 to 'de-carbonizing' transport within "two to three decades".[6] The emergence, over time, of integrated solar, offshore wind, radical battery designs, and autonomous electric vehicles is emerging as a new investor narrative. Renewable energy, for example, has a momentum that has surprised many, including the International Energy Agency, who revised their forecasts in 2016 after a surge in installed capacity in 2015. The latest offshore wind systems generate power 98% of the time. Dong Energy, the Danish supplier, has recently offered prices at Eur 72.7 per kilowatt hour, well below previous records.

Even so, beneath the rhetoric, reports in 2016 suggest that only 94 of the world's 900 major companies are doing enough to meet the goals set in Paris.

Meanwhile, many leading scientists argue that these changes, however well-intentioned, will not be enough. Some say that we have to move to negative emissions rapidly, to meet the two-degree target.[7] There is a "disconnect between what is being done and what is required".[8]

The scale of the impact of climate, particularly on water, may also be greater than current models suggest:

→ **"If global warming is kept to 2 degrees, the availability of water is expected to decrease in some areas, such as the Mediterranean, by up to 50%. Globally, the additional warming could lead to a 20% increase in the number of people affected by chronic water scarcity."[9]**

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5. Source: Tom Burke, E3G
6. http://www.theclimategroup.org/what-we-do/programs/re100
7. http://citiscope.org/habitatIII/news/2015/12/paris-city-hall-declaration-world-mayors-throw-down-gauntlet-climate
8. http://mission-innovation.net/statement
9. The 'Paris Declaration on Electro-Mobility and Climate Change'

Against this background, one key question to ask is whether radical technologies at the intersection of climate, water, energy, agriculture, and food production may emerge in the next few decades. Beneath the radar, systemic innovation may create accelerating growth, crossing established boundaries. This kind of innovation is often underestimated, yet the rapid rise in the number of 'combinatorial patents' is clear. Ideas are distributed at an accelerated rate around the world. Similarly might new technologies address deeper ecosystem linkages, such as the relationships between the water cycle, nitrogen cycle (which releases nitric oxides from fertilizers to rivers and estuaries), and phosphorous cycle (which is linked to the extinction of aquatic life)? Can the release of methane – long a scenario wild card – be contained?

From another angle, might reforestation be extended, at massive scale, to accelerate the transition? Reforestation, soil carbon, and biochar has the potential to sequester two gigatonnes of carbon a year. "Direct air capture and silicate rocks might capture another gigatonne between them, and carbon-negative cement and carbon-negative plastics another gigatonne."[10]

More radical is the emergence of synthetic biology that may mimic natural processes, such as photosynthesis, and be applied at a global scale. Similarly, might geoengineering (deliberate large-scale intervention in the planet's natural systems to counteract climate change), once decried as too extreme and too high risk, become mainstream, particularly if the threats become clear and present dangers? Or will fusion power, another scenario wild card, emerge?

Economics: lack of imagination?

The fact is that the Paris Agreement created a framework that supports both public and private investment in a sustainable economy. The direction of travel is clear, boosting investor confidence and mobilizing new waves of capital. In parallel, intelligence about the early signs of systemic innovation will begin to create a revolution in how we think about the future.

> **The emerging picture is of a single, global, socio-political and ecological environment in which both systemic failure and systemic innovation can spread rapidly.**

That said, the economic contribution to the Anthropocene narrative is not as simple as this suggests. It is based on the idea that markets and businesses, with some help from governments, will provide the incentive structures for accelerated investment in renewables and resource efficiency. This is a big challenge, not least because of scale. It may be symptomatic of a lack of imagination. By some estimates, US$90trillion may be required in the next two decades.

10. Tim Flannery: Atmosphere of Hope p 186

As Jedediah Purdy[11] puts it, market oriented perspectives that point to positive outcomes are also a form of 'eco-utopian economics'. He challenges the argument that markets will create natural incentives, through pricing mechanisms and investment dynamics, to deliver capital where it can have most impact. The governor of the Bank of England has issued dire warnings about the scale and impact of the structural changes in the fossil fuel industry on financial stability and on long-term income for pension funds. Recent work by Professor Simon Dietz of the London School of Economics suggests that the value of the world's financial assets might be cut by US$2.5trillion. The worst case scenarios suggest that US$24trillion – 17% of the world's assets – is at risk.

On the other hand, the 'sustainability economy' may lead to large-scale systemic and compound innovation, with many opportunities for economic growth, confounding the dire predictions of some economists. There are reasons to be optimistic.

The politics of complexity and time

Having shifted on the continuum between prevarication and panic, might political action emerge, resembling a 'Marshall Plan' of urgent, global scale, increasingly innovative, and integrated intervention?

Further evidence of growing commitment came in the G20 summit in September 2016, with support for the Chinese backed the 'Green Finance' initiative to drive green investment. Again in September, then-President Obama signed a Memorandum to link climate and national security. For the first time climate related change will be factored into security policies and plans. In late October, global agreement was reached to phase out man-made hydrofluorocarbons (HFC), which may help reduce global temperatures by 0.5 degrees.

Even so, there are mixed signals. There are few signs of political stability in an age of intense media scrutiny, rising populism, and ideological fragmentation. The UK Brexit vote, EU turmoil, and growing international tensions with Russia and in the Middle East are amongst the many signs that political institutions can fall short of the visionary leadership needed to deliver collective action to meet long-term grand challenges.

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11. Jedediah Purdy: After Nature

The scale of the challenge, as Jeffrey Sachs has recently argued in the context of comments on energy markets, may be beyond national governments:

→ **"'The world's governments have never before attempted to remake a core sector of the world economy on a global scale with such an aggressive timeline... if governments plan only 10-15 years ahead, as is typical in energy policy, rather than 30-50 years, they will tend to make poor system-related choices."[12]**

Yet the evidence is growing that countries facing major crises are beginning to act in ways that Mariana Mazzucato suggests in calling for the intervention from the 'entrepreneurial state':

→ **"On its own, the free market will not develop new sources of energy fast enough. The payoff is still too uncertain. Just as in previous technological revolutions, rapid advances in clean energy will require the intervention of a courageous, entrepreneurial state, providing patient, long-term finance that shifts the private sector's incentives. Governments must make bold policy choices that not only level the playing field, but also tilt it toward environmental sustainability."[13]**

Whilst concerted international policy and institutional interventions may live up to the promises made in Paris, we are beginning to see fundamental structural changes in political attitudes at all levels, right down to local communities.

Creative cities: integrated action?

Against this background, the most likely scenario on the horizon is that we will face both a volatile, unstable climate and radical, integrated, systemic innovation. And with it, political and social upheaval.

This brings us to the key question, the answer to which will largely determine ecosystem security for most of the world's population.

Who can act, coherently and strategically, within a long term framework, in these 'system of systems' terms and deliver integrated solutions? The answer in principle is not all stakeholders, or global leadership teams, but creative cities.

...the most likely scenario on the horizon is that we will face both a volatile, unstable climate and radical, integrated, systemic innovation. And with it, political and social upheaval.

In practice it is cities that have the potential to become the hubs of innovative, effective, and financially viable action, despite the fact that many of them are on the front-line – literally and metaphorically – facing rising sea levels and storm surges. They may emerge as islands of stability in a turbulent world.

It is to cities that we now turn.

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12. https://www.project-syndicate.org/commentary/clean-energy-implementation-politics-by-jeffrey-d-sachs-2016-04

13. Mariana Mazzucato: The Entrepreneurial State

CHAPTER 2

Megacities

complexity, risk, and creativity

It is well known that cities are growing at unprecedented rates.

About 51% of the world's population already live in cities, and this is projected to rise to 75% by 2050. There are 425 metropolitan centres of 1 million plus people, with 650 expected by 2025.

According to the OECD, by 2025, one billion urban residents will join the 'consuming class', 60% of them "concentrated in 440 cities in emerging economies that are projected to account for nearly half of global GDP growth between 2010 and 2025".[1]

In some ways, the growth of cities is a success story. They are not only sources of creativity, innovation, and growth, but many are intrinsically resilient and resource efficient.

Yet climate change, food security, health, energy, base level resources, poverty, and inequality all present severe and growing threats to security, the economy, the financial system, and, above all, the megacities that stretch along coastal regions – the so-called 'littoral states'.

The more extreme climate scenarios that project a possible rise in global temperatures by four or more degrees centigrade may see many major cities vulnerable, including Bangkok, Dhaka, New Orleans, Miami, Greater New York City, Tokyo, and Rotterdam. Some coastal cities may be forced to resort to a managed retreat, as the projected costs of defenses against storm surges, flood, and extreme weather become prohibitive – risks potentially amplified by shortages of credit and finance.

The more moderate 'two-degree world' still suggests that higher temperatures will have deep and unpredictable impacts on water resources, with knock-on influence on energy supplies and particularly food production, with impacts on not only land based productivity, but changes in the sea acid balance threatening fishing – a primary source of protein.

From another perspective, a question asked some time ago by the IMF was "who will pay?" This still unanswered question is more pressing than ever, with government institutions at all levels facing ever-accelerating financial demands in a low-growth and potentially deflationary long-term environment.

1. Cities and Climate Change, OECD, September 2014

Escalating risk?

What is less well recognized is that urban growth, combined with rapid technological development in cyberspace, artificial intelligence, robotics, and the Internet of Things (IoT), will create rising levels of interdependence and, in turn, potentially unmanageable risk.

The last few years have seen important progress in mobile computing; complex systems theory and methodologies; predictive big data analysis; remote, embedded and mobile sensors; and crowd-centred data aggregation. These are all positive developments, yet one of the critical uncertainties is whether this 'information layer' and embedded intelligence will bring net benefits to dealing with threats, or become a source of threat and risk itself.

As we describe elsewhere, the positive scenario may not play out easily. New governance models may not emerge. The arrival of Internet Protocol Version 6 (IPV6), the enabler of the IoT, may lead to rapid innovation that enables integration, but may also drive growing insecurity. Political, business, and city leadership teams may not work together towards a common purpose, but remain fragmented.

If the cycle typical of rapidly evolving complex systems holds true then we will first see early benefits, as connectivity and interdependence will generate novelty and innovation. Over time, systems will reach high levels of fragility, in part because leadership teams cannot understand how to govern a world with innumerable and densely interconnected working parts.

This may then ultimately lead to vulnerability and collapse, unless city systems are deliberately designed and integrated – a set of strategic and design skills that remain rare at any level of government and policy making.

Core infrastructure: a growing opportunity

Yet there are signs that the nature of these risks is being recognized. The Cities Climate Leadership Group (C40) is committed to action on climate mitigation and adaptation. The Rockefeller Foundation is focused on resilient cities and a new way of thinking based on predict and prepare. There are many other similar initiatives.

The more positive and likely scenario outcome is that at the city level, the boundaries between energy, water, and food production will become blurred and then disappear relatively quickly, giving way to highly integrated, holistic strategies focused on resilience and innovation. This will be driven in part by socio-economic factors that increase the risks of inequality, or urban terrorism, but more importantly by community-level concerns about the physical environment and demands for radically improved resource efficiency – above all air and water quality.

We will see the emergence of novel approaches that address the emerging and long-term challenges of urban resilience and security as a system-wide set of inter-related services and capabilities.

STANTEC EXPERIENCE

City of New Orleans, Louisiana Flood Risk Reduction.

From one of the world's largest drainage pumping systems to neighborhood-based green infrastructure improvements, a holistic approach is helping the City of New Orleans improve all their interactions with water.

Cities have the opportunity to address all these challenges. They have the potential to become macro-level systems integrators, working with ecosystem designers and infrastructure engineers to deliver real world solutions.

Leadership teams, recognizing their power to act, are beginning to embrace the idea of the 'creative city', leveraging their entrepreneurial, innovative talent and sense of shared identity and belonging. More important, by focusing on climate-resilient, decentralized and integrated renewal of outdated infrastructure, there are opportunities to drive economic growth.

In financial terms, as the OECD put it, cities have the chance to deliver "systemic change that raises only slightly, or even lowers, overall investment costs".[2] As many cities are recognizing, long-term strategies focused on resilience and efficiency attract funding from institutional investors and sovereign funds focused on dealing with climate risk.

Cities have the opportunity to attract investors looking not only for long term returns, but willing to invest risk capital associated with innovation. This is a higher-level strategic and systems design agenda and goes beyond water-related linkages with energy and agriculture. It is about distributed, networked systems integration, the topic of separate essays.

In summary, megacities are at the heart of many of the grand challenges over the next two decades. Whether city leaders and empowered communities have the vision to meet these challenges and put vision into practice is one of the most important questions the world faces.

2. Cities and Climate Change, OECD, September 2014

CHAPTER 3

Distributed, networked infrastructures

an emerging new paradigm

One of the uncertainties that has long pervaded the energy industry is the economics of decentralization.

The question is simple: will new thinking, business models, and technologies, such as high efficiency micro-solar panels, battery storage, and novel generation systems, drive a revolution in energy production and localized distribution for cities, local communities, households, and businesses?

The answer is that this is not just a possibility, but highly probable. The relationship between efficiency, cost, and scale in solar, for example, means that in the next decade, we will see an explosion in growth in micro-generation and distribution not just in the developed world, but even in the most remote areas.

In the same period, we can expect battery technology to deliver tenfold improvements in power and storage capacity, at lower prices. Combine this with high efficiency building design and some of the pieces of the energy security puzzle fall into place. Taken together, these developments may threaten centralized electricity utilities, and at the extreme, leave them and their investors with stranded assets.

The question is then whether similar models might be applied to water and wastewater recycling and whether these might be linked both to energy and agricultural infrastructures. The answer appears to be yes.

If we take this a step further and link all this to systems software and sensors that enable novel combinations of centralized and localized distribution and production, then we have the beginnings of a new paradigm in which distributed networks and ecosystem design play a decisive role.

None of this is as far-fetched, nor as difficult as it may seem. We can see the opportunities as three related themes: political and institutional vision and design; system-wide technology innovation; and investment funding.

Political and institutional vision and design

How this vision of distributed, highly integrated and resource efficient water, energy, and agriculture systems might be delivered is a primary challenge facing national, city, and utility leadership teams around the world.

Re-thinking how scarce resources are managed is a top priority. For some countries and local communities, weather conditions and near-term climate forecasts are creating a sense of a clear and present danger that, at a superficial level, might be seen to guarantee decisive action.

Even so, there is scepticism: will entrenched political, institutional, commercial, and financial interests and, more importantly, short-term cultural world-views stand in the way of radical change? After all, inertia is a tough barrier. Utility firms, amongst others, are often seen as stable and reliable as a source of investment returns. Why change when the risks seem abstract and far ahead in the distant future?

Either way, there is little doubt that visionary, collaborative leadership is critical if some of the more extreme outcomes are to be avoided. And given the time lag in development, speed counts.

The question is simple: will new thinking, business models and technologies, such as high efficiency micro-solar panels, battery storage, and novel generation systems, drive a revolution in energy production and localized distribution for cities, local communities, households, and businesses?

Fortunately, both world-views and technologies are changing. Corporations and local communities want action on resource efficiency and sustainability. Some city leaders are beginning to act. Complexity is seen as something to be understood and managed. The Internet is both an infrastructure and a guiding metaphor for network design that encourages leadership teams to look at infrastructure holistically. The need to take a long-term view and act on it is widely recognized – even if it is not reliably translated into practice.

Against this background, decentralization, which implies one size fits all localized services, is, in reality, a misnomer. Networks can be made up of large scale hubs and small scale nodes. The key is that they must be designed specifically to meet local conditions. ‘Distributed networks’ is more accurate.

We can see the components of the overarching design principles clearly. The starting point is to envision water, energy, and agriculture as inter-related, as we argue elsewhere. There are some early examples, such as Sydney's Green Infrastructure Plan to 2030, which as the authors put it "enables us to look at green infrastructure holistically by combining the Master Plans for Decentralized Energy and Decentralized Water into a single Green Infrastructure Plan."[1]

What is missing in the Sydney vision is agriculture, but the call to action is explicit:

→ **"Similar to centralized energy, centralized water solutions are inefficient, unsustainable and highly vulnerable to climate change. Similarly, the amount of pollutants entering our waterways is not acceptable. We cannot allow such outdated solutions to compromise the social, economic and environmental wellbeing of the city."**

It is becoming clear that the efficiency gains to be achieved through integration and system design will soon enter the mainstream and can be applied globally. The question is how they can be delivered. This depends not just on leadership and institutional design, but, more than ever, emerging technological solutions and innovation.

STANTEC EXPERIENCE

Integrated Water Cycle Solution, Googong, New South Wales, Australia.
A new 6,000-home township near the Australian capital of Canberra planned to use only 40 to 45 percent of the potable water typically consumed by similar communities.

1. http://www.cityofsydney.nsw.gov.au/vision/towards-2030/sustainability/water-management

Waves of technological innovation

The expression 'systemic failure' is ingrained in peoples' minds after the 2008 financial market crisis. Less familiar, but equally important, is the idea of 'systemic innovation', which describes how the convergence of technologies creates disruptive change.

Whilst individual inventions may enable us to make accurate predictions, large scale systemic innovation is more challenging. This is where the role of systems integrators is critical: the fundamental challenge is about both ecosystem design and innovation.

The convergence of disruptive changes in automotive, oil, and electronic matching systems, such as Uber, is a recent example of how quickly market fundamentals can change in peoples' imagination. Long before technologies mature, the new ecosystem narrative for urban transport is driving innovation, market, and investor behaviour. By definition, the principle is that physical distribution can be seen in a similar way to electronic networks, where some functions, such as wastewater treatment, may remain as centralized utilities while others are decentralized to the level of individual homes, workplaces, and devices.

Of the many white space opportunities on the horizon, the intersection of water, energy, and agriculture stands out and has the potential to become one of the defining themes of global innovation.

As we will see in a separate essay on the digital revolution, the IoT, which envisions multiple interconnected devices operating under standard protocols across cloud networks, will play a vital role.

From another perspective, 3D manufacturing and a 'maker' culture is growing rapidly at the intersection of digital technologies and DIY traditions, particularly in China. This networked culture and technology delivers localized production, driven by openly available databases of designs and technologies. We can expect large scale disruption, as the best locally developed, low cost solutions to specific problems will be distributed via electronic markets that operate in a similar way to App stores. If, for example, 'at tap' 3D manufactured filtration treatment systems emerge, we can expect them to be distributed very rapidly across the globe.

All this will create momentum and innovation hot spots. Yet this is only part of the story.

The more important development is invention focused in 'white space' (see separate essay). Whereas hot spots are overcrowded and ultimately low value and low margin, white space inventions have the potential to transform markets and generate systemic innovation across sector boundaries.

The intersection of water, energy, and agriculture has the potential to become one of the defining themes of global innovation.

Investment and funding

Over the last decade, investment in utilities and infrastructure businesses has shifted and is now highly globalized, as sovereign funds and long-term wealth managers in particular have sought out steady income in the face of fragile, low return markets. Cross-border ownership is the norm in many markets. There is, however, a looming problem: estimates of the funding requirements for renewing infrastructure range up to US$90trillion over the next two decades.

The difficulties with these estimates, authoritative as they are, is that the assumptions do not take account of the disruptive nature of technology. Many begin with expressions like 'on current trends'. Bringing together water production (such as desalination) together with energy and agriculture has the potential to transform not just innovation, but the economic and investment landscapes.

If we think about the technologies already on the horizon, the world may look very different. We may see investors becoming increasingly cautious about funding utilities unless they demonstrate they are committed to radical cost saving and efficiency. The possibility of 'stranded assets' is always a key question, so any infrastructure strategy that assumes steady state, low technology development with cash returns skewed to the long term will find little support.

On the other hand, many of the technology developments that encourage distributed networks can be widely applied across water, energy, and agriculture. They will find global markets, produce relatively short term returns, and attract substantial funding. Integrated micro-solar, water purification, and irrigation systems are just one example.

This leads to the conclusion that there is an emerging alignment of interests between governments and city leaders seeking efficiency; utility firms aiming to enhance their license to operate; and institutional investors, who are looking to invest in coherent, integrated strategies that meet the wide array of demographic, social, economic, and climate demands.

The challenge for cities and utilities above all is to quickly rethink strategies that match the emerging, more diverse, networked, and distributed operating environment.

We may yet find that public opinion and local community action become the primary drivers of both technological and cultural change.

There is no doubt that cities have a vital role. Yet it is the emergence of specialist systems integrators that may become decisive. This is where we turn next.

CHAPTER 4

Systems integrators and white space

from theory to practice

Nanotech. Robotics. Machine intelligence. Predictive analytics. Whilst a myriad technologies will play vital roles in defining the future of water, energy, and agriculture, their real impact depends not on the transformative power of the specific technologies themselves, but also how they will be financed and integrated across systems.

To put this in context, water both cuts across and links all primary infrastructures. It is essential in the production of both food and energy and therefore at the heart of economic and human security.

At another level, as with any deeply interconnected 'system of systems', a decision made within one domain can trigger repercussions in another. For this reason, infrastructure and resilience issues cannot be tackled by any single sector or set of stakeholders alone.

This means system integration is vital, both in terms of technology and stakeholder strategies and market structures. If distributed networks are the emerging new paradigm, then systems integrators will make the paradigm a reality.

We have seen this structure and pattern develop in other industry sectors. To illustrate, two large-scale integrators dominate aircraft manufacturing: Boeing and Airbus. Each has a network of suppliers, with just two or three specialists for engines, windows, and seats. We can see the same structure in enterprise software with SAP, IBM, and Oracle. In real time financial information, Bloomberg and Thomson Reuters dominate. Facebook, Twitter, Google, and Apple shape social media and consumer technology. Scale matters. The big get bigger. Integrators operate as networks, drawing on the inventive skills of innovative startups and collaborative partners alike.

If distributed networks are the emerging new paradigm, then systems integrators will make the paradigm a reality.

The same structures can be expected to emerge over time at the intersection of water, energy, and agriculture. Multinational and non-governmental organizations are beginning to fulfill the role, but are some way from building the level of innovative cross-sector linkages and technological architectures that will drive new models and ensure advances in one sector, say energy, are not made at the expense of water or food.

Transforming the landscape

More important, given the scale of investment required to support infrastructure development, broadly based systems integration has the potential to transform the economic and financial landscape.

Two scenarios are emerging. In one, highly innovative, integrated systems deliver step changes in resource efficiency, security, resilience, and returns on investment. In another, fragmented infrastructures leave entire communities and many major cities fragile and vulnerable, particularly in the face of a changing climate.

Integrated systems have genuine disruptive potential. To take one example, an early 2015 study by Gary Gold and Michael Webber suggests that desalination facilities powered by wind and solar energy could reduce “grid-purchased electricity costs by 88% during summer months and 89% during winter when compared to a stand-alone desalination plant”.

Take another example: food production. The annual rate of efficiency improvement in agricultural water use between 1990 and 2004 was just one percent across both rain-fed and irrigated areas. There is a long way to go. There was a similar rate of improvement in industry during the same period. If agriculture and industry to sustain this modest rate to 2030, improvements in water efficiency would address only 20 percent of the supply-demand gap, leaving a large deficit to be filled.[1]

Dramatic improvements are clearly essential, since agriculture makes up 70 percent of global water usage and as much as 30 percent is wasted. Achieving real gains in this sector will require the widespread adoption of updated precision farming techniques and energy saving investment in new digital infrastructures and machinery, together with radical improvements in food transportation practices — where millions of gallons of water are lost each year.

Energy policy brings together another set of complex interdependencies and trade-offs. The International Energy Agency (IEA) has consistently forecast that global energy demand will increase by 35-40 percent over the next two decades. Equally important, the IEA’s 2014 World Energy Outlook forecasts the investment required in energy supply in the region of US$40 trillion and US$8 trillion in efficiency terms.

The increase in global energy pressure could lead to a 165 percent increase in fresh water needs.[2] Energy production requires water and vice versa. The spiralling effect is clear.

1. Water Security: The Water-Food-Energy-Climate Nexus. World Economic Forum Water Initiative. Island Press, 2011

2. The Danish Hydraulic Institute, A Water for Energy Crisis?, 2007

Interdependency, integration, and white space invention

There is a world of difference between interdependence that emerges over time and integration by design.

This distinction is becoming clearer than ever, as the growing complexity of the human-made world is better understood. Advances in one sector can offer unique opportunities for effective, design-led integration and innovation in another.

For example, wind and tidal energy installations can be deployed to provide localized power to desalination plants located near oceans and other large bodies of salt water. As solar power becomes cost effective, the potential for large scale roll-out becomes viable. There are projects underway that provide solar powered desalination units to communities separated from utility grids.

We can see these early stage projects as the first signs of white space innovation across the water, energy, and agriculture boundaries. To put this in perspective, white space is usually defined as an area at the intersection of technologies and markets where the products or patent coverage is weak or non-existent, but commercially valuable.

STANTEC EXPERIENCE

Adams Crossing, Brighton, Colorado.

A Net Zero community in Colorado with integrated agriculture, energy harvesting (photovoltaics and geothermal), and water reuse.

Inventing in white space is about creating new paradigms and by definition market leadership; generating higher margins and returns and sustainable differentiation. In contrast, innovation hot spots are overcrowded, with many overlapping and competing claims, patent 'clusters' that ultimately mean low returns.

White space is where disruptive technologies emerge that have the potential to transform markets, particularly if they create innovation across established system boundaries.

This is where we can expect large-scale invention between water, energy, and agriculture, not just in technological terms, but also in business models and resource management. It is also where the role of the forward looking, innovative systems integrators, working in partnership with communities and cities, will have a decisive role.

We can see these early stage projects as the first signs of white space innovation across the water, energy, and agriculture boundaries.

Here, entrepreneurial investors and specialist fund managers will look for exceptional returns. After all, many of the most successful products, services, and businesses are based on inventions in white space.

While the prospective synergies between sectors will grow rapidly, innovation alone will not be enough. Close collaboration and integrated design is required to ensure that other high risk and potentially counterproductive scenarios do not play out.

For example, in some cases, renewable energy production is directly at odds with water conservation efforts. Concentrated solar thermal technologies, whilst holding promise as a long-term renewable energy source, are also heavy consumers of fresh water. Similarly, many biofuels promise to counteract global warming but, in turn, use far more fresh water in their production than some conventional fossil fuels. An increase in water used for the cultivation of natural biofuel materials could have a knock-on effect for food production, increasing competition for both water and arable land.

Even so, if innovation is the primary driver of economic growth, as people like Robert Gordon suggest, then the landscape of early stage ideas, hot spots, and potential white space are key leading indicators not just of industrial transformation, but broader global social and economic well-being.[3]

Systems integrators will move centre stage.

3. Robert J Gordon 'The Rise and Fall of American growth'

IN BRIEF

The secret world of invention

Invention is the source of wild cards: developments that cannot easily be foreseen, yet have major impact.

Commentators and economic forecasters are often silent on the potential value and impact of disruptive ideas, simply because they are not yet articulated, or even imagined. Ideas belong to a secret world.

The conundrum is simple: how to forecast the future value of innovation in a world of profound uncertainty?

Yet beneath the surface is a silent revolution. We can begin to map the world of ideas and intellectual capital to improve forecasting accuracy and insight.

Given the lag between invention and commercialization, these so-called intellectual capital landscapes have strategic value, since patterns in the evolution of ideas give vital early indications of the shape and structure of industrial, product, and economic revolutions well before commercial products and services emerge.

The long heralded knowledge-driven economy is, after all the early hype, transforming itself into an economy driven by innovation. Knowledge is becoming increasingly codified, distributed, and transparent. Open innovation is growing.

This means that taken together, intelligence about invention is set to become a key driving force of self-replicating waves of change. This will go some way to correcting the common mistake in forecasting the impact of new technologies.

Most analysts focus on specific devices and applications, rather than on systemic innovation. There are few genuine foundational inventions, but the integration of multiple inventions frequently creates new markets. In other words, this form of innovation is difficult, but not impossible, to forecast.

This is important, since there is growing evidence that the ‘sustainability economy’ is an emerging, yet still early stage hot spot, particularly as China focuses on core water, energy, and agriculture infrastructures. China is on track to become the world leader in R&D spending by 2022.

As we note elsewhere, if innovation drives economic growth, then the landscape of ideas is a leading indicator not only of industrial transformation, but of prospects for broader community, social, and economic well-being.

CHAPTER 5

Digital intelligence

ecosystem design and engineering in the emerging Anthropocene age

The digital revolution in water, energy, and agriculture has only just begun. It will play a vital role in transforming ecosystem design and engineering in an increasingly volatile environmental and political future.

A myriad of digital technologies are emerging and reaching maturity over the next decade. They will bring with them ever-greater connectivity and speed, transforming the inter-relationships between the natural world, human activity, and machines.

Technologies range from microscopic, embedded chemical and visual sensors at one extreme, to complexity modelling and simulations, predictive analytics, and new generations of city-scale infrastructure design at the other. Real-time analytics will drive new forms of decision support, operational efficiency, and customer services.

Further ahead, we can see the prospect of general purpose learning machines and potentially novel forms of artificial intelligence.

In the short term, it is easy to be dazzled by individual devices, but the dominant emerging narrative is not the technologies themselves, but the growing importance of digital intelligence integrated with large scale infrastructure architectures.

Growing interconnections increase the risks of fragility. Yet these developments point to systemic innovation where it matters most: in ecosystem design and management, and the efficient use of natural resources.

From sensor world to systems of systems

The simplest way to view the rapidly evolving landscape is from ground level up, on a scale starting with the sensor devices that will generate vast amounts of data about the dynamics, behaviour patterns, and conditions of the real world.

We are already seeing the emergence of embedded laboratories that can measure, monitor, and report to network control systems about water quality, chemical changes, pollution, and toxicity in real-time.[1]

1. See Libelium's range of smart water devices and applications: http://www.libelium.com/smart-water-sensors-monitor-water-quality-leakages-wastes-in-rivers-lakes-sea/

In energy, sensor networks are already pervasive, improving efficiency and reducing the need for human intervention. In agriculture, irrigation systems operate remotely and sensors detect early indications of disease and soil conditions. Remote control drones, with high definition video and analytics, complete the picture of total surveillance and monitoring.

This is just the beginning. Sensor arrays combining multiple modes of analysis will emerge as interoperability standards for the IoT[2] are established.

Companies like Samsara already offer 'The New Data Platform for the Physical World' and 'Plug and Play Industrial IoT'. Major industry players, such as Microsoft, are investing heavily.[3] As Marc Andreesen puts it: "In 20 years, every physical item will have a chip implanted in it." We might say lab, rather than chip. Some would say 10 years, not 20.

To put this in another context, some estimates suggest that over the next two years, we will add more computing power than in all previous history. Others say that we will add a 1,000 times more in the next 24 years. The implication is that digital intelligence will follow a pattern driven both by Moore's Law[4] and Metcalf's Law (the more connections, the greater the value of the network).

What does this mean in practice? Some of the applications enabled by the explosion in sensors are about straightforward remote management and autonomous operations. Others are more specifically concerned with robotics. Patent filings covering robotics technology have soared. According to patent research company IFI, annual filings have tripled over the past decade. China alone accounted for 35 percent of robot-related patent filings in 2015.[5]

In practice, we are seeing the emergence of the long heralded convergence between artificial intelligence, sensors, robotics, and distributed networks.

Other applications echo the decentralization and distributed networks themes, with domestic devices integrating solar power, new generations of battery storage, and smart meters. Similar solutions are emerging to monitor usage and automate rainwater collection, waste, and recycling. Some of this is driven by entrepreneurs and public-private-partnerships focused on solutions in the developing world.[6]

The fact that so much investment is focused on areas where there is little investment capacity for large scale infrastructure supports the argument that digital intelligence and invention will lead to distributed networks that combine both large-scale plants and domestic resource management. Taken together, this will act as the catalyst for radical innovation focused on taking domestic energy and water off-grid, both to improve security and reduce costs. It will also form part of locally driven community action. Everything will be digitized, from the water and energy usage of individual households to short term weather forecasts and satellite based climate monitoring.

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2. IoT is defined by Pew Research as "A global, immersive, invisible, ambient networked computing environment built through the continued proliferation of smart sensors, cameras, software, databases, and massive data centers in a world-spanning information fabric."

3. http://www.ft.com/cms/s/0/c8e2e1d0-0861-11e6-a623-b84d06a39ec2.html#axzz46TWCqSr4

4. The simplified version of this law, which is coming into question, states that processor speeds, or overall processing power for computers, will double every two years.

5. https://next.ft.com/content/5a352264-0e26-11e6-ad80-67655613c2d6

6. See Breakthrough Energy as an example: http://www.breakthroughenergycoalition.com/en/index.html

From systems to complexity risk

If one extreme outcome over the next 20 years is a perfect, dynamic, living map of the real world imagined by Borges[7] and deepening inter-operation between people, places, things, and the natural world, there are some critical uncertainties and risks that must be addressed.

First, there is evidence that integrated systems will increase risk, rather than reduce it. This suggests that the IoT, coupled with the rise in cyberwar and terrorist activity, will lead to an increase in vulnerability. The growth in the scale and impact of major cyber-attacks show that even mission critical systems are at risk. The major denial of service (DOS) attack that brought chaos to the East Coast of the US in 2016 (hitting sites like Twitter, PayPal, and Spotify) linked to Dyn, an Internet infrastructure hub used in IoT devices, such as outdated security cameras.

Recent headlines illustrate the fundamental weaknesses in core infrastructures. For example, a headline about insurance, finance, telecommunications, entertainment, and US federal security agencies: "Cyber Breaches Hit Staggering Levels".[8] Core infrastructures are prime targets, from multiple sources. Cyberwar incidents are part of the fabric of international politics and diplomacy.[9]

The second is more abstract: the risk of complexity itself. Layers of complexity — of natural systems, basic resources, man-made infrastructures, business, media, finance, and global trade — first created growth and now, as these critical networks become more densely linked, a web of fragility.

By definition, as interconnections in networks grow, so does interdependence and over time, fragility. Networks become, in the language of complexity theorists, 'tightly coupled', which means that they are more vulnerable to systemic failure emerging from small and seemingly benign events. They are inherently unpredictable.

The greater the complexity and speed, the greater the challenge to understanding, control, and leadership. There is growing evidence that the messy world of politics, the economy, and, above all, financial markets are beyond understanding. The still unexplained 'Flash Crash' and the risks associated with high frequency trading illustrate the problem. After the US$81million heist at Bangladesh Bank in 2016, SWIFT, the interbank money transfer system at the core of the financial markets, reported further intrusions later in the year, illustrating the scale of the challenge.

From complexity risk to ecosystem design and engineering

The same is true of other complex infrastructures. Leadership teams are often ill equipped to deal with emerging risks in the world around them or the systems on which they depend. They lack the strategic intelligence, diversity, and inventive capacity to adapt. They risk finding themselves overtaken by waves of shocks.

7. On Exactitude in Science

8. http://www.ft.com/cms/s/2/698deb42-200b-11e5-aa5a-398b2169cf79.html#axzz3zZstp7th

9. http://uk.reuters.com/article/us-usa-cyber-obama-statement-idUKKCN0VQ2PH

To many, this implies a world of runaway machines beyond human control and deepening risk. Yet there is evidence that digital intelligence, and in particular AI, holds many of the answers. There is race between exploitation and security.

What is missing from the risk narratives is that as interconnections develop, so does innovation. If we step back and look at how complex systems evolve, we can see increasing novelty, radical invention, improved efficiency, and better performance. This is how we can expect the next cycle in water, energy, and agriculture to play out as digital technologies become pervasive.

In an ideal world, growing fragility will be met by innovation in the systems design, specifically developed to reduce interdependency and tight linkages.

This means that the first strategic benefit emerging from this 'system of systems' perspective, driven by increasingly rich and well codified data about the physical world, is ever wider and deeper understanding of the structures, dynamics, and potential risks of ecosystem complexity. This is driving the new 'urban ecology' philosophy – the analysis of the relationships between living things with each other and their surroundings in the context of urban environments.

Modelling software, some of it with roots in engineering, is already capable of analyzing levels of interconnectivity, system density, and fragility, and in turn identifying both complex relationships and potential trigger points of failure.

The second benefit is that complex systems will come under the control of predictive models, enabling a new generation of secure, integrated, city-wide systems structured to reduce vulnerability. Third, these systems will become pervasive and increasingly accurate as data is more sophisticated. This promises a revolution in adaptive systems design, integration, and management.

These developments are already entering the mainstream. The two overarching themes are not sensors, big data, or AI per se, but simulation and prediction.

The digital revolution is just beginning, led by ecosystem engineers and integrators at the intersection of the physical and digital worlds. The prize is self-sustaining, bespoke local infrastructures optimized to manage scarce resources, delivering water, energy, and agricultural security and, in doing so, mitigating widespread fears about existential risk to societies around the world.

General purpose learning machines: AI summer?

In 2016, DeepMind's 'Alpha Go' beat the world's leading Go player. Go, a 2,500 year old skill based game, even more complex than chess, was not expected to be beaten by a machine for at least another decade.[1] Is this milestone, which some say heralds the emergence of a new era dominated by artificial general intelligence, a stepping stone towards general purpose learning machines?

The DeepMind system used deep neural reinforcement learning from human experts (similar in principle to how animals learn using dopamine reward mechanisms), together with 'value networks' and techniques that incorporate long term planning and 'look-ahead searches'.[2,3] It is no coincidence that Demis Hassabis researched the neuroscience of futures thinking before founding DeepMind.

Yet the goals of current AI revolve around integrating insights from large scale source data that may not be available in the real world. Critics argue that without deep, high grade data, AI faces severe limitations. And unlike games, the real world cannot be easily simulated over millions of iterations. In other words, deep learning AI techniques depend on investment in application-specific big data.

This means that questions remain about whether new generations of AI systems will deliver, for example, genuinely valuable analysis in modelling core infrastructure.

"AlphaGo, the computer program developed by Google DeepMind, won the board game Go against the world's best player because it could use a database of around 30 million moves and play thousands of games against itself, 'learning' how to improve its performance." *- Luciano Floridi*

Some specialists, including Gary Marcus and Luciano Floridi, question whether AI progress is genuinely important, or whether it will, for some time yet, remain valuable in only specialized, narrow applications.[4,5] Floridi's argument is that 'true AI' is utterly implausible. In practice, however, whilst fundamental strategic, ethical, and philosophical uncertainties will remain, AI will make a major impact.

Over the next decade or two, we can expect waves of specialist AI applications to make use of the vast array of both open and proprietary data to pervade all industrial sectors, driving major structural change. More important, AI will act as the bridge between sectors, enabling new generations of predictive analytics and simulation services to play a central role in the design, monitoring, and management of large-scale infrastructures.

In the meantime, the competing narratives, clear indicators of deep uncertainty about the possible long-term outcomes, look set to run and run, with AI summers and winters, for the time being, both on the horizon. Expect surprises.

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1. Nick Bostrom: Superintelligence
2. http://www.nature.com/nature/journal/v529/n7587/full/nature16961.html
3. http://www.nature.com/nature/journal/v529/n7587/full/nature16961.html
4. https://www.edge.org/conversation/gary_marcus-is-big-data-taking-us-closer-to-the-deeperquestions-in-artificial
5. https://aeon.co/essays/true-ai-is-both-logically-possible-and-utterly-implausible

CHAPTER 6

Desalination, brine mining, and resource efficiency

One of the founding principles of the so-called circular economy is to develop novel solutions to the reuse and recycling of waste materials, across the board, in all sectors of the economy and industry.

Circular can be seen to mean resource efficiency. It is a well-established principle in the water industry, but applies equally to energy and agriculture.

New technologies are opening up the possibility of not only reducing waste, but of generating new sources of revenue from rare earth mineral extraction in industrial water and wastewater treatment plants. In parallel, we are seeing the emergence of technologies to improve undersea mining with a similar purpose – mineral extraction – that may cross over and accelerate longer term development. The potential and scale of one particular and emerging variant – integrated desalination and brine mining – has not yet been recognized.

The outcomes, as ever with advanced technology, will remain uncertain for some time yet. But there is evidence of steep rises in the annual rate of patent filings and in the quality of the applications, both clear indicators of the scale and value of research and the likelihood of breakthroughs.

Desalination: a slow revolution?

Desalination and brine mining may be a partial solution to the otherwise intractable problem of producing vastly increased amounts of fresh water to meet fast rising demand.

Some analysts argue it is the only solution, beyond step changes emerging in fresh water efficiency. The reality is that efficiency alone will not be enough and ultimately the world needs to produce more water. In practice, if long-term water security is to be achieved, there seems to be no alternative to desalination at both large and small scale.

This view is borne out by the rapid growth in desalination plants around the world, which have tripled since 2000 and now stand at more than 16,000. Perth, facing the prospect of becoming the world's first 'ghost metropolis'[1] because of water shortages, now generates 47% of its total supply from desalination. Singapore has commissioned a fourth major plant and aims to be 85% self-sufficient by 2060, up from about 55% in 2016.

1. Tim Flannery, 2004

A variety of integrated and sensor-driven, membrane and other technologies are emerging that may lead to smaller, mobile plants that can be delivered more economically and quicker than the 10- to 15-year cycle typical of large scale installations – a lead time that has acted as a deterrent to private and institutional investors. Some nano filtration technologies are designed specifically to reduce energy consumption. Graphene membranes have been shown in the lab to cut consumption by as much as 46%.[2] Graphene-based desalination systems hold the promise of cutting overall costs by 15-20%.[3]

Desalination technology is also playing a part in international technology transfer and patterns of investment. To illustrate, Israel, which relies on desalination for 25% of total water production, is a leading exporter, particularly to China. The operational costs of desalination in China are falling quickly, with the increase in installed capacity.

Brine mining

Nanotechnologies may reduce energy consumption, such as the integration of hybrid solar/water plants, but brine disposal remains a significant barrier to genuine efficiency. Typical plants generate about 55 percent brine from seawater production. Returning the brine to underwater ecosystems, or transporting waste for disposal, presents formidable ecological and financial problems.

Desalination and brine mining may be a partial solution to the otherwise intractable problem of producing vastly increased amounts of fresh water to meet fast rising demand.

Whilst disposal of brine acts as a brake on the scalability of desalination, mining brine to extract rare minerals may begin to change the dynamics in other ways. Brine contains about 60 elements of the periodic table in the form of metallic and non-metallic ions. Depending on the region, these constituent elements can be mined for numerous uses as fertilizers, plastics, solvents, and even construction.

Brine mining technology has been around for years, but its application in desalination has been limited due to insufficient volumes. As desalination becomes more cost effective on the back of other technological advances, these volumes may increase - radically improving the underlying economics of brine disposal.

About 30 percent of the materials in brine can be extracted through a simple evaporation process. These ‘evaporites’ are of relatively little value. However, through the use of more complex and less well-developed approaches, more valuable materials, such as sodium (Na), magnesium (Mg), potassium (K), bromine (Br) and boron (B), might be harvested for use as fertilizers, alloys, ceramics, and pharmaceuticals. Additional trace metals, while more difficult to extract due to their low concentrations, hold an even greater commercial value. Elements like Rubidium (Rb), Lithium (Li), Indium (In), Caesium (Cs), and Germanium (Ge) are used in fibre optics, electronics, batteries, and aeronautics.

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2. Jeffrey Grossman, MIT
3. John Stetson, Lockheed Martin

Perhaps the most potentially transformative technology in this market is Zero Liquid Discharge (ZLD), the focus of GE's patent activity over the last decade. As the name suggests, ZLD ultimately aims to achieve 100% water recovery rates, with GE currently claiming 95%.

China: driving innovation

It is well known that the speed of China's economic and population growth has contributed to serious problems of widespread water inefficiency and pollution. Chinese industries are generally 10-20 percent less water efficient than their counterparts in developed countries. About two-thirds of China's nearly 700 cities have less water than they need. Clean water has been identified as a top domestic priority in China's latest five-year plan and is arguably the most significant limiting factor in China's long-term economic growth.

What is less well known is that China's share of patent filings has been increasing not just in water but also in nanotech related water treatment.

Compared to other parts of the world that are self-sufficient and resistant to water and food shocks, China will likely need to continuously divert investment to meeting near-term water needs to maintain economic and social stability.

The sheer scale and urgency of this problem are primary drivers of water-related innovation within China and of cross-border collaboration with specialist foreign desalination companies. We can expect China to become a leading innovator, a pattern that is already clear from government investment figures.

Looking further ahead, we can begin to see revolutionary new applications of algae-based technologies. Certain types of algae thrive in high saline environments. Under the right conditions and in sufficient numbers, these minute organisms can produce valuable proteins, beta carotene, and even biofuels, whilst at the same time cleansing the water.

Whilst the potential impact of these and other technologies remains uncertain and timing even more uncertain, the direction of travel seems clear.

Desalination may yet, as some argue, change the world.

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CHAPTER 7

Precision Agriculture

opening the door to water security?

Picture 2035: micro-managed agricultural systems, engineered to deliver maximum yield, maximum recycling, and minimum water usage. High levels of integration between water, energy, and agriculture, all designed and implemented to optimize resource efficiency and deliver long term sustainability – even in the face of rapidly changing local and global climate conditions.

Whether this can be achieved is one of the grand challenges facing not just the leadership teams of major cities and utility operators around the world, but national governments and humanity itself. The question is whether radical changes in agricultural practice can play a significant role.

Agriculture: a primary driver of water consumption

To put this in context, it is clear that demographic changes will increase demand for food production around the world. Population is growing by 80 million a year. Some projections suggest that to feed a global population of 10 billion, a 70% increase in food production will be necessary.

According to UN figures, agriculture already accounts for 70% of all water consumption, with 20% used by industry and 10% attributed to domestic use. In the industrialized nations, "industries consume more than half the water available for human use. Belgium, for example, uses 80% of the water available for industry".[1] Agriculture is also, by some measures, the largest employer in the world.

At the same time, lifestyle changes are increasing water consumption per capita. Energy and bio-fuel production, as well as changes in climate and falling aquifer levels, add to supply pressures.

Precision agriculture

Against this background, the market for precision agriculture is growing rapidly, with much of the early innovation concentrated on large-scale, industrial farming.

1. Source: Worldmeters.info.

Precision agriculture is a catch-all term that includes everything from sensor and data driven software modeling and field management to imaging.

The established industry leaders, such as Monsanto, are focused on satellite imaging, as well as IoT and big data techniques, using field level data collection and analysis to raise yields by improving soil, fertilizer, and water management. In parallel, livestock management is already producing improvements in performance and animal welfare.

In practice, the most interesting and disruptive future innovation is likely to emerge at the intersection of markets and technologies. Market growth is most obvious in large-scale crop management, the other in 'connected farming', illustrated by Trimble's 'Field360' initiative and 'Farm 2050'[2]. We can also expect urban agriculture to grow rapidly as the industry focuses on cost across the entire life-cycle, reducing 'food miles'.

There are several innovation hot spots that illustrate the rate of change and help paint a picture of the emerging landscape towards 2035. Some will have short term impacts - notably software and services that improve efficiency and yield and enable micro-management. Sensors, combined with GPS and remote management software, are already driving rapid growth. The market for software alone is projected by some analysts to grow rapidly to US$1.77billion by 2020. With businesses like Granular, we are seeing the emergence of enterprise software for farm management.

These software-driven techniques also contribute to a change in world-view: farm operators and conglomerates are beginning to see industrial farming in systems terms. Networks of technologies will soon become the overarching design theme. We can expect to see the integration of multiple predictive analytics tools that not only improve efficiency, but reduce network failure rates and minimize losses. Software may be "eating the world", as Marc Andreessen put it in 2011, but in time may help feed the world.

At a more granular level, technologies include image recognition and sensors, machine vision, and autonomous labs embedded in remote devices. The applications range from soil sensors and software that optimize fertilizer performance; to localized micro weather forecasting, water use detectors, and monitoring; to insect alerts, crop health systems, and livestock management. Drones and robotic farming are already part of the language.

Whilst all these changes will over time begin to revolutionize agricultural production, water-related agricultural innovation already ranges widely. Linking real time weather forecasting to farm management control systems is already a reality. There are also innovation hot spots around sophisticated filtration, recycling, and remotely managed irrigation systems.

Even so, the annual rate of efficiency improvement in agricultural water use between 1990 and 2004 was just one percent across both rain-fed and irrigated areas, and there is a long way to go. There was a similar rate of improvement in industry during the same period. Were agriculture and industry to sustain this modest rate to 2030, improvements in water efficiency would address only 20 percent of the supply-demand gap, leaving a large deficit to be filled.[3]

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2. http://www.farm2050.com/#index

3. Water Security: The Water-Food-Energy-Climate Nexus. World Economic Forum Water Initiative. Island Press, 2011

As recently as 2010, it was estimated that only US$10billion was invested around the world in irrigation systems, "a surprisingly low figure given the importance of water for the agricultural sector (in comparison, the global market volume for bottled water in the same year was US$59 billion)". [4] This example, amongst many, suggests that we are seeing the early stages of what may become revolutionary change.

More radical technologies are emerging that may also contribute to easing the pressure on water and agriculture. To take just one example: 3D printing of food and biological systems may transform agricultural production and, in turn, water demand over the next 20 years.

Systemic innovation

All this illustrates that the rate of innovation in precision agriculture and water-related efficiency is accelerating.

The bare facts and sometimes alarmist projections about demographics and food consumption, repeated in different ways around the world, are primary drivers of change. Expressions like 'water stress' are similarly used to describe the need for urgent innovation in water management.

Yet water and agriculture are used as high level categorizations that suggest that the two industries and sectors, long shaped over time as specialist domains, are separate. They no longer bear much relation to reality and must be seen in a new context.

... software may be "eating the world", as Marc Andreesen put it in 2011, but in time it may help feed the world.

The major breakthroughs will emerge at the intersections – not only between water and agriculture, but also of energy, as we have argued throughout these essays.

Echoing one of the most important themes, systemic innovation, ecosystem design and engineering, not simply software, may yet feed the world.

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4. Wild et al., 2010 quoted in WWDR4 p52.

CHAPTER 8

Nanotechnology

small worlds, big disruption?

Recent breakthroughs in nanotechnology have the potential to disrupt the water industry at all levels, from domestic water purification in the developing world, to industrial scale plants.

After the initial hype, sustained investment activity and invention of novel water-related applications suggest that this rapidly growing field could become a primary driving force of the future operating landscape.

Operating on scales 1/5000th of a red blood cell in diameter, nanotechnology is particularly well suited for water applications where the critical challenge involves the separation of pollutants, micro-organisms, and other unwanted substances from molecules of pure H_2O.

Today, reverse osmosis desalination plants around the world rely on saltwater being pushed at high pressure through the minute pores of semipermeable membranes. Across the market, novel technologies are emerging. Variants of nanoparticles, nanofibers, and zeolites are already in commercial use.

At one end of the scale, Liquidity,[1] a California based startup, has developed a low cost, small-scale nano-filter. Their ambition is to bring the same technology to the home market.

At the other end of the scale, several technologies promise to dramatically improve water filtration in major plants, at a fraction of current costs: aligned nanotubes, nanobubbles, aquaporins, and graphene.

Aligned nanotube technologies enable water to be filtered according to size by excluding contaminants, most importantly salt. The nanotubes have the potential to improve performance across a variety of treatment applications, including electrode-based desalination.

Nanobubble technologies, which pass microscopic bubbles through a solution to create free radicals, are also attracting growing interest due to their wide applications in fields like treatment, disinfection, and defouling.

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1. Source: Worldmeters.info.

Aquaporins, which have been described as "the plumbing system for cells"[2] by Peter Agre, who was jointly awarded the 2003 Nobel Prize in Chemistry for their discovery, are minute protein channels that control water flux across biological membranes. While in early stages of development, aquaporin-based technologies may hold the greatest transformational potential for membrane-based water treatment. Danish company Aquaporin has been granted several international patents during 2016.[3]

The most recent addition to the water-related nano world is graphene – the 2D 'wonder material' that will impact industries as diverse as semi-conductors and optics to aerospace.[4]

In a computational study, researchers at the Massachusetts Institute of Technology (MIT) have demonstrated the potential for graphene's use as a porous membrane in passive (and very rapid) desalination. In a 2012 experiment revealing both potential applications and the team's sense of humour, researchers at the University of Manchester used a graphene membrane to passively distill vodka.

Beyond their transformative impact on the water industry, each of these technologies shares another important feature: they are developing faster than usual for early stage nanotech, which in the past has been characterized by long cycles between invention and commercialization. By some estimates, some have the potential to be market-ready in less than five years.

These particular technologies only occupy a small percentage of the overall water-related nanotechnology sector. This is due in part to the recent growth in research and development (R&D) investment in water applications, drawing on experience from other industries. Graphene, for example, relatively new to water, has been a hotbed of R&D in aerospace, semi-conductors, and consumer electronics technologies for several years.

These technologies also happen to be amongst the safest in the nanotech sector. Each have unique natural attributes that should raise fewer regulatory barriers as they form either an integral part of a composite material (as in the case of graphene), do not remain in a solution indefinitely (as in the case of aquaporins), or are inherently short-lived (as in the case of nanobubbles).

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2. A Conversation With Peter Agre: Using a Leadership Role to Put a Human Face on Science, By Claudia Dreifus, New YorkTimes, January 26, 2009

3. http://www.aquaporin.dk/156/News/73/expanding-the-patent-portfolio.aspx

4. Tannock Q., 2012, Exploiting Carbon Flatland, Nature Materials, 11, 2-5

When considered against forecast global water shortages, the accelerated development timescales of these applications may become particularly important. Yet they are only one piece of a changing picture.

From invention to investment

Whilst there are many possible futures that might emerge, each with innumerable combinations of new and existing water technologies, the integration of nanotechnology and brine mining in desalination (see separate essay) suggests the emergence of an interesting and potentially compelling scenario.

Major corporations, utilities, high tech start-ups, and universities are already active in some of the most potentially transformative segments within both the water-related nanotech and brine mining technology sectors, with investment and patent activity accelerating.

Recent breakthroughs in nanotechnology have the potential to disrupt the water industry at all levels, from domestic water purification in the developing world, to industrial scale plants.

To illustrate, NanoH_2O, which produces nanoparticle and zeolite-based composite membranes for desalination and also has interests in nanotubes, emerged on investors radar in 2012. It was acquired by LG Chem in 2014.[5] NanoH_2O claims their membranes can allow up to a 20 percent reduction in energy consumption and up to a 70 percent increase in water production over similar sized, state-of-the-art reverse osmosis membranes.

We may soon see the emergence of corporate venture capital models in the water industry, as utilities and the businesses that serve them compete to find big ideas and fund radical invention to improve efficiency and performance. Nanotechnology will remain, for some time, a high priority target.

5. http://www.bloomberg.com/news/articles/2014-03-17/lg-chem-to-acquire-u-s-desalination-membrane-innovator-nanoh2o

http://www.lgwatersolutions.com

IN BRIEF

Securitizing water?

One of the critical questions that these essays raise is whether the world's economy and financial system has the capacity to fund infrastructure change at the scale necessary to meet the challenges of sustainable development. Some of the questions surround the pros and cons of the 'financializing' or 'securitization' of water.

To put this in context, the investment challenges in water, energy, agriculture, and related systems raise critical issues about both the scale and potential rate of change. There are no reliable estimates of the overall potential costs of renewal of water, energy, and agricultural systems, but to illustrate, global investment in energy may need US$48trillion over the next two decades. In the US, the investment needed in water infrastructure alone, by 2040, "will amount to US$195billion and the funding gap will be US$144billion".[1] Some suggest that the total may be beyond US$90trillion.

The fundamental question is whether the cost of redesigned infrastructures will be greater than 'business-as-usual' renewal. Whilst these questions remain unanswered, funding challenges are already being met in a variety of novel ways. The commitments made in Paris illustrate the sea change in cultural attitudes, with clear contributions emerging from national and city leaders, investors, and businesses, such as the automotive industry. All have a central role to play.

In parallel, there has been substantial growth in exchange-traded funds structured around water-related businesses. Investors in 'scarce water' are buying companies that "conserve, purify and treat water as well as those that make equipment and deliver new technologies".[2]

Whilst results have been mixed, some funds have attracted substantial interest and short-term gains. For example, since its inception in 2010 through 2016 Pictet's water-focused fund has delivered returns of 166.89% against the MSCI world index of 42.3%'.[3]

The attraction of pricing natural assets for governments, private companies, international organizations, and investors alike is obvious, but there are risks.

Such financial systems might easily go awry and rather than stabilizing or reducing prices, increase them. The impact of failed regulation, as experienced in other derivative markets, might impact the survival of entire communities. More fundamentally, there is an ongoing debate as to whether water is a commodity, a universal human right, or both.

This suggests that novel financial models will be needed to deal not only with the unique challenges of water, but the scale of infrastructure renewal. As Jeffrey Sachs recently commented about investment in energy and as we note elsewhere:

> **"The world's governments have never before attempted to remake a core sector of the world economy on a global scale with such an aggressive timeline…"**

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1. Source: American Society of Civil Engineers. Failure to act: the economic impact of investment trends in water and waste water treatment, 2011.
2. Source: Bloomberg: http://www.bloomberg.com/news/articles/2014-09-03/water-etfs-are-smarter-than-they-look
3. http://www.pictetfunds.com/nns_fi/browse.fund?fundId=LU0104884860&navId=NAV_ID_DETAIL_GENERAL

Epilogue

It is generally accepted that unless large-scale reinvention and coordinated system-wide action is taken both locally and regionally, the world faces something like a 40 percent shortfall in fresh water supplies well before 2035 — even in stable climate scenarios that exclude major regional or global shocks.

The consequences of such a shortfall would be profound: widespread systemic failures, not solely in water, but through interlinked energy and agricultural systems, would create widespread economic, social, and political turmoil.

The scale of potential climate-related disruption in infrastructure and security terms may be particularly marked in the extended megacities and urban conglomerates in coastal regions around the world – the so-called 'littoral states' – from Bangkok and Dhaka, to New Orleans and Miami. Many of the major ports, including Greater New York City, Rotterdam, Tokyo, and Osaka-Kobe, are exposed.

The central question explored in these essays is whether the combination and integration of water, energy, and agriculture, together with a wide range of industry structures, technologies, and new business methods, might shape a transition to a low carbon, sustainable, resource efficient, and stable future.

Several themes are threaded through the essays. We use the term Anthropocene to describe a future environment where human control over planetary systems begins to become a reality.

We believe that cities are uniquely positioned, with the creative resources, financial strength, and governance structures that may enable them to integrate core water, energy, and agricultural systems to build long-term resilience, even in a potentially rapidly changing climate.

We make the case that there are many opportunities for white space and systemic innovation at the intersection of water, energy, and agriculture. We argue that distributed networks, systems integrators, and ecosystem design and engineering, particularly at urban scale, will become the driving force of sustainable development.

Any future projection should, of course, be treated with caution: they tend to discount future disruptive technologies, often because they are unimaginable or deeply uncertain. Ideas belong to secret worlds, some invented but beneath the surface, others not yet imagined.

The challenge is to identify these possible technologies and business model changes early and map out how they can create systemic innovation to counter what otherwise may turn out to be systemic failure.

Scenarios are embedded throughout the essays, essentially raising two questions. The first is "what might happen?" The second, critically, is about strategic options in the here and now: "what might we do?"

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