# Future Technology Overview

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3 September 2014

## Introduction

This short paper lists a selection of existing and emerging technologies likely to play an increasingly important role in the social and economic life of people in Australia over the next few decades. This list, in common with other such lists produced by a wide range of organizations, is not uniformly quantized in the way 'technology' is defined. For example some technologies in the list are narrow engineering/scientific advances while others are broad technology based systems. Analysis of lists produced by McKinsey, Forbes, MIT, IEEE, Deloitte, Energy and Capital, and a number of other sources, indicates that they all share several items in common including 3-D printing, driverless cars, fast DNA sequencing, humanoid robotics, wearable computers, internet-of-things and embedded sensing, new energy systems, and various aspects of data analytics and its diverse applications. The list below was developed without direct reference to the above-mentioned lists. Unsurprisingly this list shares many items in common with various other lists and also contains additional items believed to be particularly important in the Australian context. This list also distinguishes certain technology convergences that hold the potential for large impact.

Technology forecasting, while often seen as an activity of critical importance to both industry and government, is well known to be a notoriously difficult and unreliable process. It is an activity subject to intense formal study with several scholarly peer reviewed journals dedicated to the publication of research and performance assessment of forecasting methodologies. Some of the key approaches include analysis of evidence in patent data bases to determine likely directions, seeking expert opinion from a broad range of technology and industry leaders, analysis of business and investment opportunities and exploration of user desires including science fiction imaginations of the future. Apart from one

or two moderately successful forecasting exercises most have been largely inaccurate. Many national defense organizations attempt technology forecasting and many countries produce technology forecasts as part of their national planning processes. Industry also invests significantly in such activities. To understand the challenge, imagine for a moment that you are living in the 1890's and you are asked to describe what the world will be like in the 1930's. Who would have been able to anticipate electrical power to all homes, offices and factories, air travel, extensive deployment of cars and tractors, plastics, high-rise sky-scraper technology, radio communication and free to air radio, colour talking movie technology, mechanized warfare technology, and many other emerging technologies (radar, jet engine, television, penicillin) which resulted in huge changes in life over a mere 30 years?

The Institute of Electrical and Electronic Engineers (IEEE) in the USA produce regular short term technology forecasts. The IEEE represents a significant portion of the 'high tech' innovation research and industry sector. In 1964 the IEEE published a 50 year prediction to coincide with the launch of a new journal Spectrum which looks at broad technology directions and advances. Today, 50 years on, it has come to pass that the 1964 forecast by the body most deeply involved in the modern high-tech boom was essentially completely off the mark, partly because they underestimated the impact of integrated circuit technology - a technology generated and advanced by IEEE members. The IEEE have recently published a next-50-years list covering expected advances in biomedical engineering, space, science, movies, energy, cars, mobile everything, robotics and the 'dark-side' of technology advances. The opening words to the 2014 foresight papers published in IEEE Spectrum are revealing.

*"1964, the year of IEEE Spectrum's founding of the New York World's Fair, was a time of bold and futuristic thinking. Visionaries then predicted that the world of 2014 would be shaped by remarkable technological triumphs. And indeed it is. But hardly any of them are the ones that were forecast in 1964. So, for this 50th anniversary issue, we've described what we hope will be achieved in coming decades, rather than guess what will probably be achieved. We've put together*

*desirable scenarios for eight of the most promising of today's technologies. To broaden the perspective, we've also considered what could go wrong and produced a bracing new work of science fiction, written for this issue by Nancy Kress. Though we didn't set out to predict what life would be like a half a century from now, we do think we can do better than our peers did in 1964. Some of the key technologies then-integrated circuits, nuclear power, space vehicles, and optoelectronics – were very new in 1964 and therefore hard to visualize decades out. …".*

The IEEE 2014 list is contained in the appendix for reference.

## Future Technologies

The future technology lists below are structured as follows: an ***underpinning technology list*** containing basic technology advances that will within the next 10 years underpin a large range of application technologies, a ***technology systems and convergence list*** that describes several convergences that within 10 to 15 years are likely to directly enable applications with high societal impact, and finally a short ***disruptive technology list*** that might lead to totally new ways of doing things over the next 10-20 years. We have also included a very short ***long-shot list*** of technology solutions to looming and somewhat urgent problems.

The methodology employed to create the lists below was based on technical literature (journals, conferences, national academy reports etc) and information which emerged from a number of meetings with groups of experts. This data was then tested against a number of other published lists based on perceived business opportunities (McKinsey, De Loitte, Forbes etc) and technical directions (IEEE, MIT, etc). Finally the resulting lists were tested against lists of challenges and problems facing humanity where technology is expected to form part of the solution (US National Academies, etc). A summary of these various reference lists is contained in the appendix to this short paper.

The separation of future technologies into underpinning technologies which can be more confidently predicted, technology systems and convergences which describe the much harder to predict impact paths, and disruptive technologies

which hold the potential for dramatic change but are almost impossible to predict, appears to be a helpful approach which from our observation is not commonly employed.

In generating the future technologies list we have also considered the complex interplay between the supply of new technology and the demand for new applications. The impact of technology is essentially determined by the level of uptake and adoption of the various newly developed technology platforms and user applications. Much of the 'surprise' with respect to technology impact arises from the unexpected ways in which technologies end up being adopted. While this aspect is generally considered to be the source of difficulty in technology prediction, as discussed above, there are sometimes clear signs that the supply of some classes of technology is likely to outgrow demand.

Consider the case of computing platforms where impact now appears to be ***application constrained***. Broadly, growth in raw computer power is not in itself a major driver of new economic impact. Past generations of computing platforms (mainframes, servers, desktops, laptops, mobiles, tablets) have experienced quite similar maturation curves. Early phase demand has far outstripped supply capability - the latter being the principle constraint on consumption. Each new technology increment has opened up more applications and increased economic value. Each of these 'computing platform' domains has seen maturation to a point where further increases in underpinning technology capabilities has rapidly reached a point of diminishing economic returns. All of these platforms are, by and large, at points where they individually have more potential performance than buyers 'need'. The rate of value saturation has accelerated rapidly, with the flattening of tablet sales just the latest market of a technology domain that has transformed from one where platform improvements drove rapid replacement cycles and large changes in economic impact to one where the platforms are now largely stable.

Similar observations can be made in relation to communications bandwidth where fixed (in contrast to mobile) bandwidth supply is likely to outstrip

demand in the near future. Video is the most bandwidth intensive application area and even 4K video is comfortably handled with sub 30Mbps streams which will not require any fundamental technology innovation to deliver. It is the same in the mobile domain where micro-cell architectures will have little trouble delivering high density wireless consumption at this level of bandwidth - even Long Term Evolution (LTE) has little trouble for moderate densities today. This situation, of course, might not persist for long and new unforeseen applications can easily re-create a technology constrained (as opposed to an application constrained) environment.

There are, of course, many areas where impact is currently ***technology constrained.*** Moore's law (the exponential growth in electronics capability) will remain highly significant in terms of 'compute distribution'. The continuing marginalization of the compute power demands and associated economics costs, taken together with wireless communications, is redistributing and massively increasing the density of compute capability. This is integral to the 'big data' and 'internet of things' dynamics which are placed to have massive societal and economic impact.

Cognitive computing is a further illustration of impact constrained by technology. We are still tantalizingly but unknowably far from the emergence of cognitive systems comparable at any real level with human 'wetware'. But technologies that make incremental steps down this path will have profound impact resulting in automation of many human activities including many white collar work activities, both administrative and professional. Demand is certainly not the constraint in this case.

## Underpinning Technologies

The underpinning technology list presents a selection of existing and developing technologies that are advancing in a reasonably predictable manner. Hence the likely capabilities within 10 - 20 years can be determined with some degree of confidence. Computer performance that underpins many of technology system

advances has progressed according to Moore's Law for around 50 years and recent materials technology advances such as graphene and other emerging technologies pave the way for a further 10 - 20 years of exponential increase in performance and exponential reduction in size and cost. Integrated circuit technology relentlessly following Moore's Law resulted in a high performance computer in the mid to late 1960's (occupying many tens of cubic meters volume, drawing many kilowatts of power, and costing several million dollars) being transformed by 1980 to the size of a thimble, drawing just a few watts of power, and costing a few dollars while achieving similar computing performance. Similarly a high performance (super) computer from the 1980's, was installed in hand held mobile phones by the early 2000's. Roughly speaking, computing performance (calculated by combining the increases in speed and memory, with reductions in size, and power consumption) undergoes an increase of somewhere between 100 billion and 1000 billion over any 20 year period. This staggering increase is very difficult to fully comprehend, even for the technologists who make this happen. This makes it virtually impossible to accurately assess the likely new applications of a supercomputer in your pocket 20 years into the future. History tell us that the uses of yesterday's supercomputers differs dramatically from the uses of today's equally powerful but now miniaturised reduced-cost tiny chip computers. A little thought reveals that this is not surprising but it does make 'use prediction' nearly impossible.

In a similar albeit considerably slower manner, data communications and networking technology is continuing on a steady path of increasing speed and increasing mobility. There has been a roughly 100 million fold increase in wired data rates over the past 50 years, due largely to optical communications technology, and an increase of around 1 million in mobile data rates to hand-held technology due largely to advances in communication theory and advances in radio frequency integrated circuit chip technology (Moore's Law). Spectrum limits present an increasing challenge for mobile wireless communications however further advances in communication theory and networking and areas such as small cell technology will continue to provide increased data rates. Long Term Evolution (LTE) technology already provides up to 150 megabits per

second data rate for mobile communications and the 5G program now underway will deliver gigabit per second data rates for mobile applications over the next 10 years. Millimeter wave wireless networks are now available with data rates up to 5 gigabits per second over short distance and demonstrator long range systems achieve in excess of 1 gigabit per second over distances of 40 kilometers. Work is underway in many companies to develop 100 gigabits per second wireless links over distances around 1 km. By way of comment it is important to remember that growth in wireless data-rates is dependent on accompanying growth in supporting 'back-bone' optical fibre capacity.

***Underpinning Technology List***

- Computing power and memory –excluding quantum computing – likely to experience a 10 million fold increase in integration density with a similar reduction in cost and a many-fold increase in speed resulting in today's supercomputers capability (such as, for example, the IBM Blue Gene super computer) forming the compute/memory elements in hand-held consumer devices in 2025. How this massive increase in compute power will be used is unclear.
- Steadily advancing cognitive computing capability is likely to lead to a large increase in automated machine 'thinking' ability that will be available for consumer devices by 2025. The IBM Watson computer is a first serious step in this direction.
- Steadily increasing capability in networking,10 – 100 GB/sec in the home, public transport, 1 – 10 GB/s mobile
- Near instantaneous and near-zero cost DNA sequencing.
- 3-D printing – fast, highly capable, low cost, widespread. Also large expensive very powerful 3-D printing systems capable of printing a huge range of products and devices currently manufactured via complex processes. Already 3-D printers are employed to manufacture advanced components such as turbine blades and aerospace components, orthopedic replacement parts, a range on electronic components, etc.
- Increasingly capable and rapidly reducing cost of humanoid robotics and natural user interface technology within 20 years.

- Autonomous vehicles, driverless cars, UAV's, electric vehicles—low cost, safe, efficient, widespread within 15 years.
- Smaller, cheaper, more capable sensing and monitoring technology including new nano-technology based sensor systems such as low cost chip based bio-chemical analysis.
- Improved large and small scale alternative energy technology, better storage, wireless transfer for low power levels, energy scavenging technology for many consumer and monitoring applications, advanced power grid control and micro-grid technology (smart-grid).
- New energy technologies and more efficient use of existing gas, oil, coal.

## Technology Systems and Convergences

The 'systems and convergences' list presents technology convergences that are already underway or are highly likely to happen. It is particularly difficult to predict the diverse impacts of such convergences so below we indicate some clear directions where significant societal impact will occur within the next 10 - 20 years. The old battle-line between 'personalisation' and 'centralised control' appears to be further reinforced with the anticipated technology progression. Technology will increasingly provide the opportunity for people to shape life to best match their perceived personal requirements. This trend has been accelerating in recent years and is likely to further accelerate over the coming few decades. Technology will provide opportunities for people to effectively personalise most aspects of their interaction with their environment and they will increasingly expect the environment to match their person requirements. Industries such as retailing and advertising are already well down the path of extracting personal information from data enabling them to better appeal to, and match, individual needs. People already shape their entertainment and communication environments to their individual needs. Armed with a rapidly growing array of new technologies, health care is set to embark on a program of increasingly 'treating the individual' and there is a growing pressure and desire to personalise education. The technologies which enable increasing personalisation (and consequential increasing expectation of personalised

attention) also bring the clear ability of observing detailed person information and the possibility of this being available to others. Many of the technology 'dark-side' prophecies and fears are based on this aspect of coming technologies. Curiously however, there is increasing evidence pointing to a softening of the 'battle lines' and a growth in resigned acceptance of reduced privacy and increased availability of personal data for a variety of purposes such as advertising and security.

***Technology Systems and Convergences List***

- Computing power + analytics + networking = automation of brain work
- Computing power + robotics = further automation of manual work
- Autonomous cars + sensing + networks = safe personalised (public) transport
- Renewable energy sources + sensing + networking + analytics + extensive distributed energy sources = green power (smart grid)
- Fast DNA sequencing + analytics = personalised medicine
- Extensive sensing + analytics + networks + autonomous vehicles = safe, green, sustainable (smart) cities along with wide scale surveillance of human activities
- Nano-technology + analytics + RFID technology = automatic food quality monitoring, body function monitoring
- Cyclic economies, increased re-cycling
- Meso-scale modelling and simulation + low cost high performance computing = new era in real-time decision making.

## Disruptive Transformation Technologies

This list presents technologies that hold the potential to totally transform the way certain activities are conducted and hence might result in some industries disappearing and new ones emerging – such as is now happening with the newspaper industry and might happen to some degree with education.

Disruption can also refer to completely new and unforeseen activities and behaviors as occurred with social networking. This list takes a 'disruptive transformation' view of some of the technologies listed above. No additional technologies are listed.

***Disruptive Transformation Technologies List***

- 3-D printing (matter transport for both good and evil, health, crime, convenience, impact on manufacturing, additive manufacturing, predicted loss of $100B in IP over the next 10 years)
- Autonomous vehicles (safety, vulnerability, monitoring movement, centralised control, extensive surveillance, infrastructure efficient transport)
- Wearable internet (surveillance, health monitoring, internet-of-you)
- Energy storage, low-power wireless energy transfer, extensive distributed green energy sources
- Natural Human Computer Interfaces, immersive interfaces
- Embedded sensors and computation (internet-of-things, machines talking to machines on a huge scale and in all areas of activity)
- New view of education.

## Long-shot Technologies

As with any time in history the world today faces a number of significant (even existential) challenges. Since technology can and will play a leading role in addressing these problems there are very likely to be large technological advances in certain relevant directions. Below we list a small number of long-shot technology directions which address some of these challenges. We avoid being specific about the precise technological advance rather we list broad the technology category where we consider a high impact advance will occur over the next 30 years.

***Long-shot Technologies List***

- Green replacement for base-load power generation
- Large advance in brain science leading to solutions to diseases such as epilepsy, schizophrenia, etc.
- Large scale replacement of human intellectual based activities such as 'science' by cognitive machine systems
- Space business.

## Summary

It is demonstrably clear that prediction of technology at its applications over a 20-30 year forward horizon is unreliable so we have attacked the task in a layered manner dividing technology and its diverse applications into underpinning technology, technology systems, disruptive technology and finally long shot technology. Underpinning technology is the base technology on which many applications will be built and is for most part reasonably predictable and often follows a planned research and development path. Technology convergences and systems are less predictable as they represent the high impact applications and adoptions. While considerable uncertainty exists as to what will be adopted there are clear trends and commercial opportunities especially over a 10-15 year horizon. Many of these are already visible in the research literature, patents, new start-up companies and early phase products. Disruptive technologies are more unpredictable but are listed because of the possibility of huge impact and strong underpinning research activity. The list is informed by current developments and by examining 'big' problems (or opportunities) which have an urgency indicating that a solution 'must' be found. Finally the long shot technologies are in the realm of guesses at what might happen based on what is inspiring the research community.

These future technology lists were also informed by demand/supply considerations. Where historically, computing and bandwidth limitations have constrained demand and economic impact, this appears to be far less so today. All indications are that in many application domains we are now in a period of application limited impact. At the same time, while new compute

performance/economics is less likely to drive economic impact *per se* it is likely to be rapidly leveraged as and when there are breakthroughs on other fronts such as AI/cognitive systems, new computational medicine techniques, a deeper understanding of brain science, new algorithms capable of effectively dealing with large data, etc.

Moore's Law is set to continue driving exponential growth in integrated electronics (computers/memory) performance and equivalent reductions in cost. Both fixed and mobile connectivity will continue on a path of steadily increasing data rates and a strong expansion in the scope of connectedness embracing vast sensing systems producing huge amounts of data. The urgency to reduce green-house gas emissions will result in smaller more efficient energy conversion technology, high density energy storage technology, and new highly efficient and flexible source and load controlled power distribution technology. Nano-sensing technologies, fast, low-cost DNA sequencing and new analytical methods coupled with high capability compute/networked systems will transform health technology. New materials, 3D printing and advanced modelling and simulation technology will transform many domains of manufacturing. Advances in automation/robotics will continue to replace manual work and advances in large–scale modelling, low-cost high performance computing, and data analytics hold the promise of transforming decision making. Cognitive computing advances will have an even greater impact on decision making and could lead to significant automation of 'brain work' activities enhancing and in certain sectors replacing white collar work.

The availability of low-cost, high-power computing and the large scale interconnectedness and increasing computer based processing and decision making are already leading to significantly opportunities for malicious activity. This trend will increase significant over the next 20 years and there appears to be no easy solution or potential 'silver bullet' solution. Security will be a major challenge, this will be addressed in a separate paper.

# Appendix

## McKinsey-2013 Disruptive Technology List

- Mobile Internet
- Automation of Knowledge Work
- Internet of Things
- Cloud Technology
- Advanced Robotics
- Autonomous Vehicles
- Next Generation Genomics
- Energy Storage
- 3-D Printing
- Advanced materials
- Renewable Energy
- Advanced oil and Gas Technology

## Forbes 2014 List of 5 Big-Bang Disruptors

- Embedded sensors
- Wearables -The Internet of You
- Exponential Energy
- Driverless vehicles
- Immersive Interfaces

## World Economic Forum's Top 10 Emerging Technologies 2014

- Body-adapted Wearable Electronics
- Nanostructured Carbon Composites
- Mining Metals from Desalination Brine
- Grid-scale Electricity Storage
- Nanowire Lithium-ion Batteries
- Screen-less Display
- Human Micro-biome Therapeutics

- RNA-based Therapeutics
- Quantified Self (Predictive Analytics)
- Brain-computer Interfaces

## Deloitte Top 10 Technology Trends 2014

### Disruptors

- CIO as venture capitalist – Trading on IT's assets, talent risk and results
- Cognitive analytics – Wow me with blinding insights, HAL
- Industrialised crowdsourcing – Sometimes more is better
- Digital engagement – Context + content for marketing… and beyond
- Wearables – On-body computing devices are ready for business

### Enablers

- Technical debt reversal – Lowering the IT debt ceiling
- Social activation – From passive to active tense
- Cloud orchestration – From Cloud to Clouds (to core)
- In-memory revolution – An answer to Big Data
- Real-time DevOps – Empowering the business of IT.

## Energy and Capital Disruptive Technology 2014 List

- Additive Manufacturing
- The Automated World
- The Internet of Things
- Next Generation Interface
- Next-Generation Genomics

## IEEE Spectrum 2014 'Next 50 Years' Technology Forecast

- The end of disability: Prosthetics and neural interfaces will do away with biology's failings
- Fewer launches, more space: Technologies that exploit space resources will

finally open up the solar system.

- Infinitely malleable materials: People will conjure objects as easily as we now play music or movies.
- Leaving the valley behind: Computer generated humans are paving the way for new forms of entertainment.
- The rise of the personal power plant: Agile power systems will let every home and business generate, store and share electricity.
- Robot, you can drive my car: Autonomous driving will push humans into the passenger seat.
- Beyond words: Wearable computers will let us share thoughts and sensations.
- So, where are my robot servants: Tomorrow's robots will become true helpers and companions in people's homes
- Someone to watch over me: Every technology has unintended consequences.

## USA National Academy of Engineering 2014 Grand Challenges

- Make solar energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse-engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalized learning
- Engineer the tools of scientific discovery

## MIT Emerging Technologies

### Digital Life

- Internet of Things (IoT) marking a revolution in technological advancement
- Emerging platforms and a new era of computing
- Wearable technology and the latest frontline innovation
- Robotics: Moving well beyond the factory
- Drones interacting with us in new ways (agriculture, healthcare, and more)

### Healthcare & Life Sciences

- Dramatic advancements in the field of neuro engineering
- The future of Genomics
- Med tech innovations that deliver cheaper, faster, more efficient patient care

### Space 3.0, the Next Frontier

- Leveraging on the impact of satellite technology in everyday life
- Space tourism – A near future reality
- Exploiting commercial applications

### Sustainable innovations addressing real world challenges

- Responding to changing demands for renewables and low carbon technology
- Integrating emerging technology to feed a growing global population
- Next Generation urban development and sensible cities