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The circular economy: international case studies and best practices

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What now for the Lucky Country?

The paradox that titled this forum implies movement towards a new future but admits significant uncertainty about the direction and the final destination. In his 1964 critique, Donald Horne felt that Australia was still a place where arriving immigrants and perhaps the whole nation was still "making life anew". Over half a century later, a fresh and furious impulse of nation building is still underway in Sydney and Melbourne, but there is ample evidence of a Britain-like transition to a post-industrial services economy where China supplies so many of the goods purchased. As an American who arrived in Sydney after long periods living in Britain and Shanghai, this author observes a bifurcated society with one half rapidly realising how consumption orientation and consumerism are incompatible with the fundamental value many Australians assign to the social amenity of natural beauty, the continent's uniquely fragile flora and fauna, and the national 'fair go'. "Towards a prosperous yet sustainable Australia — What now for the Lucky Country?" It's a well-aimed question. This author sees a rising generation of young people who reject the consumerism that was imported from America in the '50s and '60s. Older societies like Britain, continental Europe and even China are offering new views of a future economic model, the so-called Circular Economy. The ageing architects of 20th century industry are being overtaken by a new generation of business leaders and consumers who consciously balance ecology with economy and self-convenience with the preservation of the commons.

This paper and its presentation at Government House in November 2018 offer an answer to the "what now" question posed at the forum. Australians and many others in the world are reacting emotionally to evidence that their personal microeconomic behaviours aggregate to contribute to the decline of planet Earth. This realisation creates the "what now" question. One answer is a transition towards Circular Economy concepts. This paper showcases some of the emerging ideas about what the "Circular Economy" means. It also examines social discourse in 2018 that changed perceptions, created a sense of urgency and may drive Australia over a tipping point of economic and political resistance towards taking action.

Human-centred design

Basic science informs fundamental engineering. When engineers turn their minds towards human needs and practice Human Centred Design, new technologies leap out from laboratories to cross the threshold of successful commercial innovation. Superior new products and processes serve the market of the 25 million people of Australia and then move overseas to build economic impact in the global market of 7 billion

people. This cycle of innovation builds wealth and prosperity for Australians. It builds a high quality of life. Experts who study systems of innovation know that the communities that practice this well build competitive economies that spiral upwards in the global knowledge economy, providing sustainable jobs, strong local enterprises and prosperity.

Human Centred Design yields solutions that support human health and acknowledge that humanity depends upon the health of the entire planet. Sustainable designs support long term cycles of innovation and growth. As basic science has informed the modern understanding of climate change, human impact on flora and fauna, and the role of persistent molecules in the environment such as perfluorinated alkyl substances, there is a demand on engineers and entrepreneurs to acknowledge new science and to develop new designs and new business methods. Engineers and entrepreneurs have a vital role of economic renewal in the innovation cycle.

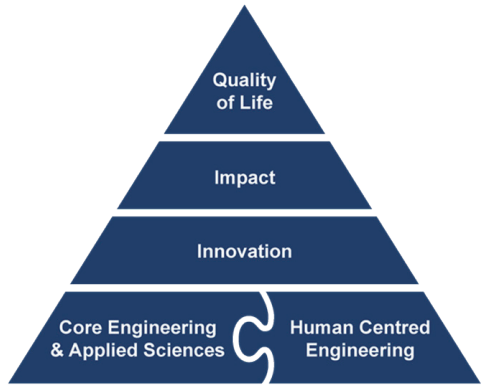

Diagram 1: How engineers and scientists innovate to deliver high quality of life

The Accumulation Problem

The first and most fundamental law of chemical engineering governs material flows in a system: mass in minus mass out equals accumulation. Chemical engineers, and indeed all industrial engineers from the 20th century, have created a problem that can be called the Accumulation Problem.

Societies are accumulating waste. Electronic waste and defunct consumer goods accumulate. The standard 20th century supply chain and production process is a linear process (Brocklehurst 2015). Goods producers extract raw materials, build parts, assemble machines, and sell to consumers. When goods are no longer useful or when consumer preferences change, consumers and societies landfill the obsolescent goods.

Diagram 2: The Accumulation Problem: e-waste. Curtis Palmer / CC-BY 2.0

Diagram 3: The Accumulation Problem: plastic. Shutterstock, licensed to the Warren Centre

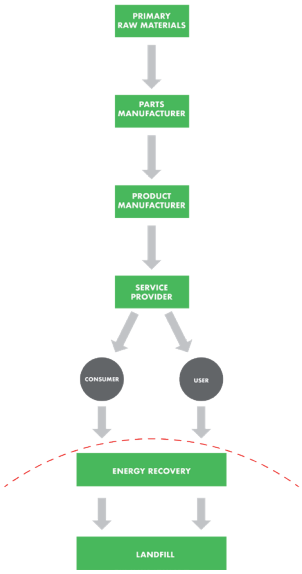

Diagram 4: The Linear Economy: Take, make, use, dispose. ©The Warren Centre, permission granted to reproduce. Adapted from World Economic Forum.

The profitability equation for this manufacturing is also linear. Increased sales revenue requires more raw material extraction, faster product redesign cycles and faster product obsolescence. Existing manufactured goods deployed and functioning perfectly well in the economy must be discredited, superseded or made unfashionable to drive demand for premature retirement from use to drive sales of new models. Incremental new functionality features and trivial changes in form factor and visual cues communicate between goods owners who has a trendy mobile phone, the newest automobile and the latest smart watch. In this linear economic system, increased profit is correlated to increased extraction and landfill waste.

Plastics that were engineered for the remarkable chemical stability of their polymer molecules are accumulating in oceans and on beaches. An often-cited statistic warns that the rate of accumulation of plastic in the oceans will lead to a day in the middle of the century when the mass of all the plastic in the oceans is greater than the mass of the fishes in the oceans. The Accumulation Problem is real.

The Circular Economy alternative

The Circular Economy is an idea that the linear process should be turned into a cycle of distribution, use, re-use, repair, collection, sorting, and recycling. However, the Circular Economy is much more than just recycling. A fundamental re-design revolution is required for products and production processes. This is not a small task, and in many sectors, it is not an incremental task.

The concepts that constitute the Circular Economy are emerging but are not presently exact and definitive. In different countries and among different thinkers, there are multiple conceptions.

Diagram 5: The Circular Economy—Raw materials to residual waste. ©European Union, used with permission

Some concepts present separated biospheres of agriculture, fresh water systems, sanitary waste and fertilisers connected to

industrial production processes that produce energy, use water, produce chemicals and manufacture goods in urban, suburban and industrial land use environments.

Diagram 6: Connected urban, industrial, agricultural and nature segments.
© WWF Bioplastic Feedstock Alliance, used with permission

The Share Economy: "Why buy a car when you can Go Get?"

Within these conceptualisations, recurrent themes broadly define the Circular Economy. The Re-Manufacturing Economy refurbishes, upgrades and re-deploys used goods. Instead of owning the photocopier, hardware is serviced continuously by the copier company. Instead of purchasing consumable ink cartridges, the contract supplies photocopies on demand at a variable cost. Ownership transforms towards a services orientation. New business models of the Share Economy are increasingly relevant. Why buy a car when the passenger can call a taxi? Why dedicate capital to a yellow taxi if car owners share their capital on Uber, Lyft or Ola or if drivers share in Car-Next-Door or GoGet schemes?

Reddy Go, oBike, MoBike and Lime mobile phone apps enable on-demand use of dockless bicycles and e-bikes. Local manufacturing, local remanufacturing, distributed manufacturing technologies like 3D printing, and local food production are themes within the broader Circular Economy discussion.

Diagram 7: oBike at Putney Bridge, London, by EdwardX / CC-BY-SA 4.0

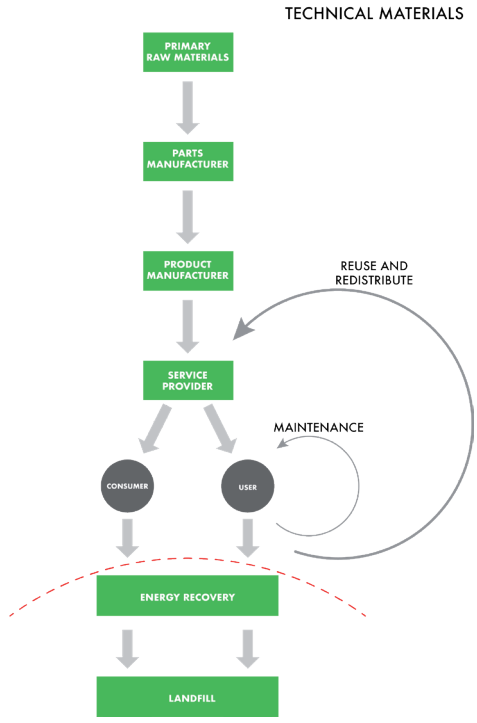

Diagram 8: Service Systems ©The Warren Centre, permission granted to reproduce

Industrial aggregation and Denmark's experience

The first step is industrial aggregation. From head to tail, in the bio and techno-spheres, integrated suppliers and consumers can be co-located to gain economies of scope and economies of scale in materials and energy efficiency.

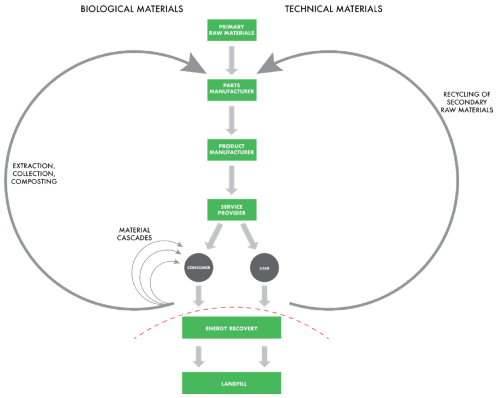

Diagram 9: Industrial Aggregation in biological and technical spheres ©The Warren Centre, permission granted to reproduce

Diagram 10: Kalundborg Power Station in Denmark, CC0

The case study of the Kalundborg Denmark Eco-Industrial Park demonstrates advantages of industrial aggregation (IISD 2013). The Kalundborg Park developed between the 1960s and the early 1990s. A 1.5GW coal-fired power plant supplies electricity and steam. Statoil Petroleum Refinery supplies natural gas and uses waste steam for reboilers. Pharmaceutical supplier Novo Nordisk integrates with fresh water fish farms, yeast processing and the City of Kalundborg sanitary waste water processing to supply fertiliser sludge to offsite land agricultural users.

Gyproc is integrated with the coal-fired power station, and fly ash from the power station feeds an Eco Park Portland cement manufacturer. Elements of head-to-tail recycling are being tested in Australia, but the scale of Kalundborg's industrial integration is far beyond domestic Australian industrial co-location and integration.

Professor Ali Abbas at the University of Sydney School of Chemical Engineering has demonstrated a coal fly ash cement technology that incorporates flue gas carbon dioxide into cement carbonates to reduce CO_2 emissions yielding cement with compressive strength substantially equivalent to conventional cement kiln products. In late 2018, Professor Abbas and colleagues hosted the Australian Circular Economy Conference at Kooindah Waters, Central Coast NSW. Nanyang Technology University Singapore, Tsinghua University, Shanghai Jiaotong University, University of California Santa Barbara and UTS participated. NSW Dept of Industry, IChemE and Engineers Australia participated. The World Economic Forum Beijing and from industry Suez, Downer and Dow Chemical participated. Following the Australian Circular Economy Conference, Professor Abbas said, "It's not just recycling. We've got to redesign *everything*. Everything you see around us, it ALL has to be re-designed." The technical discussion in Australia must shift from just recycling to design, Advanced Manufacturing, longevity of product life, re-use and re-purposing.

Carbonate trapping cement pellets are an example of tail-to-head industrial agglomeration and recycling. In Scotland, MacRebur company is replacing petroleum tars in asphalt with pelletised recycled plastic. Several domestic Australian innovators are demonstrating plastics recovery processes to convert ploymers to olefins, diesel fuel or clean hydrogen gas. These steps are substantive and important, but they are not enough. Recycling is necessary, but not sufficient, to address the scale of the Accumulation Problem.

China's approach to the Circular Economy

Multiple, successive Five Year Plans by China feature increasing commitment to the Circular Economy (Su et al., 2012). President Hu Jintao, an electrical engineer, led the People's Republic of China from 2003 to 2013. President Xi Jinping, a chemical engineer and lawyer, has led the country since 2013. There is absolute alignment between the government and the single political party. On matters of industrial development, for most of the past 20 years, the Chinese Communist Party acted as an evidence-based, scientifically driven technocracy.[1] When Shanghai banned free plastic shopping bags, the change was immediate, with high compliance, and no turning back. The speed of industrial reform is fast. Integrated industrial aggregation features prominently in the Suzhou Industrial Park and Tianjin Park.

In 2017, China's National Sword Policy prohibited the import of plastic waste starting in 2018. That policy caused shocks in the US, Japan and Germany. Indeed, it shocked Australia. Plastics are diverted to Malaysia, Thailand and Vietnam, but hundreds of millions of tonnes of plastic are stranded globally. Local solutions are urgently needed. Today's supply chains are global. Manufacturing, consumer purchase, and ultimate recycle/recovery geography are not generally local and not integrated-agglomerated due to distance. Global supply chains can appear to be economically efficient in the linear economy if externality costs are zero. However, sprawling supply chains create intermediate stockpiles that can temporarily hide the Accumulation Problem. Disruption in those chains, such as the National Sword Policy, can create shocks.

Europe's Circular Economy design and manufacturing approach

Re-design is critical. The economy must be restructured from a linear economy to a Circular Economy as the European Commission Vice President Frans Timmermans stated in 2015, "Our planet and our economy cannot survive if we continue to pursue the throw-away approach. We must conserve valuable resources and fully exploit their economic value. A circular economy reduces waste accumulation and protects the environment; but it also means a fundamental change in the functioning of our economy" (UNGCNG, nd). Mercedes-Benz, and indeed the whole German manufacturing industry, is redesigning products for maintenance, service, refurbishment, re-manufacturing and redeployment. Germany's DIN Standards are a leading influence upon the development of ISO Standards that are influencing nations adopting the Circular Economy.

A few examples of the thinking and standards follow. DIN 14040 and ISO 14040:2006 are standards for environmental management using life cycle assessment principles and frameworks. The standards

[1] See for example, Zhou (2017).

were formally adopted by ISO in 2016. DIN EN ISO 14044 is closely related. In the automotive industry, ISO Standard 22628 — "Road vehicles — Recyclability and Recoverability — Calculation Method" is an example used by Mercedes Benz. ISO TR 14062 covers the integration of environmental aspects in product development. ISO 14001, ISO 9001 and ISO 14006 are part of a European style design approach alongside environmental certification in accordance with ISO TR 14062.

Industrial design reform

The first older phase of reform, as demonstrated in Kalundborg, was industrial aggregation. The next two newer phases are industrial design reform and the transition from product sales towards lease, service and share economy business models. Each year the Warren Centre features a prominent Australian innovator in the annual Innovation Lecture. Professor Andrew Harris of University of Sydney developed one of the world's largest 3D printers, an invention conceived in Australia and deployed in England to produce mass customised wax forms for concrete acoustic tiles in the London Cross Rail project. Professor Harris stands with one foot in industry, leading Laing O'Rourke's Engineering Excellence playground of new technologies, and one foot in academia at the University of Sydney. At the 2017 Innovation Lecture Professor Harris described how digital design tools yield infinitely and easily customisable production with sensors built into products and infrastructure to allow machine learning and to capitalise on the efficiencies of artificial intelligence. The plastic printer car by Local Motors is an example of digital customisation and local manufacturing. Distributed manufacturing and re-manufacturing further enable refurbishment in situ and new share economy and lease business models like the photocopier example described previously. Some industrial reformers in Europe believe that jobs displaced by robot factory automation might be supplemented by new labour demand in maintenance and refurbishment.

Diagram 11: Apple's Daisy robotic iPhone cracker (Apple press release, 2018b)

Apple has a different idea about maintenance, refurbishment and materials recovery. On a market capital basis in February 2019, Apple is the second most valuable company on the planet behind Amazon. CEO Tim Cook is a leading proponent of sustainable electronics manufacturing. Apple is powered with 100% renewable energy (Apple press release, 2018a). The company's iPhone XR contains 32% bioplastic (Bioplastics News, 2018). In May 2018, Apple announced co-financing for a zero-carbon aluminium smelting pilot process with Rio Tinto Alcan (Ker and Ludlow, 2018). With two billion iOS devices produced, Apple is part of the e-waste accumulation problem. To address this in 2016, Apple demonstrated Liam, a robot that disassembles iPhones for recycling parts. Apple demonstrates not only robotic factory assembly, but now product disassem-

bly by robots. Liam's daughter robot is Daisy, the next generation of phone crackers (*Tech Crunch*, 2018). Daisy is recovering sufficient tin metal that Apple hopes it can close loops and discontinue tin mine extraction in the future.

Thought leadership, influence and the role of public sentiment: a convergence?

Presently, the Circular Economy is an idea being promoted. Some elements are clearly already being demonstrated, but other elements are still hopeful thinking and may even be poorly defined. In the UK, the Ellen MacArthur Foundation catalyses thought leadership on the Circular Economy.[2] The various universities are active in New South Wales, and it is easy to observe engagement and aspirations by tech companies like Apple. Ecological cooperation reached an international pinnacle at the 2015 Paris Conference. Perhaps this forum, "Towards a prosperous yet sustainable Australia", is an indication that aspirations continue to rise.

It appears that a convergence of thought is coalescing. That convergence is social, political and technically led, perhaps "tech sector" led, within the long established environmental and sustainability discourse. Today's technologists are increasingly politically active, and they skilfully use digital media platforms to influence social attitudes.

Students aspire to align careers to sustainable goals. At the University of Sydney, Professors Maryanne Large, Andrew Harris and Ron Johnston built a program called "Invent the Future". Ph.D. candidates from science, engineering, business and design faculties collaborate to imagine a new product or service innovation to commercialise. The Biochite/Carapac team developed a bioplastic film. Company co-founder and agriculture PhD candidate Michelle Demers hopes to sell this plastic made from polymerised, recycled seafood shells to mushroom farmers to displace petroleum plastics. This rising generation of students and researchers has the aspiration to solve the so-called wicked problems inherited from the last century.

Diagram 12: Carapac bioplastic film © Carapac, used with permission, and permission granted to re-use by Royal Society

Based on solid science and the precautionary principle, a significant, influential segment from the professional technical community sees the impact of the accumulation problems of e-waste and plastics. They use social-political-technology convergence to influence public opinion and business decisions. On June 8, 2018, the Thailand Department of Marine and Coastal Resources uploaded photographs of a whale autopsy onto Facebook. Eighty plastic bags were removed from the belly of the dead whale and displayed for a photograph showing some of the blood of the whale (Sriring, 2018).

Three weeks before the Thailand whale incident, McDonald's USA shareholders met and voted down a proposal to discontinue single-use plastic straws (Meyer, 2018). Four weeks after the whale autopsy social media

[2] https://www.ellenmacarthurfoundation.org

Diagram 13: Plastic bags removed from Thai whale. Placed in the public domain by Thailand Department of Marine and Coastal Resources

furore, Starbucks announced a phase out plan for single-use plastics.[3] A long-time environmentalist, Sir David Attenborough, is increasingly using his public persona to leapfrog over today's business leaders and engage directly to the new generation of children and, of course, to their mothers who are the next generation of consumers. This consequential social media and traditional television media influence on young family consumers is a new force indirectly influencing corporate shareholders and boards of directors. "The David Attenborough Effect" via Facebook and digital media shapes public opinion and influences business decisions. Mothers and children love whales. The Thai whale photograph unmistakeably associates plastic bags with death.

On June 9, 2018, social media feeds were inundated with images of floating plastic from a garbage patch at the Dominican Republic in the Caribbean (Kratz, 2018). #StrawsSuck began trending in June 2018.

[3] "Starbucks" (2018).

While US President Donald Trump tweets that climate change is a hoax, a rising generation of young people is pushing back with a response that is socially conscious, political, tech-enabled and increasingly technologically sophisticated. It is visible globally and supported locally by campaigns such as the ABC's *War on Waste* and student support at Australian universities.

Diagram 14: Student appeal at a USyd café outside the Chemical Engineering School. Photo by author, public domain

On November 20, 2018, photographs of a 9.5-metre dead whale from Wakatobi National Park in Indonesia were distributed. Six kilograms of plastic from hundreds of cups and plastic bags were in the dead animal's belly. The cause of death was unknown, but associations of marine life deaths with plastic have become irresistible on social media platforms.

What next on the science?

Plastics are appearing in numerous unintended environmental locations, and the images frame spoiled natural beauty, ruination of the ocean and death to fishes. It is a public relations challenge for the plastics industry.

Diagram 15: Dead whale filled with plastic waste, Wakatobi National Park, Indonesia. Public domain, Twitter, WWF Indonesia

As the anti-vaxxer phenomenon has shown, science and conspiracy theories on internet platforms can intensify or distort public perceptions of risks, especially where there is a significant scientific question with an absence of reliable research or where there is weak research combined with deficient science communication from the media (e.g., commercial television breakfast shows featuring the cancer cure of the week stories). Through product stewardship and extensive toxicity testing, there is general industry and scientific community acceptance that plastic materials in macro form are not toxic to humans. However, eroded microplastics are appearing in the human food chain, and new questions are being asked. Table salt (Yang et al., 2015), fish (Karami et al., 2017), saltwater oysters and fresh water mussels (Rochman et al., 2015) have shown microplastics contamination. Strict curb side waste segregation and recycling in Germany is recovering kitchen vegetable and fruit wastes to municipal composting programs, but plastics are entering that compost and appearing in fertiliser supplied to German farms (Weithmann et al., 2018). A small scale feasibility study by a Medical University of Vienna researcher included tests from six European countries plus Japan and found microplastics in eight out of eight human faeces samples tested (Schwabl, 2018). The FTIR pilot study showed plastic particles in the size range of 50–500 µm, especially polypropylene and PET. The Science Advice for Policy by European Academies organisation issued a report in January 2019 concluding, "The best available evidence suggests that microplastics and nanoplastics do not pose a widespread risk to humans or the environment, except in small pockets. But that evidence is limited, and the situation could change if pollution continues at the current rate" (SAPEA, 2019). A recent broad review of scientific literature and a critique from an industry viewpoint were provided by *Chemical & Engineering News* in early February 2019 (Scott, 2019). *C&EN* highlights the current concerns of microplastics as: preferential adsorption and concentration of organic pollutants like benzene compounds due to lipophilic surface tension; collection of microbes such as *E. coli* on microplastics in shellfish; and the possibility of transmitting plastic precursor monomers or plasticisers such as bisphenol A into human food chains. It is hotly debated science. However, as the saying goes, "We are what we eat", and clearly people are unintentionally digesting micro-plastics and anything attached to the plastics. Connection of marine and bird deaths attributed to macro plastics obstructing gut function is extending to human health concerns for micro-

plastics. This logic extension will occur with or without validated causation, especially on internet and social media platforms that connect to viewers first on an emotional level based on shock and fear and then later on an intellectual level after the cognitive bias has already been activated.

What next on public policy?

Looking forward, the convergence of social-political and tech factors could yield sufficient alignment to trigger a tipping point. This will be obvious when governments begin to use the words of economists to justify legislation and regulation to implement Circular Economy reforms. Governments are themselves massive purchasers. Secondary materials markets are presently insufficient for recycled materials, but governments could create markets using their procurement powers.

In late 2018, NSW Government released a Circular Economy Policy Statement. In early 2019, a Circular Economy Innovation Network was initiated prior to the State's 2019 election season.

In early 2018, the Warren Centre released a report on the Circular Economy. In its conclusions, that report describes the legislation, logistics, technology and linear economy inertia barriers needed to achieve change. These actions were also identified as important steps towards the circular economy:

- Pricing of negative externalities through taxation or trading schemes
- Support for businesses transitioning to circular economy concepts
- Further research and development in materials science for more efficient identification and separation of plastics
- Information systems to create databases of secondary raw materials
- Establishment of secondary raw materials commodity markets

Conclusion

"What now for the Lucky Country?" There is strong evidence for the case for re-designing industries and products to align towards the Circular Economy. Increasingly, public opinion in Australia aligns towards support for Circular Economy concepts, especially due to social-political-digital technology influences. A new generation of young Australians connect as global citizens on worldwide digital media platforms, experiencing in real time environmental incidents that occur anywhere in the world. This generation questions the consumerism of the 20th century and appears keen to adopt a new Circular Economy. Some businesses are already re-engineering themselves to align with the aspirations of a new generation of consumers and customers. Governments are also taking action.

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