European Union Centre on Shared Complex Challenges

WP_03

Imagineering Australian climate futures 2050

Geoengineering Scenarios Workshop Report 2016

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WORKING PAPER

AUSTRALIAN-GERMAN CLIMATE & ENERGY COLLEGE

Acknowledgments
For their generous contributions, participation and/or help in organising this event, thanks are due to:

- The EU Centre on Shared Complex Challenges, which is co-funded by the European Commission and The University of Melbourne,
- The Office of Environment Programs,
- Professor Kate Auty,
- Professor David Karoly, Dr Sebastian Thomas, and Associate Professor Peter Christoff,
- Julie Groce, Stephen Pollard, Graham Palmer, Dimitri Lafleur, Alex Nauels, Sonya Fiddes, Lyn Spokes, Megan Reichstein, and
- All the participants (who are listed in the Appendix).

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Executive summary

We live in a turbulent world where problems and their 'solutions' are complex, interconnected and uncertain. Climate change is one such problem. How we will manage climate change as a global community is dependent on many intersecting factors. One concept that has been flagged as a way to tackle climate change is geoengineering. Geoengineering is the collective term for a diverse set of techniques and technologies that aim to manipulate the planet's environment to address climate change.

That geoengineering is being proposed is an indication that traditional efforts to manage climate change may prove inadequate. Although climate change presents a series of daunting unknowns, many of the methods that sit under the geoengineering umbrella also engender severe risks and potentially irreversible impacts, both environmental and social. How those risks are managed will depend on how, when, where and under what conditions geoengineering might ultimately be deployed.

To date, Australia has not engaged heavily with the geoengineering debate. However, given its inherent vulnerability to climate change, Australia has a lot at stake in any discussion of geoengineering. Will geoengineering present a risk or an opportunity for Australia? Can Australia contribute to geoengineering decision-making in a unique way?

This project sought to explore how Australia and the world might manage climate change in 2050 as a way to understand the diversity of situations in which geoengineering might be deployed. A workshop was held to produce multiscale scenarios to 2050. A method of deduction forecasting was used to explore the key driving forces and uncertainties that might underlie how the world (and Australia) manage climate change in 2050.

The four scenarios that were produced—'Corporatocracy', 'The Purge', '1984' and 'Spaceship Earth'—illustrated four very different worlds and worldviews. Drivers or uncertainties that were identified as determinants of how the world manages climate change in 2050 were:

- Global geopolitical stability
- Cultural acceptance of geoengineering
- Social and political pressure to act on climate change
- The role of private technology and financial interests in acting on climate change and in developing geoengineering technologies

The drivers of Australia's management of climate change were seen to be:

- The effectiveness/longevity of the Paris Agreement
- Generational change: the potential for a new cultural paradigm
- Climate change impacts and our ability to adapt
- The potential for major socio-economic or 'ecosystem' events
- National security views of climate change
- Role of the media in Australia

In all but one scenario, geoengineering was deployed to manage temperature increases and other climate change impacts. However, the direct justification for the geoengineering deployment and the way in which the act took place differed between scenarios. Generally, where geoengineering deployment is considered, Australia is seen to be involved and to cooperate with other 'rich' countries.

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1 Introduction

In December 2015 in Paris, at the 21st high-level meeting of the United Nations Framework Convention on Climate Change, negotiators drafted the Paris Agreement, establishing the aim of

> *'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels' (*Paris Agreement*, art II)*

Just days before the meeting, Paris had been shaken by its second bout of terror attacks that year—the meeting was almost cancelled. In 2015, the world also witnessed more than 250,000 deaths across Syria; the appearance of the Zika virus in Brazil one year before the Rio Olympic Games; Elon Musk's announcement of Tesla's Powerwall battery technology; the announcement of Donald Trump's US presidential candidacy; a million refugee arrivals at European borders; the adoption by 193 countries of the United Nations Sustainable Development Goals; NASA's discovery of water on Mars; and Malcolm Turnbull's successful internal party challenge making him the eighth Australian Prime Minister in five years.

Many of these events had the capacity to influence the December meeting or its outcomes. In the 21st century, the world we inhabit is highly complex, interconnected and uncertain. The problems we face have high stakes and require long-term decision-making. Although the Paris Agreement has been lauded as a political breakthrough, real success will be judged by whether and how the treaty is implemented. Designing policies in this context means appreciating the multitude of potential futures, their key driving forces, uncertainties, and would-be turning points.

Geoengineering, defined by the Royal Society as '*the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change*' (Royal Society, 2009, p. 1), could fundamentally influence global efforts to implement the Paris Agreement. This report describes a project that explored how climate change might be managed in Australia in 2050 and the role that geoengineering might play.

1.1 Aims of the project

The aim of the project was to develop scenarios to explore whether geoengineering might play a role in climate policy in 2050, and if so, what type of role that might be. The purpose of the scenarios was to inform geoengineering governance debates, to identify focus areas for future research, and more generally to start a conversation about geoengineering in Australia.

The specific questions addressed were:

(1) What key drivers and uncertainties might affect how *the world* manages climate change in 2050? and
(2) What key drivers and uncertainties might affect how *Australia* manages climate change in 2050?

This report is an account of the workshop process and a description of the four scenarios that were developed. The report consists of four main sections: first, some relevant background on geoengineering, its relevance to Australia and the use of scenarios; second, a description of the scenario process; third, a description of the four scenarios; and fourth, a discussion of what can be learnt from the project. The report is a practical account of

the project, including some examples, relevant sources and insights into the theories, principles and concepts underpinning the project are provided in breakout boxes.

2 Background

2.1 Geoengineering

Geoengineering, also known as 'climate engineering', 'climate remediation' and 'climate intervention', consists of proposals that alter the Earth's energy balance to affect temperature. The broad range of methods that have been proposed is generally classified into two categories, referred to as carbon dioxide removal and solar geoengineering in this report:

- **Carbon dioxide removal** seeks to reverse the impact of greenhouse gas emissions by drawing heat-trapping carbon dioxide out of the atmosphere. Proposals include expanding forest coverage; adding iron to the marine environment to stimulate the growth of ocean biomass; adding silicate or carbonate minerals to the ocean to react with and consume carbon dioxide; building artificial trees that extract carbon from the atmosphere; and growing bioenergy crops then capturing the emissions from their combustion. The latter two processes require that the captured carbon be permanently sequestered underground or in the deep seabed. All these proposals are generally considered technically feasible, but they have limited capacities to alter the climate, they act on long timescales, and they have high implementation costs. Many carbon dioxide removal methods also present risks of unintended impacts and unavoidable environmental and social trade-offs. For these reasons, carbon dioxide removal techniques are currently considered to be economically, environmentally and socially viable on small scales only.

- **Solar geoengineering** seeks to either intercept incoming solar radiation (providing a sunshade) or to reflect radiation away from the Earth. Proposals include placing mirrors in space; dispersing reflective aerosols into the upper atmosphere; modifying low-lying clouds to make them whiter; covering glaciers, deserts or oceans with white material; genetically engineering paler plants and crops; and painting roofs and roads white. There are several drawbacks to solar geoengineering. First, none of these methods would reduce ocean acidification. Second, reducing incoming radiation does not exactly offset the effects of increased atmospheric carbon concentrations. Although global temperature may reduce on average, there will be highly variable regional climate effects. Specific impacts of solar geoengineering on local temperatures, rainfall patterns, and climate systems such as monsoonal flows, are unknown. Thirdly, if deployed, solar geoengineering would need to be maintained until atmospheric carbon concentrations were brought under control, because abrupt cessation would trigger the 'termination effect'—a sudden temperature spike. As a result, while solar geoengineering methods are generally considered to be fast-acting and cost-effective responses to global warming they are currently considered imperfect and risky.

On a global scale, the environmental risks posed by geoengineering proposals are uncertain, unevenly distributed and, when dealing in the ocean and atmosphere, difficult to confine within national borders. Yet, the economics of some geoengineering schemes make them attractive, potentially undermining international resolve to reduce greenhouse gas emissions. As long as there is no clear international governance of geoengineering any nation could undertake unilateral geoengineering action in its own national interest.

Professor Clive Hamilton, member of the Climate Change Authority, the Australian Government's advisory body, describes geoengineering as ethically indefensible (Hamilton, 2013). He argues that managing the climate amounts to 'playing God', displaying excessive hubris. Geoengineering addresses only the symptoms of climate change, rather than the behavioural causes, transferring the burdens of both emissions reduction and the continuation of geoengineering onto future generations. In response, some scientists argue that such concerns lose significance in the face of a climate crisis (Keith, 2013). Therefore, a moral duty to protect the vulnerable justifies the choice of geoengineering over impending disaster. Such a proposition forms the basis of the 'emergency scenario', often used as an argument for supporting geoengineering research.

2.2 The Australian focus

An international debate on geoengineering is beginning to emerge. At this stage, no binding international treaty exists to regulate geoengineering as a collective. However, discussions on certain geoengineering schemes have been held within existing international treaties.

Australia's contribution to geoengineering policy discussions and research has been minimal (BOX 1). In 2013 Australia took an strong international stance against marine geoengineering, leading a proposal to restrict ocean fertilisation through the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. The centrepiece of the government's climate policy, the Emissions Reduction Fund, finances projects that reduce or remove carbon emissions, many of which could classify as geoengineering proposals. These conflicting positions suggest that Australia does not have a firm policy position on geoengineering.

BOX 1: Australian government's contribution to the geoengineering literature:

- The first Garnaut Climate Change Review dedicated just one out of 634 pages to geoengineering (Garnaut, 2008).
- The updated Garnaut Review made only a few mentions while not addressing the topic directly (Garnaut, 2011).
- The Academy of Sciences hosted a symposium entitled 'Geoengineering the Climate? A Southern Hemisphere perspective' in 2011.
- The Office of the Chief Scientist published a short briefing on geoengineering (Reekie & Howard, 2012).
- The Antarctic Climate & Ecosystems Cooperative Research Centre has published position analyse on ocean fertilisation (ACE CRC, 2008, 2016).

Every geoengineering scheme will have 'winners' and 'losers'. For example, research suggests that seeding clouds, while having a cooling effect in some parts of South America, could have a destructive effect on the Amazon forest (Jones et al., 2009). Space-mirrors may lead to a significant decrease in precipitation in the Tropics but a slight increase in rainfall in certain regions north of the equator (Lunt et al., 2008). Aerosols in the upper atmosphere may slow the recovery of the ozone layer by up to 70 years (Tilmes et al., 2008), affecting skin cancer rates in some countries.

To date, the majority of research on geoengineering proposals has been undertaken in the United States, Germany and the United Kingdom (Belter and Seidel, 2013). As a result, there is limited understanding of the potential effects of geoengineering proposals on Australia specifically, and whether Australia is likely to be a 'winner' or a 'loser'.

Australia's vulnerability to climate change has been qualified as the highest amongst countries of the developed world, because of unique ecosystems, a dense coastal population, and an important land sector (Garnaut, 2011). On the one hand, geoengineering and any discussion of geoengineering, could present a threat to Australia by drawing attention away from serious action to curb climate change. On the other hand, geoengineering could present an important opportunity for Australia, potentially reducing climate adaptation costs, saving species from extinction, and freeing up resources to build resilience and mitigate the risks of climate change.

Another important consideration is the physical capacity for Australia to undertake geoengineering projects within its borders (BOX 2). The expansive and remote nature of the Australian continent, in combination with the country's stable and safe political climate, could make Australia an ideal testing (and potential deployment) ground for many geoengineering proposals.

BOX 2: Examples of Australia's geoengineering 'assets':

- Large uninhabited areas that could host projects and trials.
- The Southern Ocean has been identified as an ideal location for testing iron fertilization (Boyd et al., 2000).
- The Nullarbor Plain offers a large deposit of limestone that could be processed and added to seawater to react with carbon dioxide (Kruger, 2010).
- Australia has safe airports close to an airspace that is relatively clean, providing good testing space for cloud or aerosol geoengineering.
- Australia has the capacity to lift objects into space and deploy missiles, as might be needed for aerosol geoengineering (Victor, 2008).

2.3 Scenario-based research

Scenarios are plausible descriptions of the future that provide platforms for thought experiments. They are not predictions; they are hypothetical futures. They allow ideas, relationships, goals and theories to be understood and tested without physical limitations. This is useful where there are high levels of uncertainty and interlinkages between events are hard to understand or unravel.

Scenarios can be used for many different purposes. For issues of local relevance, scenarios are often constructed to build consensus among different stakeholders around a common strategy. Scenarios are also used to test policy proposals by envisioning possible outcomes of the policy under different circumstances and identifying potential turning points. Scenarios are also sometimes used to communicate complex problems and their possible outcomes to a non-expert audience.

In this project, scenarios were used as imaginative tools to explore the interactions and events that might affect how climate change is managed up to and in 2050. The scenarios were conduits for making explicit and for questioning the underlying assumptions and expectations that are held around geoengineering.

As research tools, scenario exercises can make scientists uncomfortable, because the scenarios themselves do not fit within the classical model of scientific method where reproducible results are generated from verifiable data. However, if the process of scenario construction is based on sound reasoning, the process can produce new

falsifiable information and hypotheses that can be communicated, recorded, and tested, which is the goal of all scientific inquiry.

3 Workshop process

The scenarios were constructed through an iterative process of collaborative inquiry in a group setting. The multistep process that was followed is described here, with some details on the key assumptions and methodological choices.

3.1 Preparation

Before the workshop was convened, a thorough review of the existing geoengineering scenarios literature was undertaken. The review revealed a limited number of (published) examples where a formal scenario methodology was followed, and where the underlying drivers and assumptions behind the scenarios were made explicit. Of these, six were based on participatory workshops convened between 2011 and 2015, mainly in Germany, the US, the UK, and Canada (Banerjee et al., 2013; Bellamy and Healey, 2015; Böttcher et al., 2015, 2016; Haraguchi et al., 2015; Milkoreit et al., 2011). The review found that the six workshops employed various methods each with strengths and limitations. The focus of all six workshops was global. In most cases, the study was restricted to solar geoengineering. The review also found four underlying uncertainties or drivers of a geoengineering future that were common to many of the scenario exercises. Specifically, whether or how (solar) geoengineering was deployed was influenced in some part by:

- The degree of global coordination on climate change governance
- The degree of public acceptability of geoengineering
- The degree of controllability of geoengineering technologies
- The degree of climate sensitivity (severity of climate change impacts)

3.2 Assumptions

The workshop aimed to produce narrative style storyline scenarios so that drivers of change could be identified. It was the first (to our knowledge) to develop multiscale scenarios focussing on a specific continent or region. This decision was based on the desire to instigate a conversation on the potential role and influence of geoengineering on Australian policy. The time horizon was chosen to 2050 (BOX 3). This was based on two considerations: the likely timing of reaching a 2°C temperature increase; and the inclusion of carbon dioxide removal methods in various climate and economic models starting sometime between 2030 and 2070. All geoengineering and energy technology options were included. The questions were framed around climate change

BOX 3: Choosing the scenario time horizon:

Generally, the utility of scenario methods increases with the time horizon. Scenario analysis is most appropriate to longer-term decision-making, and the choice of time horizon should reflect the matter under consideration. Decision-making in some activities have inherent timeframes: the development of pharmaceuticals has a 10-year lead time; decisions around nuclear power must factor in 25 years; and forest management requires forward-thinking by as much as 100 years (Molitor, 2009). It is always helpful to consider how far in the future resources are being committed and the duration of large changes in the environment (Armstrong, 1985; Linneman & Kennell, 1977).

rather than geoengineering to include the possibility that geoengineering may not play any significant role in future climate policy. Finally, participants were told to consider both continuous trends and potential disruptive events.

3.3 Participants

To dilute the influence of any individual preconceptions, disciplinary predispositions, or organisational prejudices, a diverse group of individuals was brought together (BOX 4). In a structured manner, the process drew upon inputs from multiple disciplines, knowledge types and worldviews.

Twenty participants were selected to represent the diversity of stakeholders and experts relevant to climate change and geoengineering policy. The group included scientific and experiential expertise in engineering, marine science, geology, energy systems, water science and policy, ecosystem science, Australian Federal and State politics, Australian environmental law, international climate negotiations, carbon markets and risk, finance, Chinese politics, European politics, international relations and security. Experts from the various areas were selected based on certain criteria such as holding a senior position within a relevant academic, government, business, or non-profit organization. The group also include an art curator, and youth and indigenous outreach officers.

BOX 4: Choosing the participants:
Although it is time-consuming, deliberation and participation that integrate different types of values and knowledge, are key to a well-designed scenario exercise (Wilkinson and Eidinow, 2008). It helps to define the problem and its connection to society, to generate new and unexpected learning, to access and connect authoritative and specialist knowledge from different areas, and to expose or challenge preconceptions (Kok et al., 2007; Richards et al., 2004). It also promotes credibility and legitimacy (Patel et al., 2007). It is important, however, that participants be selected with consideration of the issue area, and that these experts be able to open their minds, to detach themselves from the context of their institutions, and to engage in a creative process without advancing any agenda (Volkery et al., 2008).

The recruitment method ensured a gender balance, an even mix of academic, government, business and civil society, and a representation from social (and cultural), technological, economic, environmental, political and legal disciplines, perspectives and interests (See Figure 1).

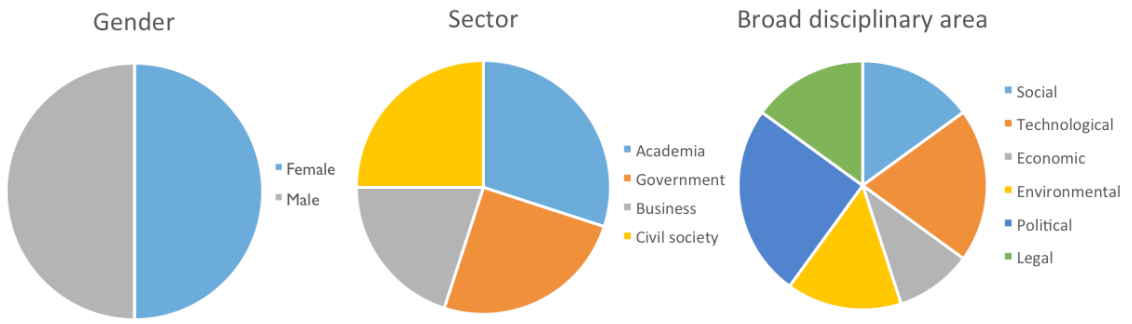

Figure 1: Distribution of gender, sector and disciplines within the group of participants

3.2 Method

The scenario construction aimed to develop multiscale scenarios (BOX 5) where Australia is the focus against the global background. The process followed a method of deduction forecasting adapted from the Mãnoa School four-futures method (Dator, 2009;

Dator et al., 2015). This method starts by understanding what already is and how it has come to be, and then forecasts challenges and opportunities of the future. The outcomes of these challenges and opportunities are envisaged through a set of several alternative futures based on different worldviews and the confluence of mixed trends and issues. This last step is assisted by the use of four scenario archetypes (Figure 1). The benefit of using the Mãnoa School four-futures method is that it drives participants to consider worldviews and paradigms that may be outside their experiences, without limiting the discussion to cover only a defined number of issues.

BOX 5: Linking scenarios across scales:
When the interactions between the wider system and the system in question are strong and bidirectional it makes sense to build multiscale scenarios. There are different ways to link scenarios across geographic scales. It can be done through the content of the scenarios, such as the driving forces, and through the scenario development process. The degree of linkage needed determines whether the same elements are used across scales and whether scenario processes take place independently, consecutively, iteratively, in parallel, or jointly (Zurek & Henrichs, 2007).

The workshop was held on 19 September 2016 at the University of Melbourne. The workshop was the first part of a three-phase process that included a post-workshop discussion and a final review of the scenarios, both over email. The next section describes the multi-step workshop process and the follow-up phases.

3.3 Multi-step process

The workshop process was as follows:

1. The participants were shown a short video on geoengineering. This was to ensure a base level of literacy in the technologies and their implications.
2. A question and answer session was led by the facilitator but allowed everyone in the room to share information, asking and answering questions and queries about geoengineering, the status of research and the importance of governance discussions.
3. In groups of five, the participants were asked to brainstorm, discuss and report back on the drivers and uncertainties that might affect how the world manages climate change in 2050.
4. A brief discussion compared the outcomes of the brainstorm session and those from the literature review of geoengineering scenarios.
5. In breakout groups, the participants were then asked to brainstorm, discuss and report back on the drivers and uncertainties that might affect how Australia manages climate change in 2050. Groups were instructed to consider the outcomes of the previous session but not to be restricted by them.
6. In their groups, the participants were asked to rank and then discuss, the Australian drivers and uncertainties in terms of their potential impacts and levels of uncertainty.
7. In plenary, the top six ranked driving forces were selected.
8. Each group was allocated a future archetype (Figure 2) and details of that future's elements, and asked to envisage and then present a scenario that fitted the archetype.

BOX 6: 'Black swan' events:

- are unexpected;
- have extreme impacts; and
- we naturally seek to understand and explain them so that they may seem to have been predictable (Taleb, 2007).

9. Before closing, the entire group brainstormed and discussed the types of 'black swan' events (BOX 6) that could disrupt the future.

Following the workshop:

10. First iteration: basic short narratives were drafted to illustrate the scenarios described at the workshop. Each was emailed to the relevant group. Participants were asked to provide feedback and more detail on their scenario by means of an email discussion. In particular, participants were asked to focus on the credibility and internal consistency of the scenario and to provide as much detail as possible around potential turning points.
11. Second iteration: the email discussions were used to refine the scenarios. These were then emailed to all participants, who were asked to comment on and discuss the scenarios individually or as a collective.

'Growth'		**'Collapse'**	
Population:	Increasing	Population:	Declining
Energy:	Sufficient	Energy:	Scarce
Economics:	Dominant	Economics:	Survival
Environment:	Conquered	Environment:	Overshot
Culture:	Dynamic	Culture:	Stable
Technology:	Accelerating	Technology:	Stable
Governance:	Corporate	Governance:	Local
'Discipline'		**'Transform'**	
Population:	Diminished	Population:	Post-human
Energy:	Limited	Energy:	Abundant
Economics:	Regulated	Economics:	Trivial
Environment:	Sustainable	Environment:	Artificial
Culture:	Focused	Culture:	Complex
Technology:	Restricted	Technology:	Transformative
Governance:	Strict	Governance:	Direct

Figure 2: The four archetype scenarios of the Mãnoa School four-futures method and their seven driving forces

4 The scenarios

4.1 Corporatocracy

A growing and continuously-developing global economy fuels urbanisation and high population growth. This sees in 2050 a world with 10.9 billion inhabitants highly concentrated in megacities, where energy demands are high.

As the State has continued its transition from the 'welfarist' model of the 20th century to widespread privatization, corporates now hold strong influences over global and national economies. Governments have outsourced most of their service delivery. Corporations now provide the police service in many countries, the national media regulating service, and the delivery of welfare.

In this strong global economy, the culture is heavily consumerist. Technology development is continually accelerating, driven in part by the constant demand for novel products. Cultures that see themselves as integrated and connected to nature have been increasingly marginalized or

disempowered. This has resulted in a loss of knowledge about the natural world and harmonious ways to interact with it. In 2050, the natural environment is not so natural. Given the detachment of this population from 'nature', they readily accept brave new technologies. Desalination plants, monoculture plantations, and new or diverted rivers are commonplace.

At the same time, trust levels between government (that are now seen to serve corporations) and the people are at historical lows, but the relatively high standard of living of the majority of the population stymie any real uprisings. Despite evidence of localised public agitation, there are no major transformative or disruptive forces to the political system because corporations effectively 'own' political parties. The reform agenda is increasingly dictated by the corporations that support the major parties. A sense of political stability seems to permeate.

The Paris Agreement began to transform climate change from a longer-term threat to the economy (through its physical impacts) into a short-term threat to corporations (through policy-accelerated economic transition risks). Corporations, due to a combination of profit-seeking and moral duty, have seen a notable shift over the past decades with directors and boards taking climate change into consideration in decision-making. Change is underway, but the transition is initially slow and steady, heavily controlled to maximise upside risks and minimise downside risks for corporations. This allows large corporations to diversify their operations but maintain profitable fossil-fuel investments until they reach maturity. They methodically siphon some of those profits into clean technology investments to profit from emerging markets.

However, the trend eventually takes on its own momentum as the clean technology industry begins to demonstrate genuine medium-term economic benefits. As a result, the clean technology industry begins to dominate. There is gradual introduction of a hydrogen economy based on a gasification of biomass grown in fertilized oceans. Global energy is sufficient. Carbon concentrations have begun to stabilize but because the transition was initially slow, the 2°C threshold was not avoided. It has become increasingly difficult to feed the growing population. Strong agricultural conglomerates push for a more effective Paris Agreement that reflects the measurable outcomes mentality of the Corporatocracy. The Paris Agreement is amended deleting all references to greenhouse gas emissions and atmospheric carbon concentrations, both of which are difficult to monitor and verify. Instead, the Paris Agreement is amended to aim only for temperature reductions. This ultimately justifies the use of solar geoengineering to create a climate where agriculture can feed 11 billion people. The climate, like the rest of the environment, becomes controlled, artificial and conquered.

However, as is inevitable, inequality rises both within nations and between nations as only certain sections of the global population have the opportunity to hold decision making positions in key corporations. There exists an undercurrent of social resistance in those countries where the population still holds some faith in representative democracy and the need for those in charge to listen to the people. These countries most likely have also missed out on the highest levels of economic growth, which has further fuelled the uprisings and resistance. The technologies that have been developed are maintaining a 'survivable' planet but are increasing the need to continually manipulate the environment. These social pockets of resistance are spread across the globe.

Led by environmental movements and indigenous rights activists, a grassroots campaign starts convincing communities to reject a society controlled by undemocratic profit-seeking (no matter how 'benevolent') corporations, and to join the creative and destructive project of imagining and building a new way to organise society. An opportune window appears for these campaigners as solar shields begin to fail. How will this play out? Will the (corporately-

sponsored) military step in to quash resistance and to protect the climate management infrastructure? Will society collapse as the geoengineering technology crumbles and as resistors, equipped with only social capital, resort to violence (people power) to force change? Or will these resistors, having managed to raise sufficient financial capital, invest in society-changing initiatives and win back the power establishing more direct forms of governance and doing away with geoengineering all together?

Corporatocracy in Australia

In Australia, the population readily accepts the Corporatocracy. Popular social reforms like same-sex marriage have been promoted (and passed through parliament) because corporates targeted these issues to appease the population while they increase their control of the economy and society in general. The reform agenda is increasingly dictated by the corporations. Senate rules are being amended to reduce the influence of disruptive independents. This plays into the hands of larger parties (backed by corporates) that then ensure that corporate-friendly agendas are passed through parliament.

Following the success of the Paris Agreement, emissions intensive corporations must diversify their operations away from fossil fuels to remain internationally competitive. The question is whether Australian corporations will be able to ride the wave of economic transformation and remain strong and prosperous into the future. The prominence of corporations drives and defines society and the economy. Therefore, it will be the ability of Australian corporations to transform that will dictate how powerful Australia as a nation remains over coming decades. This has implications for how directly involved Australian corporations (and by extension Australia overall) is in setting global reform agendas.

4.2 The Purge

Over time, an engrained culture of short-termism negatively impacts on the ability of governments and corporations to proactively manage complex longer-term risks, such as those presented by climate change. This endemic short-termism leads to failure of the Paris Agreement to catalyse meaningful emissions reductions across the global economy.

Temperatures soar due to rising greenhouse gas emissions. A series of extreme climate events in close succession caused by worst-case scenario global warming create recessionary conditions across the global economy. These events occur within a context of perpetually high levels of public and private debt. The stalling of economic growth triggers multiple corporate defaults because record debts cannot be serviced in the recessionary environment. This in turn creates a systemic crisis, triggering the collapse of the global economy.

At the same time, intra- and inter-state conflicts over increasingly scarce natural resources become more frequent and violent. The confluence of economic calamity and adverse physical impacts of climate change cause food supply chains to fail and disease to become widespread. Political tensions are high. Populations are weakened and significantly reduced because they are now much less resilient to the impacts of natural disasters. There is no capital available for innovation or invention whether for health, environmental or other reasons. The collapse in economic activity leads to a plummet in greenhouse gas emissions, but atmospheric concentrations are already high.

This world is in crisis. Although the backbone of inter-state communication and basic diplomacy still remain, States turn inwards. Many of these succumb to authoritarian regimes. In the United States certain states (such as California and Texas), governed by strong centralised political authorities declare political independence from the federation and begin to rebuild.

Political communities are fragmented but despair and collapse is not evenly distributed with populations in urban areas having the lowest levels of resilience. In most states, the welfare state has been nearly entirely abandoned. Some pockets of civilisations and individuals within civilisations manage to take advantage of the situation. These 'survivalists' thrive. These are people that had always eked their own living, never dependent on insurance companies to bail them out or on handouts from governments when disaster obliterated their worldly possessions. Rural areas are where the world begins again, building from a clean slate. Small agricultural ventures begin to appear across landscapes. Some decentralised energy systems are able to continue functioning but in an unreliable manner. There is a revival of semi-autonomous rural colonies as cities collapse. Population patterns undergo big changes– structures begin again to resemble ancient times.

Countries with political systems that favour longer-term planning, such as China or Russia, weather the crisis best. Although somewhat altered, their political cultures remain strong and in 2050 they lead the world.

The Purge in Australia

Australia's action to mitigate the physical impacts of climate change over coming decades is, like the rest of the world, frustrated by short-termism. In Australia, rainfall patterns become extremely erratic. Prolonged droughts and heatwaves turn the lucky country into a dustbowl. Droughts are broken only by intense storms and floods that wash away any remaining utilities, infrastructure and livelihoods. Virtually no ecosystem is left untouched by climate change; most are destroyed completely or overrun by weeds and pests that opportunistically colonised after the disturbances.

Physical and human damage of extreme climate events become catastrophic, and financial costs unsurmountable. Australian insurance companies collapse. The bill for repairing the damage fall far beyond what governments can afford. It doesn't take long for Australian agricultural and mining industries, vulnerable to disasters and heavily dependent on water, soils and other natural resources, to fold. Vast tracts of once prime agricultural land in the north are now marginal and have been abandoned. Centralised energy systems are damaged and dysfunctional, and pollution in town water supplies has rendered tap water unsafe for drinking.

The southern parts of Australia present a few places left that are still viable for cropping. Dotted across these regions, small farms begin to appear and link. By this stage, the Australian government is weak and decentralised. The government has limited influence over what is effectively an array of semi-autonomous colonies linked to small decentralised grids. These communities rebuild from the ground up.

4.3 '1984'

A series of extreme weather events around the world causes damage that exacerbates costs of living in several countries. Insurance premiums rise to excessive levels. People in exposed locations can no longer afford to insure their assets. In some locations insurance companies no longer offer cover. This brings climate action into political focus globally. The world begins to consider shifting away from commodities that had been the mainstay of economies over the previous two and a half decades (metallurgical and thermal coal, iron ore and natural gas). This leads to the proliferation of stranded assets over many sectors and the impending collapse of some major banks and multinational investment funds that were too slow to diversify. In a number of countries, national governments are required to step in to guarantee customer deposits. At the same time because of their increased exposure to risk, asset values begin a

rapid decline, eroding consumer confidence. Governments are again required to step in but find themselves limited in their capacity to stimulate the economy. A period of economic contraction ensues.

By 2050, economies around the world are characterised by low growth, high unemployment and record government debt. To recoup their debt, some governments impose high taxes. In these nations, intergenerational angst develops as the youth resent the restriction of their opportunities and having to forgo large amounts of their income to taxes to pay down government debt. Unconventional monetary policies, such as printing money, become the norm to keep the system afloat.

With the move away from fossil fuels and the collapse of some sectors, atmospheric carbon concentrations have begun to stabilise. However, climate sensitivity and feedforward mechanisms have proven higher than anticipated. Governments work closely with banks and insurance companies to further joint interests, prioritising and co-funding climate adaptation efforts that are strictly implemented and accountable to objective criteria. New and innovative infrastructure is created for climate adaptation generating mass employment opportunities and is thus widely supported by local communities. For example, artificial reefs replace natural reefs to ensure that marine ecosystems are not lost and to provide new revenue streams (fisheries, tourism etc.).

However, severe weather events are still frequent and adaptation is not deployed fast enough or at the scale required. Reduced resilience leads to localised population collapse, which stalls global population growth. Mitigation has been too late and geoengineering has become the one last hope. People accept that geoengineering is the only hope of avoiding total collapse of Civilisation (which has already manifested itself in many locations around the world leading to the movement of millions of displaced people each year).

Rich countries of the world deploy geoengineering technologies. Citizens of the world unite in their hope that this technology will work. The few dissenting voices are rapidly silenced. The management of geoengineering is recognised as far too important to be subject of partisan localised politics. The United Nations (or equivalent body) oversees the technology's global deployment. National governments are increasingly recognised as subservient to this form of supreme governance. Geoengineering is 'rebadged', like the artificial reefs, as a way to prioritise and protect natural ecosystems until such time as temperatures are brought down to manageable levels. It is also recognised as an economic growth platform.

This increased awareness of the need for rapid carbon emissions reduction and drawdown, the culture shifts to one where nations are no longer compared on the metrics of GDP but on natural capital accounting and resilience. Top-down emissions and energy budgets are imposed at the national and subnational scales, driving the proliferation of carbon dioxide removal technologies. Population policies are implemented in many countries to help meet environmental targets. Tariffs are applied to all goods that embody carbon emissions; organisations are required to undertake cost-benefit analyses and lifecycle assessments that incorporate environmental values. High taxes are placed on meat to account for its social and environmental costs. People increasingly adopt plant-based diets with meat seen as a luxury food item and older members of the community nostalgic about the 'good old days' when meat was eaten most nights. The circular economy is no longer an option but a requirement.

Despite its perceived success this totalitarian governance approach is inherently vulnerable and unstable. Strong black markets develop trading in carbon-intensive products and in technologies

that exploit carbon accounting loopholes. Protest political movements begin to appear, challenging the 'command economy' and its long-term sustainability.

'1984' in Australia

Australia's economy undergoes an extended period of fluctuation between low growth and recession as the world has ceased to value its primary export products. Despite perpetuating a strong rhetoric of proactively de-risking its portfolio against climate change risks, one of the Big 4 banks fails. The Federal government bails it out. Each year, Australia is saddled with at least half a dozen extreme weather events that are scientifically proven within days of the event to be due to a warming climate. Australian costs of living increase further.

The collapse of Rupert Murdoch's media empire opens up a new phase in Australian media. Support for action on climate change in Australia is strong. The government seizes on the opportunity to embed its ambitious policies on climate change mitigation. The Australian 'clean tech' economy finds its niche in renewable energy and energy efficiency. Australia also begins to experiment with genetically engineered crops. The research is not overly questioned or resisted by the community, which is burdened by record high food prices. Australia joins with other rich nations in deploying geoengineering.

4.4 Spaceship Earth

Technology now permeates everything. Everything you could need to learn or use is available online. With it comes change, such as novel GM foods and robot cities. Artificial intelligence is embedded everywhere. The human body now has so many artificial elements added to it that the boundary between human and non-human is blurred. In developed nations, humans move toward a more cyborg-like existence: naturally applying problem-solving efficiently and effectively, making 'wise' decisions, but also becoming more indifferent to 'nature'.

The concepts of family with children and of work are changed from what they were traditionally. Education levels have increased, especially for women. As a result, the global population peaks and declines. The global population naturally reduces its greenhouse gas emissions to near-zero by 2050. The Paris Agreement is no longer needed.

Humans are living longer. Although globalisation has continued, with it has developed a societal appreciation of collective global security. Scientific and technological advancements are tuned into complexity theory, and a deep appreciation of the limits of human attempts to manipulate and predict the outcomes of complex, non-linear and dynamical systems and a keen understanding of the presence of persistent 'unknowables'. At the same time, given the changed nature of humans, the relationship with the Earth is seen as symbiotic rather than harmonious.

Coming from this perspective, the Sustainable Development Goals are renewed and achieved. Carbon dioxide removal is widespread, colonising Mars and other planets is considered to be part of the near future. Energy is abundant because of the use of renewable sources, carbon capture and storage, and energy efficiency.

Plants and crops are 'engineered' to maximise root growth. Agricultural staples such as wheat and sugar, which are harvested annually, are engineered to draw down more carbon. The sucrose is then converted to protein in high-tech chemical factories to feed the population, with flavours to suit all palates. To maintain the required growing conditions, solar geoengineering is rolled out. Geoengineering becomes a tool for achieving a controlled clean atmosphere and climate stability to grow the 'new' foods.

By 2050 there is a treaty strictly regulating any form of solar geoengineering. It came after long negotiations that brought together principles and ideas from the Convention on Long-range Transboundary Air Pollution, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the Vienna Convention for the Protection of the Ozone Layer and Montreal Protocol on Substances that Deplete the Ozone Layer, the Paris Agreement and the Nuclear non-proliferation treaty. To ensure that its strict rules are observed the treaty includes independent inspection of facilities as part of a verification process, applied to all solar-geoengineering. Carbon dioxide removal is far less regulated.

There is also a UN Security Council overlay. The treaty interfaces with the Geneva Convention and the Laws of Armed Conflict. For geoengineering above the Karman line, there is an overlay with the UN Space Treaties, particularly the Convention on International Liability for Damage Caused by Space Objects.

Spaceship Earth in Australia

Australia, with its technological advancement and early adoption of information technology, takes on a soft leadership role in this world. Australia's vulnerability to climate change sees increasing engagement in mitigation, adaptation and climate intervention. It recognises and capitalises on the potential of its abundant wind and solar energy resources. Australia is also a pioneer and strong adopter of carbon dioxide removal, because of the significant amount of available land and territorial seas relative to smaller and more populous countries.

Australia continues to value its US alliance above all others and therefore hitches its star to US initiatives on geoengineering as part of a balancing effort against what is a much more powerful China.

5 Discussion

A detailed analysis of the scenarios is beyond the scope of this report. However, some insight can be gleaned from a cursory examination of the content of the four scenarios and the construction process.

5.1 Scenario content

The workshop provided an opportunity to validate findings from the review of previous geoengineering scenario workshops. When asked to brainstorm the drivers and uncertainties that might affect how the world manages climate change in 2050, the groups found that four themes were likely to be key determinants. These were

- Global geopolitical stability
- Cultural acceptance of geoengineering
- Social and political pressure to act on climate change
- The role of private technology and financial interests in acting on climate change and in developing geoengineering technologies

These four themes differ from those identified in the review of previous geoengineering scenario workshops. However, a side-by-side comparison (as shown in Table 1) suggests that the broader framing of the question might explain the disparities. In previous geoengineering scenario workshops, the formative question was focussed specifically on

geoengineering, and in many cases only on solar geoengineering. Our workshop asked about climate change more generally.

Drivers/uncertainties identified in the literature review	**Drivers/uncertainties identified in the workshop**	**Comparison**
Degree of global coordination on climate change governance	Global geopolitical stability	Broader issue (without geopolitical stability coordination of climate governance is unlikely)
Degree of public acceptability of geoengineering	Cultural acceptance of geoengineering	Broader issue (public acceptability derives from cultural values)
Degree of controllability of geoengineering technologies	No equivalent	
Degree of climate sensitivity (severity of climate change impacts)	Social and political pressure to act on climate change	Broader issue (climate sensitivity or climate impacts contribute to pressure to act)
No equivalent	The role of private technology and financial interests in acting on climate change and in developing geoengineering technologies	

Table 1: Comparison of drivers and uncertainties identified in workshop versus those highlighted in the literature review

Although the focus was more broadly on climate change management, in all but one scenario, solar geoengineering was seen as a viable option. What differed across the storylines was the reason for considering geoengineering and the framing used to justify it. In the '1984' scenario solar geoengineering was seen as a 'last resort', whereas in both the Corporatocracy and Spaceship Earth scenarios it was seen as a means to continue agriculture to feed the global populations. Where solar geoengineering was deployed, it was managed within some form of global governance, but deployed by a small group of nations. In the '1984' scenario geoengineering was framed as a form of climate adaptation infrastructure that allowed ecosystems to survive and thus was marketed as a 'necessary aid' to the natural world. In the Corporatocracy scenario, it was framed as a calculated way to meet the amended Paris Agreement goals. In the Spaceship Earth scenario, geoengineering was considered in the context of a new symbiotic relationship between humans and the Earth.

It was clear from the nature of the post-workshop comments that participants found the '1984' and Corporatocracy scenarios either more relatable or more interesting. It is interesting to note that these two scenarios shared a number of attributes. Both scenarios exist in an environment of geopolitical stability (although the underlying natures of these differed); in both scenario emissions are decreasing but climate impacts worsen thus increasing the pressure to act on climate change; both scenarios were defined in some way by private interests (although in the '1984' scenario this was manifested more

indirectly); and in both scenarios there was initial cultural acceptance of geoengineering that was then threatened.

When asked to focus on Australia, and the drivers and uncertainties that might affect how Australia manages climate change in 2050, the discussion revealed a different set of indicators, which were clearly evident throughout the four scenarios that transpired. These were:

- The effectiveness/longevity of the Paris Agreement
- Generational change: the potential for a new cultural paradigm
- Climate change impacts and our ability to adapt
- The potential for major socio-economic or 'ecosystem' events
- National security views of climate change
- Role of the media in Australia

The participants' views of Australia's part in managing climate change in 2050 differ with the scenarios. In the Corporatocracy scenario Australia is seen to play no major role, it merely falls in line with the global norm. A key determinant of Australia's place in the world is determined by Australian emissions-intensive companies' ability to move away from fossil fuels. In the other three scenarios, climate impacts and particularly extreme weather events are seen as driving forces in Australia's future. Generally, where geoengineering deployment is considered, Australia is seen to be involved and to cooperate with other 'rich' countries.

5.2 Scenario process

Given the time-consuming and experimental nature of scenario building, it is important to reflect on the scenario process itself. Shared learning involves an iterative process and this usually entails lengthy discussions. It was noted from feedback from the workshop that a two-day event would have allowed more time to explore some of the controversial issues. However, the biggest challenge was in bringing together a heterogeneous group of participants that included a range of stakeholders and experts reflecting some of the issues involved in discussing geoengineering. More than one hundred invitations were sent out for the twenty participants that accepted. Those that could not attend explained that the time commitment was too great. It may have been difficult to attract such a high-profile and expert cohort of participants had the event been planned as a two-day event.

Comments and feedback from the groups suggests that the step in the process that proved most challenging was step 8 in which each group was allocated a future archetype and asked to envisage a scenario that fitted the archetype. This stage required participants to question and expose their worldviews in the exploration of another worldview. This step succeeded in dissolving some of preconceptions and assumptions. However, this step also proved the most time-consuming. The groups became absorbed in the archetypes and some of the focus on the purpose of the exercise was lost. More time was needed to integrate the findings from the previous discussions into that important eighth step.

Finally, the two iterative rounds over email were both useful and challenging. Despite there being only one or two weeks between the stages, a number of respondents commented that their memories of the discussions had faded. Further, although the email rounds were intended as discussions, many respondents felt more comfortable responding privately. This post-workshop stage could be improved by targeted interviews with participants.

5.3 Scenario evaluation

Assessing the usefulness of scenarios is difficult as there are no objective standards against which stories can be tested. Scenarios cannot be valued for their predictive value since the purpose of the exercise is not to result in any one scenario that matches how the future is likely to evolve. The future will likely be a composite of many scenarios and thus elements of different scenarios may at some stage become relevant.

The usefulness of scenarios is best assessed by how the scenarios meet the needs to the project. Here the project was designed to identify key uncertainties that might be reduced through further research, to test and inform proposals on how to govern geoengineering, and to trigger a discussion about Australia's potential role in geoengineering. The third purpose was achieved. A discussion was indeed started through the scenario workshop and this report represents the next step in continuing that conversation.

Determining whether the other two aims were effectively achieved requires closer scrutiny of the scenarios and of the scenario-building process. Four criteria have been proposed as guides for evaluating the 'quality' of scenarios (Alcamo, 2008). These are:

1. Relevance: are the scenarios designed for purpose?
2. Credibility: are the scenarios internally consistent, scientifically rigorous and sufficiently detailed?
3. Legitimacy: did the process include input from a balanced and fair representation of stakeholders?
4. Creativity: do the scenarios challenge preconceptions and worldviews?

5.3.1 Relevance

The scenario process targeted specific questions and specific regions that relate to the question under investigation. The time horizon to 2050 is relevant to decision-making and commitments on climate change and technology development. The multiscale nature of the scenarios allows understanding of the system under examination and of the wider system that may impact on it. The content of the scenarios allows further scrutiny of global governance systems and Australia's place within them. Through further analysis the scenarios may also allow identification of key decision-points and early warning signals. Finally, the presentation of the scenarios as narrative storylines allows cause-and-effect relationships to be identified for further research.

5.3.2 Credibility

The workshop included experts from various fields including climate science, international relations, economics and Australian politics. This helped to generate scenarios that were internally consistent and scientifically rigorous. In the post-workshop rounds, respondents were asked to pay special attention to internal consistency, and a number of amendments were made at this stage. As an example, the Corporatocracy scenario initially included two variants: one where climate-related issues were integrated into corporate decision-making, and another where they were not. In the second post-workshop iteration it was found that the second variant was not consistent with the other elements of the scenario.

5.3.3 Legitimacy

The workshop and post-workshop rounds were carried out under conditions of transparency. This report is being published in an accessible format in aid of transparency. It will also form the basis of articles to be submitted to academic journals where it will undergo peer-review, which lends further legitimacy and credibility to the project.

The heterogeneity of stakeholders as depicted in Figure 1 was designed to further the legitimacy of the exercise. Due to practicalities, such as the timing of the workshop and the availability of participants, some compromises were needed. For example, it proved difficult to include an urban planning expert, a representative from local government, or an agriculturalist.

5.3.4 Creativity

The use of the Mãnoa School four-futures method forced participants to explore scenarios that challenged their own worldviews. Both the Purge and Spaceship Earth scenario represent extreme scenarios that, although they may not represent the 'real' future, triggered new thinking and ideas.

6 Conclusion

This report is only the first (important) step in using scenarios to help manage some of the uncertainties that Australia may face with regard to geoengineering. Although the discussion on this topic is still nascent in Australia, the findings from this project suggest that a more involved discussion is warranted.

The scenarios were produced following a rigorous methodology, from the initial selection of participants to the design of the actual process. This lent credibility and legitimacy to the scenarios themselves. These scenarios presented four very different pathways towards 2050. Two of those scenarios resonated as 'business-as-usual' to different participants. This is an indication that worldviews and cultural lenses cannot be ignored in the design of geoengineering governance frameworks. Scenarios provide one way of capturing these worldviews without ignoring other uncertainties.

Although the purpose of this report was to present the scenarios and their construction process, a cursory analysis was also completed. This analysis suggested that how, when and why geoengineering will be deployed could be defined by the confluence of many different factors. Suggestions that geoengineering will not needed if greenhouse gas emissions begin to decline ignore the multitude of other drivers that have been uncovered in this scenario exercise.

A range of methods exist to scrutinise and analyse scenarios. Further analysis will be undertaken to draw out influential cause-and-effect relationships, gaps, key decision points and potential early warning signals. The true value of these scenarios will be in their potential to test existing governance proposals and to inform the design of global or Australian legislative mechanisms.

7 Appendix

7.1 Participants

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