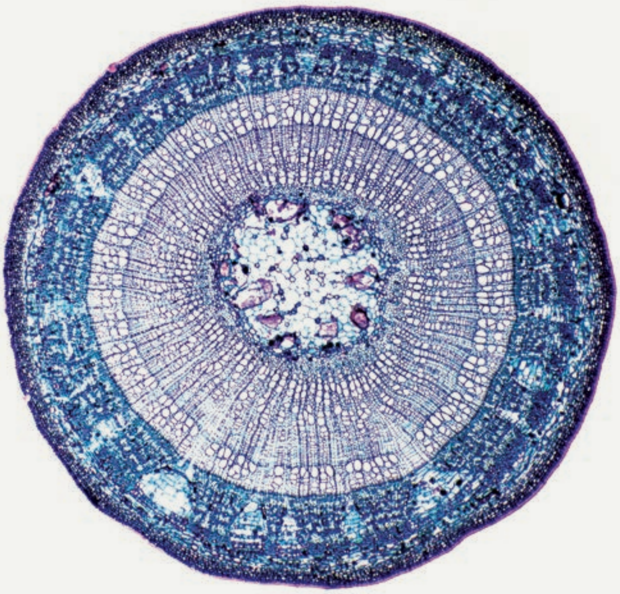
The Climate Institute

Moving Below Zero: Understanding Bioenergy with Carbon Capture & Storage



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Cover: Hands holding charred wood which can be used to produce bio-char or be the product of bioenergy generation.

Inside Cover: The image on the inside cover shows the cellular structure and three annual growth rings of a plant stem at 25 times magnification.

Moving Below Zero: Bioenergy with carbon capture and storage and associated content, including the *Below Zero* summary snapshot and an animation, can be accessed at **www.climateinstitute.org.au**

The lead author of this report is Clare Pinder, Policy and Research Fellow of The Climate Institute. Special thanks for the support provided by Erwin Jackson, John Connor and Garrett Stringer of The Climate Institute.

The Climate Institute

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MOVING BELOW ZERO: UNDERSTANDING BIOENERGY WITH CARBON CAPTURE & STORAGE

WHY

If we are going to have a reasonably high chance of staying within the internationally agreed guardrail of below 2°C global warming, much of the modelling (including that used by the Intergovernmental Panel on Climate Change) suggests that we need to be removing, not just reducing, carbon from the atmosphere.

The Climate Institute has been advocating the need for carbon-removal technologies since 2007 – not as an alternative to deep cuts in emissions but as a vital part of the package to deliver a safer and more prosperous future than the one we are heading for.

While The Climate Institute's previous publication *Below Zero* examined a range of technologies being considered, this report delves deeply into bioenergy with carbon capture and storage (bio-CCS).

HOW

This report contains the world's first ever in-depth national study of bio-CCS, focused on Australia. Through it, The Climate Institute sets out to identify the implications for an economy to meet ambitious climate goals with and without bio-CCS. We asked the international engineering firm and one of Australia's leading energy modellers - Jacobs SKM – to model how Australia can adapt (both in terms of behaviour and technologies) to meet climate goals consistent with a high chance of avoiding a 2°C increase in global temperature. The Australian Government supports this global goal and has agreed to play its part in meeting this objective.

As this work is the first of its kind, we hope that it stimulates deep discussion of the role of bio-CCS and other carbon removal technologies in national carbon policy debates both in Australia and elsewhere.

CLIMATE CHANGE IS ABOUT MANY THINGS...

FOREWORD

Climate change is about many things. It is about physics, it is about biology, it is about technology and critically, it is about society. As this report illustrates, understanding the intersection of these themes is vital to achieving a transition to a world that avoids very dangerous levels of climate change.This is the spirit in which we have approached the *Moving Below Zero* project.

Physics tells us that if we are to avoid very dangerous climate change of more than 2°C then net global greenhouse gas emissions need to fall below zero around 2050. Biology tells us that many natural systems have potential but also limits in how much carbon they can remove from the atmosphere and how much energy we can utilise from this system. Natural sciences also points us to possible solutions, whether it is locking up carbon in wood, the soil or deep underground. Technology tells us we have the know-how to unlock innovative solutions like combining bioenergy and carbon capture and storage, or others not yet fully appreciated. Society tells us that such changes may not be easy; we need policies to encourage investment and we need the community and policy makers to start to explore the risks and opportunities that these technologies will bring.

For many years, The Climate Institute has advocated for a portfolio approach to managing climate risks. This approach involves exploring controversial technologies like carbon capture and storage, and we have weathered criticism from some for this position. But at its heart, this position is driven by a view that the risks of climate change are so great, we need to expand our emission reduction options, not limit them. Achieving a below zero emission economy can be done. But limiting our options will make the shift more disruptive and risks moving our goals out of reach.

We expect that some of the conclusions from this project will be controversial. We welcome debate and hope, if nothing else, it prompts us to not limit our thinking but expand it.

I would like to acknowledge the support from the Global CCS Institute which has allowed us to undertake this project. I would also like to thank Clare Pinder, The Climate Institute's first Policy and Research Fellow, for leading this project, undertaking the research and engaging with many stakeholders and expert reviewers along the way.

John Connor CEO

IT IS ABOUT PHYSICS, BIOLOGY, TECHNOLOGY AND CRITICALLY IT IS ABOUT SOCIETY.

SUMMARY

Carbon dioxide (CO_2) in the air is already at dangerous levels – 40 per cent above pre-industrial quantities, and rising fast. To reduce the level of CO_2 in the air and limit dangerous climate change,[1] we need to boost our *carbon sinks*. We need to find ways to remove that excess carbon from the air.

In this report we turn our attention to one of the more prospective large-scale carbon removal technologies: bioenergy with carbon capture and storage (also known as bio-CCS, BECCS or renewable-CCS). As plants grow, they harness energy from the sun and CO_2 from the air. Certain plants can be harvested, transported and processed to form a fuel which can be combusted or fermented to produce bioenergy (heat, power or transport). This process releases the CO_2 which can be captured, compressed and transported to a location for geological storage. This means the CO_2 absorbed from the air during plant growth can be removed from the natural carbon cycle.

The first large-scale bio-CCS plant is due to open this year in Illinois which captures CO_2 from the industrial processing of bio-ethanol. If bio-CCS is deployed commercially, it may offer significant potential benefits: in addition to removing CO_2 from the air, it could displace the use of coal or gas with renewable energy and it could store CO_2 at large scale on geological timescales.

Modelling used in by the Intergovernmental Panel on Climate Change (IPPC) Fifth Assessment Report[2] highlights the importance of bio-CCS in meeting climate goals. In many scenarios avoiding 2°C by 2100 was not possible without bio-CCS and the global macroeconomic costs for those scenarios that could, was substantially higher than scenarios that included bio-CCS.

In a world first in-depth national study of bio-CCS, The Climate Institute sets out to identify the implications for an economy to meet ambitious climate goals with and without bio-CCS. We asked the international engineering firm and one of Australia's leading energy modellers – Jacobs SKM – to model how Australia can adapt (both in terms of behaviour and technologies) to meet climate goals consistent with a high (75 per cent) chance of avoiding a 2°C increase in global temperature, which found bio-CCS could play a significant role.

However a big question still remains over whether the level of bioenergy needed could be produced in a socially and ecologically sustainable manner. The process would require proper consultation to ensure the protection of conservation and cultural values as well as enhancing, not hindering, poverty-alleviation efforts.

Imagine a bath tub overflowing with water. To get atmospheric carbon levels back to manageable levels (lower than they are today) we not only need to turn off the tap by reducing emissions but also pull out the plug by boosting our carbon sinks. We need to find ways to remove that excess carbon from the air.

The Climate Institute's previous publication *Below Zero* provided an overview of the range of carbon-removal technologies being considered, including afforestation and wood storage, bio-char, bio-CCS as well as emerging technologies like artificial trees. This report delves deeper into bio-CCS as one technology that shows significant potential.[3]

MODELLING FINDINGS

In a world first in-depth national study of bio-CCS, The Climate Institute sets out to identify the implications for an economy to meet ambitious climate goals with and without bio-CCS.

We hope that this work stimulates deep discussion of the role of bio-CCS and other carbon removal technologies in national carbon policy debates both in Australia and elsewhere.

The modelling found:

1. Bio-CCS could play an important role in Australia. Bio-CCS could have the capacity to remove and displace 65 million tonnes of CO_2 equivalent (Mt CO_2-e) annually by 2050 in Australia. For comparison, this is around 1.5 times current emissions from all cars in Australia. In total, bio-CCS could contribute 780 MtCO_2-e of emission reductions over the period to 2050.

2. Strong and early action on energy efficiency and other renewables is also needed regardless of whether bio-CCS is available or not. Afforestation and other emission-reduction options relating to land-use change are also critical. For example, energy efficiency and other renewable energy sources like wind and solar are required to reduce emissions from electricity from around 200 MtCO_2-e today to 100 MtCO_2-e in 2030 across all scenarios.

3. There will be environmental and economic trade-offs without bio-CCS. Without bio-CCS a number of trade-offs become clear. These include accepting higher levels of climate change; higher economic costs in achieving goals and/or greater reliance on international emission permits. Modelling indicates that excluding bio-CCS, even if putting maximum effort into other emission-reduction options, reduces the chance that national climate goals can be achieved domestically. In the analysis, with no bio-CCS the national carbon budget would be exceeded by around 1.7 billion tonnes or a 20 per cent overshoot by 2050. This increases the reliance on the use of international emission offsets to achieve national goals. The economic (or resource) cost of transforming the economy in line with internationally agreed climate goals is also 10 per cent higher if Australia can't deploy bio-CCS before 2050.

RECOMMENDATIONS - SUSTAINABLE BIO-CCS GENERATION

1. National climate policies need to be aligned with global goals. While 190 countries have agreed to steer clear of 2°C, current commitments and national policies would deliver roughly 4°C of warming. In recognition of this ambition gap, this year, countries are discussing how ambition can be increased in the short-term by strengthening 2020 emission goals, driving additional investment in energy efficiency and renewable energy and establishing longer-term post-2020 emission pathways consistent with 2°C. Aligning national policies should include longer-term carbon-reduction strategies for all major emitting sectors (including Australia's current Energy White Paper process). If Australia is serious about staying below 2°C, targets would also be set for 25 per cent reduction from 2000 levels by 2020 and around 60 per cent by 2030.

2. A broader recognition of the role of carbon removal is needed. Governments should take a more holistic and long-term view of national climate strategies, implementing policies to develop a portfolio of technologies. Focusing on a narrow suite of measures or sectors increases the risk that long-term climate goals won't be achieved, and increases the cost of carbon reduction.

3. Long, loud and legal incentives are needed for CO_2 removal. Currently, there is little incentive for companies to invest in large-scale research, development and deployment of carbon removal technologies. This can be addressed by, for example, escalating performance standards, carbon pricing, creating specific ongoing revenue streams for specific low-carbon emission technologies and/or systems of credits and offsets to reward technologies that can remove existing CO_2 from the air.

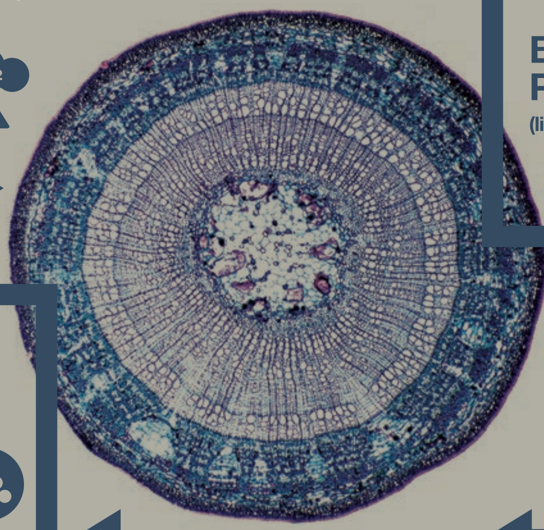
4. CCS and new bioenergy technologies should be demonstrated urgently. The priority is to move ahead quickly with projects that demonstrate the range of CCS applications at scale, to avoid the so-called "valley of death" (the period after demonstration, but where private capital is not forthcoming). In addition to long, loud and legal policy signals this will require upfront capital grants and the development of ongoing revenue streams for low-carbon technologies.

5. Internationally recognised standards and accounting for bioenergy are required, that take full account of life cycle emissions, particularly from land use change. These would help to ensure sustainable production that truly reduces carbon emissions over international borders. Wider sustainability issues are unlikely to be addressed with international standards and need targeted national community-based strategies.

HOW DOES IT WORK?

Utilisng nature's blueprint and human ingenuity.

The life and death of plants creates a natural carbon cycle.While biomass can be harvested, more must be planted to start the cycle again.



BIOMASS IS PLANT MATTER

(like wood and crop stalks)

As plants grow they take in energy from the sun and absorb CO_2 from the air.

CO_2

If left to decompose the CO_2 is released back into the air.

CO_2

IF HARVESTED, CO_2 STAYS IN THE BIOMASS

Biomass can be harvested, processed and transported to the bioenergy plant, but each stage in the process requires energy.

BIOMASS CAN BE USED TO PRODUCE BIOENERGY

Bioenergy can take the form of electricity, industrial heat or transport fuels.

The CO_2 from these processes can be...

1 CAPTURED

Separating CO_2 from a mixture of gases and compressing it into a liquid. Commercial-scale plants can capture around 90 per cent of emissions.

2 TRANSPORTED

Transporting the compressed liquid CO_2 via pipelines, or in some cases ships or trucks.

3 STORED

Storing it in underground geological formations such as depleted or near depleted oil and gas fields and saline formations. It is stored between 0.8 and 5 km deep.

CO_2

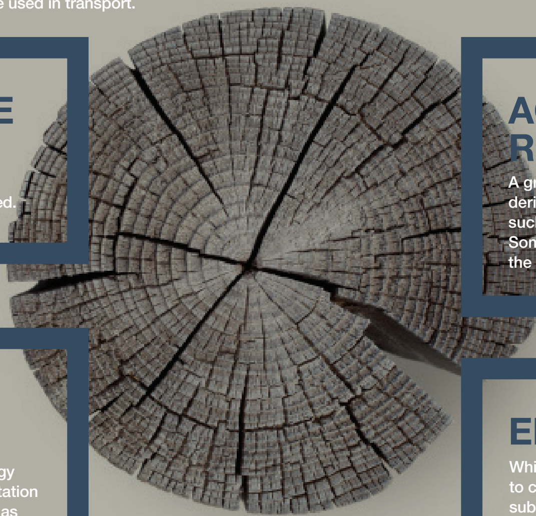
CO_2

CO_2

WHAT GOES IN?

Sources of biomass

Biomass energy (or bioenergy) involves creating energy from plant materials either through combustion to generate heat and electricity or through gasification to produce liquid fuels which can be used in transport.



URBAN WASTE

Despite an abundant supply of this sustainable biomass source, which includes things like kitchen and garden discards, it is still underutilised.

AGRICULTURAL RESIDUES

A growing proportion of bioenergy is derived from agricultural waste products such as crop stalks and manure. Some material needs to be returned to the soil to replenish nutrients.

FOREST BIOMASS

Forest biomass for modern bioenergy utilises wood from sustainable plantation forests. However, much wood used as biomass is harvested illegally in developing countries from native forests.

ENERGY CROPS

While corn and other cereals can be used to create diesel and ethanol, this can have substantial negative impacts on food and feed prices. Advanced feedstocks like algae are being developed to try to combat this.

Biomass currently provides 10 per cent of the world's heat, power and transport.

WHAT COMES OUT?

There are a range of potential bio-CCS applications both in the power and industrial sectors.

OUTPUT

POWER

Direct combustion of biomass could produce power with around 90 per cent of CO_2 captured from the smoke. In some instances, existing coal plants could be fully or partially converted to run on biomass, or new bio-CCS plants could be built.

PRODUCTION OF BIOFUELS & CHEMICALS VIA GASIFICATION

Non-edible feedstocks can be dried and ground and pressurised to form a gas, which can be used to form fuels and chemicals: hydrogen, substitute natural gas, and bio-diesel. The CO_2 can be captured and stored.

INDUSTRIAL APPLICATIONS

Fossil fuels can be substituted with biomass alternatives to reduce emissions from large industrial operations, such as cement kilns and blast furnaces for steel. The CO_2 could be captured from these processes.

PRODUCTION OF BIO-ETHANOL

Sugar and starch crops (and in future algae) can be fermented to form a tansport fuel. One third of the CO_2 contained in the sugars forms a near-pure stream of CO_2, however the remaining two thirds stays in the biofuel, which is released when used for transport.

THERE'S NO SILVER BULLET THAT WILL STOP CLIMATE CHANGE. A BROAD SOLUTIONS MIX IS NEEDED.

LIVING WITHIN LIMITS

Below Zero

There is no silver bullet that will stop climate change. The solutions mix requires not only existing zero-carbon technologies like wind and solar, but also changing the way we behave with more sustainable farming practices and more efficient use of energy. Part of the portfolio could include innovative processes that remove CO_2 from the air, known as carbon-removal, or negative-emission technologies.

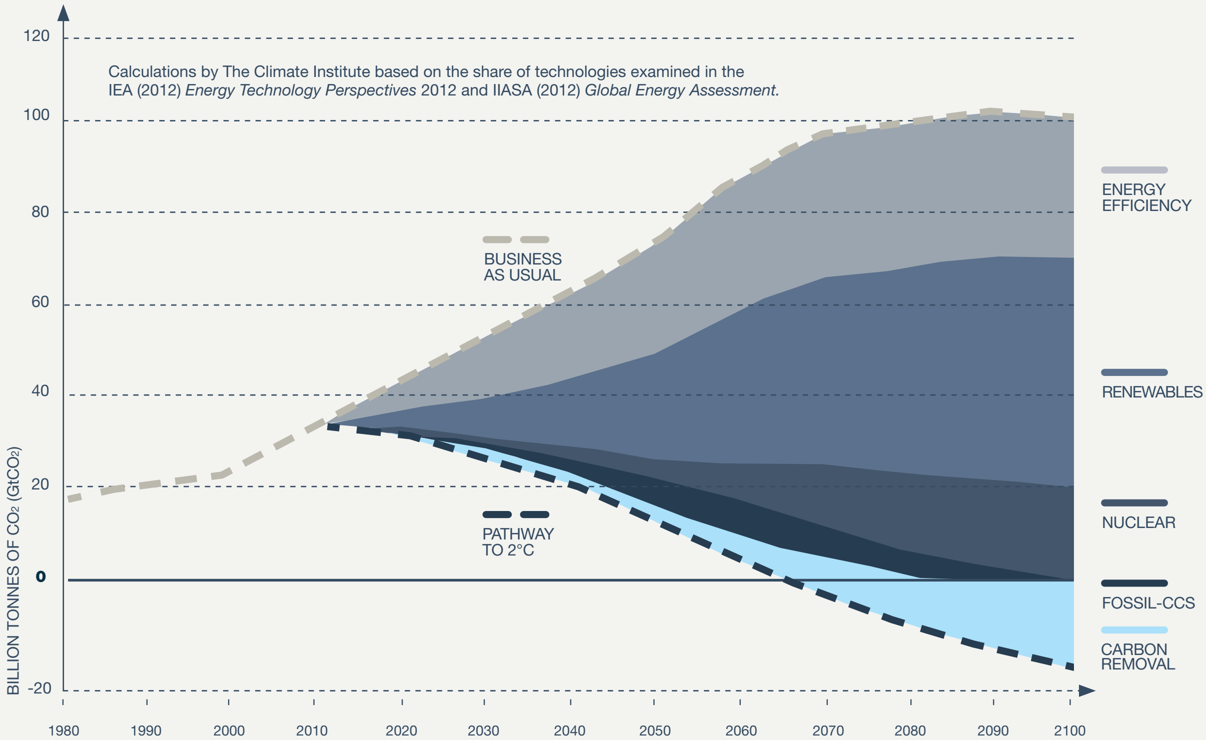
There are a range of technologies that could remove CO_2 from the air. Four key technologies including afforestation and wood storage, bio-char, bio-CCS and emerging technologies like artificial trees, are discussed in our snapshot summary report, *Below Zero: Carbon Removal and the Climate Challenge*. In this report, we draw attention to one of these technologies: bioenergy with carbon capture and storage (bio-CCS). Bio-CCS (also known as renewable-CCS) involves the combination of two well-known technologies: bio-energy and carbon capture and storage (CCS).

Modelling used by the Intergovernmental Panel on Climate Change's Fifth Assessment Report highlights the importance of bio-CCS in meeting climate goals. In many scenarios avoiding 2°C by 2100 was not possible without bio-CCS and the global macroeconomic costs for those scenarios that could do so, was substantially higher.

Why Bio-CCS?

Bio-CCS may offer significant potential benefits over other carbon-removal technologies, provided it is done with full regard to sustainability and other values.

+ **Permanence.** Bio-CCS does not rely on the biological properties of biomass to store the CO_2 (as do wood storage, afforestation and bio-char). With appropriate storage site selection, 99 per cent of the CO_2 is likely to be locked up for over 1,000 years, becoming more secure over time.[4] This is particularly important given that climate change itself will have major impacts on biological systems turning them from carbon sinks to sources.[5]
+ **Double the benefit**. Bio-CCS could be used in industries, such as biofuel or steel production, and to generate power, which means that it has a double advantage because not only could it remove CO_2 from the air, but also displace fossil-based energy and industrial processes.
+ **CO_2 removal.** Bio-CCS could have the potential to remove a substantial amount of CO_2 from the air, the analysis for the International Energy Agency for example finds up to 10 billion tonnes of CO_2 per year in 2050.[6]
+ **Status.** CCS and bioenergy components are currently operational at commercial scale (albeit separately), meaning bio-CCS could use some existing power stations and pipelines.
+ **Cost.** As a relatively new technology, there is a large scope for cost reduction. The developer also receives revenue for power or industrial products so would not rely solely on carbon credits as a revenue stream, adding to its viability.



INTERNATIONAL CONTEXT

Policy is not aligned to national interest

The global community has committed to avoiding a 2°C increase in global temperature above pre-industrial levels. However, it is certainly not a benchmark to aim for; it is a guardrail to steer clear of. It still poses threats to national interest: economic success, national security, natural ecosystems and cultural values. A mere 2°C temperature rise averaged across the whole planet would present unprecedented damage to our health, security, economic growth, and way of life.[7] Leading global institutions such as the World Bank, the OECD and International Monetary Fund are warning with increasing urgency that warming threatens to set back development and poverty alleviation in many countries.[8]

To avoid a 2°C increase in global temperature, action is needed across all sectors and by all major-emitting countries. The foundation to steer clear of 2°C exists: all major economies are implementing policies such as regulation and carbon pricing to encourage renewable energy and energy efficiency.

However, despite these positive steps, the global temperature is on course to rise by 4°C or more even if current policy commitments are met. There is a growing gap between the path that is being carved out by government action and the path that is in the interest of their population: jeopardising their future prosperity.

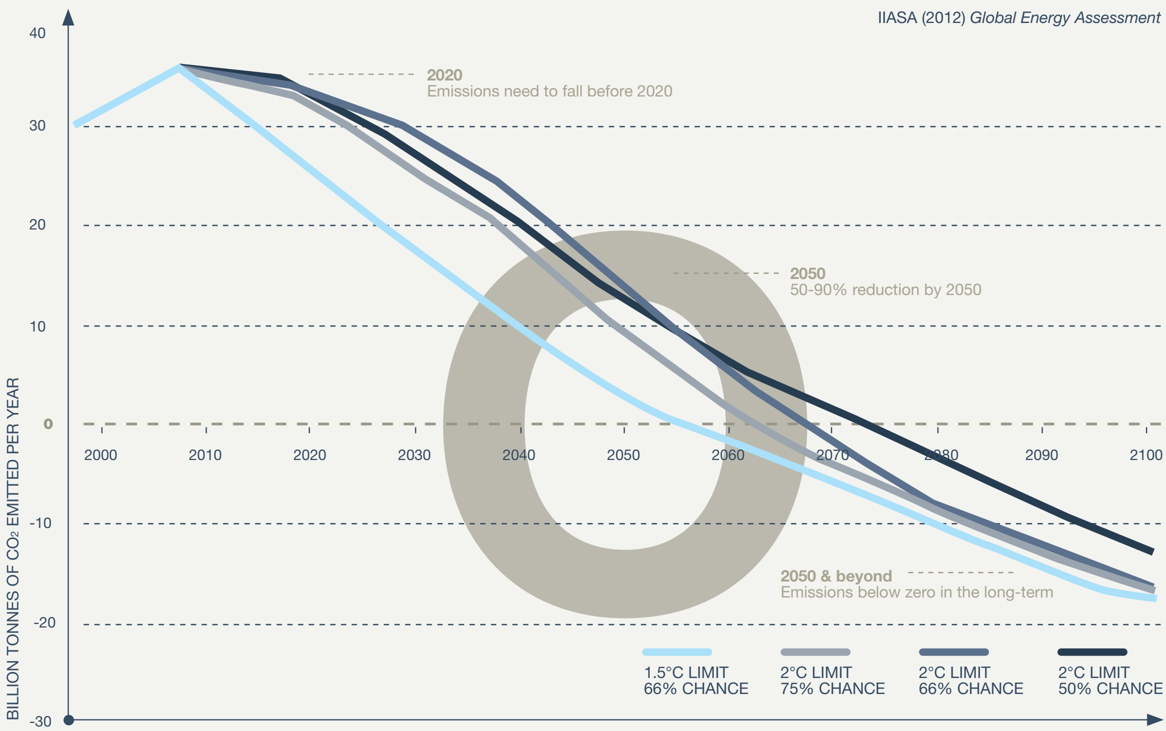
Carbon Budget

To be in with a good chance of avoiding a 2°C increase in global temperature above pre-industrial levels, the world needs to emit no more than 1,500 billion tonnes of CO_2 between 2000 and 2050.[9] It is cumulative emissions which will largely dictate the extent of future climate change we experience, rather than the level in any particular year.

As such, delaying action means greater reductions will need to be made in the future, resulting in far more costly and disruptive action.[10] Continuing on our current pathway, means at some point the required reductions will become unobtainable without major economic disruption. For example, Potsdam Institute found if we delay by 15 years, the likely minimum attainable temperature change is set to increase by almost half a degree.[11]

In fact, international assessments warn that global emissions need to reach net zero emissions by 2050 if we are to avoid 2°C.[12] Despite this, global emissions have grown by a third since the UN Framework Convention on Climate Change was agreed in 1992, and are still growing.

Figure 1 above shows the growing gap between the pathway laid out by governments (business as usual) and action to avoid 2°C. This climate goal can still be achieved through a portfolio of technologies and behavioural change including CO_2 removal.



THE CHALLENGE

Achieving Climate Goals

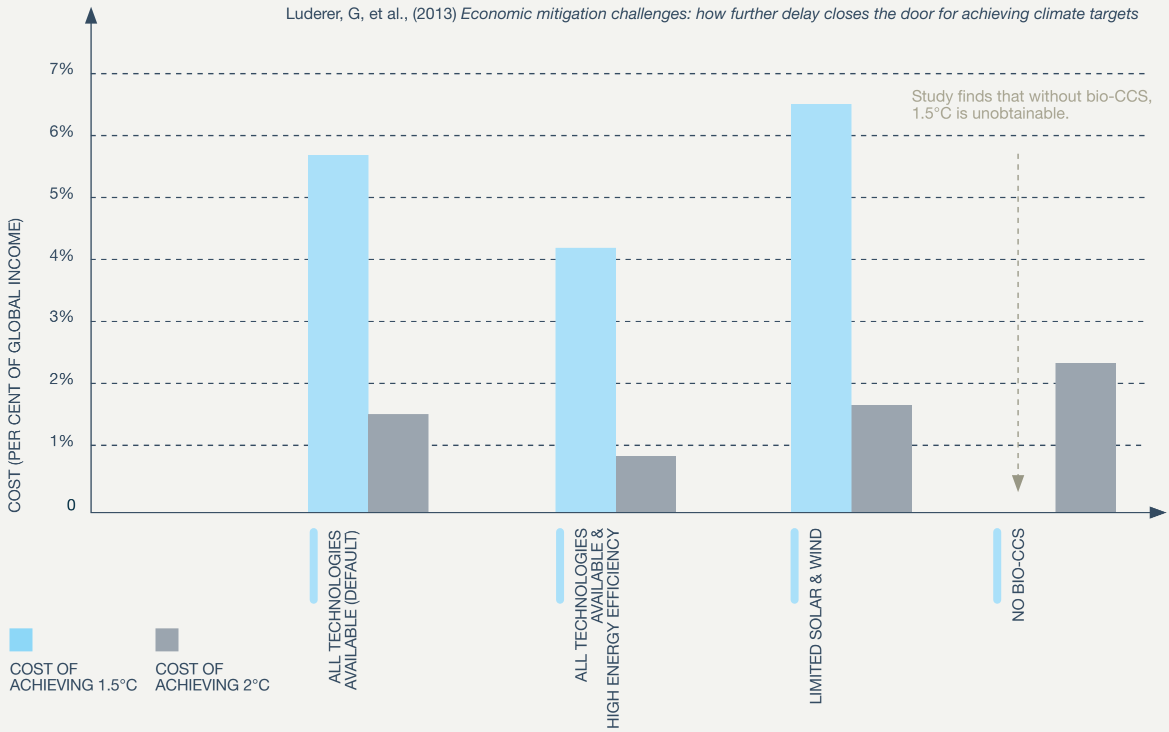
Carbon removal is needed to manage climate change risks – without it, our options become much more limited. A recent study by the Potsdam Institute shows that we would likely overshoot 2°C by more than 10 per cent if bio-CCS does not become available.[13] That is the same effect as delaying action for 30 years.

Carbon removal is important in our transition and future economy because it can offset higher-emitting processes, allowing us to reach (and move below) zero emissions overall. Some industries like steel and sectors like agriculture currently have very limited options for reducing their emissions to zero. In addition, having the ability to remove CO_2 from the air provides important insurance in the case that either we don't reduce emissions as quickly as planned; or the climate turns out to be more sensitive to CO_2 than we had anticipated.

While it may be possible to avoid a rise in average global temperature of 2°C without carbon removal, relying solely on zero emission technologies such as wind and solar is a higher-risk option. The analysis undertaken since the last IPCC assessment report in 2007 finds that the majority of emission pathways that avoid 2°C require CO_2 levels to move below zero in the latter half of the century (See Figure 2).[14]

The use of bio-CCS is a key component of these global assessments. For example, the Global Energy Assessment models how the global economy can limit temperature increase while complying with energy affordability, health and environment goals.[15] It shows regardless of our temperature goal, emissions will likely need to go below zero. They assessed pathways based on differing levels of demand for energy, and they concluded that only in scenarios that are very optimistic about energy efficiency can we avoid 2°C without bio-CCS: bio-CCS technologies are "likely to be required to achieve atmospheric stabilisation of CO_2".

Figure 2 above shows the declining global annual CO_2 emissions required for four temperature pathways: 50, 66, and 75 per cent chance of avoiding 2°C, and 66 per cent chance of limiting to 1.5°C temperature rise.



WHAT IF WE LIMIT OUR OPTIONS?

The Cost

Assessments also show that bio-CCS becomes increasingly important if aiming for higher chances of avoiding 2°C.[16] Keeping temperature rise to 1.5°C - the goal of the world's most vulnerable nations - is not possible without large-scale carbon removal.

For example, a recent study by the Potsdam Institute for Climate Impact Research assessed the global costs of meeting 1.5°C and 2°C, given various constraints on the availability of technologies. Cost here is estimated as a per cent of expected global income. All scenarios assume the use of bio-CCS unless it is explicitly excluded. The technology scenarios are:

1. The first scenario assumes all technologies are available, including bio-CCS.
2. This scenario assumes all technologies are available including bio-CCS, but with particularly high energy efficiency, with energy demand falling faster than has ever been seen historically.
3. This scenario has limited wind and solar, assuming that they only ever achieve a maximum of 20 per cent of electricity demand.
4. The final scenario assumes no bio-CCS.

Figure 3 above shows the results of the study. It presents the cost of reaching 1.5°C or 2°C given different availability of technologies set out in the scenarios.[17]

The study shows two things: firstly, without bio-CCS, the cost of achieving temperature goals will be much higher (it costs 2.3 per cent of global income to achieve 2°C in the 'No bio-CCS' case compared with 1.5 per cent of income in the 'All technologies' case); and secondly without bio-CCS the study found it is not feasible to limit temperature to 1.5°C above pre-industrial levels. Higher global costs also imply a greater risk of not achieving the temperature goal, and greater trade-offs such as higher government spending would need to be made.

Developing these technologies early also helps us avoid a world where potentially high-risk geoengineering technologies need to be explored.

CONVERSATION MAP

The Climate Institute asked a leading climate change researcher Dr Malte Meinhausen about the benefits and viability of bio-CCS technologies.[18]

Q 1

What does the latest science tell us about the carbon budgets required to avoid a 2°C or 1.5°C increase in global average temperature?

That we have very little time left. The carbon budget would still be quite large if we weren't trapped with all the existing fossil fuel infrastructure that causes us to 'eat' around 38 $GtCO_2$ [billion tonnes of CO_2] per year from the remaining budget. In fact, at the moment, we are eating ever larger pieces of the cake each year... and differently to eating a real cake, our appetite for more carbon doesn't appear to be sated. The more we eat per year, i.e. the more fossil fuel infrastructure we build to meet our energy needs, the hungrier we are for more.

The latest science - from the just-released IPCC report - confirms that the total global budget that gives us a good chance of staying below 2°C is around 2,900 $GtCO_2$. Until 2011, we had emitted around 1,900 $GtCO_2$ of that budget. And every year thereafter we've emitted around 38 $GtCO_2$. That leaves us with around 900 $GtCO_2$ left from 2014 onwards, an amount that we are going to consume in just under 25 years, if emissions stay at today's levels. Thus, it is time to slow down with our emissions, if we do not want to be faced with lots of costly stranded assets, such as fossil fuel power plants retired at young age.

For 1.5°C, the budget is going to be much smaller. Even under very high emission reduction rates, there is a relatively high risk that we could overshoot 1.5°C. However, in this scenario, we could bring average temperatures back down again to 1.5°C by the end of the century. Roughly speaking, the carbon budget for such a 1.5°C pathway is going to be half of the 2°C one.

Q 2

What role could carbon-removal technologies play in the task of meeting these carbon budgets?

Unfortunately, it seems that even under the 2°C scenario, one day we will have to be sucking the CO_2 out of the atmosphere that we are now putting in. Of course, not emitting that CO_2 in the first place would be the far cleverer option. For a scenario with likely chances of staying below 2°C, like the lowest of the IPCC scenarios, the so-called RCP2.6, around half of the models suggest that by 2070/2080, we are going to need zero or net negative CO_2 emissions. And even in scenarios where the gross emissions are slightly above zero, it seems likely that we won't make a 2°C scenario without those carbon-removal technologies one day. Of course, the big challenge is to implement them wisely so that conflicts with other sustainable development goals can be avoided or minimised.

Dr. Malte Meinshausen

Senior Researcher at the Potsdam Institute for Climate Impact Research, Germany and Director of Australian-German College of Climate & Energy Transition, University of Melbourne

Q 3

What do the climate and energy scenarios tell us about climate change if carbon-removal technologies are not available?

That we still might have a chance to stay below 2°C, if we take decisive action. However, it's going to be a tough call. And it seems that we cannot hope for a good chance to get to 1.5°C without those carbon-removal technologies. Thus, we need carbon capture and storage – but not in combination with fossil-fuel plants. While pilot projects of carbon capture and storage are often seen as a lifesaver of coal, we actually need the geological storage potential for use in combination with bioenergy to achieve negative emissions in the longer term. For the large point sources of carbon emissions, like large power plants, zero emissions is just not good enough in the long term. We need those larger power plants to be carbon-removal technologies in order to offset a whole lot of smaller and/or mobile emission sources that we are not likely to be able to get rid of so easily.

Q 4

What do you think are the biggest risks with these type of technologies, and what could be done about them?

The biggest risk I see with bioenergy with carbon capture and storage is the potential for unsustainable use of biomass that could increase food prices and be a threat to biodiversity. There are a lot of competing demands on land areas and strong bioenergy demand can obviously impact on some of them. The task is to minimise those potentially negative side effects by going to advanced biomass production, such as using wood, agricultural waste products or algae. Rotating crop varieties is obviously important too. Clearly, there are limitations to the biomass we can produce sustainably, so the challenge is to invest as much as we can in energy efficiency and renewables to minimise the need for large biomass programmes.

Another risk is more about policy and vested interests in relation to CCS. The fact that most fossil fuel companies are interested in research of carbon capture and storage, as it is potentially a way to reduce emissions from fossil fuels, is a risk for the public perception of carbon capture and storage. Arguably, the interest of fossil fuel companies is in the research, not the deployment of CCS, as long as there are no regulatory or strong market incentives. Thus, somehow, while it might be okay that some pilot projects are co-financed by fossil fuel companies, it is important to disentangle fossil fuels from CCS as we might otherwise have a strong inbuilt incentive to 'never finish the research'. And public policy needs to take bold steps, such as requiring that any new fossil fuel power plant, if any, is 'CCS ready' or rather 'CCS operational' before receiving its operating license. The requirement for CCS operation of fossil fuel power plants would of course, tremendously spur the research into CCS and allow us to then quickly use that knowledge for biomass CCS plants. Such regulatory policy would need to be flanked by strong market incentives, i.e. keeping and increasing a price of carbon.

Finally, there is another risk of perception: It wouldn't be wise to continue to emit CO_2 on the false understanding that we invent one day the mop with which we can clean up the mess. If done wrongly, the use of large amounts of biomass could potentially do a lot of harm. If done carefully, it might be okay - and help to bring temperatures slightly down for a 1.5°C degree scenario or keep them below 2°C at the very least.

LINKING A 2°C WORLD TO NATIONAL ACTION IN AUSTRALIA.

CASE STUDY

Why Australia?

Global models are very complex and so need to make very simple assumptions about each region. To date there have been no detailed studies to assess the implications for rolling out bio-CCS at a national level. The world-first detailed national study on bio-CCS aims to bridge the gap between international and national models, by answering the following questions for Australia:

+ What role could bio-CCS play on a national level?
+ What would happen if bio-CCS does not become widely available: How certain could we be of steering clear of 2°C, and what trade-offs would need to be made?

Australia has one of the highest emissions per person in the world. For Australia, climate change is a very real threat. It is set to be among the developed nations worst affected, with increasing incidence of bush fires, record-breaking temperatures, and a coastally-located population living in the path of rising seas.[19] The Australian Government has retained formal international commitments to reduce emissions by 5 to 25 per cent below 2000 levels and to help avoid 2°C warming. Only the stronger 25 per cent target would represent a fair contribution to that goal.

In February 2014, Australia's independent climate advisory body - the Climate Change Authority - released its recommendations on emission-reduction goals. It endorsed an effective 19 per cent emission-reduction target by 2020, rising to 40 – 60 per cent by 2030.[20] This is underpinned by a 10 billion tonne carbon budget out to 2050, consistent with a 67 per cent probability of avoiding a 2°C rise. While the focus on Australia's national interest in avoiding 2°C is welcomed, 67 per cent is not a low-risk option: it still presents significant risks to Australian communities and natural systems. A more stringent budget with a 75 per cent probability (or 8.5 billion tonnes of CO_2-e from 2013–2050) of avoiding 2°C would be more prudent, and it is this carbon budget we seek to meet in our modelling.

Australia has the resources to begin this shift,[21] and in particular is well placed to play a key role in developing bio-CCS. It is a major agricultural producer and exporter, providing a large capacity of crop wastes and biomass production, and has established trade links with neighbouring nations.[22] In addition, it has extensive networks of deep saline formations, both onshore and particularly offshore, with potential to geologically store many hundreds of years of emissions.[23] However, there has been slow progress on CCS in Australia due to its policy environment and to some extent, local public opposition.

01

Default

A world where bio-CCS is developed by 2030 and technology costs fall in line with global projections (by around 20 per cent from 2030 to 2050).

02

Ambitious bio-CCS

A world where technology development is taken seriously in Australia and globally, leading to earlier than expected readiness of the technology from the mid-2020s, and CCS and bioenergy costs being 10 per cent lower than in the default.

03

No bio-CCS

Barriers to developing bio-CCS are not overcome, meaning that it is not developed until after 2050 (not within timeframe assessed).

04

No afforestation

There is no policy to support afforestation, and no substantial new plantations are established.

05

No carbon removal

There is no bio-CCS or afforestation and so Australia cannot achieve below-zero emissions.

06

Ambitious energy efficiency and no bio-CCS

Australia focuses efforts on improving energy efficiency among households, businesses and industry, with uptake of energy-efficient appliances reaching 43 per cent (compared with 33 per cent in the default case). Bio-CCS is not available to be deployed until after 2050.

THE MODELLING PATHWAYS

The Approach

In a world-first detailed national study of bio-CCS, The Climate Institute explores the implications of bio-CCS deployment by asking international engineering firm and one of Australia's leading energy modellers – Jacobs SKM – to model how Australia can adapt (both in terms of behaviour and technologies) to meet ambitious climate goals. A more detailed technical report on modelling assumptions is also available.[24]

Jacobs SKM used a two-stage approach to model the impacts of adoption of bio-CCS.[25] The first involved their economy-wide Sectoral Emission and Abatement Model (SEAM) to determine how low-carbon options could be adopted given constraints on costs and build rates. These options include technologies like wind, solar, gas-CCS, coal-CCS as well as changing practices in farming and industry and being more efficient with energy. It also looked at carbon-removal technologies like bio-CCS and afforestation.

The model determines the potential emission reduction of all the available options across the economy and ranks the options from lowest to highest cost of reducing emissions and then chooses the lowest cost options to meet the defined carbon budget.

The second stage involves using the outputs of the SEAM model and inputting into a model of the electricity sector to determine key impacts on generation levels, emissions, prices and investment levels for different generation technology types.

Figure 4 shows six example pathways that were assessed by Jacobs SKM. Each pathway aims to limit emissions to the 8.5 Gt carbon budget, while characterising either a constraint or ambitious progress with a certain technology. This could be indicative of the outcome of a set of policies which broadly deliver that constraint or progress.

RESOURCE LIMITS

Constraints

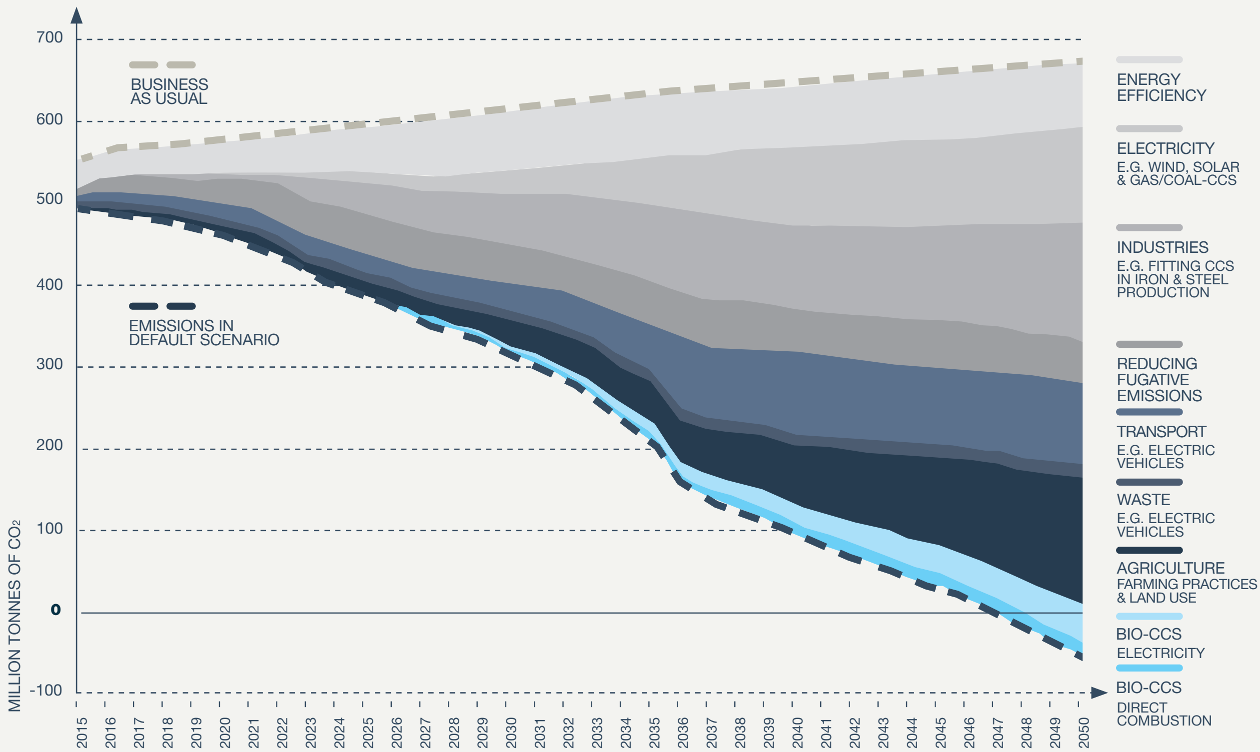
Given the tough emission reductions required to achieve credible carbon budgets with domestic actions alone, the technical and economic constraints in the model are important assumptions. For example, while it is possible to replace our entire electricity generation fleet with zero-emission technology, this takes time.[26] The modelling imposes constraints on how quickly this transition can occur based on assumptions around possible build rates and ensuring reliability standards for electricity supply are achieved.

Given the focus of the report, assumptions around bioenergy potential are particularly important. Bioenergy sources are modelled by source and by state region. The sources modelled include food industry waste, other sources of waste organic material, used cooking oils, vegetable oils, energy crops and algae. Each source is modelled with a total available resource potential (for example the maximum area of marginal land to grow energy crops), physical characteristics (mainly energy content) and cost of collecting, handling and delivery to a generating site.

Additional hard constraints on land availability are used to mimic social and/or environmental constraints that may limit the use of bioenergy. These are based on work undertaken by CSIRO.[27]

It is also assumed that biofuels (bioethanol, biodiesel and biojet) are imported for use as a transport fuel. The costs are assumed to increase exponentially as the demand for the raw material increases, and the model will choose the lowest cost technology options, subject to the resource constraints. The multiple uses for biofuels such as fuel for transport as well as a source of energy for power generation may limit the amount available for use in a bio-CCS facility.[28]

Critically, although the current carbon-reduction framework in Australia could allow short and long-term climate goals to be met cost effectively,[29] the delay in effective climate change mitigation over the last two decades has already made achieving emission reduction goals more difficult.[30] At current emission levels Australia's 2050 carbon budget would be exhausted in 13 years. As a result, the short-term technical and economic constraints in the model mean that achieving our carbon budget domestically requires a rapid acceleration of emission reductions post-2020. To illustrate, to 2020, pushing the limits of current technologies see emissions fall by 3 per cent per year and emissions need to fall to below zero in the 2040s.



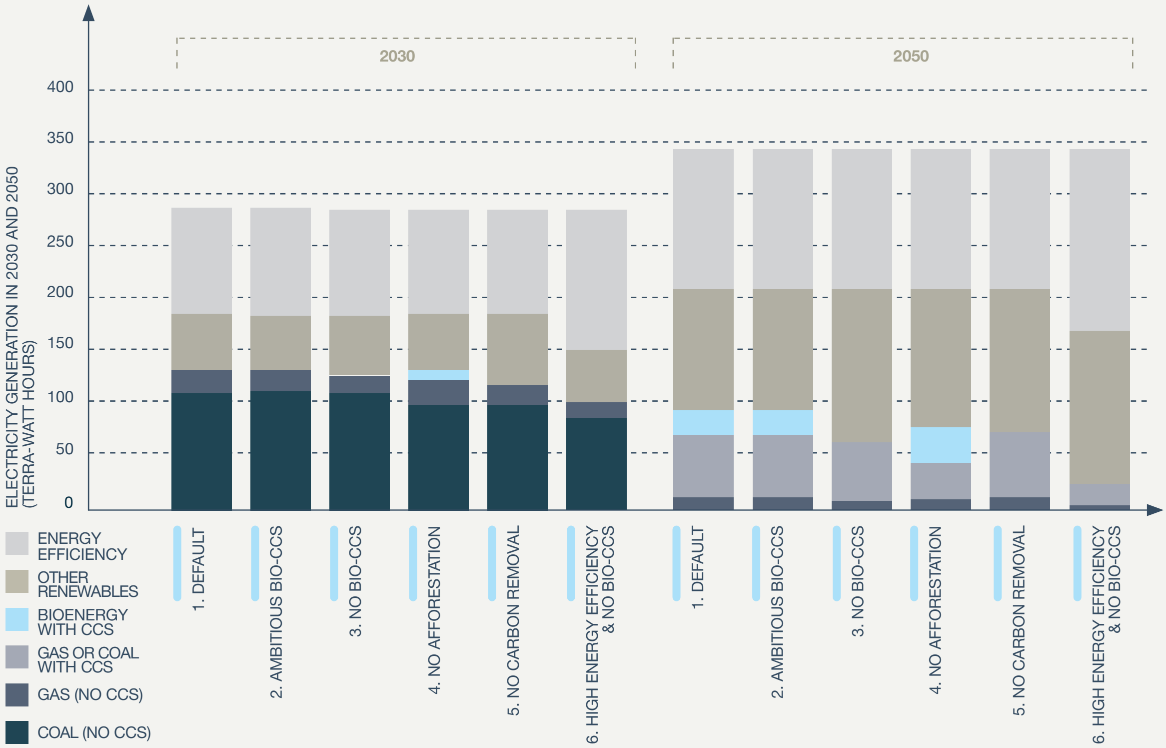
RESULT 01

Bio-CCS could play a significant role in Australia

Bio-CCS could have the capacity to remove and displace 63 million tonnes of CO_2 equivalent ($MtCO_2$-e) annually by 2050 in Australia. For comparison, this is around 1.5 times current emissions from all cars in Australia. Bio-CCS produces 27 terawatt hours (TWh) or 12 per cent of Australia's projected national electricity demand in 2050 after accounting for energy efficiency improvements, as well as some direct combustion in industries. In total, bio-CCS could contribute 780 $MtCO_2$-e of emission reductions over the period to 2050.

Behavioural change, renewables, fossil CCS and changing land use all contribute to the portfolio (see Figure 5). This is broadly comparable with estimates from the International Energy Agency for OECD Asia/Oceania.[31]

Figure 5 above shows how emissions can be reduced from business as usual in Australia, to be in line with a 75 per cent chance of avoiding 2°C under the default scenario. Business as usual emissions are projected using demographic, economic and social trends and assuming an autonomous improvement in energy efficiency across all end-use sectors. They also assume no additional action is taken to reduce emissions apart from measures already in place. Each sector has a range of options available to reduce emissions and the model picks the lowest-cost pathway to meet the 8.5 Gt carbon budget.



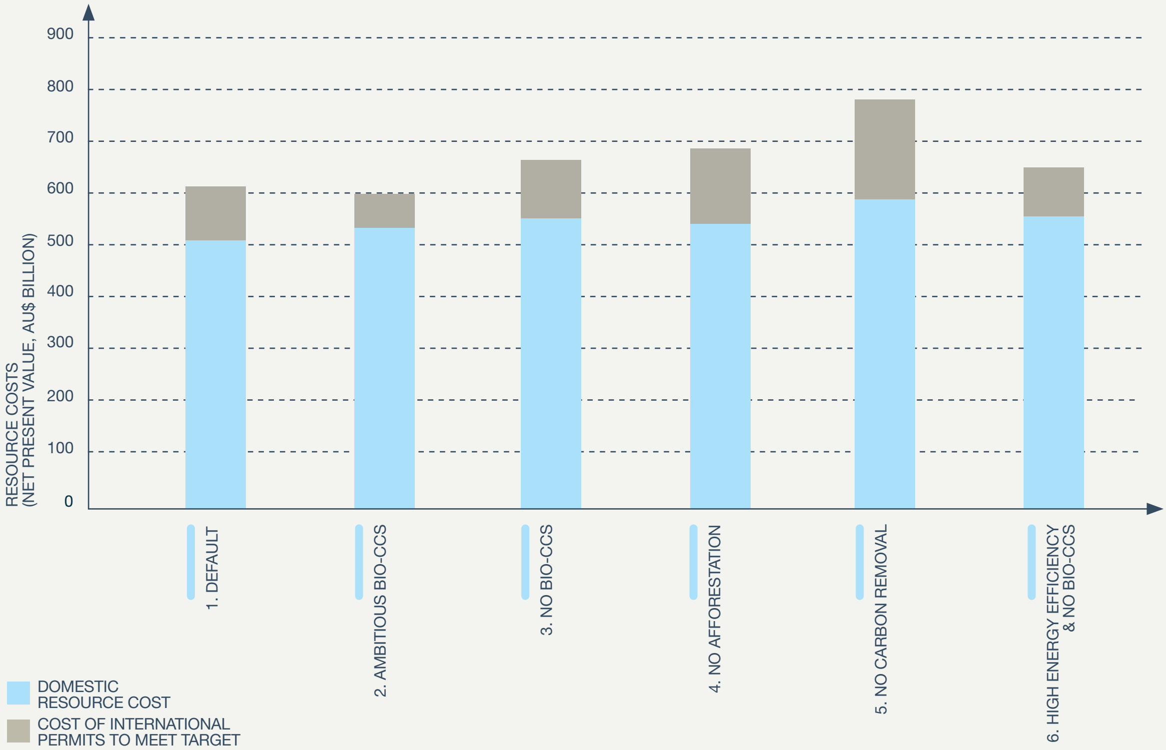
RESULT 02

Strong and early action is needed

Zero-emission renewables and other low-carbon technologies play a key role regardless of the scenario. For example, energy efficiency and other renewable energy sources like wind and solar are required to reduce electricity emissions by 50 per cent, from around 200 MtCO2-e today to 100 MtCO2-e in 2030 across all scenarios.

Figure 6 above shows the technology mix for sector – electricity. It shows electricity generation by each technology across each pathway for the years 2030 and 2050. Until 2030, the pathways look very similar (with the exception of the high energy efficiency pathway).
This is because bio-CCS is not yet deployed on large scale, and so each pathway needs to build as much low-carbon electricity capacity as possible to meet the target. After 2030, bio-CCS could meet some of the electricity demand, however, low-carbon technologies like wind, solar and coal/gas-CCS will still be needed to make up the majority of the power demand, and so effort to reduce emissions from these technologies must be maintained over the long term.

The same can be seen across the other sectors, for example afforestation and other emission-reduction options relating to land-use change. Maximum effort needs to be maintained for the full modelling period, and of course beyond.



RESULT 03

There will be trade-offs without bio-CCS

If bio-CCS is not available a number of difficult choices or trade-offs become clear.

The first would be to accept higher levels of domestic emissions and therefore either higher levels of climate change or not participating fairly in international action. Without bio-CCS, it becomes even harder to meet the carbon budget under plausible assumptions. In fact, putting maximum effort into emission reductions without bio-CCS would still lead to around 1.7 billion tonnes or 20 per cent overshoot of the national carbon budget to 2050. Ambitious energy efficiency gains could go some way to alleviating this risk: if uptake of energy-efficient appliances reaches 43 per cent, Australia could achieve a lower overshoot of 1.4 Gt (16 per cent above the goal). However, relying solely on these energy efficiency improvements is not a prudent strategy – these levels of uptake are yet to be seen elsewhere despite tighter regulations and standards.

The second trade-off is that the economic (or resource)[32] cost of transforming the economy in line with internationally agreed climate goals is 10 per cent higher if Australia can't deploy bio-CCS. This assumes international permits are purchased to meet the carbon budget (Figure 7).[33] Without bio-CCS, electricity prices would be higher and greater government subsidies would likely be required.

The third trade-off is related to domestic versus international emission reductions. We assessed how Australia could meet the ambitious carbon budget for Australia in Australia, as is the Government's current plan. This means we did not initially consider international permit trading, with the rationale that if the aim is to reach net zero emissions globally by the latter half of the century, countries will need to focus efforts on reducing their own emissions. By 2050 this assumes international permits may not be able to offset substantial sources of emissions in Australia, as other countries will need to focus on achieving their own domestic goals.

We found that in Australia, under current technological constraints, it will be difficult to meet this ambitious target with domestic action alone. Even with policy in place to enable ambitious deployment of bio-CCS, Australia will still exceed the carbon budget by 1.3 Gt (16 per cent). The rest of the carbon budget would need to be met through international permit purchases (Figure 6). If bio-CCS is not available or energy efficiency improvements are constrained, greater levels of international permit purchase are required.[34]

Figure 7 above shows for each pathway, Australia's total resource costs out to 2050 and the additional cost that would need to be borne through international permits, if Australia aims to meet the 8.5 Gt carbon budget.

CAN IT BE DONE?

How low-carbon is bioenergy?

In principle, bioenergy is carbon neutral as only the CO_2 absorbed during plant growth is released back into the air when combusted for energy. In practice however, greenhouse gases emitted throughout the lifecycle of the bioenergy production – from deforestation in some countries, fertilising, farming, processing and transporting (especially if traded over long distances) – can be substantial; and in the worst cases can even be higher than the fossil-fuels it is designed to replace. Hence it is important that indirect emissions are properly measured and minimised for example, through siting plants close to the source of biomass, and increasing the density of the materials.

Out of all these sources of indirect emissions, the greatest loss of CO_2 would result from changing the use of land from its natural state. Native forests are huge stores of ancient carbon, and if these are cleared to use the forest biomass or to grow energy crops, this creates a large *carbon debt.* Soils are also large carbon stores, especially peatland. This soil carbon is typically absorbed during plant growth, adding to the overall CO_2 released on combustion, and degrading soil quality. It will take a certain amount of time to repay this carbon debt, which will depend on the previous use of the land. For example, conversion of Indonesian tropical rainforest to grow energy crops could take 100 years to achieve carbon neutrality, and peatland rainforest could take in excess of 400 years.[35]

One solution is to use abandoned or marginal production lands which have low carbon content. Certain types of crops have been developed to be grown on these arid lands such as the oil mallee which holds a large amount of carbon in its large root and re-sprouts when cropped. Crops such as these can increase the soil carbon (removing small amounts of atmospheric CO_2) and can create additional sales for rural communities.

WHAT ARE THE LIMITS?

Technical Limits

Solar energy radiating on the Earth is 1700 times greater than our global energy demand. If we could harness only a small proportion we could go a long way to meeting our energy needs, fossil free. However the process by which the sun's energy is converted into bioenergy is very inefficient: plants draw energy from the sun through photosynthesis, transform the energy into carbohydrates, which can then be converted into usable energy, and each stage loses energy. Energy content of national crop production ranges from less than 1 per cent of national energy demand in China and the UK, to 60 per cent in Brazil.[36]

Of course only a proportion of crops, agricultural and forestry residues (in addition to urban wastes) can be used to produce bioenergy, without posing serious risks to the integrity and sustainability of the ecosystem. Globally, 25 per cent of biomass is currently used for food, energy, paper, wood and fibre.[37] Efficiency improvements over the last century have allowed only a doubling of the appropriated biomass while the global population increased fourfold, and economic output increased 17-fold. Going forward, we can expect to see greater efficiency gains, although this should not be at the expense of the environment and is likely to be at least partly offset by declines in productivity due to climate change.

Biomass is not a limitless resource. It will never be the sole source of emission reductions, and so developing a portfolio of technologies is key – including technologies like solar photovoltaic which can harness the sun's energy more efficiently, but cannot go below zero emissions.

Sustainable Limits

Sustainable biomass is a valuable and scarce resource. It requires a holistic approach to social and ecological sustainability from governments, business and communities.[38] Assessments should be undertaken to understand more about how bioenergy production affects soil productivity and biodiversity, job creation, economic opportunities, international balance of trade, and security of energy supply.[39] Uninformed targets and policies to increase bioenergy production do not recognise the physical and sustainable limitations of production.

The anticipated demand for bioenergy will create both risks and opportunities. To ensure bioenergy is produced to the best possible standards, adequate consultation and the protection of conservation and cultural values needs to happen – reaching wider than its lifecycle carbon emissions.[40]

SUSTAINABILITY

Bioenergy Production

The United Nations defines sustainable development as: *"development that meets the needs of the present without compromising the availability of future generations to meet their own needs"*.[41]

With that in mind, the UN Food and Agriculture Organization have developed criteria for policy-makers in respect to bioenergy production.

+ Poverty alleviation. Bioenergy production should create low-cost heat and power and much-needed jobs and income to bring communities out of poverty, with minimal impact on affordable supply of food.
+ Impact for wider society: Bioenergy can create important trade connections in poorer parts of the world. For this, governments should target support where the greatest benefits will be felt; profits should be distributed equitably throughout the supply chain. The wider environment, particularly biodiversity should not be damaged as a result of bioenergy production.
+ Limiting climate change. Ensuring minimal lifecycle emissions.

Rapid growth in liquid biofuels based on food crops is likely to raise agricultural prices. With an ever-growing population, the inevitable impacts of climate change and the aim to bring people out of poverty, the ability to grow cheap food is of increasing importance. A recent study found that the increase in demand for corn for bio-ethanol production increased the price by 21 per cent in 2009.[42] Demand for cheap palm oil (for food and as a biofuel) is leading to 600,000 hectares of native forest cleared each year in Indonesia to make space for new plantations.[43]

In contrast, there are many examples of communities benefiting from sustainable land practices and equitable distribution of revenues throughout the supply chain. For example, NOVIS, a private company in Senegal, Africa, provides 24-hour bio-electricity to local villages and does not require any government subsidy.[44] In Queensland, Australia, sustainable farming approaches have been implemented over the last 20 years, which has led to a 33 per cent increase in sugar cane yields.[45]

A range of approaches could be adopted to ensure sustainability standards improve. The first is that independent and third party driven certification processes such as those of the Forest and Marine Stewardship Councils will likely be critical for long term social as well as ecological sustainability. Another option being explored is to increase community ownership of local lands, particularly in developing countries. This ownership means the indigenous people can continue to use the land as they have done in the past, and these reforms are underway in at least 10 countries around the world.[46]

HOW SAFE IS CCS?

Stability and permanence

The stability of geological storage of CO_2 increases over time. The vast majority of the CO_2 could be retained for millions of years – it will gradually be immobilised by various trapping mechanisms, binding to the rock to form a mineral in the same way shells form. The Intergovernmental Panel on Climate Change finds that 99 per cent of the CO_2 is likely to be stored for over 1,000 years, providing adequate site selection, testing and monitoring is undertaken. This is based on observations from engineered and natural studies.[47]

While there have been instances of leaks in enhanced oil reservoirs (not used for CCS), these are extremely rare and have been found to be the consequence of insufficient monitoring and verification, allowed by weak regulations. Currently 25 million tonnes of CO_2 are stored each year through CCS and no adverse safety, health, or environmental effects have ever been documented from any of these operations.[48]

Challenges arise given the long-term nature of CCS, urgency of deployment, large private sector involvement and the link with emissions trading and credits. National CCS laws differ and are unlikely to harmonise. There have been recent developments in the regulatory frameworks of many countries with Australia, EU, US and Canada being early movers and many other countries following suit. In 2011, CCS was included under the UN Framework Convention on Climate Change's Clean Development Mechanism, meaning developing countries should adopt laws and regulations to govern storage site selection and environmental protection.[49]

Storage Limits

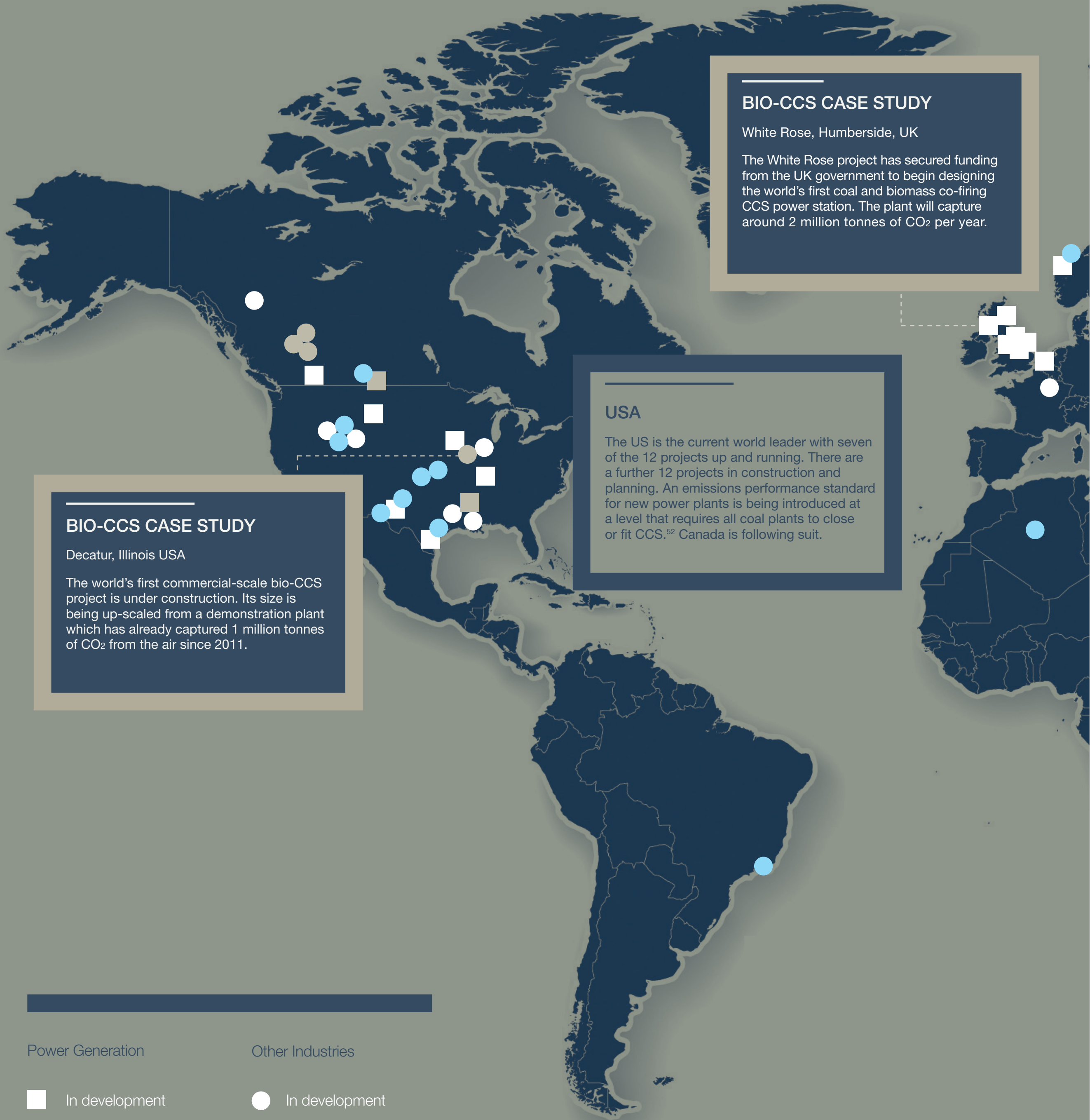
Identifying suitable storage capacity that can safely accept the desired level and rate of CO_2 is perhaps the largest challenge associated with CCS. A large amount of CO_2 would need to be stored if emissions from power and industrial processes are not substantially reduced.

Studies show that the storage capacity identified so far ranges from 500 to 6,000 billion tonnes of CO_2. This is equivalent to between 20 and 265 years of current emissions, with a best estimate of 80 years.[50] With emissions set to decline dramatically over the next century, and given that it will never be practical to capture all emission from stationary sources, this provides a reasonable buffer.

That said, uncertainties persist regarding the match between large CO_2 point sources with suitable geological storage formations, as data is limited in many countries. Regional mapping of storage sites is essential, and many countries are already undergoing detailed assessments. For example, South East Asia recently began work on a Carbon Storage Atlas of the best available estimates of potential CO_2 storage capacity. This pursuit of storage sites by early bio-CCS developers will create opportunities for future CCS applications.

In addition to geological storage, there are novel methods of storing CO_2 that are at earlier stages of research and development than the conventional approach described above. These include mineral and biological storage routes.[51]

WHERE IS CCS HAPPENING TODAY?



BIO-CCS CASE STUDY

White Rose, Humberside, UK

The White Rose project has secured funding from the UK government to begin designing the world's first coal and biomass co-firing CCS power station. The plant will capture around 2 million tonnes of CO_2 per year.

USA

The US is the current world leader with seven of the 12 projects up and running. There are a further 12 projects in construction and planning. An emissions performance standard for new power plants is being introduced at a level that requires all coal plants to close or fit CCS.[52] Canada is following suit.

BIO-CCS CASE STUDY

Decatur, Illinois USA

The world's first commercial-scale bio-CCS project is under construction. Its size is being up-scaled from a demonstration plant which has already captured 1 million tonnes of CO_2 from the air since 2011.

Europe

Europe has two operational projects in Norway and another nine in planning, demonstrating all key capture technologies between them. Europe has varied Government and public support for individual projects, but it has a well-developed carbon market which provides a sound foundation for targeted CCS policy.

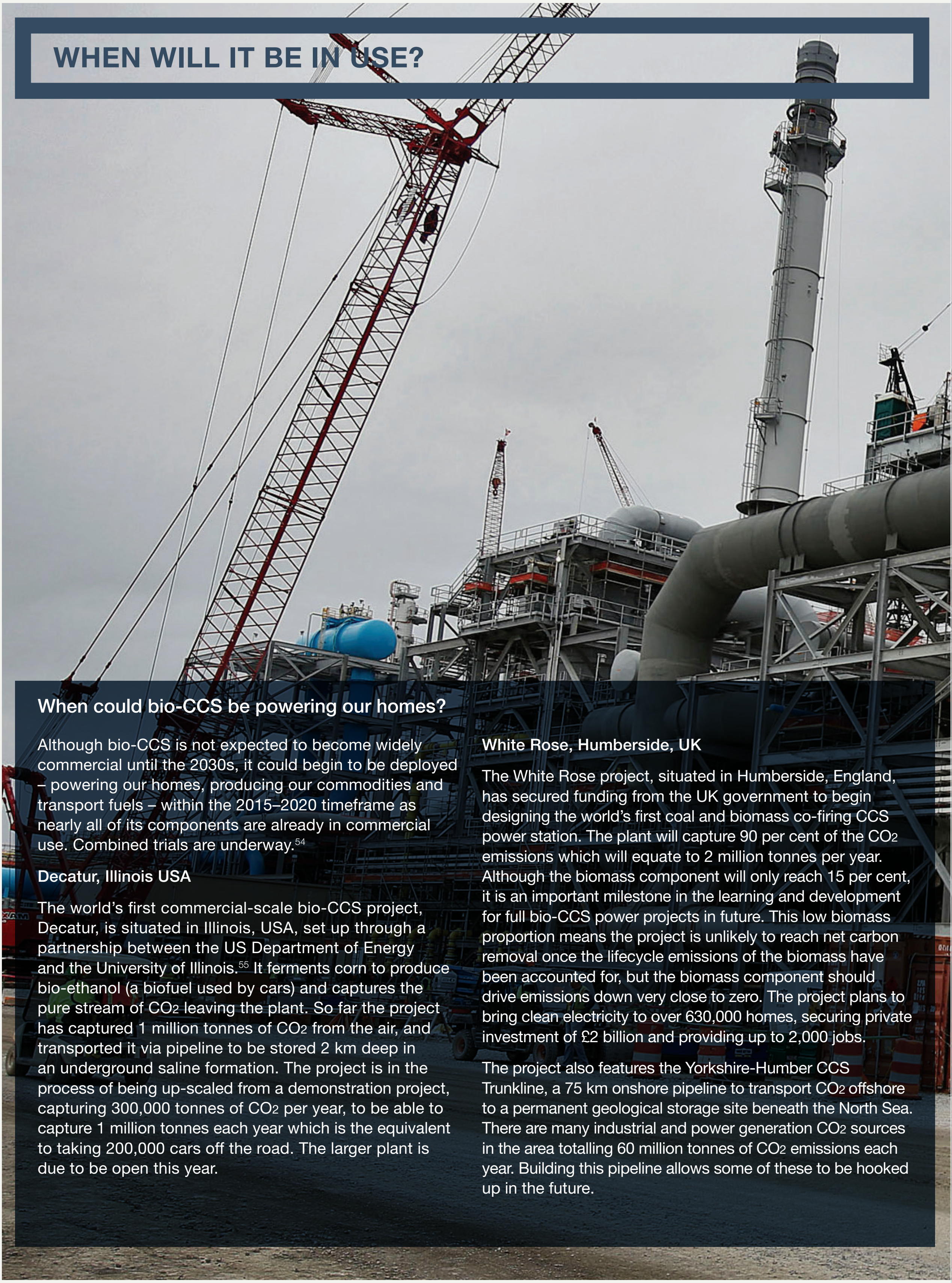
China

China has developed a keen interest in CCS. They don't have any projects operational yet, but 12 have entered planning in the last five years. China's Five Year Plan for 2011-15 has a clear focus on building CCS but is somewhat unclear on regulation.[53]

The elements of CCS have been operational commercially for decades. There are 12 large-scale CCS projects in operation around the world and a further nine projects in construction, including the first CCS-power plants due to open this year. Together these plants will store 40 million tonnes of CO_2 each year.

To put that in context, that's the same as taking 8 million cars – 60 per cent of Australia's fleet - off the road.

WHEN WILL IT BE IN USE?



When could bio-CCS be powering our homes?

Although bio-CCS is not expected to become widely commercial until the 2030s, it could begin to be deployed – powering our homes, producing our commodities and transport fuels – within the 2015–2020 timeframe as nearly all of its components are already in commercial use. Combined trials are underway.[54]

Decatur, Illinois USA

The world's first commercial-scale bio-CCS project, Decatur, is situated in Illinois, USA, set up through a partnership between the US Department of Energy and the University of Illinois.[55] It ferments corn to produce bio-ethanol (a biofuel used by cars) and captures the pure stream of CO_2 leaving the plant. So far the project has captured 1 million tonnes of CO_2 from the air, and transported it via pipeline to be stored 2 km deep in an underground saline formation. The project is in the process of being up-scaled from a demonstration project, capturing 300,000 tonnes of CO_2 per year, to be able to capture 1 million tonnes each year which is the equivalent to taking 200,000 cars off the road. The larger plant is due to be open this year.

White Rose, Humberside, UK

The White Rose project, situated in Humberside, England, has secured funding from the UK government to begin designing the world's first coal and biomass co-firing CCS power station. The plant will capture 90 per cent of the CO_2 emissions which will equate to 2 million tonnes per year. Although the biomass component will only reach 15 per cent, it is an important milestone in the learning and development for full bio-CCS power projects in future. This low biomass proportion means the project is unlikely to reach net carbon removal once the lifecycle emissions of the biomass have been accounted for, but the biomass component should drive emissions down very close to zero. The project plans to bring clean electricity to over 630,000 homes, securing private investment of £2 billion and providing up to 2,000 jobs.

The project also features the Yorkshire-Humber CCS Trunkline, a 75 km onshore pipeline to transport CO_2 offshore to a permanent geological storage site beneath the North Sea. There are many industrial and power generation CO_2 sources in the area totalling 60 million tonnes of CO_2 emissions each year. Building this pipeline allows some of these to be hooked up in the future.

WHAT NEEDS TO HAPPEN TO DEVELOP BIO-CCS?

BARRIERS

+ **Incentive Structures**
  Successful strategies to tackle climate change rest on reliable long-term domestic policies and international incentive structures such as carbon pricing, subsidies and regulation. Investors and entrepreneurs need to have a level of certainty over their future cash flows to be able to bank on them and choose to move forward with a risky venture. Progress is being made with mechanisms to support renewables and other low-carbon technologies, but the mechanisms for carbon removal are still in their infancy. The type of policies that are most effective will change over time, as the technology matures and policy objectives shift.

+ **Bioenergy Sustainability**
  There are social and environmental risks associated if demand for bioenergy rises substantially, particularly if imported from overseas as regulation may be less stringent. Methods to increase production may rely on diverting land from forest or food production, and/or rely on heavy fertiliser use. Increased demand will also create a market for waste products, likely to drive the price up substantially, and lead to cost increases for bio-CCS.

+ **Technical Challenges**
  In general, combining the technologies of fossil-CCS and bioenergy without CCS to form bio-CCS is relatively straight forward, although there are some changes that need to be made to the way the plant operates. Biomass-fired power plants tend to be smaller and more dispersed than coal plants, due to the nature of availability of the biomass resource, whereas CCS is less expensive to fit in larger plants.[56] Assessments into the feasibility and cost of scaling down these plants should be undertaken.

+ **Public Perception**
  There are varying public attitudes towards bioenergy and CCS. This needs to be addressed through public engagement strategies and demonstration projects, as well as clear legislation and policies on safety and sustainability.

TECHNOLOGY DEVELOPMENT

Developing more-efficient bioenergy

There are substantial opportunities for efficiency improvements through developing innovative technologies such as gasification and by increasing plant size.[57] New technologies can take advantage of advanced biofuels which are superior to conventional biofuels in terms of emission reductions and competition for land, food, fibre and water. These are vital to maximise energy obtained from the biomass: reducing carbon emissions and impact on the environment; and to bring down costs.

Sustainable biomass is a valuable and scarce resource. It should be prioritised in the areas where the maximum reduction in emissions can be achieved: where alternative low-carbon options are limited or particularly costly.[58] In the medium term, biofuels can help with the transition to electric vehicles. However in the long term, there are two uses that bioenergy alone can achieve: aviation fuels and carbon removal, and it should be prioritised in these areas.

Developing the range of CCS techniques

The range of technologies needs to be demonstrated at commercial scale to benefit from this learning. Substantial efficiency improvements are possible on capture technologies, as well as learning how to reduce costs. For example, after trialling on one CCS unit, the Boundary Dam project in Canada plans to fit CCS to other units and estimates the next unit will be 30 per cent less in construction costs and 20 per cent less in running cost.[59]

Retrofitting CCS to fossil-fuelled power plants will ease the transition to a zero emission economy, particularly for developing countries that will see the largest recent growth of fossil fuel generation, cutting emissions from these plants by around 90 per cent. This means fossil fuel industries putting in the investment to develop a vital carbon-reduction measure.

In its roadmap, the IEA set out the vision to see upwards of 30 operating CCS projects by 2020 across a range of processes and industrial sectors.[60] By 2050, all new coal, one out of two gas, and one out of five biomass-fired power plants should be equipped with CCS. Up to 40 per cent of all production of steel and cement are equipped with CCS globally.

POLICY AND INCENTIVES

Cap and Trade e.g. EU Emissions Trading System, China's pilot trading schemes, and Australian Carbon Pricing Mechanism.
In this system, the government sets a cap on the amount of emission permits allowed; ensuring emissions do not exceed an agreed carbon budget or limit. The permits are allocated (or auctioned) to companies who can then trade between each other, at the market price.

There is currently no tradable reward for carbon-removal technologies. However the schemes could be amended to allow additional permits to be created and sold by companies who can remove CO_2. For potential bio-CCS developers, certainty over their long-term revenue streams would provide an incentive to develop the technology, and lower risk reduces costs. In the longer term, caps could be reduced to force greater levels of emission reduction and carbon removal.

Clean Development Mechanism
This scheme, established under the Kyoto Protocol, allows developed countries to invest in emission-reducing projects in developing countries while including the benefits in their own carbon accounting. This encourages assistance from developed nations in establishing low-emission industries in developing nations. In 2011 it was extended to include CCS. As with above, the scheme could be accommodated to include carbon credits for carbon removal.

Subsidies e.g. direct grants
Most major economies are subsidising the development of low-carbon technologies. This provides additional targeted support for new technologies that are not yet able to compete against fossil fuels or more developed low-carbon technologies. Targeted government support will be needed for bioenergy and CCS technologies including bio-CCS. It should be recognised that newer technologies such as bio-CCS may not be competitive on short term horizons, but that costs are likely to fall substantially if the technology is taken up at scale, as has happened with wind and solar for example.

Australia's proposed Emission Reduction Fund is planned to provide grants to the lowest cost short-term emission reduction options. As it does not provide a long-term investment signal for new technologies it is unsuited to support technologies like bio-CCS. However, if its mandate was amended to allow investment in CCS mechanisms like the Clean Energy Finance Corporation, then it could play a role in the future.

Direct Regulation e.g. emissions performance standard
This is a mandatory requirement for emissions for a particular sector to be below a certain threshold per unit of output. For example, the UK, US and Canada are implementing the requirement for emissions from a power plant to be below that of coal. While this policy instrument may be very useful in ensuring no coal is built without CCS, the policy alone does not provide higher rewards for actions that can reduce the most emissions – there would be no reason to build wind instead of gas, for example. Over time, the value could be lowered to only allow very low-emitting technologies, which would mean carbon-removal technologies could be required to meet demand.

Other revenue streams, e.g. capacity payments, tradable renewable energy certificates
High upfront capital costs are a large barrier to low-carbon investments, and developers need predictable revenue streams to pay back their loans. The government can assist with these revenue streams for example by guaranteeing a certain price for the electricity sold. Different levels of support can be offered to different technologies, depending on their costs and maturity, and this support can be reduced over time. In China, early on in both the wind and solar sectors, tariffs paid to generators were determined by auction in designated resource-development areas.

NOTES

1 The focus of this report is largely on carbon dioxide. However, other anthropogenic emissions greenhouse gases like methane are a critical component of climate change and its mitigation. The modelling presented later in the report includes reductions in emissions from these other gas as well. Where appropriate carbon dioxide equivalents (CO_2-e) is used to capture the climate impact of these gases and their mitigation potential.

2 The Intergovernmental Panel on Climate Change (IPCC), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

3 The Climate Institute, *Below Zero: Carbon Removal and the Climate Challenge*, March 2014, http://www.climateinstitute.org.au/articles/publications/below-zero-explainer.html/section/478

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WITH SO MUCH AT RISK, ACHIEVING A BELOW ZERO EMISSION ECONOMY CAN & MUST BE DONE.

John Connor CEO

Moving Below Zero: Bioenergy and Carbon Capture and Storage is the second part of a project examining the role of carbon-removal technologies in reducing global emissions below zero. The project has been supported by the Global CCS Institute. The Climate Institute is an independent research organisation and has been advocating the need for carbon-removal technologies since 2007.

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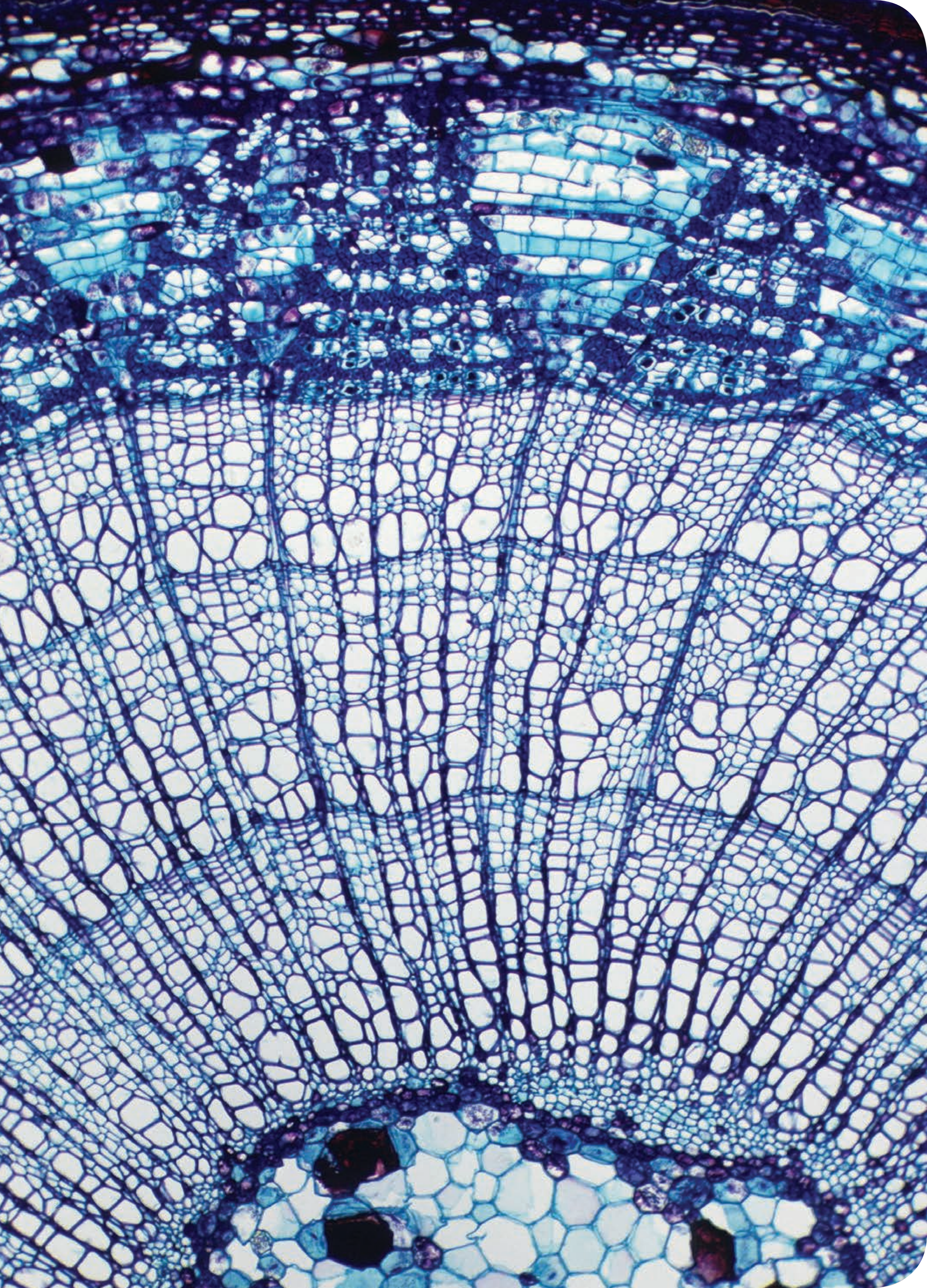


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