

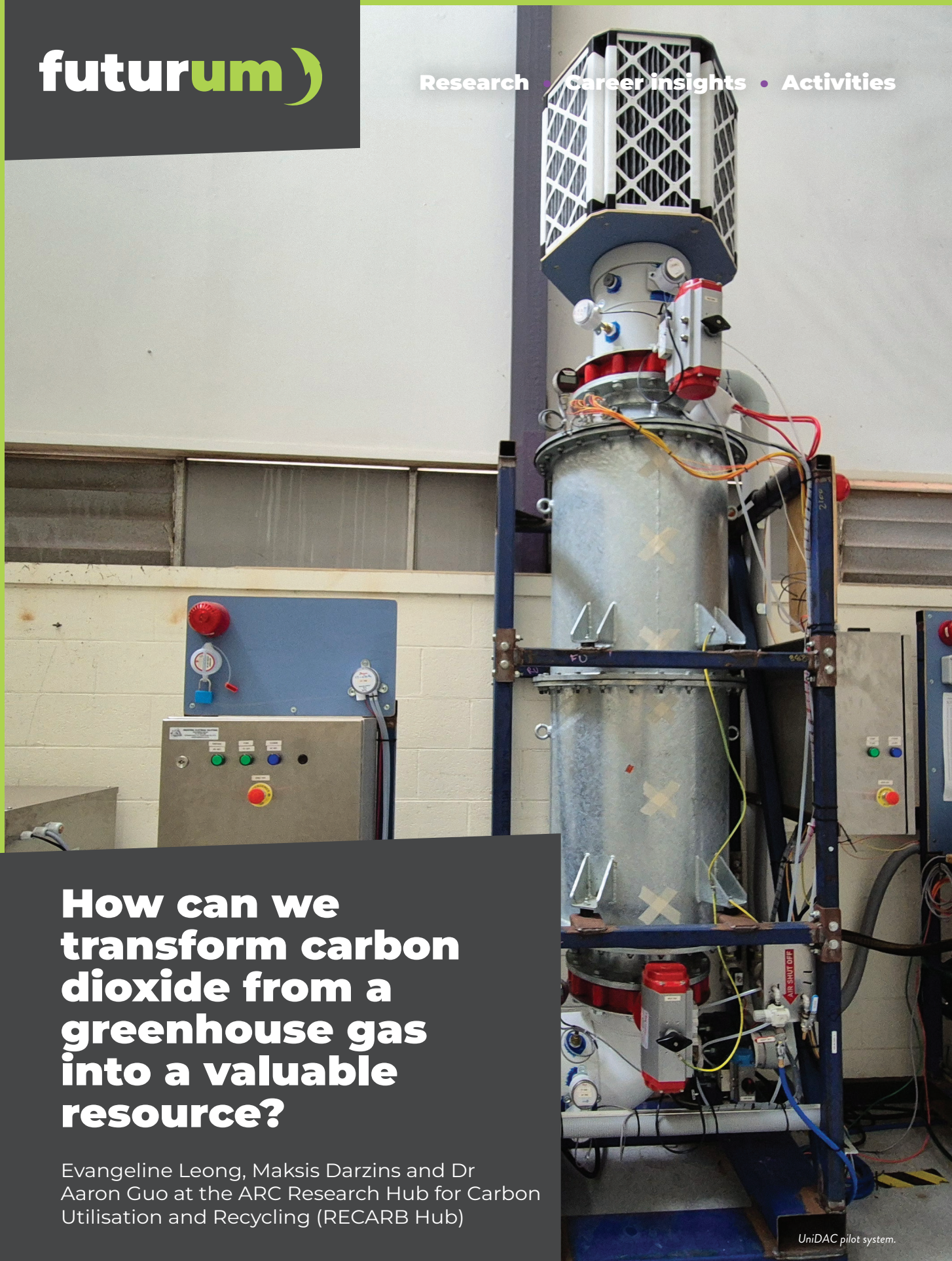
How can we transform carbon dioxide from a greenhouse gas into a valuable resource?

Evangeline Leong, Maksis Darzins and Dr Aaron Guo at the ARC Research Hub for Carbon Utilisation and Recycling (RECARB Hub)



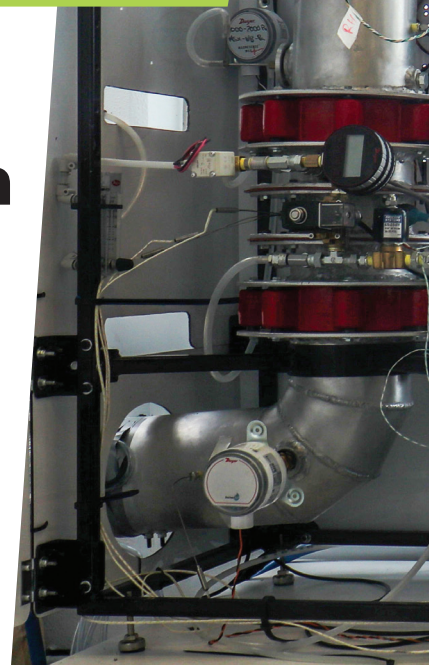
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How can we transform carbon dioxide from a greenhouse gas into a valuable resource?

Most climate change mitigation strategies focus on reducing our emissions of carbon dioxide (CO₂). However, direct air capture tackles the problem from a different angle: by removing carbon dioxide directly from the atmosphere. At the **RECARB HUB**, hosted by **Monash University** in Australia, **Evangeline Leong**, **Maksis Darzins** and **Dr Aaron Guo** have created a new direct air capture system that can supply various industries with CO₂, including the biomanufacturing industry which can use this CO₂ to create valuable bioproducts.



Evangeline Leong

Industry PhD Candidate

Field of research

Chemical engineering

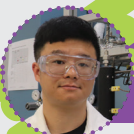


Maksis Darzins

Industry PhD Candidate

Field of research

Mechanical engineering



Dr Aaron Guo

Research Fellow

Field of research

Chemical engineering

Monash University, Australia

Research project

Developing a direct air capture system that captures carbon dioxide from the air for carbon reduction and utilisation

Funders

RECARB Hub; Woodside Monash Energy Partnership; Australia Economic Accelerator

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Talk like a ...

direct air capture developer

Adsorbent — a material that attracts and holds molecules to its surface (not to be confused with absorption, which involves molecules being taken into a material)

Bioreactor — a piece of industrial equipment within which a biological process or reaction takes place

Circular carbon economy — an economic model that aims to keep carbon in circulation, rather than treating it as a waste product

Direct air capture (DAC) — technology that pulls carbon dioxide from the air

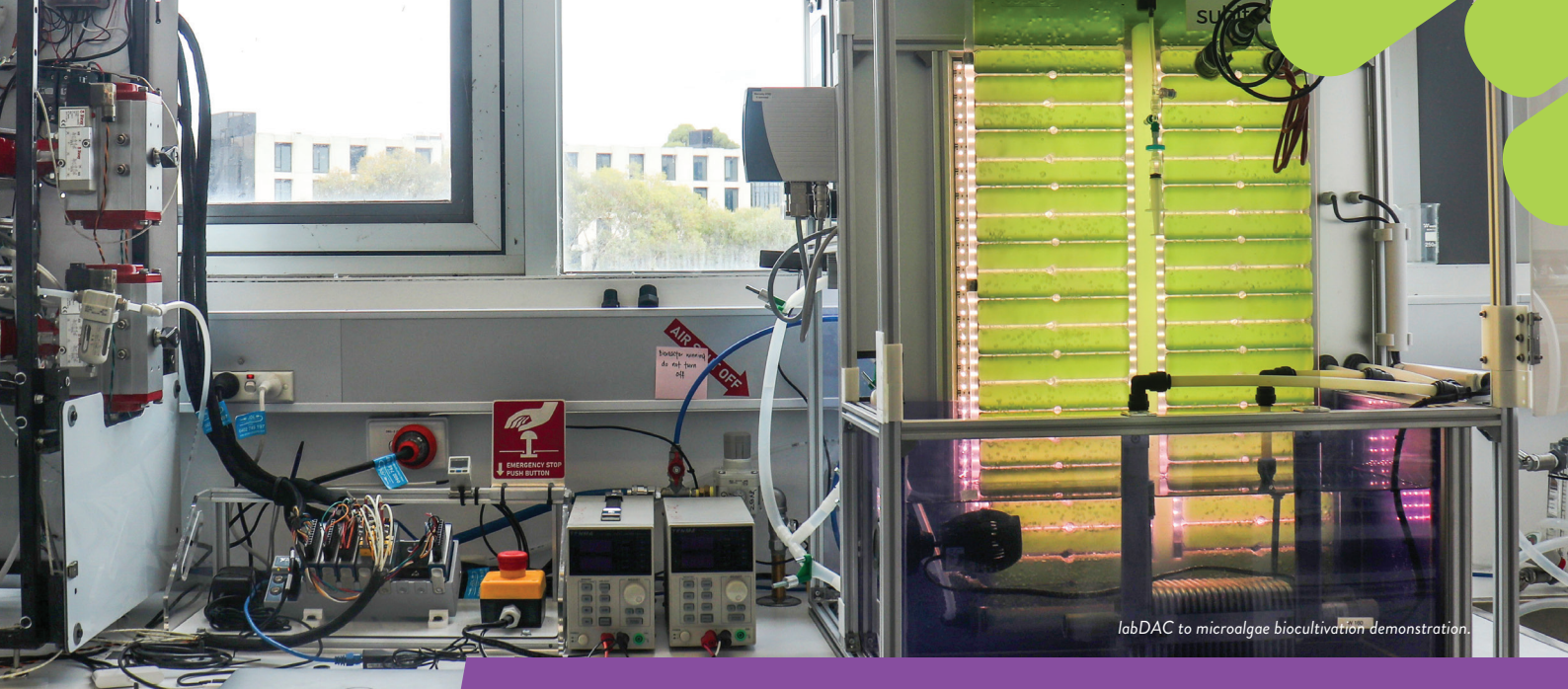
Climate change is already having measurable impacts on the environment, ecosystems and human networks around the world. “Carbon dioxide (CO₂) in our atmosphere acts as a blanket around the Earth, creating the greenhouse effect that heats our planet,” explains Maksis Darzins from the ARC Research Hub for Carbon Utilisation and Recycling (RECARB Hub) at Monash University. “Human activities have contributed to rising CO₂ levels, influencing climate patterns and environmental conditions.”

Mitigating, and ideally reversing, climate change is crucial, and direct air capture (DAC) is likely to be an essential tool in this process as it filters CO₂ from the atmosphere. “As well as directly removing surplus

CO₂ from the atmosphere, DAC can also drive a sustainable future by putting this captured CO₂ to good use,” says Maksis. “DAC has the potential to replace fossil fuels and create a circular carbon economy with a neutral carbon footprint.”

Direct air capture

Sucking CO₂ from the air is nothing new. Plants and other photosynthetic lifeforms have been doing it for billions of years. However, it is unlikely that these organisms alone can absorb enough CO₂ to fully address climate change. This is where new technologies come in. “The technology that we are researching uses a solid adsorbent to capture CO₂ molecules,” explains Maksis. “Once the adsorbent is saturated with CO₂, similar to a sponge becoming saturated with



water, we heat the adsorbent so it releases the CO₂, which we collect using a vacuum system.” The adsorbents can then be reused to capture more CO₂.

Interestingly, the team’s system does not rely on one specific adsorbent material. “We are tackling the mechanics of our design first, while remaining open about the materials we use,” says Maksis. “This flips the standard DAC design process, allowing us to tackle the issues facing other DAC systems – in particular, energy efficiency and cost – without being too preoccupied with adsorbent design and synthesis.” This means that the system can use whichever adsorbent is most effective in any particular context, without needing to redesign the entire system. “This modular package gives us the ability to scale up and work with new contractors and industries, increasing the productivity of our system,” says Maksis.

Miraculous microbes

The next stage of the process is figuring out what to do with the captured CO₂. “The CO₂ produced through DAC technology has a negative carbon footprint (it reduces the amount of CO₂ in the atmosphere), so it has potential to be a valuable resource,” says Maksis. “CO₂ is already used in various applications, such as carbonating drinks or increasing plant growth in greenhouses.” This CO₂ is conventionally produced through fossil fuel combustion, so DAC offers a much greener approach.

Some DAC systems inject and store the CO₂ in rocks underground; however, the team’s DAC2BIO programme takes a different approach.

“We are developing systems that feed captured CO₂ into bioreactors to grow microbes,” says Evangeline Leong, the primary investigator of DAC2BIO. “These microbes utilise the CO₂, alongside hydrogen and other gases, to make specific chemicals, proteins or biomaterials.” This process (known as bioconversion) is often used in biomanufacturing industries to convert waste materials into valuable products. “By integrating DAC with biomanufacturing pathways, we are showing how innovative methods can help industries be both climate-positive and resource-efficient,” says Evangeline.

Given that carbon forms the backbone of all organic molecules, the range of potential products derived from CO₂ is large and diverse. “CO₂ is increasingly used to produce synthetic fuels and chemicals that would otherwise be made from fossil fuels,” says Evangeline. “And through biotechnology, we can use microbes to convert carbon dioxide into proteins, bioplastics or other sustainable materials.”

Industry partnerships: from research to reality

The team is working with a number of industry partners, bringing together different facilities, resources and expertise. “For instance, Woodside Energy provides engineering expertise and facilities for large-scale integration, helping us understand how DAC can work within real industrial environments,” says Evangeline. “Local manufacturing companies, such as KDR Compressors

and Rudimental, contribute to the development of the post-capture gas purification and compression systems while global industry partners, such as WesCEF, BASF, and Agilent, support the team in other ways.”

Such partnerships also bring challenges. Research and industry tend to work on different timescales, there are differences in the way technical terms are used, and systems have to be established for sharing intellectual property. “But the benefits far outweigh the challenges,” says Evangeline. “Together, we’re building not just a technology, but a whole ecosystem capable of transforming atmospheric CO₂ into real-world products.”

To date, the team has piloted a small-scale DAC system, which captures CO₂ at concentrations suitable for use in a bioreactor. They have also developed a bioprocess that can make biomaterials such as biodegradable plastics. “The next step is to integrate the DAC system with the bioreactor,” says Dr Aaron Guo, another member of the team. “Our aim is to demonstrate a small integrated DAC2BIO prototype that shows the complete production line from carbon capture through to bioconversion.” The long-term aspiration is to scale up the technology so it can make a tangible difference – both in terms of tackling climate change and supporting carbon-positive industries. “We hope our work will contribute to a circular carbon economy, where atmospheric carbon becomes a renewable resource rather than a waste product,” says Aaron.

About *direct air capture*

Given the critical need to find and implement solutions to climate change, direct air capture (DAC) is a rapidly growing field of study and development. “There are a multitude of interesting design challenges that must be solved for the technology to have a tangible impact on climate change,” says Maksis. “Innovative solutions to these problems require creative thinking, which makes the field extremely appealing to work in.” The work is highly rewarding; after all, it is helping solve what many consider the greatest challenge of our time.

DAC is a highly collaborative field, combining skills from many different disciplines. “No individual can solve complex problems like DAC alone,” says Evangeline. “Progress happens when engineers, scientists and innovators learn to communicate across disciplines.” In particular, DAC involves engineers of every type. “Throughout the design process of the pilot system, the team has consulted colleagues in every branch of engineering, including chemical, mechanical, aerospace, electrical, and civil, and each discipline brought their own insights,” says Maksis.

Perhaps the biggest challenge of DAC is working out how to capture CO₂ efficiently. “Even though atmospheric CO₂ concentrations are much higher than they should be, they are still very low relative to other gases,” says Aaron. “This low concentration makes it difficult to capture CO₂ while ignoring other gas molecules, and also means that an enormous volume of air must be processed.”

Pathway from school to *direct air capture*

At school, get a good grounding in mathematics, physics and chemistry.

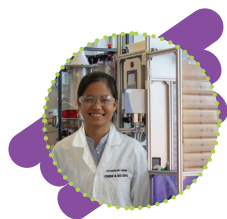
At university, Maksis suggests pursuing engineering for the most direct route to DAC research and development. “Chemical engineering and mechanical engineering are the most common, though all engineering fields are relevant,” he says.

Vocational careers can also directly contribute to DAC. “All types of practical professions are needed to support the building and development of DAC plants, as well as management and business professionals to support and help scale the emerging technologies,” says Maksis.

Explore careers in *direct air capture*

Getting experience in the field is a great way to learn about DAC and whether it could be a good fit for you. Engineers Australia hosts a huge range of resources covering work experience, internships, mentoring and more: engineersaustralia.org.au/resources/early-career-resources

Monash University has a number of outreach programmes for high schools. For instance, Monash Engineering Girls is an engagement programme for high school girls to learn more about engineering careers: monash.edu/engineering/meg



Meet Evangeline

I've always been fascinated by how things work and how they are created. As a teenager, I couldn't decide which area of science I liked best, so I ended up studying all of them at university through a double degree in chemical engineering and biomedical science. Over time, I was drawn to the practicality of engineering, but my biomedical background has also proven incredibly valuable for my current work.

I lead the DAC2BIO programme. My goal is to ensure that the CO₂ we capture doesn't just get pumped underground, but is transformed into useful products. I joined the project because I saw its enormous potential to create technologies that benefit people and the planet. Working with a world-class team of researchers and industry experts is a privilege.

Problem-solving and creativity are essential skills in this line of work. DAC and biomanufacturing are emerging areas, so we often encounter challenges that no one has faced before.

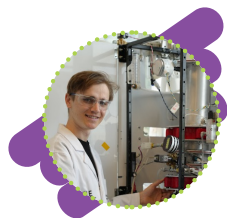
I love being surrounded by brilliant, curious minds. This includes mentors, peers and students. The trust and autonomy that I've been granted by my supervisors have allowed

me to explore bold ideas and grow as an innovator and leader.

Outside of work, I enjoy quiet time alone or with family. Simple, restful things help me recharge. I'm an introvert who has learnt to be a professional extrovert when needed; so, when my social battery runs out, I return to calm spaces to reset and find balance.

Evangeline's top tips

1. Develop your interpersonal skills. Get involved in group projects, science fairs or student innovation challenges to practise teamwork and creative problem-solving.
2. Pair your scientific curiosity with empathy and purpose. You will find yourself helping to build a cleaner, more sustainable world.



Meet Maksis

I have always enjoyed building and creating. When I was young, I spent my weekends making custom skateboards that I used to explore the neighbourhood. This passion progressed to a double degree in mechanical engineering and industrial design, which satisfied the creative and academic parts of my brain.

My true passion for mechanical design was uncovered by an extracurricular activity at

university. Monash Motorsport is a student team which engineers, designs and builds race cars to compete in student competitions. This experience honed my engineering abilities and taught me hands-on skills such as welding and machining.

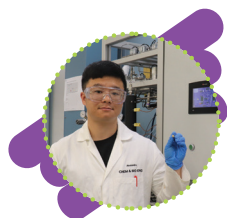
I am the lead mechanical engineer on the DAC project. This involves designing, building, testing and continuously improving the DAC system. This lets me use my skills to create a large positive social and environmental impact.

Our supervisor, Professor Paul Webley, has supported us throughout this project. He is not only passionate about DAC but also dedicated to mentoring and nurturing the next generation of researchers.

Outside of work, I enjoy cycling. Riding in all forms, from the commute to work or long-distance weekend rides, gives me the opportunity to disconnect from the rush of working life and regain balance.

Maksis' top tips

1. Be open-minded and willing to learn. What we need more than anything is young, bright people to solve current and future challenges.
2. Research is never straightforward. It's a journey towards innovation, and requires resilience and persistence. Turn your setbacks into motivation.



Meet Aaron

I enjoyed physics more than chemistry when I was young. I've since learnt that there are many connections between different fields – and drawing on these connections is vital for solving real-world problems. My bachelor's degree was in mechanical engineering, my master's was in thermodynamics, and my PhD was in chemical engineering. All have come together to serve me in my work today.

I am the leader of material development and the lead chemical engineer on the DAC project. Soon after starting the job, my first son was born. It made me reflect deeply on the kind of world we are leaving for the next generation. I started to feel a personal responsibility to help create a more promising future. DAC is one technology that can help make this vision a reality.

The DAC project requires an understanding of materials and process design. But problem-solving skills and persistence are equally important. Research often brings unexpected challenges, so being able to adapt and keep learning is essential.

I love working with an amazing team. Everyone has a can-do attitude and a

willingness to solve problems together. Being part of a supportive team makes the work exciting.

Outside of work, I enjoy fitness and hiking. Exercise helps me release pressure, while spending time in nature helps me recharge and come back to work feeling refreshed.

Aaron's top tips

1. Stay curious and keep learning. Explore new ideas, follow the latest research and don't be afraid to try new things.
2. Develop problem-solving, creativity and persistence, because research always comes with challenges.

Direct air capture

with Evangeline Leong, Maksis Darzins and Dr Aaron Guo

Talking points

Knowledge

1. What is direct air capture (DAC)?
2. What is an adsorbent?

Comprehension

3. What are two ways in which the team's DAC system differs from most other DAC projects?
4. What are some major challenges of DAC?

Application

5. Do you think the DAC2BIO approach is best described as having a negative or neutral carbon footprint? Why?
6. Research and industry tend to work on different timescales, there are differences in how technical terms are used, and systems have to be established for sharing intellectual property. How do you think the team resolves these challenges? Give hypothetical examples.

Analysis

7. Do you think the microbes that the team uses within their bioreactor are natural or genetically engineered? Justify your answer.
8. "Throughout the design process of the pilot system, the team has consulted with every branch of engineering, including chemical, mechanical, aerospace, electrical and civil," says Maksis. How do you think each of these branches of engineering is relevant to the DAC2BIO project?

Evaluation

9. To what extent do you think that DAC will play a significant role in addressing climate change at the global scale? Explain your answer.
10. What do you think a fully circular carbon economy could look like in the future? Give examples of how it might change society.

Activity

You can do this activity individually or in a small team.

Imagine you are a DAC specialist. You want to convince your nation's political leaders to establish a large-scale DAC facility in your country. In particular, the leaders are interested in getting answers to the following questions:

- What is DAC, and how does it work?
- Why is DAC important?
- Why should our country invest in this technology?

Using Evangeline, Maksis and Aaron's article and your own research, create a short presentation that answers the above questions. Consider the following while building your presentation:

- What level of prior knowledge are politicians likely to have?
- How can you get your main points across quickly and effectively?
- How much detail should you go into?
- How can images, graphics and other types of media help you?
- How can you speak to national interests?
- How can you address any likely concerns or doubts that these politicians might have?

Present your pitch to your class, who will pretend to be your nation's political leaders. Answer any questions that they have to the best of your abilities.

Afterwards, take some time to reflect on your presentation. Did your political leaders seem convinced? Did they understand what you had to say? To what extent did you address their concerns or doubts effectively? Think about how you would use this experience to improve your presentation if you were to give it again.

More resources

- The team collaborates with colleagues at the RECARB Hub that are focusing on cultivating gas-eating microbes in bioreactors. Their work is covered in another Futurum article: futurumcareers.com/tackling-climate-change-with-gas-guzzling-microbes
- Climeworks is an industry leader in the field of DAC. They explain how the technology works in a playlist of short videos: youtu.be/xEwY9b2XzLk?si=VB7TH-NnfoMs4zn0
- To learn more about the rapidly-advancing field of DAC, the team recommends seeking the latest reports from the International Energy Agency. Find one here: iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf

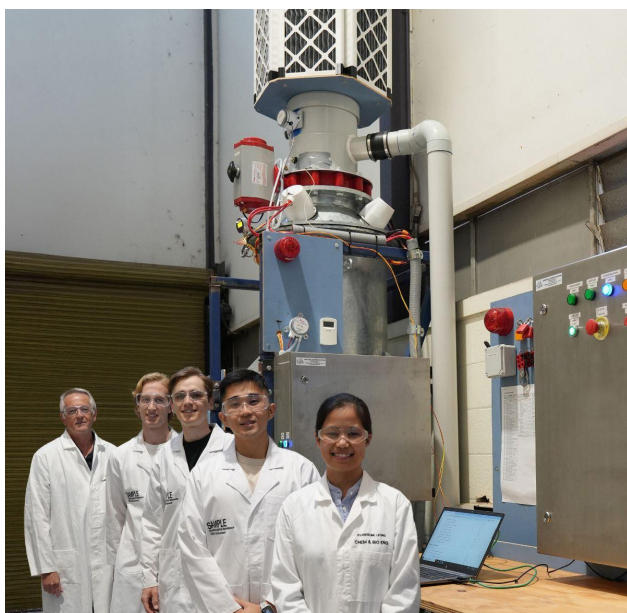
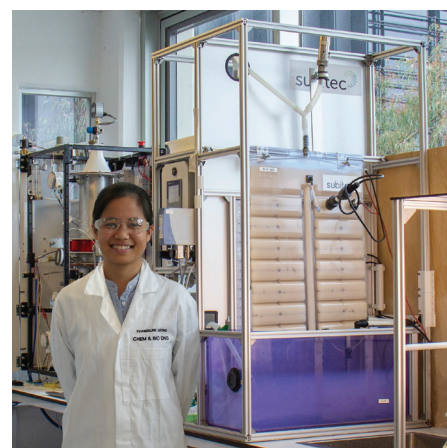
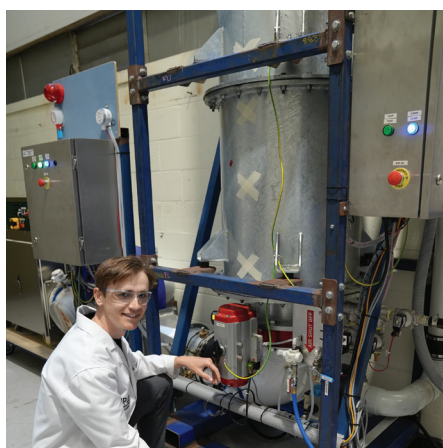


Photo montage

Top: Evangeline, Maksis and Professor Paul Webley with the LabDAC prototype.

Middle row: Left: Maksis Darzins with the UniDAC pilot system.

Centre: Aaron with the miniDAC system and a monolith adsorbent.

Right: Evangeline with the DAC2BIO system.

Bottom: Professor Paul Webley with students Jayden Cooke, Joel Wong, Maksis and Evangeline with the UniDAC pilot system.

+44 117 909 9150
info@futurumcareers.com
www.futurumcareers.com

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