Sustainable Science

Does our future depend on it?

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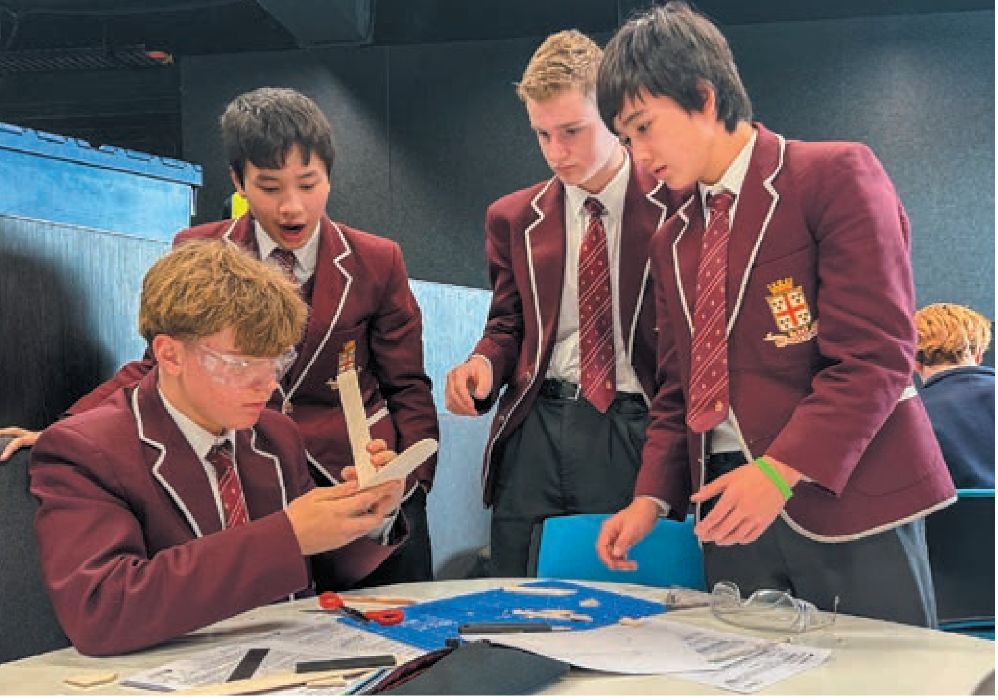
81ST EDITION

PRINCE ALFRED COLLEGE SCIENCE JOURNAL 2025



A word from the Editor

As the Science Journal proudly embarks on its 81st year of publication, we pause to reflect on the extraordinary legacy of inquiry, discovery, and innovation it represents. Since its inception in 1945 under Dr John West, this Journal has provided a platform for students at Prince Alfred College to share their curiosity with the wider community. Over eight decades, it has grown from a pioneering student-led initiative into an enduring tradition that connects generations of Princes Men, staff, parents, and alumni through the shared pursuit of science.

This year's theme, *"Sustainable Science: Does Our Future Depend on It?"* could not be timelier. At a period when climate change, resource scarcity, and technological transformation dominate global discourse, sustainability has become more than a scientific challenge, it is a societal imperative. The phrase *"does our future depend on it"* captures the urgency of this moment. It reminds us that scientific progress, while remarkable, is not without obstacles. Some innovations propel us forward, only for structural limitations, be they technological, infrastructural, or environmental, to set us back. Yet, even when theory appears constrained by Earth's finite resources, history teaches us that persistence and creativity can yield breakthroughs once thought impossible.

The Science Journal exists to provide students with a platform to share and publish their scientific work, extending inquiry beyond the boundaries of the classroom. It celebrates both the pursuit of knowledge and the breadth of scientific interests fostered at Princes, offering a space for students to engage with pressing questions in sustainability, agriculture, and the wider sciences.

I would like to extend my heartfelt gratitude to Mr Peter Hopkins, whose tireless commitment remains the cornerstone of this publication. From the very beginning of Term 2 through to its completion, Mr Hopkins has guided the Journal with steady hands, helping us select a theme, coordinating meetings, offering invaluable feedback on drafts, overseeing editing, organising our much-loved pizza lunches, and liaising with printers and designers. His generosity of time and unwavering leadership have ensured the continued success of the Journal, and for that the committee and I are deeply thankful. I am equally indebted to Josh Balacco, whose creativity brought our theme to life with striking visual form. His dedication, through multiple rounds of design and collaboration, produced both the promotional posters and the vibrant front cover that define this year's edition. A special thanks must also go to Professor Andrew Barr, who, amidst his busy schedule, contributed an exceptionally detailed and thought-provoking article that adds significant depth to this year's collection. Finally, I wish to acknowledge the tireless efforts of the entire committee, whose hours of editing, reviewing, and organising have been invaluable. This year's team welcomed several new members; hence it is reassuring to know that they will grow into seasoned contributors, ensuring that the legacy of the Science Journal will continue to flourish in the hands of the next generation of Princes Men.

On a personal note, I feel both humbled and honoured to serve as Chief Editor in my final year at Princes. Having been part of this Journal for four years, I have witnessed firsthand the dedication and creativity that define our scientific community. It is reassuring to know that the next generation of committee members will carry this tradition forward, just as countless editors before us have done. I am looking forward for the scientific writing to continue in the years to come and cannot wait to see how Princes Men will make their mark on the world of science in the future.

Aryan Parwal (Year 12)
Chief Editor, 2025

2025 Science Journal Committee
Back Row: Lachlan Logan, Aryan Parwal (Chief Editor), Eddie Lock, Charles Tang **Front Row:** Aidan Foo, Ansh Tiwari, Joshua Balacco, Veer Poredi **Absent:** Joshua Wang, Isaac Yu, Ben Logan **Staff:** Mr Peter Hopkins – Academic Leader - Science

Front cover artwork: Joshua Balacco (Year 11)

Past editors

John West, 1945

John has gone on to great heights in the scientific field of physiology. He completed a degree in Medicine at University of Adelaide before moving to Hammersmith Hospital in England. A fascination in respiratory physiology led to his involvement in Sir Edmund Hillary's Himalayan and Scientific Mountaineering Expedition in 1960-61, and the American Medical Research Expedition to Mt. Everest in 1981. Presently he is the Professor of Medicine and Physiology at the University of California, San Diego, and is actively involved with NASA in research into astronauts' physiology in space. In 2001 John was awarded membership of the American Academy of Arts and Science and he was inducted into the Princes Men Gallery. He is also a member of the Institute of Medicine of the National Academy of Sciences.

Bruce Chartres, 1946

Bruce gained top position in Leaving Honours examinations, overall and in all five subjects and followed that with a Master of Science and PhD in quick succession. He has had a distinguished academic career and his last position before retiring was as Professor of Computer Science and Applied Mathematics at the University of Virginia, USA. Sadly Bruce passed away in 2003.

Geoff Ward, 1947

Geoff graduated in Medicine from University of Adelaide in 1955. He studied Surgery and Radiotherapy at the Royal Adelaide Hospital and the Peter MacCallum Clinic in Melbourne, gaining Fellowships of both Royal Colleges. He gained further experience in Radiotherapy at the Royal Marsden Hospital in London and the Princes Margaret Hospital in Toronto. In 1970 he returned to Adelaide, where he held a visiting post in Radiotherapy at the Royal Adelaide Hospital and worked in private practice. In 1985 he was instrumental in the opening of the Adelaide Radiotherapy Centre, where he continued in private practice until his retirement at the end of 1997. Geoff passed away in 2016.

Alan McFarlane, Co-Editor 1948

After gaining a B.E. in 1952, he won a scholarship to the United Kingdom to continue his study. Alan moved to Perth and he worked as the senior process design engineer on an Australian project to provide a large natural gas plant for Indonesia. He continued working in the area of safe chemical engineering design and operation of high pressure natural gas plants. In his retirement, Alan began testing his physical capabilities on a bicycle, culminating in 2007, when he completed the Otago Rail Trail, New Zealand. Alan passed away in 2012.

Colin Schwartz, Co-Editor 1948

Colin achieved top place in examinations for the degrees of M.B., B.S. in 1954. He has since worked at the Institute of Medical and Veterinary Science in Adelaide, as the Professor of Pathology at McMaster University Ontario, and is currently Head of the Cardiovascular Department, Texas University, San Antonio.

David Prest AM, 1949

After leaving PAC, David was educated at the Universities of Adelaide, Southampton (UK), Birmingham (UK) and Oregon (USA). He holds Masters Degrees in Physics and Education. David was Principal of four independent schools including 20 years at Wesley College, Melbourne, and finished his career as Director of Foundation Studies at the University of Melbourne. In 2002 he was inducted into the Princes Men Gallery and passed away in 2018.

Bob Hale, 1950

Bob Hale graduated from Adelaide University with a First Class Honours degree in Physics in 1954. This was followed with a M.A. from Cambridge in Pure Mathematics (1958) and a Graduate Diploma in Computing Studies from Melbourne (1982). Bob taught at King's College and lectured at the Gordon Institute of Technology and the Universities of Adelaide, Deakin and Papua New Guinea. Bob is now a computer consultant.

Sandford Skinner, 1951

After leaving PAC, Sandford obtained M.B., B.Sc. and M.D. then worked in hospitals in the U.S.A. and England. Since then he concentrated on Physiology and became the Reader and Chairman of the Department of Physiology, University of Melbourne. Sadly he passed away in May 2005.

Barry Smith, 1952

Barry had an interesting, varied and exciting career. He said that this "chequered" career included teaching Mathematics and Physics at PAC, having senior positions in computing in the public service, academia and private enterprise, twice being a free-lance consultant, Assistant Secretary in the former Schools Commission, Director of a unit advising the NSW Government on technological change, heading the NSW Computer Education Unit, doing policy-oriented research in education at the ANU, statistical analysis in two government agencies, and finally being the Research Analyst at the Family Court. Barry passed away in 2018.

Michael Smyth, 1953

Michael went on to secure a First Class Honours degree in Zoology, swiftly followed by a Rhodes scholarship in 1959. Upon the awarding of his Oxford doctorate, he lectured for two years at the University of California before returning to Adelaide as Senior Lecturer in Zoology. He was the guest writer in 1966 and passed away in 1974.

Fred Symons, 1954

Dux of School, Fred went on to gain First Class Honours in Electrical Engineering and was awarded a fellowship by the General Electric Company. While studying at the University of London, he gained the Duddell Scholarship from the Institution of Electrical Engineers, London. Returning to Australia in 1964, he joined the Telecom Research Laboratories (TRL) working on a range of projects in digital networks and systems. In 1975 he was granted a Telecom postgraduate scholarship to study at the University of Essex, England for which he was awarded a PhD. In 1979 he returned to TRL as Assistant Director, Head of the Switching and Signalling Branch. Fred was a member of many Australian IT research Boards and Committees. From 1988 to 1996, when he retired, he was the Foundation Telstra Professor of Telecommunications at Monash University. Fred passed away in 2007.

Geoff Symons, 1955

In 1960 Geoff gained a B.A. in Mathematics as well as a science degree with First Class Honours in Physics. He was awarded a PhD in 1963, and a fellowship in Physics at the Kellogg Radiation Laboratories. He later spent time at New Jersey State University, the Niels Bohr Institute in Copenhagen, the Atomic Weapons Research Establishment, Harwell U.K., and Oxford University. After retirement he lectured for several years at the Open University, UK. Geoff passed away in Oxford in 2019.

John Lawton, 1956

John gained third place in the General Honours list then graduated MBBS (1962) and M.D. (1968) for research into lymphocyte metabolism. He then held positions at the Royal Adelaide Hospital, the University of Michigan and the Royal Infirmary of Edinburgh. In 1975 he joined the Department of Pathology University of Hong Kong where he attained the grade of Professor. His research in Hong Kong included immuno-deficiency in children, immunology of breast milk and autoimmunity. He retired in 1999.

Greg Bennett, 1957

Greg gained sixth place in Leaving Honours examinations followed by degrees of B.A. and B.Sc with honours in Mathematics. Post-graduate studies with the CSIRO resulted in the award of PhD in mathematical statistics. He retired from the Faculty of Mathematics at the University of Waterloo, Ontario, Canada after 31 years. Greg is still actively involved in the development of tools for data analysis using LISP as the base language.

Colin Luke, 1958

Colin was Dux of School and gained second place on the general honours list. Following on from graduating in Medicine and Surgery, he was awarded a National Heart Foundation Research Scholarship, and held positions of Senior Medical Research Officer at the University of Adelaide, Mortlock Medical Research Fellow and Honorary Virologist at the Royal Adelaide Hospital and then 15 years of private practice. Colin was engaged by Government to investigate the problem of lead exposure in young children at Port Pirie which formed the basis of a Masters Degree in Public Health. This was followed by a career as a Public Health Physician applying epidemiological principless to cancer research and in which discipline he was awarded a Doctor of Medicine. Until his retirement, he was Senior specialist Medical Consultant and Director of Clinical Epidemiology in the South Australian Department of Health. Colin passed away in 2024.

Garry Brown A.O., 1959

Garry was Dux of School and graduated from the University of Adelaide with First Class Honours in Mechanical Engineering. In 1964 he was awarded the coveted Rhodes Scholarship and went on to gain a D. Phil. from Oxford University, after which he went as a Research Fellow to the California Institute of Technology for four years. He came back to the University of Adelaide and became a Reader in the Department of Mechanical Engineering before returning to Caltech as Professor of Aeronautics. He then came to Melbourne for 9 years after he was appointed Director of the Aeronautical Research Laboratories (DSTO) before his appointment as Professor and Chair of Mechanical and Aerospace Engineering at Princeton University, USA. While at Princeton he also consulted widely in Aerospace and Defence for the U.S. In 2011, upon retirement from Princeton, he was granted Emeritus Professor, and in 2020 was awarded an AO in the Queen's Birthday Honours.

Robert Smith, 1960

Robert graduated with a B.E. in Chemical Engineering in 1965, followed by three years with ICI in Melbourne. He is now the Eastern Marketing Manager for Exxon Chemical's Additive Division in Singapore.

Geoff Trott, 1961

Geoff graduated from the University of Adelaide with a BSc, BE (Hons 1) and then from the University of Alberta with a PhD. He then spent 35 years as an academic in the University of Wollongong, finishing his working career as Sub-Dean of the Faculty of Informatics and Senior Lecturer in the School of Electrical, Computer and Telecommunications Engineering. He is currently retired and enjoying playing tennis and volunteering for Tennis Wollongong as well as travelling.

Geoff Williamson, 1962

Geoff was also Captain of the School. After Matriculation, he secured an excellent academic record while completing a M.B., B.S. A period in general practice in Whyalla followed, leading him to be Head of the Accident and Emergency Department at the Modbury Hospital. After serving as Director of Medical Services at Maroondah Hospital in Ringwood, Victoria, Geoff is currently Director Clinical Services atRockingham General Hospital, in W. Australia.

Richard Nicholls, 1963

Richard passed away during his third year of a Chemistry degree at Adelaide University.

Adrian Wilson, 1964

In 1965 Adrian gained the Elder prize for first year medicine and completed the degree in 1968, with Honours in Psychology. The years since have been spent studying and teaching history in the United Kingdom.

John Loxton, 1965

Dux of the School, John completed a B.Sc. at Melbourne University and was awarded the Wyselaskie Scholarship, followed by a M.Sc. and PhD from Cambridge University. In 1988 he was appointed Professor of Mathematics at Macquarie University and in 1995 was inducted as Deputy Vice Chancellor (Academic). John left Macquarie University in 2007 and moved to Western Sydney University. He is now an adviser to a number of independent Institutes of Higher Education in Sydney.

Rob Hall, 1966

Rob studied Medicine at University of Adelaide and trained in Neurology at the Royal Adelaide Hospital and Flinders Medical Centre. He was Clinical Teaching and Research Fellow at The Montreal Neurological Institute in 1980. He worked in private practice as a Consultant Neurologist at Memorial Medical Centre until his retirement in mid 2023 after more than 50 years in clinical medicine. He has been a member of the PAOC Management Committee for more than 26 years and was President of the Association in 2000.

Malcolm MacDonald, 1967

Malcolm graduated from University of Adelaide in 1973 with a degree in Computing Science and Applied Mathematics. At one stage, he was senior advisor to the Algerian Minister of Petrochemistry on computer applications for oil exploration. Five years were spent at University of Adelaide lecturing on Computer Engineering until invited to the Norwegian Institute of Technology. His time now is largely spent as a consultant in real-time monitoring and control.

Lindsay Packer, 1968

A B.A. in Pure Mathematics and Logic at Adelaide University followed Dux of School and fourth place in Leaving Examinations in 1968 for Lindsay.He completed a M. Sc. at Oxford University and then began Operations Research at Imperial College, London. In 1992 he completed his PhD at the University of Texas. Lindsay hasspent time at the D.S.I.R. in Wellington, New Zealand and has held positions at the University of Texas, University of Charleston and is currently Associate Professor at the Metropolitan State College of Denver.

Phil Thomas, 1969

Phil moved into several fields including truck contracting and plant propagation. 1978 saw him join the Supply Section of the Road Transport Agency, where he is now the Administration and Finance Officer, Supply.

James Cooper, 1970

James graduated with an MBBS and PhD in Immunology from the University of Adelaide. After a period of research overseas, which included time at Oxford and Harvard Universitiesand the Max Planck Institute, Freiburg, James returned to clinical practice in Adelaide. He retired from practice in 2010 and completed an MA in Art History at the University of Adelaide. He remains a director of Coopers Brewery.

Nick Birrell, 1971

Nick graduated from Flinders University with B.Sc. (Hons) and M.Sc. degrees and from King's College, London University with a Ph.D. in mathematical physics. Following a 30-year executive career in technology and finance and several years as a Professorial Fellow at Monash University, Nick now works through his private company, Kintan Pty Ltd in the fields of venture capital and consulting. Nick is involved as an advisor or director in a number of companies in fields ranging from tourism and agriculture to biotechnology and private equity. Nick was guest author in the 2008 Science Journal with an article entitled "SCIENCE, INNOVATION AND HOW TO GET RICH".

William Lee, 1972

William completed Medicine at University of Adelaide. Upon returning to Australia in 1985, he trained as an anaesthetist and is now in private practice in Lismore, NSW.

Jamie Cooper AO, 1973

Jamie was in the inaugural cohort of medical students at Flinders, did postgraduate studies in medicine, anaesthesia and intensive care medicine at Royal Adelaide, and then a critical care research fellowship at University of British Columbia, Canada. He is now Professor of Intensive Care Medicine at Monash University, an NHMRC Practitioner Fellow, Director of the ANZIC Research Centre and Deputy Director of Intensive Care at the Alfred Hospital Melbourne. He enjoys building and leading large national/international clinical research trials, aiming to improve outcomes for critically ill patients, and has published 7 original research papers in the New England Journal of Medicine.

Bill Griggs AM ASM, 1974

Bill completed Medicine at Adelaide and then specialist training in Intensive Care and Anaesthesia. He gained a tertiary qualification in Aerospace Medicine from Otago University in 2000 and completed an MBA from Adelaide University in 2009. He held multiple positions including Director of Trauma Services at Royal Adelaide Hospital, State Controller (Health and Medical) for disasters, and Director Air Force Health Reserves for SA and WA. He was deployed as both a civilian and a military officer on multiple occasions including to the Gulf War in 1991, East Timor in 1999 and 2007, both the 2002 and 2005 Bali Bombings, the 2004 Asian Tsunami and the 2009 Samoan Tsunami. In 1989 he invented a surgical instrument and technique (the "Griggs technique") to create a breathing passage through the neck. This technique was used on Pope John Paul II and is now used around the world. He was the South Australian winner of the Australian of the Year award in 2006 and the South Australian of the Year in 2009. He was awarded the honorary title of Emeritus Professor by the University of Adelaide in April 2024. He is a member of the Princes Men Gallery.

Dr Alan Branford, Co-Editor 1975

Dr Alan Branford was born at Henley Beach near Adelaide, South Australia, in 1958. He was educated at Prince Alfred College and the University of Adelaide, graduating Bachelor of Science (Honours) and Master of Science in Mathematics. Alan was awarded a PhD from the University of Cambridge, U.K., in Applied Probability in 1983. From 1984, he lectured Mathematics and Statistics at Flinders University in Adelaide, retiring as an Associate Professor in 2016.

David Hone, Co-Editor 1975

David graduated from University of Adelaide in 1979 with Honours in Chemical Engineering. He worked as a refinery engineer in Australia, then spent a time in the Netherlands until he based himself in the UK working for Shell Trading. He is now Chief Climate Change Adviser for Shell, with a focus on carbon capture and storage and the use of carbon pricing policies globally.

David Weller, 1976

David Weller completed Medicine at University of Adelaide in 1982 and undertook his PhD at Adelaide and Nottingham. From 1995-2000 he was senior lecturer, Department of GeneralPractice, Flinders University. In 2000 David was appointed Professor and Head of the Department of General Practice at the University of Edinburgh.

Randell Brown, 1977

After completing Medicine at Adelaide in 1983, Randell began specialist training in Radiology, with his final year at Hammersmith Hospital, London. He is now in general practice in Adelaide, and visiting specialist in Radiology at the Queen Elizabeth Hospital.

Michael Coats, 1978

Michael commenced a Law degree before he completed a Bachelor of Arts in English Literature and then undertook post-graduate study.

Graham Slaney, 1979

Following completion of Medicine at Adelaide University, Graham worked in the UK andNewfoundland, Canada, for several years. He was searching for 'real' winters, and the opportunity to pursue further medical trainingin Anaesthetics and Obstetrics. He has now settled in Mansfield, Victoria, as a country GP. He works at Mount Buller during the winter which enables him to perform some emergency medicine (and ski).

Nick Low, 1980

Nick graduated from the University of Adelaide in 1986 with First Class Honours in Chemical Engineering. He was awarded the Institute of Engineers Australia Award for Engineering and the Lokan Prize for Chemical Engineering. Following a two year break to chase the international tennis circuit, Nick returned to Adelaide and joined Dowell Schlumberger. During the next 21 years Nick held operational and engineering positions in Australasia, UK, France and USA. This included product development in their Global Engineering Centres in France and the USA, in collaboration with the Schlumberger Research Centre in Cambridge. Nick then worked for BP as a Well Construction and Cementing Engineering Advisor for their Global Exploration and Production Technology Group, in Algeria, Oman and Libya.

Since 2010 Nick has worked as a Project Manager and Senior Drilling Engineer for Vysus Group in Aberdeen Scotland. Nick has attained the Grade of Fellow with the Institution of Chemical Engineers.

His recent work in green energy and decommissioning is typical of the "technology refocus" with the current energy transition in the world today and aptly accommodated by the core chemical engineering and science principals attained during his time at university and PAC.

Christopher Miller, 1981

Chris studied medicine at the University of Adelaide and since graduation has worked in various medical specialisations including general practice, sexual health, health informatics and travel medicine. He developed an interest in the use of computers and the internet in medicine and gained additional qualifications in health informatics and the internet in health care and has worked in medical software and web development and consulting. Since 2010, Chris has refocussed on clinical medicine, with particular interest in skin cancer screening, diagnosis and management.

Wesley Phoa, 1982

Wesley graduated with Honours in Mathematics from ANU and then took up a scholarship to Trinity College, Cambridge, where he studied category theory and the mathematics of computing. After several years as a lecturer in the Department of Computer Science, University of NSW, Wesley worked for the Deutsche Bank in Australia in their fixed income division. He now lives in the USA where he works as a consultant to the finance sector.

Richard Moore, 1983

Richard graduated from ANU in Science with Honours in Pure Mathematics and majors in Applied Mathematics and Computer Science. In 1989, he joined the Bankers Trust in the funds Management Department. Richard moved to Salomon Smith Barney in 1996 and was Co Head of the Equity Capital Markets. After 12 years in finance in Sydney, he moved to Brisbane. Since 2001, he has been the Chief Executive Officer of Dark Blue Sea, an internet company specialising in domain names.

Andrew Moore, 1984

Andrew completed a B.Sc. and B.Ec. at ANU in Canberra. He went on to pursue a career in business and banking working in Sydney for 6 years with Price Waterhouse Coopers and Bankers Trust (gaining professional qualifications in Chartered Accounting and Finance & Investment). In 1997, Andrew spent a year in France doing an MBA at INSEAD. He then joined General Electric in London as a Business Development executive, working on corporate acquisitions for GE throughout Europe. In 2004, Andrew returned to Australia with GE as Managing Director of their Home Lending business in Australia and NZ. In 2008, Andrew joined St.George Bank as General Manager of Retail Banking. He went on to hold a series of senior executive roles within St.George and the Westpac Group until 2016. In 2017 Andrew joined the fintech business Spaceship, initially as Chairman and more recently as CEO. Spaceship is focused on enabling young working Australians to invest in their future by providing them with simple, engaging, low-cost investment and superannuation products, all supported by a highly scaleable technology platform.

Nick Falkner, 1985

After completing a PhD in 2007, Nick is currently a Senior Lecturer in the School of Computer Science at the University of Adelaide and is also an Associate Dean for the Faculty of Engineering, Computer and Mathematical Science. He has been involved in a number of educational projects involving puzzle-based learning and flipping the classroom. The Computer Science Education Research group at Adelaide is currently developing resources to support the Digital Technologies component of the new National Curriculum, in conjunction with Google.

David Fotheringham, 1986

David completed an M. Sc. in Laser Physics at ANU in 1995 and undertook a Masters degree in Theology at the Melbourne College of Divinity (now the University of Divinity). After ministering in several Uniting Church congregations David has taken up the role of Moderator of the Uniting Church Synod of Victoria and Tasmania.

David Silver, 1987

David completed a degree in Computer Systems Engineering at Adelaide University in 1991. He then worked as a Research Engineer in the field of avionics with the Department of Science and Technology Organisation (DSTO), Salisbury, and now works as Systems Engineer for Integra Australia at Technology Park.

Chor Chen Goh, 1988

Chor completed Law at University of Adelaide.

Adam Hanieh, 1989

After studying engineering, Adam devoted himself to human rights. Since 1997 he has worked for several human right organizations, including the United Nations in Palestine. He is now the Research Coordinator of Defence for Children International/Palestine Section. This role includes documenting cases of human rights violations against Palestinian children and providing legal services to children who are held as political prisoners.

Samuel Whittle, 1990

Sam was awarded the Adelaide University Medal in the Health Science division on completion of his M.B., B.S. (Hons) degree. After completing his medical degree he undertook specialist training in rheumatology in Adelaide and the UK. He completed a masters degree in clinical epidemiology in 2010 and is now a consultant rheumatologist at the Queen Elizabeth Hospital. Sam combines clinical work with research: He is currently an adjunct senior research fellow at Monash University and co-founded the Australia and New Zealand Musculoskeletal Clinical Trials Network. In 2024 he commenced a two-year term as President of the Australian Rheumatology Association.

Kingsley Storer, 1991

Kingsley completed his B Med Sc (Hons) in 1997 and MB BS in 1998. After an internship at the Royal Adelaide Hospital he moved to Royal North Shore Hospital, Sydney. In 2007, he was awarded a PhD in Neurosurgery from the University of New South Wales for an investigation of the effects of high dose radiation on arteriovenous malformations within the brain.

Since June 2007, he has lived in New York City where he is currently Assistant Professor in Anesthesiology at New York's Weill Cornell Medical College with a clinical anaesthetic practice and a research focus on how general anaesthetics cause unconsciousness.

Ben Gooden, 1992

Ben was awarded a B.Sc. (Honours) in physiology from the University of Adelaide in 1998. He then studied Medicine at the University of Sydney and completed his M.B., B.S. (Honours) degree in 2001. He researched the cause of spontaneous tendon rupture at the Raymond Purves Bone and Joint Research Laboratories and was awarded a Ph.D. from the University of Sydney in 2009. He resumed his clinical work and in 2010 became a Fellow of the Royal Australasian College of Surgeons. His post-fellowship training was at the Klinikum Emil von Behring in Berlin. He completed a Fellowship in Orthopaedic trauma, hip and knee arthroplasty at Royal Prince Alfred Hospital, Sydney. He now practices as an orthopaedic specialist at the Mater Private, Adventist and Hornsby Ku-ring-gai Hospitals in Sydney and Tamworth Rural Referral Hospital.

Andrew Newman, 1993

Andrew graduated with Honours in Mathematical and Computer Science from the University of Adelaide in 1996 focusing on game theory. After graduating Andrew worked as a management consultant at PA Consulting in Melbourne and completed a Graduate Diploma in Applied Finance and Investment from FINSIA. In 1999, Andrew joined what is now Macquarie Capital, the investment banking division of Macquarie Group. Andrew then returned to Adelaide and focuses on the infrastructure sector, and lead the Macquarie team on the successful bid for the New Royal Adelaide Hospital PPP in 2011.

Matthew McConnell, 1994

Matthew graduated in 2000 from the University of Adelaide with a M.B.,B.S. He went on to further his post-graduate studies and was awarded with a Masters in Public Health. He was a part-time Lecturer at the University of Adelaide's Medical School for six years before commencing advanced training in public health medicine with the Royal Australasian College of Physicians. Matthew became a Public Health Physician in early 2014 and is working in South Australia.

Shom Goel, 1995

Shom Goel graduated MBBS in 2003 from the University of Adelaide. He was awarded the prestigious Alumni University Medal for being ranked the most outstanding honours graduate of his year. Shom was ranked the top M.B.,B.S. student each year of his course and along the way he received 19 prizes and scholarships.

Ross Mullner, 1996

Having completed a Chemical Engineering Degree (Honours) at Adelaide University, Rossworked as a Process Technician at the Mobil Adelaide Refinery until its closure. He then joined Santos as a Senior Process Engineer, supporting various Gas Plant operations and projects around Australia.

Gwyn Morfey, 1997

Gwyn undertook a double degree in Law and Commerce, with a major in Computer Science, at Flinders University.

Tom Newman, 1998

Tom graduated in Commerce, University of Adelaide.

Mitchell Raeside, 1999

Dux of School, Mitchell began an accelerated science degree at Flinders University which he completed in 2001, winning the Bragg Medal for the best Physics student. Mitchell completed missionary work for his church in 2002-2003 in Taiwan and then undertook an MBBS (Hons) at Flinders University. He completed radiology specialist training in SA and then spent 12 months doing fellowship training in oncologic imaging at Memorial Sloan-Kettering Cancer Centre in New York City. He is currently the Managing Partner at Jones Radiology and a consultant radiologist at the Royal Adelaide Hospital.

Iain Murchland, 2000

Iain completed a Bachelor of Biotechnology (Hons) at the University of Adelaide, and commenced a PhD in the field of structure-based drug design in the Discipline of Biochemistry at the University of Adelaide.

Peter Mathews, 2001

Peter completed a degree in Engineering (IT and Telecommunications) with Mathematical and Computer Sciences at University of Adelaide.

Edward Heddle, 2002

Edward completed Science at University of Adelaide.

Mark Hosking, 2003

Mark holds a Bachelor of Laws and a Bachelor of Commerce from the University of Adelaide, and a Master of Law from the University of Cambridge. Mark currently practises as a barrister in Melbourne.

Chris Davies, 2004

Chris completed a Bachelor of Mathematical and Computer Sciences at the University of Adelaide, and Honours in Statistics for which he was awarded the Adelaide University Medal. After working at the Australian Bureau of Statistics and in the University of Adelaide School of Public Health, he completed a PhD in Statistics at the University of Adelaide. He is now a Senior Biostatistician at the Australia and New Zealand Dialysis and Transplant Registry based at the South Australian Health and Medical Research Institute.

George Evans, 2005

George graduated in 2011 from the University of Adelaide with an M.B.B.S. and was admitted as a Fellow of The Royal Australian and New Zealand College of Psychiatrists in 2020. He currently works as a general adult psychiatrist in Adelaide.

Paul Hosking, 2006

Paul completed a Bachelor of Medicine and a Bachelor of Surgery at the University of Adelaide in 2012. He was admitted as a Fellow of The Royal Australian and New Zealand College of Psychiatrists in 2020, and now works as a Child and Adolescent Psychiatrist in Adelaide.

Sam Lehman, 2007

Sam enrolled for a double degree in Health Sciences and Law, University of Adelaide.

Harry Crawford, 2008

Harry completed a Bachelor of Arts, majoring in Chinese Language, from the University of Adelaide, and worked for six months in Beijing.

Jerome Squires, 2009

Jerome is studying Law and Arts at the University of Adelaide.

Nicholas Burton, 2010

Nicholas graduated with a Bachelor's in Civil and Structural Engineering from the University of Adelaide and a Master's in Sustainable Design and Construction from Stanford University, specialising in earthquake-resilient building design. He currently works for Skidmore, Owings & Merrill in San Francisco.

Tien Chen 2011

Tien is currently undertaking the Doctor of Medicine (MD) degree at Griffith University, and hopes to become an internal medicine physician. In 2012 he graduated from PAC as joint Dux of the College, and in 2014 graduated from Griffith University with a Bachelor of Medical Science (BMedSc). Tien also holds an Associate Diploma in Music, Australia (AMusA) and over the summer, was the inaugural Summer Scholarship holder at the South Australian Health and Medical Research Institute (SAHMRI).

Henry Bui, Co-Editor 2012

Henry is studying Medicine at University of New South Wales, in Sydney.

Theo Squires, Co -Editor 2012

Theo is studying a double degree in Finance and Mathematics with Computer Science at the University of Adelaide.

Isuru Dissanyake, 2013

Isuru studied Bachelor of Science (Advanced) at University of Adelaide, recently completing it with a major in Chemistry. He has recently completed First Class Honours in Chemistry and in 2019, embarked on what was a long term goal of his of studying a PhD in orgainc synthetic chemistry. Isuru was acknowledged in an Australia Day ceremony as a "Young Citizen of Australia 2015."

Timothy Hobbs, 2014

Timothy Hobbs graduated from the Australian National University with a Bachelor of Laws [Honours] and a Bachelor of International Security Studies in 2020. Since graduating, Tim has worked with the National Security College and as an in-house legal adviser at a space-tech start-up. He's currently working as an adviser to a South Australian Senator.

Yu Le Kong-Lim, 2015

Yu Le Kong-Lim completed his IB Diploma and was a College Prefect in his final year of senior schooling. He was heavily involved in the School music program and a keen debater. On leaving school he studied Law and International Studies at University.

Eddie Han, 2016-17

Eddie graduated from the IB Diploma Program in 2017 and was the Chief Editor of the Science Journal in his last two years of senior schooling. He is currently studying Computer Engineering at New York University – Abu Dhabi.

Denny Han, 2018

Denny studied the IB Diploma in 2018-19 and after contributing to the Journal Committee for several years was Chief Editor in 2018. He is currently studying at New York University – Abu Dhabi.

Seran Perera, 2019

Seran graduated from SACE in 2019 after working as the Chief Editor during the Science Journal's 75th edition. He is currently studying Medicine at the University of Adelaide and is excited to explore the role of science in global health.

Joshua Lesicar, 2020

Joshua graduated from the SACE in 2020 and after contributing to the Science Journal for several years whilst at Princes he became the Chief Editor in his final year of Senior schooling. On graduating from Princes he studied Marine Biology at the University of Adelaide and was excited for what future scientific endeavours he will encounter.

Dinan Perera, 2021

Dinan enjoyed several years on the Journal Committee before his involvement culminated in him being Chief Editor in 2021. After graduating from the SACE at the end of that year, Dinan was accepted into Medicine and the University of Adelaide.

Hoon Kang, 2022

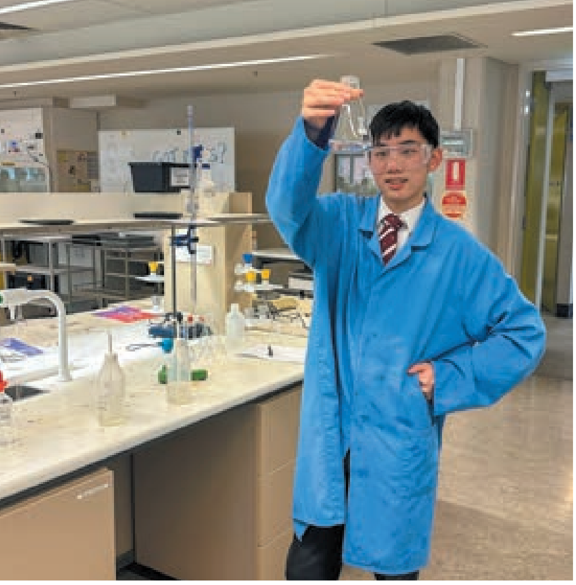
Hoon was accepted into Medicine at the University of Adelaide. With a long road ahead of him he is unsure as to what area he will specialise in at this early stage. Hoon is also interested in the research aspect of medicine and is looking forward to exploring opportunities in this area as they present. He has remained in touch with the Prince Alfred community by helping with tutoring of our boys.

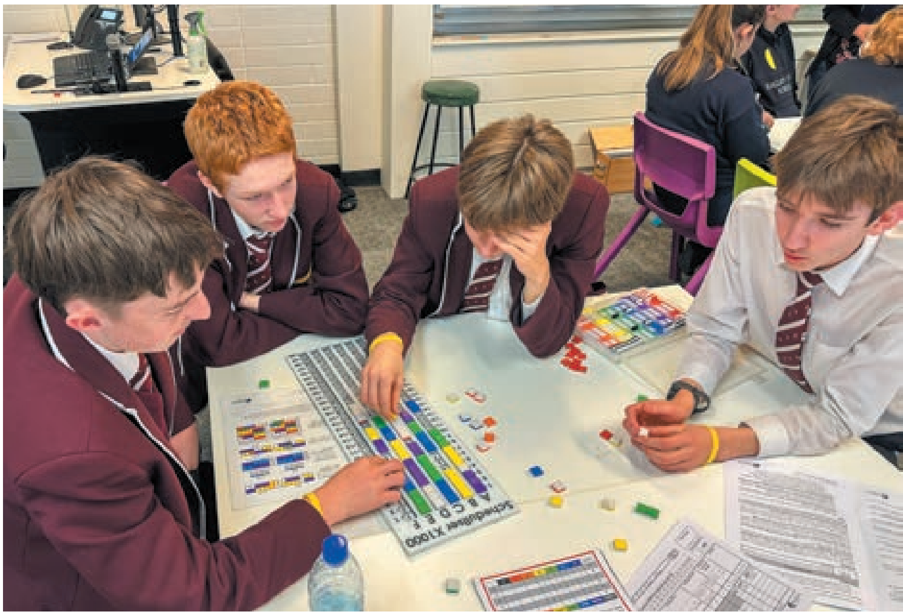
Winston Huang, 2023

Winston is currently studying a Bachelor of Biomedicine at the University of Melbourne and aiming to become a Doctor of Dental Medicine.

Caleb Tang, 2024

Caleb graduated as the dux of the IB Diploma Program in 2024 alongside winning the Oliphant Trophy that year. He served on the journal committee for many years before becoming chief editor in the journals eightieth edition. He has since accepted a place to study medicine at the University of Adelaide.





Mr David Roberts (Headmaster) , Mr Nicholas Branson (1974) and Mr Peter Hopkins (Academic Leader - Science)

The LJ Branson Prize

This year the College is honoured to be awarding the recently re-endowed *LJ Branson Science Prize* to the student who produces the best article for inclusion in this publication.

The LJ Branson prize was originally established in 1945 by Dr Harrold R Branson (1911) and Mr Vernon M Branson (1925) in memory of their brother Laurence James Branson (1913) who lost his life in 1916 in the First World War age 20.

The inaugural LJ Branson prize was awarded in the same year that the Science Journal was first published - 1945 and was awarded up until 1995.

Descendants of LJ Branson, Dean (1947), his wife Kathleen and sons Nicholas (1974), Toby (1979) and Benjamin (1987) Branson have very generously re-endowed this historic prize and are thrilled that it will again be awarded to a young brilliant scientist.

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How can science help food production systems meet the global challenges of climate change, food security and sustainability?

Words by Dr. Andrew R. Barr, formerly
Professor of Plant Breeding, Adelaide University

Guest article

Introduction

What were you hoping to read in the Science Journal this year? Maybe climate change keeps you up at night. Maybe you are interested in biodiversity or saving endangered species. Do you want to see a fair and equitable world where all are fed and watered adequately and safely? Do you want to know how your food is produced? Then, read on because agriculture and the science underpinning matters to you because it affects all those things and more.....

Background

The farming systems which support life on earth were developed in the period 9-11000 years ago in both the fertile crescent region of Mesopotamia and the highlands of South America. Their modern derivatives are now under the intense scrutiny. The debate about the future of farming has moved out of realm of farmers and agricultural scientists and into the mainstream with those presenting strong and diverse views including climate scientists and activists, naturalists, philanthropists, politicians of all colours, international agencies such as the United Nations, Food and Agriculture Organisation, CGIAR and aid organisations, food corporations and more. This is because the populous realise that farming systems can influence climate, food security, biodiversity, economic activity, the viability of farming businesses and rural communities, and the quality of life for farm and non-farm residents. Amidst all these opinions, those of agricultural scientists are tending to be lost.

What field crop farming systems are there and how will they contribute to world food production?

In this section, five candidate farming systems will be examined to ascertain their strengths and weaknesses and their likely impact. These farming systems produce the world's staple foods and feed stocks and include wheat, maize (corn), rice, barley, sorghum, millet, soybean, lentils, peas, faba beans, mung beans, canola, sunflower, safflower, oats and rye.

Conservation agriculture

A definition; *A farming system that promotes minimum soil disturbance (i.e. no-till farming), maintenance of a permanent soil cover, and diversification of plant species.*

The majority of Australia's current field crop agriculture would be described as "conservation agriculture". The adoption and refinement of these systems have contributed to improvements in overall productivity, better integration and yields of break crops such as canola, chickpea and lentils and greatly reduced soil loss due to wind and water erosion. However, two major challenges remain in a farming systems sense – the carbon cost of Scope 2 and 3 emissions arising from the nitrogen fertiliser used and the inability to raise soil carbon under most conservation agriculture systems.

Organic / Biodynamic Agriculture

A definition; *Organic and bio-dynamic systems rely upon crop rotations, use of residual crops, animal manures, legumes, green manures, mechanical cultivation, cultural control, minimal application of approved mineral-bearing rocks and aspects of biological pest management to maintain soil productivity and tilth, to supply plant nutrients and to control diseases, insects, weeds and other pests.*

Organic farming systems have been promoted by individuals and organisations but rarely by governments – until the EU released its Farm to Fork policy in 2020. Proponents argue that organic farming produces safer food and is softer on the environment by eliminating "harmful pesticides and fertilisers" (Muller *et al*., 2017). So, what does the scientific literature tell us about organic field crop agriculture? Firstly, productivity levels are lower, and a working figure is around 70% of "conventional systems" although some crops may be difficult to grow at all under organic practices (e.g., canola in Europe). Further, organic agriculture may not achieve the positive greenhouse gas outcomes that its proponents hoped for. The direct consequence of more organic agriculture is that greater areas under cultivation would be required to produce sufficient food for the world's population.

To achieve more productive organic systems, greater investment in science is required especially in integrated pest management and plant nutrition. The EU, for instance, plans to redirect 30% of R&D directed to agriculture to improvement of organic systems.

Regenerative agriculture

A definition; *Regenerative agriculture is any kind of farming that enables the restorative capacity of the earth. Regenerative agriculture preserves or improves the fertility of the soil, creates an abundance of food and other agricultural products,* *contributes to vibrant communities and equitable economies, and respects the ecology of the natural world. Fertile soil helps create nourishing food and, in turn, healthy people and robust communities.*

Regenerative agriculture is a relatively new concept to many in the field crop industries. At first glance, the goals of regenerative agriculture sit well with the goals of many farming families whose aim is to pass the farm to the next generation in a better condition than they inherited it. However, populist versions of regenerative farming present mostly anecdotal evidence as to its merits and advocate no use of synthetic fertilisers and pesticides which will inevitably lead to low productivity levels. Food Corporations are also strong advocates of regenerative agriculture (e.g. Unilever, Walmart, PepsiCo, General Mills) and after some missteps, are now promoting farming methods which have a stronger basis in science. The principles of regenerative agriculture are also receiving some serious scientific investigation with centres in Australia (e.g. Southern Cross University) and internationally (e.g. California State University).

Precision agriculture

A definition; *Precision Agriculture is a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production.*

Precision agriculture has been intensively studied and debated in Australia within the agricultural science and farming communities, and now makes a strong contribution to the farming systems adopted in Australia and globally. This trend looks likely to continue and these technologies will underpin many of the elements of good farming systems into the future.

Sustainable agriculture

A definition; *Sustainable agriculture consists of environment friendly methods of farming that allow the production of crops or livestock without damage to human or natural systems. It involves preventing adverse effects to soil, water, biodiversity, surrounding or downstream resources—as well as to those working or living on the farm or in neighbouring areas.*

Sustainable farming has become the most debated of the farming systems globally. Farmers in Australia were first exposed to concepts around sustainable farming with the introduction of the ISSC audit scheme, via the Australian Oilseeds Federation, over 10 years ago for canola exported to the EU. Farmers made a declaration through their National Grower Registry which stated their grain was "sustainably produced" and this enabled sales into the premium EU markets. Over time, the conditions around the ISCC standards have become more demanding and individual farmers are audited at random to ensure compliance with the tenets of the sustainable grain model. Audits cover many aspects of farm businesses including ISCC Grower Self-Assessment forms, grain sale contracts, production summaries, chemical/fertiliser inventory and usage records, seed purchase invoices, equipment calibration records, employment and training records, farm safety procedures and plans to manage farm waste, biodiversity and pollinators. Standards were raised further in September 2022 and now include a "no burn" and 5% "set aside" policy. Some farmers have found these audits very challenging requiring real and costly changes to their farm procedures and infrastructure, while other businesses have been well equipped to meet the guidelines with minimal changes. The schemes have expanded in the past two years to cover feed, malt barley and oats.

In the early years of the canola scheme, attractive premiums (*circa* $25 per tonne) were available for minimal changes to farming systems and minimal compliance costs. Premiums for barley have been $2 per tonne in 2021, which many farmers viewed as insufficient incentive for the increased level of compliance required. In 2022, the premium for malt barley increased to $5 per tonne. Compliance costs for audits in 2021 ranged from $10,000 – $45,000 amongst three growers who were interviewed by the author.

Sustainable farming has gained huge momentum globally with support by the United Nations (see Sustainable Development Goals), governments, corporations (including food, farm supply, grain marketing and grain processing), political parties (e.g., Australian Greens) and farmers and their organisations. Farm advisers now need to understand the requirements, the implications for their clients' businesses and the commercial opportunities presented by accreditation.

How can farming systems be objectively evaluated

So, with so many diverse views pulling farmers and their advisers in many different directions, how should we objectively evaluate the farming systems and their components? In my view, the key goals must be measurable and objective and include the following;

- **Enough food for 9.8 billion by 2050** – food security for the entire population is fundamental to a peaceful and equitable world
- **Use all the tools of modern science** to maximise yields while minimising environmental impact. I discuss five of these tools in the following sections.
- **Viable farmers in thriving rural communities** – the economic viability of farming and the decline of rural communities as farms grow larger both affect future food production
- **No new land opened up for agriculture** – while the global food balance sheet is tight, investment in improving yields on existing agricultural land would enable this to be achieved.
- **Return significant landscapes to wild areas** – increasing yields and the appropriate incentives would allow farmers to set aside lower productivity areas for refuges.
- **Promote biodiversity** – what management decisions can be implemented to promote biodiversity in farmlands?
- **Maintain soil quality** – these are the key aspects of soil health - No soil loss due wind or water erosion or degradation; maintain or increase soil organic carbon; slow the rate of acidification/salinisation in at risk soils; applied nutrients stay where you put them and not pollute surface or groundwater or the atmosphere; promote a diverse soil microbiome; efficient nutrient cycling. Soil quality

underpins yields and while much is spoken about soil health by proponents of alternative farming systems, there is a pressing need to quantitatively characterise soil health – such measures are available now.

- **Nett zero emissions**, or as close as is possible, since agriculture will not be treated differently from other industries when carbon accounting is applied.

When one applies these criteria to the five farming systems, it is immediately apparent that none of them can satisfy all the requirements. In the case of organic agriculture and regenerative agriculture, yields will be lower than current farming systems so that more land will need to be used for agriculture to feed a growing world population. This will not allow extra land to be set aside as wild areas. Proponents of these systems argue that biodiversity on organic farms is higher than on "conventional" farms but this is a poor second to genuinely wild areas.

For farms running conservation farming techniques, the big issue is the environmental cost of producing and using fertilisers especially nitrogenous fertilisers. This can be reduced using urea fertilisers coated with urease inhibitors, denitrification inhibitors or slow release coatings and such measures are now mandatory within the EU. This can be mitigated further in precision farming systems by applying fertiliser very accurately according to the needs of the crop on each different soil type across every individual paddock. In a truly sustainable farming system, new technology to produce fertiliser will be needed. Promising leads include the Jupiter Ionics patented system to produce green urea using renewable power and ammonia as a side product of "green" hydrogen projects.

The bottom line is that no one farming system has all the answers and none can meet the goals I set above. Hence, serious investment in research and development is required in agricultural and related sciences to design and implement the farming systems of the future.

An example of Changing Agricultural Policy – EU "Farm to Fork"

One of the most significant changes in agricultural policy affecting farming systems came with the launch of the EU's "Farm to Fork" policy in May 2020. The 27 actions proposed in the strategy include the following:

- a 50% reduction in the use and risk of pesticides (with 2020 serving as the base year);
- a 20% reduction in the use of fertilizers, including manure;
- a 50% reduction in sales of antimicrobials or antibiotics used for farm animals and aquaculture;
- requiring 25% of agricultural land be farmed under organic practices (an increase current level of around 8%.)
- a 10% reduction in farmland used for growing crops.

This policy is dramatically changing EU agriculture and, through European corporations such as banks, aid agencies, food corporations and others, is influencing agricultural policy in other regions. The aim of this policy is reducing the environmental footprint of agriculture, reduce fertiliser pollution of streams and groundwater and reduce the use of pesticides in general in favour of organic and less pesticide intense systems. Already farmers right across the EU have revolted against these changes. Those farmers who converted to organic farming have found that the premium for their produce does not compensate for the lower yields and their viability is under serious pressure. Those farmers who have reduced pesticide and fertiliser inputs have also shown reduced yields and lower profits and they too are under financial pressure. Hence the rise of "tractor protests" targeting many European capitals such as London, Paris, Berlin which have made prime time news services over the past 2 years.

What science will make an impact on agriculture and food production in future?

In this section, I will look at five areas of science that will make a big impact on global agriculture. The diversity of the skills required to achieve these impacts is very wide and is highlighted in these 5 sections.

1. Genetic Engineering and Gene Editing

Skills required; Genetics, biotechnology, plant breeding

Definitions; Genetic engineering is the direct manipulation of a host organism's DNA by gene cloning, gene splicing and recombinant DNA technology. It involves the insertion of a relatively small piece of DNA (typically incorporating one or several genes) from one organism into another (maybe unrelated) organism. CRISPR gene editing is a powerful tool to make precise changes to the DNA of living organisms. It uses a protein called Cas9 to cut DNA at specific locations, guided by a short RNA sequence known as guide RNA (gRNA). This technology can add, delete, or replace DNA sequences.

Genetic engineering or genetic modification ("GM") is now "old science" with the first commercial GM varieties being released in 1994, yet the controversy over its application still rages. The area planted to GM crops globally is now over 200 million hectares (as a benchmark, the area sown to wheat in Australia is around 9 million hectares) and includes corn, soybean, cotton, canola, papaya, eggplant, potato and more. The overwhelming evidence is that these crops pose no extraordinary environment problems (in fact, the opposite is often true with GM cotton leading to a 90% reduction in insecticide use in some countries) and no food or feed safety concerns. It is quite astonishing that opposition remains to these crops .....

The table below contains examples of the types of traits which can be transferred into crop plants by genetic engineering. You will notice that the technology started with just a single gene being transferred (note that an organism like a wheat plant has 100,000 genes), moving to multiple genes controlling a single trait (as in omega 3 canola – a truly incredible scientific achievement by Australia's CSIRO- see Petrie *et al*. 2019) and now targeting multiple genes targeting multiple traits.

The CRISPR Cas9 gene editing system is more contemporary science that can be used to edit DNA and produce plants with novel traits. This does NOT involve the transfer of DNA from one species to another and as such is not classed as a GM event by regulators in most jurisdictions. The very first varieties are just being commercialised, and examples include tomatoes and mushrooms which have enhanced shelf life. Plant

GM era	Trait type	Number and source of genes transferred	Commercial Examples	Impact
First generation	Insect resistance	One from bacteria	Bt Cotton	Massive reduction in the use of insecticides and better insect control
	Herbicide resistance	One from bacteria	Roundup ready canola	Better weed control options for farmers
	Virus resistance	One from virus	Papaya with ring spot virus resistance	Widely grown in Hawaii and China to control an intractable disease
	Beta carotene	One from maize	Golden rice	Reduce child hood blindness in populations where Vitamin A is deficient
Second generation	Omega 3 seed oil	Seven genes sourced from micro algae	Omega 3 canola	A sustainable source of oils rich in omega 3 fatty acids for fish feeds and eventually human cooking oils
	High oleic oil	Two genes within safflower	High Oleic Safflower	A renewable oil suitable for precision engineering applications
	Disease resistance cassette	Five genes for disease resistance in one contiguous DNA cassette	In wheat, resistance to stem, stripe and leaf rusts – experimental only	More durable and sustainable resistance to wheat disease with less need for fungicides and easier for plant breeders to incorporate in new varieties
Third generation	Climate resilience	Multiple, many sources	Under development	Crops engineered to withstand climate change extremes such as drought and heat
	Multi trait cassette	Multiple, many sources	Under development	Build cassettes with multiple novel traits that are easy for plant breeders to incorporate in new varieties

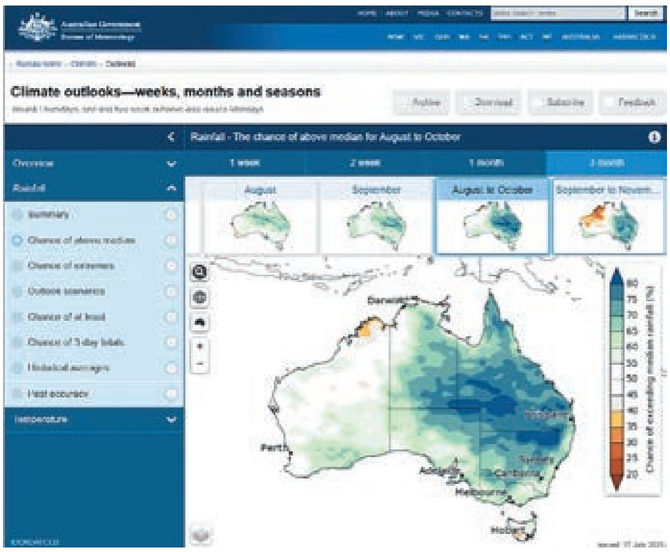
breeders across the world are looking to this and other new gene editing technologies to make important breakthroughs in crop variety development over the next decade.

2. Meteorology and Climate Science

Skills required; Physics, Meteorology, IT

Definition; Global Circulation Models (GCMs) are complex computer simulations used to understand and predict the Earth's climate system. These models simulate the interactions between the atmosphere, oceans, land surface, and ice. They are essential tools for making seasonal weather forecasts and long-term climate projections.

Ask any farmer; the weather drives their business, and a holy grail is to be able to predict the weather that influences their crops ahead of its arrival so that the optimum management decisions on, for instance, seeding time, fertiliser rate and variety can be made. The science required to make such predictions relies on "global circulation models". Each of the world's major meteorological organisations has developed their own version of a GCM – each with different underlying assumptions and algorithms. In Australia's case three models have been developed – ACCESS-S, POAMA and CABLE to produce forecasts like the one below. Great progress has been made with these forecasts often being able to at least give an indication of below average, average or above average conditions to follow over a 3-6 month period. The problem lies with the accuracy of such forecasts in some seasons – for



A seasonal forecast issued by the Australian Bureau of Meteorology on July 17, 2025

instance in 2024, the forecast for the growing season rainfall in SA were favourable yet the season was the driest on record for many SA weather stations. The prediction of autumn conditions is particularly difficult for southern Australia, yet this is when seeding begins and information regarding the seasonal break would be especially valuable.

So, here is a challenge for young physicists ..... Can you develop better seasonal forecasts?

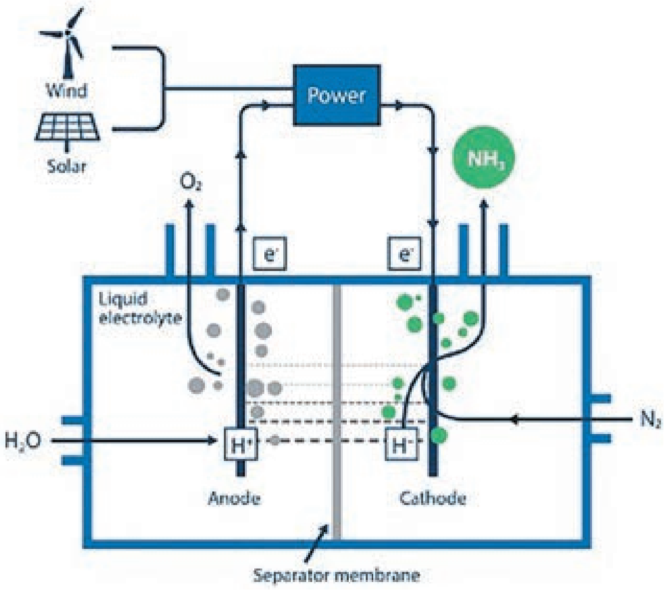
3. Novel Fertiliser

Skills required; Chemical engineering, agronomy, Renewable energy physics/chemistry, electrical engineering

Definition; Haber-Bosch Process: A chemical process that synthesizes ammonia (NH_2) from nitrogen (N_2) and hydrogen (H_2) gases under high pressure and temperature, using an iron catalyst. This process is essential for producing nitrogen-based fertilizers. Fritz Haber was awarded the Nobel Prize in Chemistry in 1918 for his role in developing the process. Carl Bosch later received the Nobel Prize in Chemistry in 1931 for his contributions to the industrial-scale implementation of the process.

As discussed earlier, the biggest contributor to the carbon footprint of field crop farming is the production, transport and use of nitrogen fertiliser. Crop productivity relies on adequate nitrogen fertiliser. The most common nitrogen fertiliser (urea) is synthesised using large amounts of fossil fuels in the Haber Bosch process. The world is desperately seeking new technologies to reduce the energy demand to produce nitrogen fertilisers and recently a team from Monash University in Melbourne have patented a new process. A start-up company built on that process, Jupiter Ionics, is now developing a flexible, modular system to produce carbon-neutral, Green Ammonia. The system, called the MacFarlane Simonov Ammonia Cell (see below), takes in air and water and uses renewably-generated electricity to convert these to ammonia. They propose that this system could be produced in container sized modules which would be distributed around the cropping regions who need fertiliser thereby reducing the energy required both in the production of ammonia and in its transport costs to the areas that ultimately use it.

How the MacFarlane Simonov Ammonia Cell works:



4. Precision Agriculture

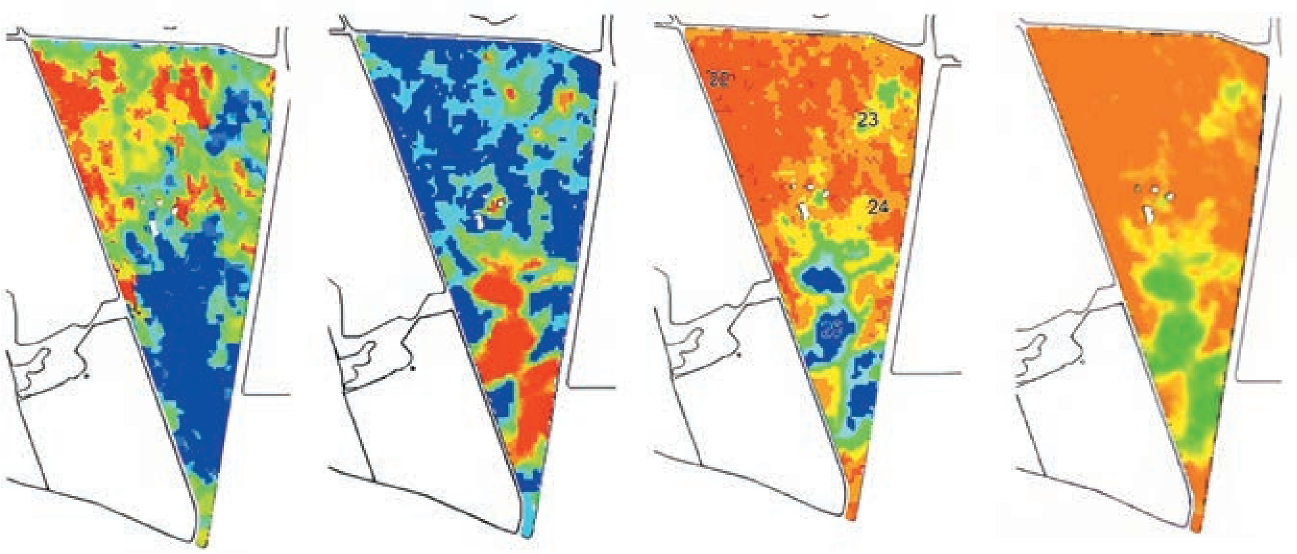
Skills required; Agronomy, IT, soil science, plant nutrition

Farming technology from 20 years ago delivered one rate of fertiliser uniformly across a whole field after an estimate was made of the average requirement of the crop for that soil type and environment. Australia's ancient soils are very variable in soil texture, water holding capacity and chemical composition and hence it is not uncommon for yields to range by a factor of 3 across a single field. The implication is therefore that each square metre of a paddock will have a different need for fertiliser. Now with ground based scans of soil pH, satellite images of the NDVI (biomass) and some clever IT, a "prescription map" can be made which will precisely determine the fertiliser requirement for each square metre of a paddock. This map is loaded into the tractors operating system while towing the seeding equipment and this will vary the fertiliser rate delivered into the soil during the seeding operation according to the calculations underlying the map. So, fertiliser is matched to crop demand and less fertiliser is applied to less productive areas.

5. Robotics and Artificial Intelligence (AI)

Skills required; Mechatronic engineering, IT, AI, Horticulture/agronomy

The first autonomous machines are hitting Australian paddocks now. In this first example, a Queensland Company called



Paddock scale contour showing (left to right) soil pH, NDVI (a measure of biomass), calculated pHnNDVI, phosphorus application map to be delivered by the seeding system

Swarm farm autonomous sprayer with optical weed sensing technology - now commercially available

Swarm Farm has developed an autonomous sprayer which can navigate its way to the paddock of your choice, unfold its spray boom, drive its way precisely across the paddock while scanning using optical sensors to detect weeds and only then does it turn on a targeted nozzle to deliver a herbicide to kill that specific weed. When finished, it will fold up and return to base to await another task.

In a second example, robotics and AI can be used to solve the perennial problem of how to get fruit (and vegetables) picked. Below is a prototype apple picking robot which can sense where the apple is on the tree, pick it, scan it for quality defects and then allocate the apple into the appropriate grade, before delivering it into a bin to take to the market.

Prototype apple picking and grading robot.

Conclusion

Farm advisers, agronomists and agricultural scientists must present well researched information to the wider community so that it is well informed and that governments make good decisions on the future of our farming systems. Agricultural science and on farm production have increased food production and, in the last 20 years, there has been a reduction of the number of people living in poverty despite the population growing rapidly. Innovation across all farming systems is crucial to meeting the global goals proposed. I am optimistic that with the appropriate investment, agricultural science can meet the challenges of a larger population, environmental targets and sustainability goals.

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The mystery behind the pigeon and its ability to always find its way home

Words by Eddie Lock (Year 12)

Thought starters

Pigeons have lived on this planet alongside humans for generations and people often disregard them as 'rats of the sky' but they fail to realise how smart these birds really are. Pigeons are some of the smartest birds of the avians in the animal kingdom and this is largely due to their homing ability, that is their ability to always find its way home, no matter where they come from. This ability has helped humans for centuries with communication, particularly in Medieval England with mail between villages and during the events of WWI and WWII, helping soldiers send messages across the globe. Their ability to find home has repeatedly saved time and lives for people throughout history. But how does this work? How do they know where to go?

Today's homing pigeon has been bred from the Rock Dove (*Columbia livia*), specifically to be able to find home in a short period of time. Homing pigeons have been known to find their way home from as many as 1,770 km away, and they can travel an average of over 100kmph with bursts of up to 145 kmph!

But how do they know where to go? Despite hundreds of scientific studies, nobody actually knows but there are many educated theories as to how they might work. Many believe that they have a compass and map mechanism in their brain where the compass part controls what direction the birds are flying in while the map part helps the pigeon determine if it has arrived at home, comparing the landscape that it is flying over to the landscape that its home is based in.

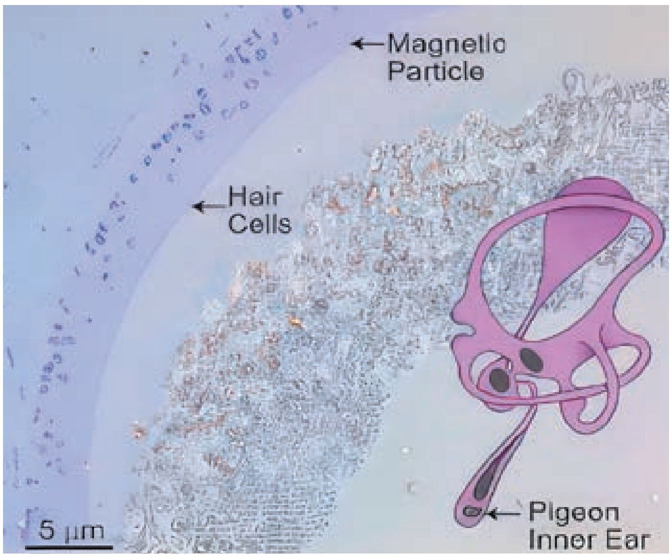

Figure 1 Inner ear of a pigeon

Another theory is that a pigeon's brainstem cells associated with the inner ear are activated when the bird is exposed to magnetic fields. It measures the intensity of the magnetic field that it is flying over and helps the pigeon find fields that are similar to home. This allows the bird to measure magnetic field intensities and follow them until it reaches an area it recognises. This concept is called magnetoreception.

Scientists are also considering the "free-radical pair" model. Pigeons and other migratory birds have proteins in their retina called "cryptochromes". These produce an electrical signal that varies depending on the strength of the local magnetic field. Although this isn't confirmed, it is believed that this allows birds to see the earth's magnetic field.

It was also believed that pigeons may have lumps of magnetic material inside them, which would help the bird control where it is flying, guiding it with magnetic force. Considering this, scientists have looked into the bird's ear, looking for any magnetic particles that are located near the sensory systems (Figure 1). This was later disproven as the magnetic particles would need to be 100,000 times stronger to activate the sensory pathways required for magnetoreception in pigeons.

So, while no theories are yet to be proven, one of the biggest questions in the animal kingdom still stands. How does a homing pigeon find its way home?

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Neuroprosthetics and brain-machine interfaces: innovations and challenges

Words by Ansh Tiwari (Year 9)

Thought starters

Neuroprosthetics and brain-machine interfaces (BMIs) constitute a rapidly evolving interdisciplinary field that merges neuroscience and engineering. These systems establish a direct communication pathway between the brain and external devices, translating neural activity into operational commands. Originally conceptualised for clinical rehabilitation, neuroprosthetics have expanded to encompass a wide array of applications including motor restoration, sensory substitution, and cognitive enhancement. This report critically examines the scientific foundations, engineering considerations, societal implications, practical applications, and limitations of neuroprosthetics and BMIs.

Neuroprosthetic devices operate by detecting and interpreting neural signals, which are the electrochemical outputs of neuronal communication. Neurons transmit information via action potentials, or rapid voltage fluctuations across their membranes. These signals can be captured using electrodes either placed invasively within the brain tissue or non-invasively on the scalp. The acquired electrical signals are amplified, digitised, and decoded using sophisticated algorithms, enabling control of external actuators such as prosthetic limbs or computer cursors. Key brain regions typically targeted for implantation include the motor cortex, somatosensory cortex, and hippocampus, depending on the intended function of the device (Figure 1).

The successful interpretation of neural signals requires the identification of consistent patterns across large neural populations. Brain-machine interfaces often rely on ensemble coding models to extract meaningful information from population-level firing rates. These models assume that the combined activity of multiple neurons represents a specific motor intention or cognitive state, which can then be mapped to device control outputs. Increasingly, decoding algorithms employ machine learning techniques to improve accuracy and adaptability across varying environments and users.

The engineering of neuroprosthetic systems involves complex integration of biocompatible materials, microelectronics, and signal processing technologies. Electrode materials must exhibit high conductivity, biostability, and mechanical compatibility with neural tissue. Commonly employed materials include platinum, iridium oxide, polyimide, and emerging nanomaterials such as graphene and carbon nanotubes. To minimise foreign body responses, researchers are exploring ultra-flexible electrode arrays that conform to the brain's surface, thereby reducing mechanical mismatch and chronic inflammation. In addition, advances in wireless power transfer, hermetic encapsulation, and miniaturised amplifiers have significantly enhanced the longevity and reliability of implanted systems (Figure 2).

Another area of interest in engineering is the interface between neural tissue and synthetic devices. The mechanical mismatch between rigid electrodes and soft brain tissue is known to cause micromotion-induced inflammation and glial scarring. Recent research has prioritised the development of flexible bioelectronic interfaces, such as mesh electronics and injectable neural probes. These technologies aim to minimise the immune response while maintaining high-resolution, long-term neural recordings.

Neuroimaging techniques, including functional magnetic resonance imaging (fMRI) and computed tomography (CT), are essential for preoperative planning and device placement.

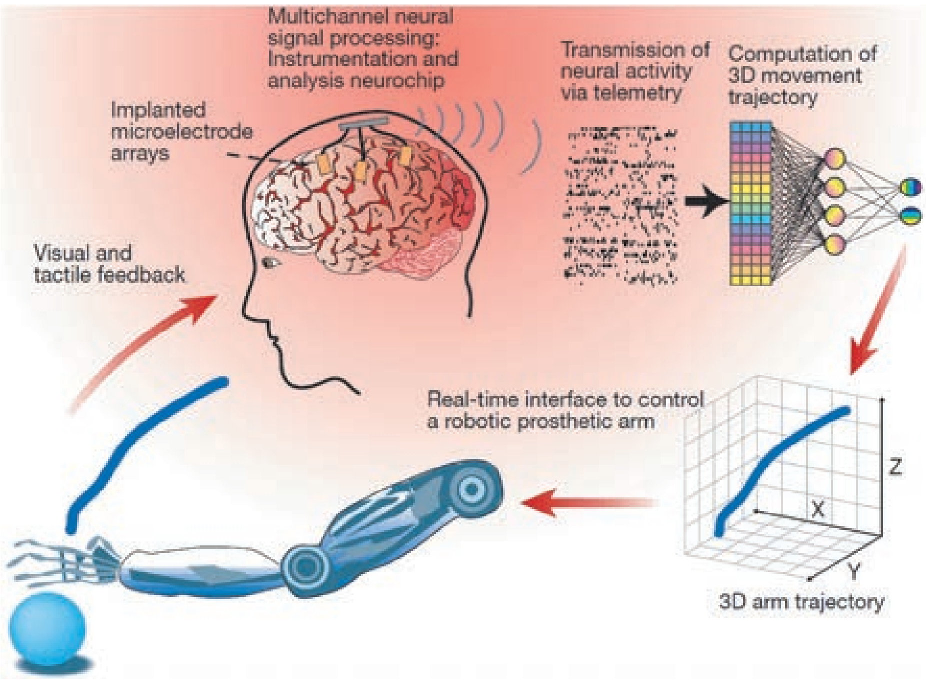

Figure 1. Core architecture of a brain-machine interface, showing how neural signals are acquired from the brain, processed through signal decoding algorithms, and translated into control commands for external devices.

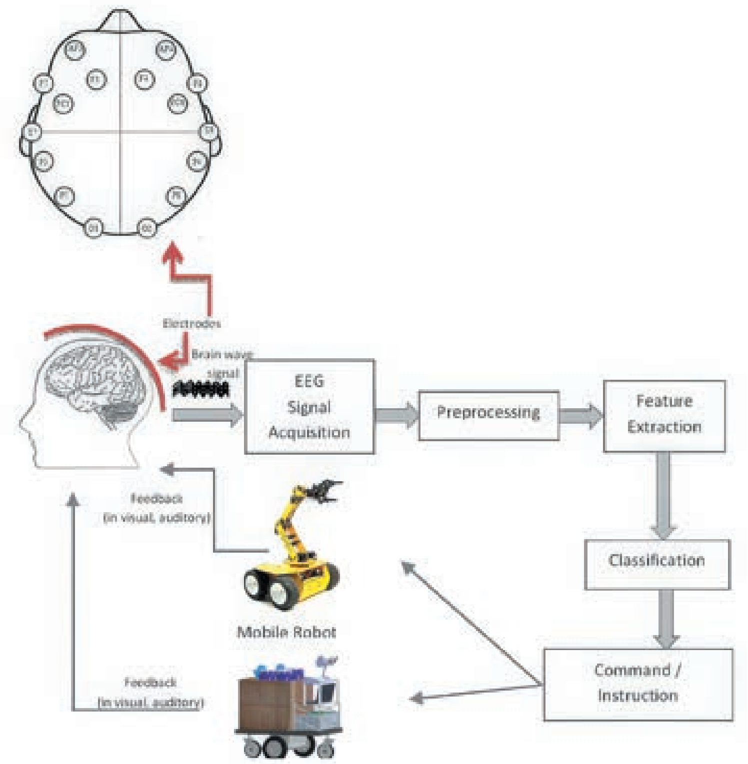

Figure 2. Comparison of non-invasive and invasive brain-machine interface systems, illustrating electrode placement, data processing pathways, and their implications for signal quality and biocompatibility.

These modalities enable precise targeting of neural substrates responsible for motor control, sensation, and cognition. Moreover, intraoperative electrophysiological mapping ensures optimal electrode positioning, thereby maximising signal yield and functional outcomes. Post-implantation, machine learning algorithms facilitate adaptive decoding of neural signals, accommodating individual variability and signal drift over time.

Emerging imaging techniques, such as high-density optical imaging and diffusion tensor imaging (DTI), provide more nuanced maps of neural circuitry. These tools enhance surgical targeting and improve understanding of the anatomical and functional connectivity required for optimal device integration. In the future, closed-loop imaging-guided implantation may become a standard protocol, ensuring real-time feedback during electrode deployment.

Clinically, neuroprosthetics have demonstrated substantial efficacy in restoring function to individuals with neurological impairments. In motor applications, intracortical BMIs allow patients with spinal cord injuries or amyotrophic lateral sclerosis (ALS) to control robotic limbs through volitional thought. These systems typically involve high-density electrode arrays implanted in the motor cortex, which decode intended movement trajectories and translate them into robotic actuation. Sensory neuroprosthetics, such as cochlear and retinal implants, have enabled partial restoration of hearing and vision by electrically stimulating peripheral nerves or retinal ganglion cells (Figure 3).

Recent advances in spinal cord neurostimulation have allowed some patients with partial paralysis to regain the ability to walk with assistance. By stimulating specific spinal segments at precise frequencies and intensities, researchers have restored voluntary leg movements in individuals previously diagnosed with complete paraplegia. These breakthroughs illustrate the potential for neuroprosthetics to reintegrate damaged circuits, even in cases where the central nervous system appears irrevocably compromised.

Communication neuroprosthetics represent another significant advancement. By interfacing with language-associated cortical areas, these devices can reconstruct intended speech or text from neural activity. Such systems offer critical communication pathways for individuals with locked-in syndrome or severe motor speech disorders. Furthermore, hippocampal prostheses have been investigated for their potential to restore memory function in patients with cognitive deficits, utilising patterned electrical stimulation to enhance memory encoding and retrieval.

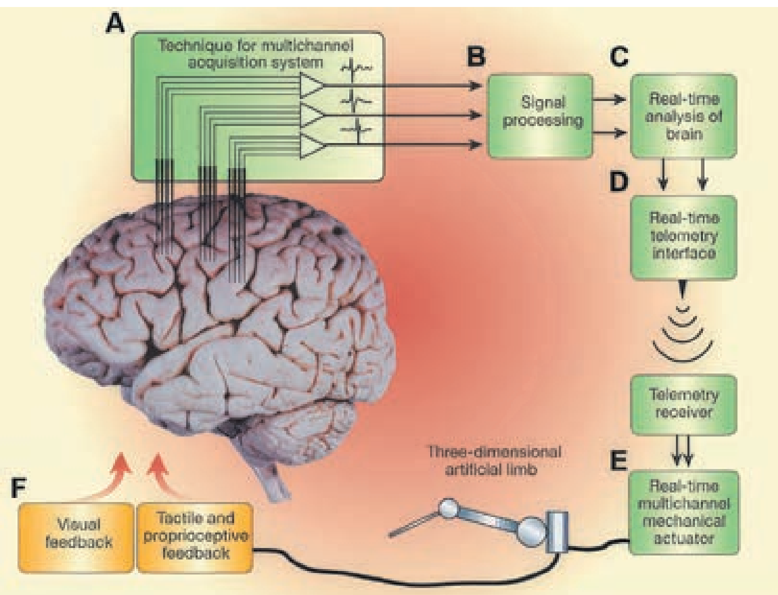

Figure 3. A visualisation of a neuroprosthetic arm controlled via cortical implants, detailing the neural signal decoding loop enabling voluntary movement restoration in paralysed individuals.

Experimental BMI systems have also demonstrated potential in brain-to-brain communication. Although in its early stages, such systems have enabled limited transmission of binary signals between individuals, opening avenues for cooperative tasks in gaming or rehabilitation contexts. Moreover, cognitive prosthetics are being explored to augment executive functions such as attention, working memory, and decision-making by interfacing with prefrontal and parietal cortices.

Despite these advancements, neuroprosthetics face substantial technical and translational challenges. Signal fidelity is a major concern, as neural recordings are susceptible to noise, signal degradation, and biological variability. Chronic implantation often leads to gliosis and electrode encapsulation, which impair signal quality. Non-invasive alternatives, such as electroencephalography (EEG), offer improved safety but suffer from low spatial resolution and signal-to-noise ratio. Algorithmic decoding also remains a complex task, necessitating continuous calibration and robust adaptation to inter-subject and intra-subject variability.

Additionally, the scalability of current systems remains a concern. Most successful demonstrations are conducted in research laboratories under highly controlled conditions. Translating these technologies into daily use requires robust hardware, seamless integration with assistive devices, and intuitive user interfaces. Failure to meet these design criteria limits clinical adoption and long-term user satisfaction.

Safety and biocompatibility are paramount considerations in neuroprosthetic design. Implantable devices must maintain structural integrity and functional performance over extended durations within the hostile environment of the brain. This necessitates rigorous material testing, hermetic sealing, and adherence to medical device regulations. Additionally, power supply remains a limiting factor; current systems often rely on inductive charging or battery replacement, which can constrain usability and patient convenience.

Wireless energy transfer systems, such as resonant inductive coupling and ultrasonic charging, are being investigated to address this challenge. These systems aim to deliver consistent power without the need for external leads or frequent surgical interventions. Furthermore, researchers are exploring the feasibility of energy harvesting from metabolic processes or mechanical motion within the body to extend device autonomy.

The cost and accessibility of neuroprosthetics represent another significant barrier to widespread adoption. The development, production, and clinical implementation of these systems are resource-intensive, limiting their availability to specialised research centres and clinical trials. To ensure equitable access, future efforts must focus on cost reduction, streamlined manufacturing, and integration into public healthcare frameworks.

Public-private partnerships and government-supported research initiatives are essential for scaling neuroprosthetic technologies. Collaborative projects between universities, biomedical companies, and healthcare systems have the potential to drive innovation while making these technologies more accessible. Cost-effectiveness studies and health economic modelling will also be necessary to justify reimbursement and public funding.

From a societal perspective, neuroprosthetics introduce complex ethical and legal considerations. The potential to access or manipulate neural data raises concerns about privacy, autonomy, and cognitive liberty. Regulatory frameworks must evolve to address issues such as data ownership, informed consent, and the permissible scope of neural enhancement. Additionally, the delineation between therapeutic use and cognitive augmentation remains contentious, necessitating public discourse and policy development.

Societal perceptions of neuroprosthetics also play a crucial role in shaping acceptance and usage. Public engagement, inclusive policymaking, and transparent communication between scientists, clinicians, and communities are essential to address fears of dehumanisation or unequal enhancement. Cross-cultural perspectives and indigenous knowledge systems may further contribute to a more holistic and ethically grounded approach to neurotechnology.

In conclusion, neuroprosthetics and brain-machine interfaces represent a transformative convergence of neuroscience and engineering with profound clinical and technological implications. These systems have demonstrated the capacity to restore lost sensory, motor, and cognitive functions, thereby improving the quality of life for individuals with neurological disorders. However, significant challenges remain in terms of signal robustness, long-term biocompatibility, affordability, and ethical governance. Continued interdisciplinary collaboration and responsible innovation are essential to advance the field and ensure that the benefits of neuroprosthetics are accessible, safe, and ethically sound.

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CRISPR technology in agriculture: enhancing herbicide resistance for a novel climate change solution

Words by Henry Yang (Year 11)

Thought starters

Introduction

Pests and weeds cost farmers over 5.8 billion dollars last year in Australia. Weeds make up 82% of this figure and are the biggest problem facing agriculture. Considering that approximately one third of global CO_2 emissions come from food production, scientists are continuously investigating methods to combat these production emissions. With the development of modern biotechnology, a promising solution has emerged in the production of herbicide resistance. CRISPR technology is theorised to edit the genomes of these crops with an increased efficacy and efficiency compared to previously used technologies. However, the use of this new technology may be influenced by safety and environmental concerns, that may hinder its implementation into society.

Herbicide Action

Weeds actively compete for nutrients, light and space which reduces the productivity of crops. Tilling is a method of crop management that aerates the soil to achieve optimum conditions for growth. Herbicides are commercially employed solutions that act as inhibitors in key metabolic pathways, such as growth, leaving plants to die. The main commercially used herbicides are norflurazon, imidazoline and glyphosate. Using glyphosate as an example, the shikimic acid pathway which is directly responsible for plant growth is inhibited. Glyphosate is a competitive inhibitor of EPSPS, and when enough EPSPS is inhibited, it will cause plant death as the plant will not make key amino acids as shown in Figure 1. Therefore, EPSPS gene duplication can provide resistance to glyphosate. However, problems arise in herbicide function due to the inability to differentiate between weeds and crops.

Implementation of CRISPR Technology

Genetic modification of plants has been pivotal in the advancement of modern-day agriculture. Scientists have recently identified novel uses for the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR). This system comprises of two components: a Cas9 protein, as well as an associated single guide RNA (sgRNA). The sgRNA is loaded onto the Cas9 protein and has a complementary nucleotide sequence that binds to the target gene. The Cas 9 protein essentially acts as 'molecular scissors' so that the gene can be removed, modified or replaced (see Figure 2).

Herbicide resistance can be achieved through several mechanisms as shown in Figure 3, such as mutagenesis (A), transgenesis (B) and CRISPR (C). Using CRISPR, the Cas 9 protein generates a double stranded break at the target gene. Then non-homologous end-joining, which is an error prone repair system for the breaks, allows for gene editing. The gene can have deletions, insertions or substitutions to change its DNA sequence. Proteins can then be produced that confer herbicide resistance, allowing farmers to utilise herbicides to inhibit weed metabolic pathways while leaving the crops unaffected.

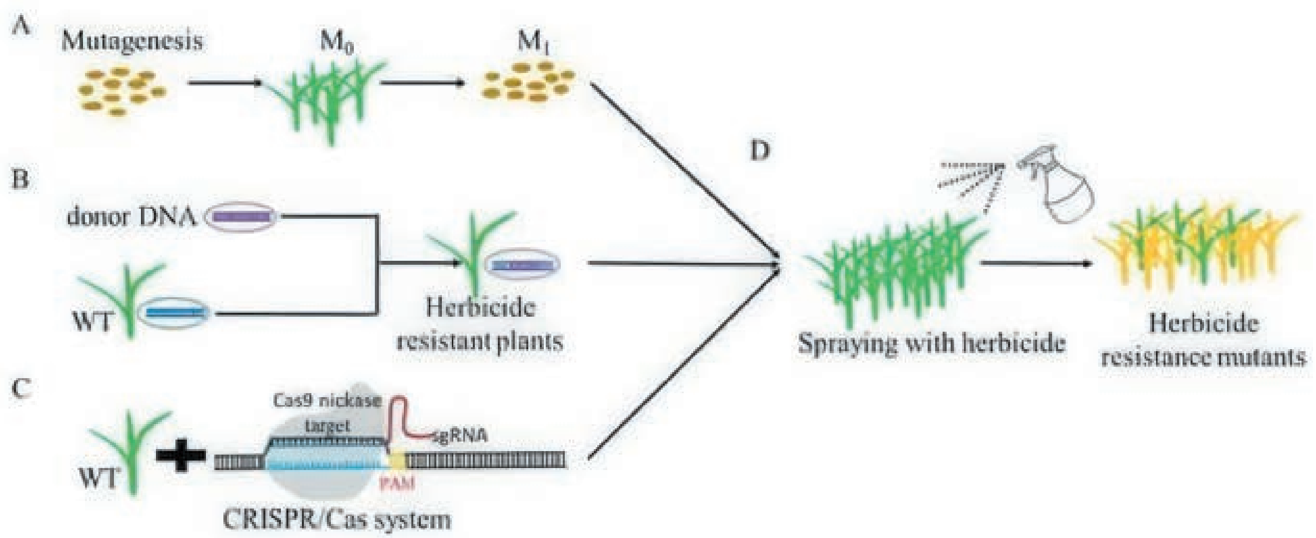

Figure 1: A schematic depicting the mode of action of glyphosate in the shikimic acid pathway

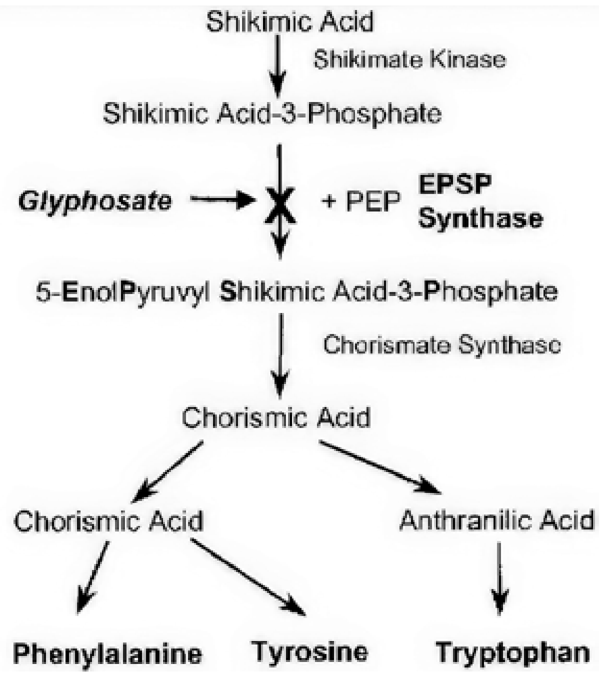

Figure 2: A schematic depicting the function of the CRISPR/Cas9 technology.

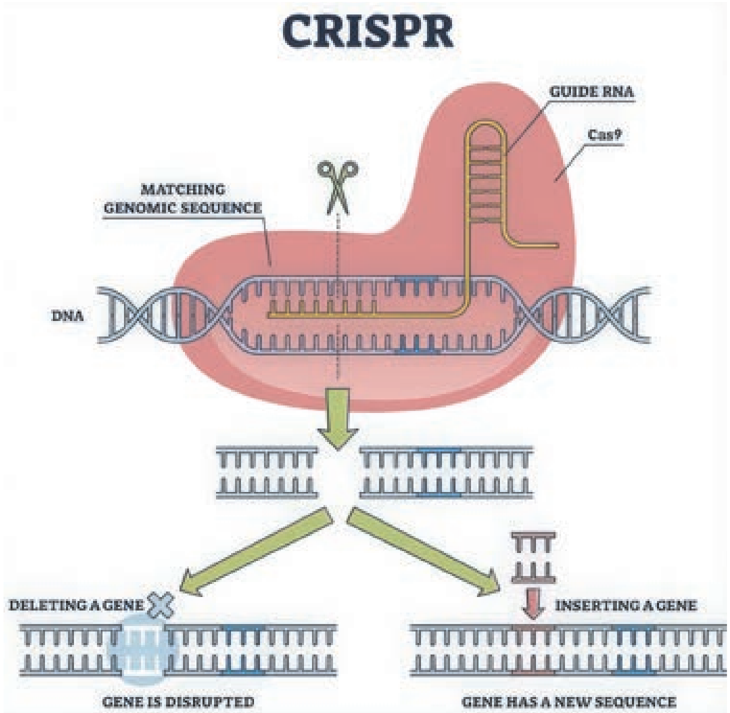

Figure 3: Diagram illustrating the process in creating herbicide resistant plants.

Development of Herbicide Using CRISPR

Prior to the modern understanding of the genome, scientists have been able to manipulate the traits of plants. Older methods such as mutagenesis and transgenesis were inefficient in creating desired traits like herbicide resistance, often requiring months or years to produce noticeable results. Mutagenesis uses radiation and UV light to induce mutations. This can be imprecise, as genetic changes often occur at random locations in the genome, potentially causing unintentional effects on gene expression. Another model, transgenesis, creates recombinant DNA by combining DNA from multiple species. The insertion of foreign DNA into the plant genome called for regulatory measures to be implemented. In addition, these processes often had high costs and had labour intensive operations.

A recent study conducted by Yang et al displayed that herbicide resistance was able to be developed in tomato plants using CRISPR. This demonstrates CRISPR's ability to edit genes with a high level of precision and efficacy without the need for foreign DNA. With CRISPR, gene editing can now be completed within a few days. Different sgRNAs have varying efficiencies for editing the ALS gene in herbicide tolerance. Namely, AlS1-W, ALS2-W and AlS2-P, were 0.4, 0.207 and 0.7% efficient respectively. Using the most efficient sgRNAs, tomatoes were successfully produced that had ALS resistance. This displays the potential for herbicide resistance using CRISPR technology for efficient large-scale cultivation in a cost-effective manner, along with significant labour reduction that further contributes to this economic saving.

Another study conducted in 2023, successfully used CRISPR to create herbicide tolerance in Basmati rice. Over 50% of the world relies on rice for their diet. To fulfil demand, the efficiency of weed control needs to be increased to maintain crop yield. Herbicide tolerance in Basmati rice was achieved through established repair pathways to introduce point mutations in the OsALS gene. Using CRISPR, the genome of Basmati rice was successfully edited to provide resistance against the Bispyribac-sodium herbicide. Given that in some cases weeds have reduced rice yields by up to 76%, editing herbicide resistance can provide more food for society. These studies demonstrate how the development of CRISPR has provided a more efficient approach in achieving precise gene editing.

Despite the success of scientific advances in the field of genetics, the use of this new technology may have safety and environmental concerns.

The primary risk associated with CRISPR is the potential for off-target genome editing effects. Off-target effects, where the sgRNA does not bind to the correct location, could impact important genes which may cause changes in chemistry or protein production. There is also the risk of on-target events that have unintended consequences. This happens when the change occurs at the correct locus but could potentially create unknown gene products that are harmful for human consumption. These changes can often go unnoticed as the phenotypic expression can be very similar. Food allergens are mostly proteins, so these mutations may have significant implications for food safety. Off-target and on-target events created by CRISPR can be reduced by using sgRNAs that have high editing efficiency which still have low off-target activity.

The global average surface temperature has increased by 0.89°C since 1940 (see Figure 4). This rise in temperature is the single biggest health threat facing humanity. Anthropogenic climate change theory describes how human carbon emissions are creating an enhanced greenhouse effect. Sea levels are rising and will cause a mass migration crisis if society does not find ways to reduce emissions. This has influenced the use of herbicide resistance via CRISPR technology as it reduces production emissions from mass machinery that output pesticides and till the soil.

Without herbicides farmers must till to deal with weed infestation. Soil tillage releases CO_2 as bursts immediately after tillage. Minimum tillage practices have been reported to be able to reduce greenhouse gas emissions. In fact, a net carbon sequestration can reach up to 50 centimetres beneath the soil after 20 years of no tillage. A study showed that no tillage practices can reduce CO_2 emissions by up to 51%. By using CRISPR to create herbicide tolerance farmers will be able to embrace minimum tillage by using herbicides, thus reducing carbon emissions.

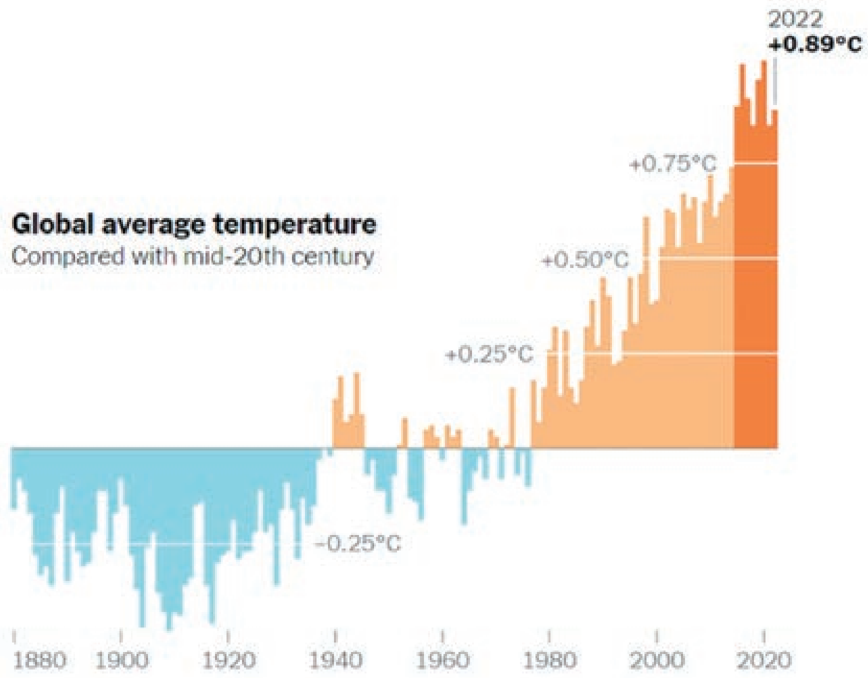

Figure 4: Increasing global average temperature from 1880 to 2020 (NASA, 2022)

Pesticides can be harmful to the environment but are used as solutions to weed infestations. Pesticides can leach into rivers, damaging fragile marine ecosystems. A study showed that 730 tonnes of pesticides enter rivers each year, which is well above safe chemical limits, the extent of these impacts on aquatic life is unknown. This environmental concern from society influences the use of herbicides as an alternative solution.

In addition, machines that distribute pesticides and till the soil produce greenhouse gases (Figure 5). Machines can emit CO_2, nitrous oxide and methane gas. In 2017, production emissions from pesticides peaked at 71 megatonnes of carbon dioxide. Reducing the need for mass machinery could significantly reduce greenhouse gas emissions from agriculture. This can be done using CRISPR to create herbicide tolerance.

Although scientists understand the risks of CRISPR, environmental concerns such as the enhanced greenhouse effect have influenced its research and continued application.

The world population is predicted to reach 9.7 billion by 2050. To maintain production to meet food demands, scientists will be tasked with finding solutions to increase yields while combatting the effects of global warming. CRISPR can be further developed in agriculture to create more drought and heat resistance plants. This would allow crops to be grown in more extreme climates as land with viable conditions are decreasing. In fact, by 2015 the world has already lost a third of arable land.

The recent development of CRISPR in agriculture can provide a solution to weed infestation while reducing production emissions that are enhancing the greenhouse effect. However, the implementation of this technology is influenced by safety and environmental concerns of society. With agricultural land decreasing, CRISPR will also be used to find new ways of increasing crop yield. Ultimately, by integrating scientific knowledge with safety and environmental considerations, society can utilise the transformative potential of biotechnology and genetics to minimise climate change and set up sustainable agricultural systems for future generations.

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Figure 5: Image depicting machinery that is tilling the soil which is releasing dust and greenhouse gases.

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Is science helping our planet or hurting it?

Words by Billy Ang (Year 7)

Is Science Sustainable?

Figure 1 The Three Pillars of Sustainability

Introduction

"Sustainable Science." What a great, catchy, and relevant title for a science journal, especially in the midst of the climate change crisis. Science has a huge impact on sustainability, and the two have so much in common. For example, we are constantly designing renewable energy systems and researching endangered species and climate change. Is the relationship between science and sustainability really this straightforward? Yes, there is a lot of overlap between science and sustainability, but they aren't the same thing and can even conflict. This article will thoroughly examine science and sustainability and whether they meet or clash, with a focus on climate change. We will then see some examples of positive uses of science and sustainability together and learn how modern science and technology aren't the only ways of learning about sustainability. So, if sustainability is the destination, is science the most reliable path to reach it? Let's find out.

What is Science?

Before we can examine whether sustainability and science complement or contradict each other, we must first understand both. To begin, let's first define science. Science is a process of discovery that includes methodical observation and experimentation, as well as the testing of hypotheses against collected evidence. Importantly, science does not involve moral judgements; it reveals the truth about the world without stating what should be done. However, scientific advancements can also have bad consequences. The invention of plastic, which produced cheap and strong materials that transformed technology and packaging, was seen as a miracle of science. But now, there is a crisis of plastic pollution. Science does not automatically lead to sustainability; rather, it is a tool that can be applied to achieve sustainable outcomes. Let us now think about sustainability and how this goal shapes our use of science.

What is Sustainability?

Sustainability is taking care of current and future needs. The three pillars of sustainability are the environmental, social, and economic factors (see Figure 1). You need all three to be sustainable. Sustainability is less about following a process and more about sticking to a principle. It shapes how we live, use resources, and make decisions. The goal of sustainability is to create long-term benefits for both people and the planet. It is looking ahead to the future and considering the kind of future we aim to create. Sustainability is value-driven, so it may conflict with science, which is understanding-based. For instance, deep-sea mining provides rare earth metals for technology but damages marine ecosystems. This shows that science does not always result in sustainability; rather, it can be used to both harm and benefit sustainability. Building a sustainable future doesn't just require scientific advancement but also the values and decision-making of our society.

Where Science and Sustainability Meet

Science and sustainability can work together effectively in many fields. Science teaches us about the world, while sustainability directs us to protect the planet for future generations to succeed. For example, renewable energy reduces our reliance on fossil fuels and cuts down carbon emissions. Electric vehicles (EVs) replace petrol-powered cars with cleaner alternatives. Modern agriculture uses new techniques that use less land and water. Essentially, scientific advancements directly contribute to the achievement of sustainability goals.

Meeting in the Climate Crisis

There is no better way to show this collaboration than climate change. Science is responsible for understanding the causes and impacts of climate change, while sustainability drives action towards possible solutions. Some examples of science helping sustainability in climate change include renewable energy, electric vehicles, and agriculture.

Where Science and Sustainability Clash

However, the relationship between science and sustainability is not always this straightforward. There are many conflicts between the two. Science focuses on what is possible, but sustainability asks us if that should be done. A focus on short-term economic gains can compromise long-term sustainability goals. Let's look at the same examples from before from a different perspective. Renewable energy depends on materials like rare earth metals for solar panels and wind turbines, and mining those metals can destroy habitats and damage the environment. Electric vehicles (EVs) need lithium, cobalt, and other metals for their batteries. Extracting these can also lead to environmental destruction and sometimes even unethical labour practices. Modern agriculture may increase yields, but it can also overuse technology, leading to soil damage or over-reliance on synthetic fertilisers and pesticides.

Figure 2 Vertical farming

Clashing in the Climate Crisis

Even in the climate crisis, not every scientific solution is sustainable. In every scientific solution for climate change, there is a trade-off. Hydropower dams can power entire cities, but they can flood entire ecosystems. Biofuels seem renewable, but they can lead to deforestation and food shortages. These trade-offs highlight an important point, which you may have already realised. So, what is the big takeaway?

Science is fundamentally not sustainable.

It offers solutions, but not all of them are safe, fair, or sustainable. It must be applied with caution, being aware of the full picture (environmental, economic, and social impacts) before immediately going ahead with any new solution. Because if we're not careful, science that is meant to save the planet could end up harming it in new ways. So, let's keep using science, but always pair it with wisdom, responsibility, and sustainability.

Intentional Innovation

So, now that we know how science and sustainability best work together, let's dive deeper into how we can use them together to innovate. Sustainable science goes beyond problem-solving to create new technologies with minimal environmental impact. It's about solving the right problems in the right way. For example, look at vertical farming (see Figure 2).

Compared to traditional farming, which uses lots of land and water, vertical farms grow crops in stacked layers using LED lights and hydroponic systems. They use much less water and can be built indoors. What about the issue of plastic (as mentioned previously)? Biodegradable plastics, made from cornflour or algae, can do the same job, but most importantly, they decompose in just a matter of weeks. These are examples of science, but they are also sustainable. Truly sustainable innovation requires a fundamental mindset shift. We must go from "What can we do?" to "How can we solve problems without creating additional environmental challenges?"

Indigenous Knowledge

Although we frequently look to modern science when discussing sustainability, Australia's Aboriginal peoples have been leading sustainable lives for tens of thousands of years. Their knowledge of the land, weather, animals, and ecosystems is detailed, deep, and incredibly relevant to today's environmental challenges. One of the best examples of this is their cultural burning (see Figure 3). For thousands of generations, Aboriginal people have used carefully planned spot fires to manage the land. These burns clear away dry undergrowth without harming larger trees or animals. These fires reduce the risk of large and dangerous bushfires and support biodiversity. Unlike many modern fire control methods, cultural burning works with the land's natural cycles, not against them.

Figure 3 Aboriginal cultural burning

But fire management is just one example. Aboriginal communities across Australia have sophisticated systems of knowledge about many aspects of the environment. They don't just focus on "using" the environment; they focus on caring for it. Modern science has only recently begun to recognise just how effective this knowledge is. This kind of knowledge is incredibly valuable for sustainability. We need to respect, pay close attention to, and have a long-term perspective of our environment. What's exciting is that Aboriginal knowledge and modern science don't have to be separate. The best outcomes happen when the two are combined, when scientists, land managers, and Traditional Owners work together, learning from each other. Traditional knowledge is just as important as new ideas if we really care about creating a sustainable future. Aboriginal Australians have been practicing sustainability longer than any other culture on Earth, so it's time that we recognised that and learned from it.

Conclusion

Science is powerful. It has helped us understand the world and solve problems. Sustainability, on the other hand, is not about invention; it's about intention. It challenges us to think not just about what we can do, but what we should do. When they work together, science and sustainability can be a force for real progress. But when they pull in different directions, the results can be dangerous. This is very clear in the example of climate change. Scientific knowledge has exposed the problem and proposed solutions, but those solutions come with trade-offs. Just because it is effective doesn't mean it is sustainable.

So, if something is sustainable, is it science? Can "sustainable science" truly exist? Absolutely. Our future depends on combining scientific discovery with sustainable practices, along with innovation and indigenous knowledge. It's true that science is not fundamentally sustainable; we must just be cautious applying science to sustainability. We must be able to tell whether science and sustainability meet or clash. Ultimately, science may build the road, but only sustainability can choose the direction.

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How the rapid rise of plastic pollution has influenced the applications of pyrolysis in the future of plastic recycling

Words by Aidan Foo (Year 12)

Is Science Sustainable?

By 2050, it is expected that global production of plastics will triple, accounting for a fifth of global oil consumption. However, only 9% of the 400 million tonnes of plastic produced annually is currently being recycled, the remainder polluting landfills and oceans. The synthetic nature of plastics prevents their decomposition thereby posing significant environmental consequences. Recent advancements in pyrolysis have allowed the extraction of renewable oils from waste plastics, through heating in oxygen-free chambers.

Plastic recycling is the process of recovering and repurposing wasted consumer plastics into new products. Polyethylene is the highest produced polymer accounting for approximately 26% of global plastic production, however also contributing to 50% of microplastic waste. Therefore, the introduction of pyrolysis as a chemical recycling method specifically targeting low-density and high-density polyethylene (LDPE and HDPE respectively) will have a substantial impact on reducing plastic pollution. LDPE and HDPE are derived from polyethylene, created through the addition polymerisation of ethylene monomers into long non-polar polymer chains (see Figure 1). The structure of LDPE chains has additional branches preventing tighter compaction, characterising it to have a lower density as there are weaker dispersion forces between adjacent chains (see Figure 2).

However, both plastics are virtually non-biodegradable. Depending on their applications, they take between 2-250 years to disintegrate as plastics have limited reactive sites for natural enzymes involved in microorganism decomposition to break the strong intramolecular forces within long polymer chains. The impacts of pollution are especially prevalent in oceans where fragmentation into microplastics causes significant harm to marine life (see Figure 3).

Since LDPE and HDPE are thermoplastics, they possess relatively low melting points (115-135°C) making them mouldable when heated, ideal for recycling. This has prompted scientists to utilise pyrolysis as a plastic recycling method. Converting post-use-plastics including non-recyclable plastics into feedstock (e.g. pyrolysis oil) to be upgraded into new plastic materials. Pyrolysis can be broken into three steps: initiation, propagation and termination, and can be conducted with the presence of three catalysts: ZSM-5 derived from silica (SiO_2) and alumina (Al_2O_3), H-Y which is a zeolite treated with ammonia ions (NH_4^+), and MCM-41 comprised of silicate (SiO_4^{4-}) and aluminosilicate materials (Al_2SiO_5) (see Figure 4).

As seen in Figure 5, initiation involves the formation of free radicals from the cleavage of the long polymer chains under high heat. During propagation, the free radicals decompose into lower hydrocarbons such as polyethylene as molecular species are cracked into smaller molecules in a series of reactions. The now unstable free radicals must then undergo disproportionation or recombination to form stable molecules in the termination stage. The products of this reaction are approximately 20% hydrogen gas and hydrocarbons, and 80% pyrolysis oil, highly valuable as a renewable source of fuel and feedstock in the production of new plastics.

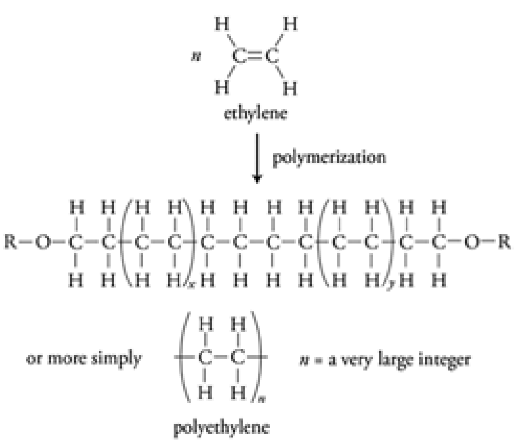

Figure 1: Addition polymerisation of ethylene into polyethylene.

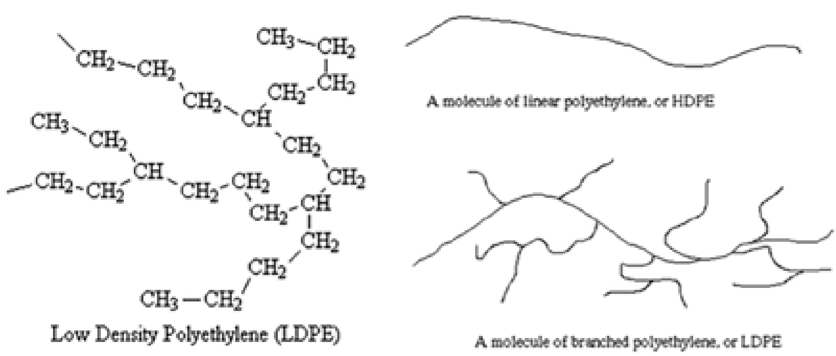

Figure 2: Diagram of low-density and high-density polyethylene (LDPE and HDPE).

The economic and environmental consequences brought about by the rapidly growing plastic industry have influenced scientists to seek new ground-breaking innovations to support the future of plastic consumption. Approximately 80% of annual plastic pollution, including LDPE and HDPE, is collected and disposed of in landfills and oceans contributing to environmental pollution. However, due to the non-biodegradable nature of these plastics, consistent exposure to UV radiation from the sun and mechanical abrasion, they frequently fragment into smaller particles (sizes <5mm) called microplastics, having detrimental environmental and social consequences on society. In aquatic environments, the presence of microplastics through improper disposal and runoff, increases rates of plastic ingested by marine life, consequently raising risks of biomagnification and amplification of toxic compounds. In landfills, plastics can take hundreds of years to degrade, meanwhile leaching harmful chemicals into surrounding soil and groundwater, and occupying valuable space that could be reallocated to more biodegradable materials. Society has already placed significant importance on this issue recognising bioaccumulation in landfills and waterbodies as a worldwide public health concern. Thereby influencing policy changes globally to enable scientists to develop new recycling methods that path the way to a sustainable future.

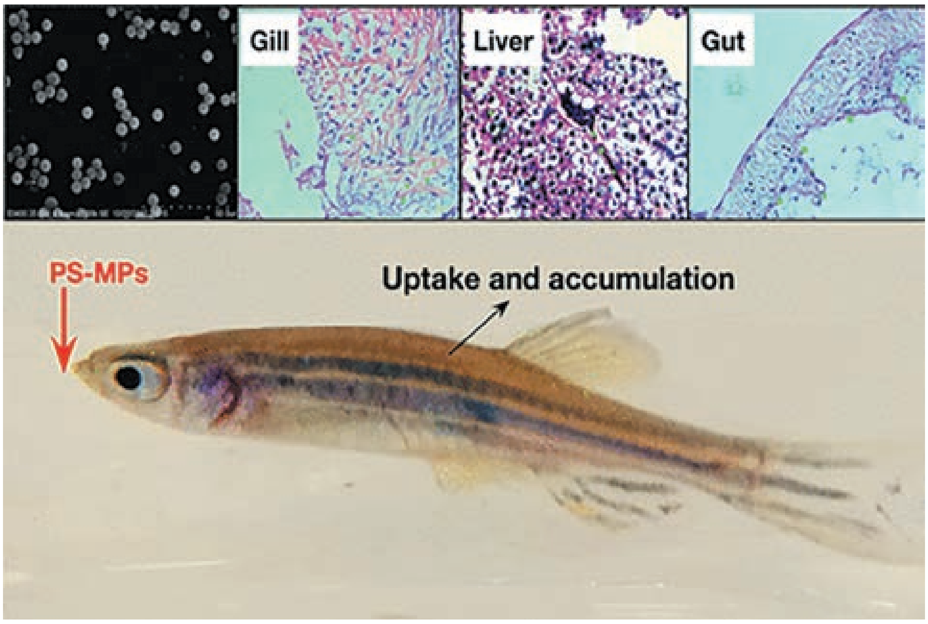

Figure 3: Accumulation of polystyrene microplastics (PS-MPs) in a fish.

Additionally, existing recycling methods (ie. incineration) have substantial health and environmental impacts on society, producing harmful gases during the incomplete combustion of polyethylene and other plastics. The toxic fumes released comprised of dioxins such as ethyl acetate ($C_4H_8O_2$), carbon monoxide (CO), hydrogen sulphide (H_2S), polycyclic aromatic hydrocarbons (PAHs) and furans (C_4H_4O) are carcinogenic to humans, compromise air quality and pollute waterways. This has encouraged scientists to design actions for sustainability by investigating pyrolysis oil as an alternative renewable energy source. The UN Environmental Programme already expects that these new recycling techniques such as plastic pyrolysis could save governments up to $70 billion USD in waste management resources and society upwards of $4.5 trillion USD by 2040. Simultaneously, providing new jobs in recycling and waste management sectors, having positive economic implications in expanding society's workforce.

Scientific advancements have created new application opportunities for pyrolysis oil enabling scientists to create sustainable LDPE and HDPE as part of plastic-plastic upcycling. According to industry experts, the market for chemical recycling and chemically recycled goods is estimated to grow from $17 billion USD currently to $37 billion USD by 2034, with plastic pyrolysis at the forefront of this new market for previously unrecyclable plastics that will continue to expand as pyrolysis technology matures. This is promising to scientists in bringing society a step closer to a circular economy, where supply chains will experience a continuous flow of products and materials, reducing finite resource consumption. Pyrolysis oil has already reduced water usage by an estimated 48-55% and solid waste by 116-118% compared to other recycling methods, relieving detrimental environmental strains that the plastic industry places upon natural resources.

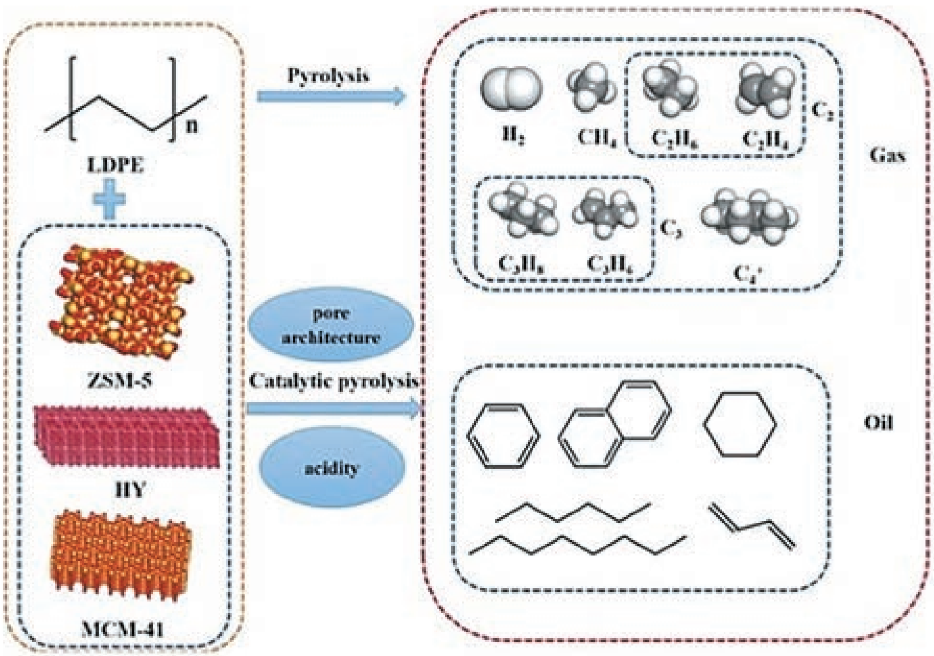

Figure 4: LDPE undergoing pyrolysis with the presence of catalysts.

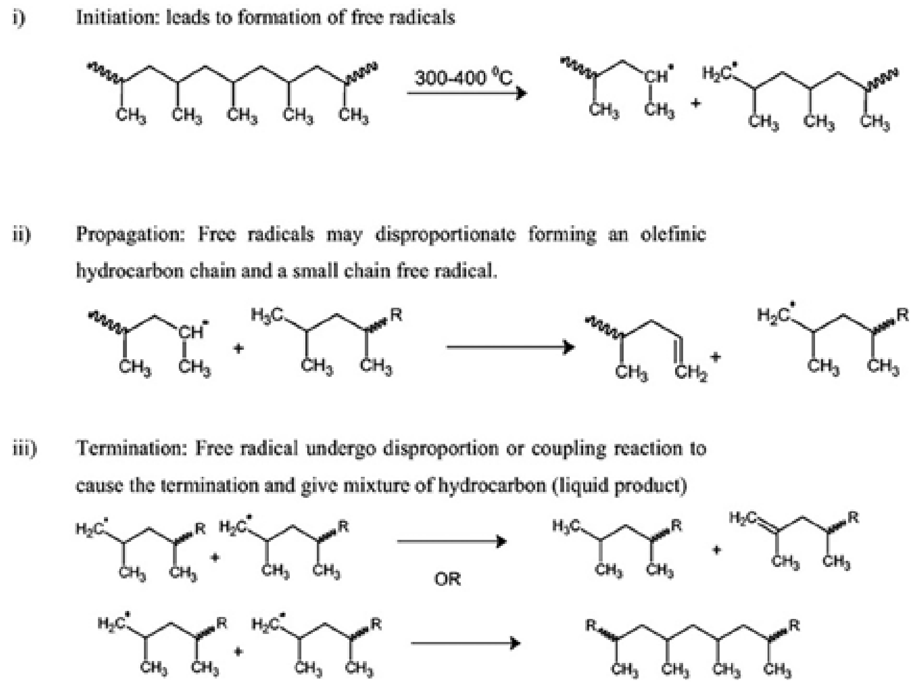

Figure 5: Three stages of pyrolysis: i) Initiation ii) Propagation iii) Termination.

With the rise in global energy demand from growing populations and expanding economies, alternative renewable energy sources are being sought as opposed to finite sources such as gas, oil and coal. The reusing of feedstock (ie. pyrolysis oil), as opposed to extraction of additional raw materials, serves to reduce society's dependence upon fossil fuels, a core energy source in the production of plastics. The recycling of feedstock has already shown a 65-70% reduction in fossil fuel emissions and an 18-23% decrease in greenhouse gases compared to fossil fuel-derived LDPE and HDPE. Thus, preventing further environmental damage and reducing costs associated with mining and extraction illustrating the range of applications of pyrolysis.

Furthermore, current initiatives in Australia have already successfully applied pyrolysis technology in the first steps towards commercialisation. In 2022, APR Plastics implemented Australia's first WASTX P1000 in collaboration with the Victoria Government, a machine capable of recycling 1000kg of plastic per day via pyrolysis to produce pyrolysis oil. Plastic recycling technology could see upwards of $1 billion AUD being invested by states and territories nationally paving a promising future for sustainable practices such as pyrolysis in society.

Nonetheless, pyrolysis technology still possesses critical limitations that hinder its potential benefits across the plastics sector. Post-use-plastics are typically composed of numerous types of polymers creating challenges when recycling as they must be physically separated before undergoing pyrolysis. Hence, further resources, time and money are required for mechanical recycling. This produces barriers for industrial applications as a profitable business, these additional costs need to be overcome before scaling up can occur.

Complications with the oxygen-sensitive and acidic nature of pyrolysis oil can also hinder the effectiveness of pyrolysis recycling. Corrosion may cause severe damage to boilers, and refinery equipment making it increasingly difficult to store and transport the oil. The alternative to this involves the upgrading of pyrolysis oil to enhance hydrocarbon contents, remove impurities and remove reactive oxygen species. The presence of contaminants such as sodium, calcium, iron and magnesium that can result from poor separation of post-use-plastics can also lead to heavy fouling in catalysts and equipment. Consequently, all these factors create heavy maintenance and operation costs that make it unappealing for society to adopt as consumers currently may have to pay comparatively higher prices for recycled LDPE and HDPE products.

Although, pyrolysis provides an environmentally favourable alternative to other waste management techniques such as incineration, the higher costs of pyrolysis oil and its subsequent products limit its competitiveness against the existing price and quality of fossil fuels used in plastic production and as an energy source. Therefore, maximising of the cost-efficiency of pyrolysis technology is still necessary before being utilised as a primary renewable energy source.

Overall, plastic pyrolysis for waste recycling has been influenced by current environmental and social concerns that society must address to ensure a sustainable future. Although the variety of applications with pyrolysis to synthesise raw materials and renewable energy sources is promising, it is still limited by the hesitance of industries to adopt a potentially more costly method compared to established pathways. Nevertheless, pyrolysis technology has a defining role in the future of plastic recycling as society aims to combat the ever-growing problem of plastic pollution.

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Net zero concrete recycling

Words by Charlie Harris (Year 11)

Is Science Sustainable?

Concrete is one of the most widely used and important construction materials in the world, with use dating back as far as the Roman Empire. Concrete is essential in the construction of nearly everything in a modern city – high-rise buildings, airports, roads, dams, and bridges all require large amounts of it (Figure 1). However, the production of concrete is a significant contributor to carbon dioxide emissions, as well as consuming many resources to produce, including limestone, clay, water, sand, and gravel. To help alleviate this burden on concrete production, the Cambridge Electric Cement (CEC) method of recycling concrete (Figure 2) removes the carbon dioxide from the production process by using electricity (preferably from renewable sources) instead of a kiln to decompose the limestone and uses recycled concrete particles from demolished concrete to do so. However, the recycled concrete can have a lower compressive strength and relies on renewable energies, placing a significant limitation upon it. This report aims to investigate the potential of the CEC method for continued use in society.

Figure 1

Concrete is comprised of cement, sand/gravel and water. Cement is traditionally made from a mixture of limestone ($CaCO_3$) and clay (SiO_2). To make cement, a kiln is heated to 1450°C, ensuring the decomposition of the ionic limestone and thus creating calcium oxide, shown by the following reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

The basic calcium oxide then reacts with the acidic silicon dioxide to form the salt calcium silicate, shown by the reaction:

$$2CaO + SiO_2 \rightarrow Ca_2SiO_4$$

Figure 2

This is then hydrated with water to form calcium silicate hydrate and calcium hydroxide, shown by the reaction:

$$2Ca_2SiO_4 + 5H_2O \rightarrow 3CaO + 2SiO_2 + 4H_2O + Ca(OH)_2$$

The resulting compound is then hardened with sand/gravel (aggregates), forming concrete. To remove the carbon-heavy kiln from the process and use resources more efficiently, the CEC method crushes old or demolished concrete into fine particles, most commonly calcium carbonate. This is due to the carbonation reaction of the existing calcium hydroxide, shown by the reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

These calcium carbonate particles are then put into an electrical arc furnace, which exceeds the required temperature (1450^{o}C) to break calcium carbonate's ionic bonds. This paste is then combined with an aggregate, producing concrete. This eliminates the need for a fossil-fuel reliant kiln and effectively turns waste concrete into fresh concrete.

The CEC recycling method has significant applications to limit the harm that concrete production can cause to the environment and alleviate the resource burden that concrete production places upon the world. The use of recycled concrete particles offers a substitute for limestone when producing recycled cement, as over 10 billion tons of concrete are demolished annually (Figure 3), while just 6.6 billion tons of limestone are mined annually. Although this is an unsustainable way to lower carbon dioxide emissions, it will significantly reduce the emissions that are produced by the mining until more sustainable ways of lowering carbon dioxide emissions are established. This will help prevent the

Figure 3

negative effects associated with global warming, such as rising sea levels, ocean acidification and disrupted ecosystems. Furthermore, if powered by renewable energy, the CEC method will contribute significantly to the Australian goal of net-zero emissions by 2050. 1 ton of concrete made using a kiln requires the burning of approximately 200kg of fossil fuels, releasing 600kg of CO_2 into the atmosphere. By removing fossil fuels from the production of concrete, it will eliminate approximately 1.6 billion metric tons of carbon dioxide emissions (8% of global emissions) that concrete produces yearly. Moreover, existing steel recycling infrastructure (Figure 4) can be used to recycle concrete, so less development is needed for the CEC method to have real-world applications. This means that there is a low-cost burden for the consumer

Figure 4

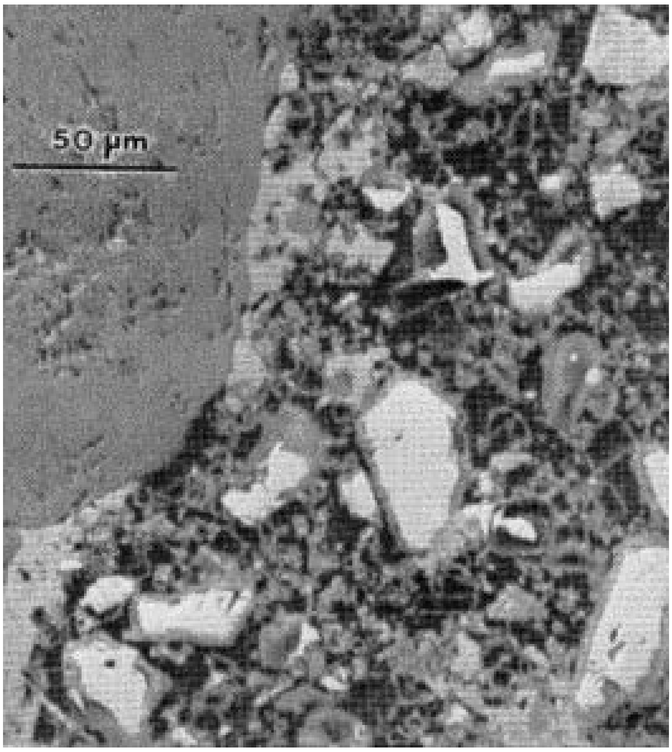

Figure 5

as production of the infrastructure can simply be upscaled, so the price of concrete would not increase significantly if this method saw widespread adoption.

However, this method of recycling concrete still has limitations that decrease its effectiveness. Recycled concrete often has a higher porosity rate (vacant space within the concrete), due to the recycled cement aggregate (Figure 5). This causes a reduced compressive strength and increased shrinkage rate within the concrete, discouraging its use by many construction firms. Even if it was used in the construction of a mainstream building, it will have a much shorter life span compared to virgin concrete and could potentially pose significant safety issues towards the end of its lifespan. This poses potential safety risks for people who interact with this recycled cement. Furthermore, this method puts an overreliance on renewable energy to achieve zero carbon emissions. In China, where the bulk of concrete production is done, only 30% of all energy is renewable. This means that the CEC method of producing concrete, if implemented globally, will still have a high amount of carbon dioxide emissions. Moreover, the decreased mining of limestone will most likely have a poor effect on the overall carbon dioxide emissions produced from mining, as companies will likely divert resources into other areas of the market like coal, iron ore, and lithium mining to maintain profitability. Therefore, while the CEC method of recycling concrete shows significant promise in the reduction of carbon emissions, the limitations currently impede it from becoming a mainstream method of concrete production.

The CEC method of producing concrete has made significant strides for a more sustainable future for the second largest consumed resource in the world. However, before widespread adoption occurs, the world needs to transition to renewable energy sources to truly capture the potential that this method offers society.

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How the use of recycled polystyrene as a jet fuel additive affects society

Words by Aidan Obst (Year 12)

Is Science Sustainable?

In 2023, 2.5% of carbon dioxide emissions were produced as a result of airline travel, significantly more than other forms of transportation. As a result, various scientists have found a method to recycle polystyrene to be used as a sustainable additive in biofuels to make their function more effective. This study is significant as it serves as a sustainable fuel development for the aviation industry, while also establishing thermal decomposition methods as a viable plastic recycling pursuit.

Used in various industries, polystyrene is a clear, cheap thermoplastic polymer. This material is manufactured from the monomer styrene, which is a liquid hydrocarbon predominately used as a raw material for the fabrication of other goods. The addition polymerisation process from which it is made can be seen in Figure 1.

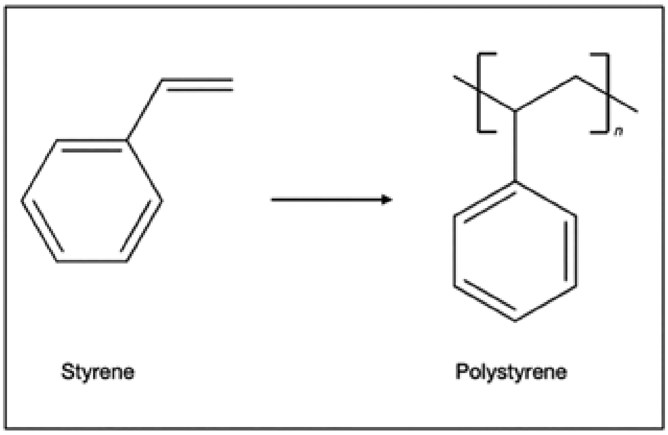

Figure 1: Addition polymerisation of Polystyrene

The additive ethylbenzene derived from styrene is manufactured from an alkylating reaction between ethylene and benzene, both being derived from fossil fuels. In addition to its use as feedstock, ethylbenzene is also utilised as a fuel additive in aviation. This is because of its 'anti-knock' properties, which increase the octane rating of the fuel and make the engine run more smoothly as a result. Octane rating concerns a fuel's ability to withstand being compressed without spontaneously combusting from the pressure. Therefore, higher intensity engines require fuels with higher octane ratings in order to resist engine knocking and to run efficiently. The manufacture of ethylbenzene utilises pyrolysis, the act of heating plastics to high temperatures with the absence of oxygen to break them down through thermal decomposition. This allows plastics which can't be broken down naturally, like polystyrene, to be depolymerised and repurposed for their basic hydrocarbons. Therefore, the polystyrene is thermally decomposed to produce ethylbenzene, which can then be added to various fuels to increase their efficiency. This process can be seen in Figure 2.

The intention is for the ethylbenzene is to be added to biofuels, which is a type of fuel created from biomass, (such as plant materials) that is used in blends with jet fuel. It's sustainable considering the feedstock can be replenished at a fast rate, unlike fossil fuels.

This advancement has been influenced by a variety of factors, including climate agreements, plastic waste remedies, and emerging technologies. In addition, the technology has the potential to influence the utilisation sustainable processes in global industry. The rise of climate awareness and attempts to limit damages has led to papers such as the Paris Agreement being formulated in 2015. This is a legally

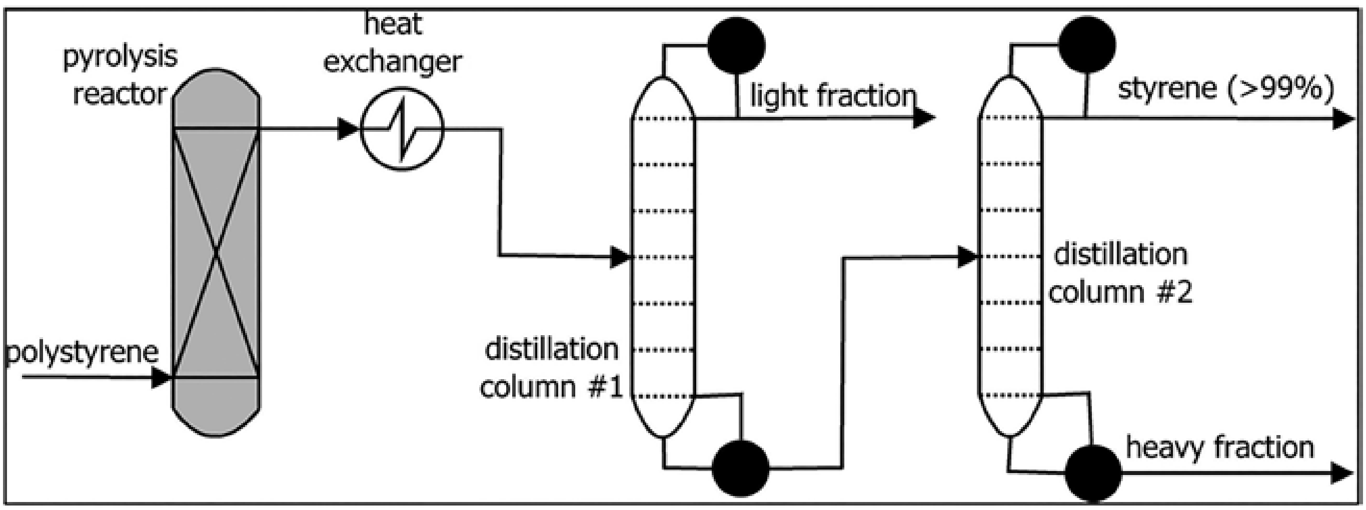

Figure 2, Pyrolysis of Polystyrene

binding treaty intending to limit rising temperatures to 1.5˚C. Such arrangements rely on sustainable innovations to make reaching the goals more attainable and less costly. As a result, there is significantly more reason for environmentally safe practices to be adopted, which is beneficial for society and the preservation of the natural world.

Furthermore, this process is based around controlling airline emissions through the use of ethylbenzene as a biofuel additive, which is influenced by additional agreements. In particular the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which plans to cap carbon dioxide aviation emission levels from 2020 to 2035. Hence, in order to achieve this goal, biofuel blends which can function effectively and efficiently will be vital in ensuring that emissions are limited. Moreover, the success of the recycled ethylbenzene as a fuel additive in achieving said goals may influence recycling plants and biofuel factories to utilise this additive to a much greater extent.

Although, the study has also been influenced by advancements in pyrolysis application, which has been initiated by increased plastic waste in the environment. Over 2.5 million tonnes of polystyrene are produced every year in the United States, which when unused is sent to landfills, invoking many scientists to find a solution. Many have turned to pyrolysis as a viable option, seen by the recent development of a large recycling plant in Böhlen, Germany which will include pyrolysis facilities.

Although these advancements in the technology are being influenced by environmental experts, who believe pyrolysis at a large scale is unable to combat the current waste stream and will cause unnecessary environmental harm. As a result, the effectiveness of the pyrolysis additive in practice will greatly influence the public about whether it can be applied at an industrial level. Overall, the principal argument is whether the environmental benefits of the product are able to outweigh the negative effects of the process.

This scientific advancement has various applications, including ethylbenzene manufacture being cheaper than traditionally manufactured variants, it's high purity yield, and reduced emissions. It is cheaper due to decreased costs for the sourcing of raw materials compared to obtaining ethylene and benzene from fossil fuels, which requires high energy and temperatures of up to 900˚C to extract. By being more cost effective, the material is more likely to be adopted more broadly by companies and recycling plants. This is beneficial because as biofuels become more utilised, sustainably produced additives are going to become increasingly important, and being cheaper is a bonus which will make this process easier to implement. In addition to cost, this method is said to produce a 90% pure yield which functions almost as well as ethylbenzene derived from fossil fuels. High purity is a key aspect when using pyrolysis to depolymerise plastics, especially if they were going to be reengineered to be used for containers or otherwise. Although a high purity allows it to compete with fossil fuel variants, which reduces the chance of more manufactured polystyrene entering the market, which then promotes the use of recycled ethylbenzene instead. This promotes sustainable practices and applications throughout the airline industry. Also, the recycled variants could potentially reduce carbon emissions by 50-60% in comparison to those derived from crude oil. This is because ethylbenzene's traditional manufacturing materials, ethylene and benzene, both require fossil fuels as feedstock, which produces extensive carbon emissions in comparison. This has the potential to reduce the overall emission output of airlines to move towards a generally more sustainable transport system.

Although there are also limitations with the method, such as the lack of a circular economy for the process, and damages as a result of pyrolysis recycling. Ethylbenzene can only be recycled once when used as an additive. When added to the fuel blend, it is combusted to propel the aircraft, therefore it is single use. This is restricting, as a supply of polystyrene is required to continue the recycling process, so eventually ethylbenzene will have to be made traditionally using fossil fuels. As a result, more finite resources would have to be utilised, which is naturally unsustainable for society. In addition, the recycling of plastic packaging like polystyrene has received a 55% goal for the future, therefore it may be more sustainable to contribute towards a polystyrene circular economy rather than combusting its parts. Another limitation is the particular use of pyrolysis to breakdown the polystyrene. This process requires extensive energy, and there is the possibility of pollution as a result of carbon monoxide, sulphur dioxide, and other nitrogen oxides being emitted from it. This is due to fossil fuels generally being used to heat and power the pyrolysis process, which is not beneficial as it increases air emissions, and has increased cost for purchasing and burning the fossil fuels. As a consequence, the process is going to be increasingly expensive, which may discourage companies from utilising it. In addition, the pollution released from pyrolysis can damage the environment, which would cause alternate issues like smog that can affect wildlife and society in general. So pyrolysis emissions must be balanced with the damage caused by traditional manufacturing processes of ethylbenzene to find the most environmentally safe option.

In closing, the recycling of polystyrene to be used as a biofuel additive is an innovative process which serves as a response to growing environmental concerns in society. It can be applied to limit emissions and plastic waste, although pyrolysis highlights questionable considerations to it remaining a sustainable process.

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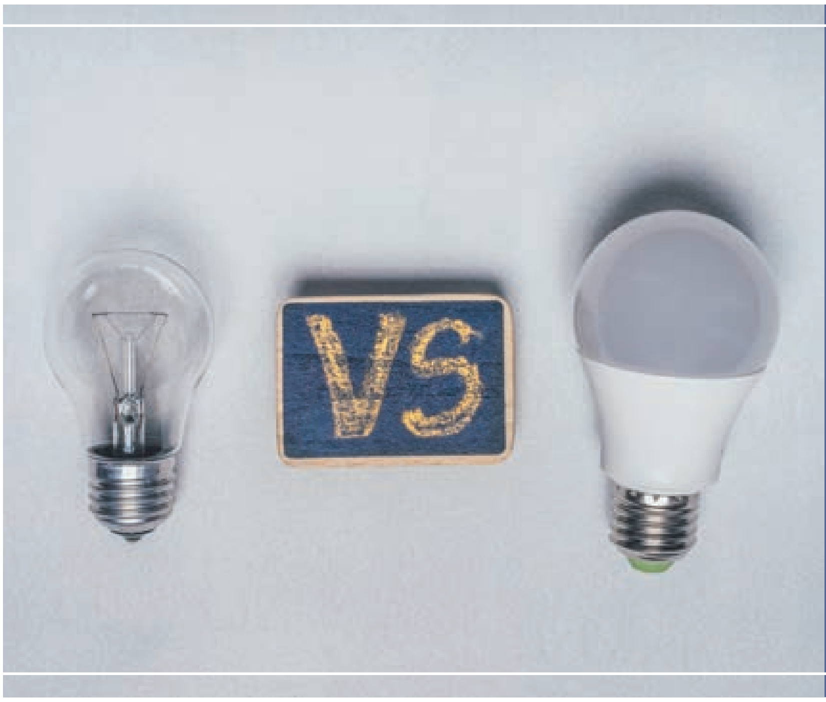

Bright idea

LEDs use up to 80% less energy than old incandescent bulbs.

Recycled plastic roads, a sustainable solution for modern infrastructure

Words by Aryan Parwal (Year 12)

Is Science Sustainable?

In 2024, Australia built approximately 6,000 kilometres of roads. If all these roads had incorporated recycled plastic, it would have removed 9,600 tonnes of plastic from landfill. Reducing plastic pollution has become a critical goal for individuals, industries, and nations. Recycled plastic roads represent one potential solution to this global challenge, offering a way to repurpose plastic waste while addressing infrastructure needs.

Recycled plastic roads are primarily composed of four types of plastics commonly found in municipal solid waste: polyethylene terephthalate (PET), Polyvinyl chloride (PVC) and two types of polyethylene - low-density polyethylene (LDPE) and high-density polyethylene (HDPE). These plastics are all synthetic thermoplastic polymers, known for their strength and lightweight properties. Their durability, flexibility, and resistance to environmental degradation make them ideal for road construction.

PET is produced through a condensation polymerisation reaction between ethylene glycol (an alcohol) and terephthalic acid (a carboxylic acid), as illustrated in Figure 1. This reaction forms long polymer chains held together by covalent bonds, with water released as a byproduct:

PET's, polar functional groups create permanent dipoles due to differences in electronegativity, leading to stronger dipole-dipole interactions, as shown in Figure 4. These interactions, though stronger than dispersion forces, can be overcome with heat energy, allowing for intermolecular movement and contributing to PET's flexibility. This property makes PET suitable for road construction, as it can withstand varying temperatures and stresses.

Polyethylene (as seen in Figure 2) is formed through the addition polymerisation of ethene monomers. LDPE has a branched structure, making it more flexible, while HDPE has a linear structure, providing greater strength and rigidity, see Figure 5. Both polymers are subject to dispersion forces, which arise from temporary dipoles created by the random movement of electrons. Weaker dispersion forces in LDPE allow greater movement between polymer chains, enhancing the material's malleability, while stronger forces in HDPE contribute to its rigidity.

PVC (as seen in Figure 3) is formed through the addition polymerisation of vinyl chloride monomers. However, PVC poses environmental and health risks, releasing toxic substances like dioxins, hydrochloric gas (see equation below), and phthalates during degradation. These byproducts can contaminate water sources and cause respiratory issues.

$(C_2H_3Cl)_n \rightarrow (C_2H_2)_n + nHCl$

When disposed of in landfills, PET and polyethylene degrade

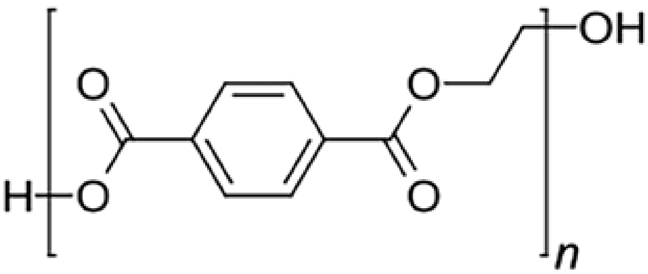

Figure 1: This figure shows the structure of PET and its synthesis equation

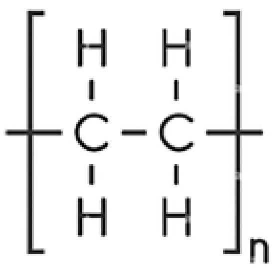

Figure 2: This figure shows the structure of polyethylene

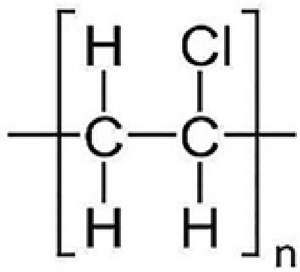

Figure 3: This figure shows the structure of polyvinylchloride

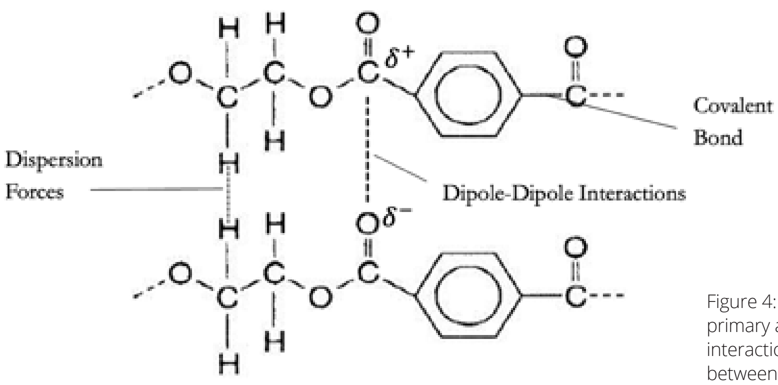

Figure 4: This figure shows the primary and secondary bonds and interactions respectively within and between the PET polymer chains.

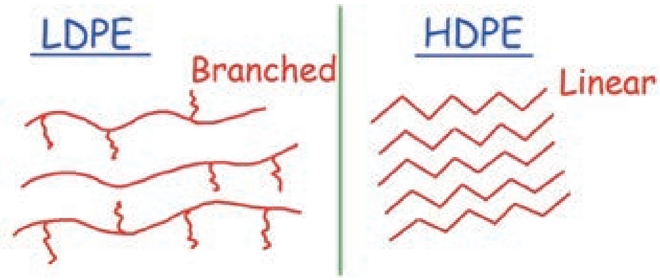

Figure 5: This shows the structure of both LDPE and HDPE

very slowly due to their high degree of structural rigidity. This rigidity increases tensile strength and compactness making it difficult for enzymes to access and break down the ester linkages in PET. Furthermore, most microorganisms have not evolved to break down carbon-carbon bonds, requiring thousands of years of UV radiation and heat to degrade these materials.

The growing global plastic waste crisis has influenced the adoption of recycled plastic roads as a sustainable solution. With over 400 million tonnes of plastic produced annually and only 9% being recycled, the environmental and societal impacts of plastic waste have become impossible to ignore.

In recent decades, the quantity of plastic production has doubled, as seen in figure 6, leading to increased awareness of its negative environmental effects. For instance, an estimated 11 million metric tonnes of plastic enter the oceans annually, threatening over 800 marine species through ingestion, entanglement, and habitat destruction.

This has influenced and motivated chemists and corporations to develop innovative methods to reduce plastic waste, such as recycled plastic roads. By diverting plastic from landfills and oceans, these roads address both terrestrial and marine environmental challenges. Such efforts have shown promise in mitigating plastic pollution, aiding the recovery of endangered species like the Loggerhead Sea Turtle, whose population has declined to 35% of its original size.

The affordability of recycled plastic roads has influenced its widespread use in road construction across both developing and developed countries. These roads can cut government costs by up to 50% and reduce the need for traditional materials like bitumen and cement by up to 60%. Additionally, their durability lowers maintenance costs by approximately $1547 per kilometre, ensuring they remain in optimal condition for up to three times longer than roads made with traditional materials. Energy consumption is reduced by at least 50% compared to traditional road construction, as manufacturing these roads requires lower temperatures, reducing heating costs and carbon emissions from fossil fuel combustion.

Organisations like 'Pothole King' have been instrumental in recycling plastic and constructing recycled plastic roads, offering a ten-year pothole-free guarantee. These initiatives have created employment opportunities for people living in poverty, who collect and recycle plastic from their local towns. This not only supplies the "raw" materials needed for plastic roads but also improves livelihoods. Workers in India have seen their daily earnings rise from less than $2 to up to $25, significantly improving their quality of life. This demonstrates how innovative solutions can create positive social and economic impacts, benefiting both society and the environment.

Recycled plastic roads represent one of several initiatives that have significantly propelled the economic growth of the recycled plastic industry, sustaining an annual growth rate of 9.0%. As illustrated in Figure 7, the recycled plastic industry, currently valued at around $49.12 billion USD, is projected to triple in value, reaching $127.25 billion USD by 2034. This growth underscores its potential to generate considerable economic and employment benefits in the coming years. Additionally, governments and industries are increasingly prioritising environmentally positive and sustainable practices, leading to greater investment in initiatives like recycled plastic roads to align with their sustainability goals.

However, the lack of reliable future data, as current figures are only estimates and predictions, may hinder the ability to draw accurate conclusions about the industry's future trajectory.

Despite this uncertainty, the scientific validation behind these projects has garnered trust from consumers, governments, and industries alike, encouraging more governments to implement such initiatives within their regions. This not only establishes a new niche within the recycled plastic industry but also drives the broader growth of the recycled plastic sector, particularly through the integration of recycled plastics into areas of daily life where they were previously unused.

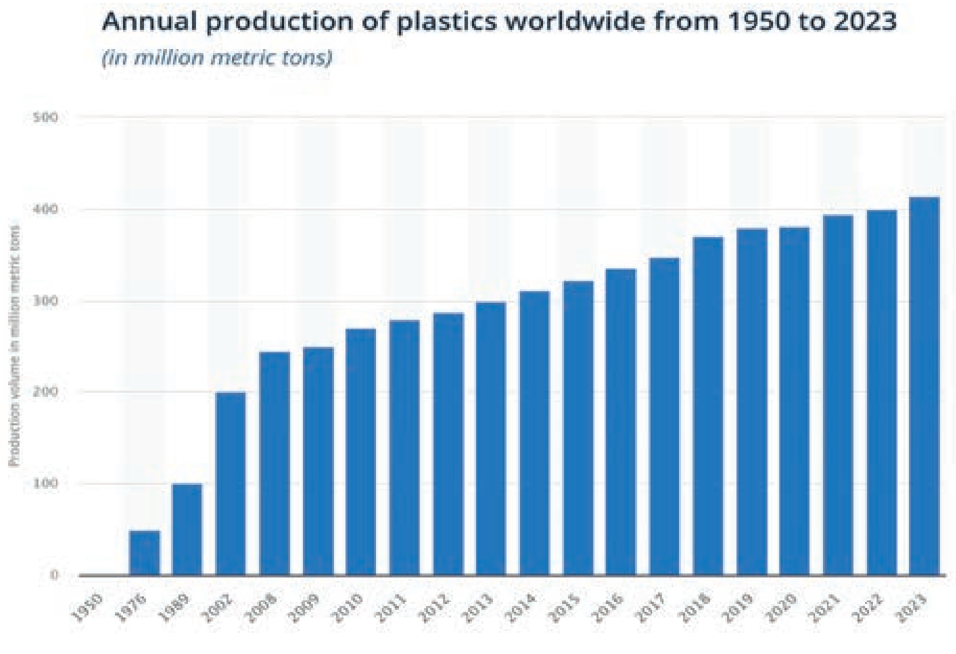

Figure 6: This figure shows the amount of plastic produced since 1950.

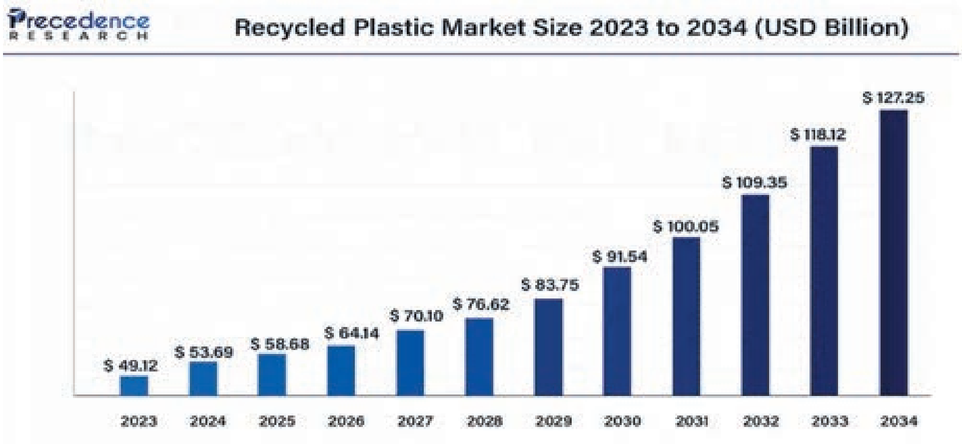

Figure 7: This figure shows the future growth of the recycled plastic industry.

For instance, the adoption of recycled plastics in fashion, supported by high-profile endorsements, has significantly boosted the popularity of this niche market, which is growing at an annual rate of 15.7%.

In countries like India, Ghana and Bhutan, early pioneers of this innovation, constructing roads out of plastic waste is now enforced by the state and federal governments to combat the amount of plastic waste sent to landfill. This has influenced other developed countries around the world, such as Australia and the Netherlands, to follow suit. For example, the Australian company RedCycle and the Downer Group have begun developing roads where soft plastics are injected into asphalt mixtures, which are then laid to form roads in New South Wales and Victoria, as seen in Figure 8. This demonstrates how scientific knowledge and innovation from countries around the globe can inspire and enable scientists in other countries to develop similar solutions, driving global progress towards sustainability.

In addition to plastic roads being durable and longer lasting, the recycled plastic road infrastructure can be applied to the construction of bridges, kerbs, footpaths, roads, pavements, pipes (large plumbing), drain covers and parking lots. Furthermore, this technology is currently being scaled down to allow for the development of pavers which would enable their use in residential applications, further expanding the recycled plastic industry.

Recycled plastic roads can be engineered for enhanced weather resistance, making them durable in both cold and hot climates. This reduces damage and replacement needs after severe weather, promoting long-term sustainability and cost-effective infrastructure maintenance.

While this technology offers numerous applications and benefits, it also presents several limitations, including end-of-life challenges, potential toxic gas production, and microplastic pollution. At the end of their lifespan, these roads would be nearly impossible to recycle, as it would take vast quantities of heat energy to separate the materials, and the resulting substance would still be contaminated, requiring them to be sent to landfills. Additionally, although the risk is low, some methods of producing recycled plastic roads may release toxic gases, such as chlorine. These limitations warrant the need for further research and innovation before recycled plastic roads can be scaled up globally, as the current practices risk delaying rather than resolving existing environmental issues.

Recycled plastic roads offer a sustainable solution to the global plastic waste crisis, addressing environmental, economic, and social challenges. By repurposing plastic waste, these roads reduce landfill dependency, lower construction costs, and minimize carbon emissions. Their durability and affordability have driven adoption in countries like India, Ghana, and Australia, showcasing their potential for global scalability. However, challenges such as end-of-life recycling and toxic emissions require further research and innovation. Rising plastic production and pollution highlight the need for legislation mandating recycled plastics in new road construction, though increased government funding is essential to develop end-of-life solutions. Recycled plastic roads exemplify how scientific advancements can transform waste into valuable resources, paving the way for a cleaner, more sustainable future.

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Sustainable gold extraction from electronic waste

Words by Ben Logan (Year 8)

Is Science Sustainable?

Gold is a vital part of the global economy and is used in many industrial technologies. Currently, the world's gold supply depends heavily on non-sustainable mining and extraction from electronic waste, which releases numerous toxic gases and substances into the Earth's atmosphere, such as cyanide salts and mercury, causing environmental pollution. Instead of mining about 3500 tonnes of gold each year from the Earth's surface, we can recycle and reuse it from the devices in your pocket. Pure gold is found in many electronic devices, like phones and laptops. It is ideal for such devices due to its excellent conductivity, resistance to corrosion, and durability, which are all essential for a device's long life.

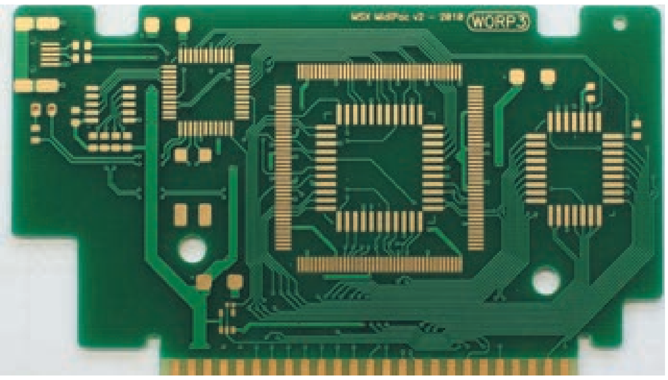

Figure 1: Circuit board with gold

Currently, gold is extracted from electronic waste using toxic gases such as Cyanide salt, which is extremely bad for our planet. To reduce our reliance on unsustainable extraction methods, scientists have developed ways to extract gold from electronic waste without using toxic gases.

In every tonne of printed circuit boards, (Figure 1) there is approximately 10 to 1600 grams of gold, worth between $1600 and $263,000, demonstrating its vital role in electronic devices and the importance of recycling this gold to prevent economic decline.

The current method for gold extraction involves leaching it with a cyanide solution called Black Cyanide ($Ca(CN)2$), a carbon-contaminated form of calcium cyanide. This process can produce up to approximately a billion tonnes of cyanide annually. Cyanide is highly toxic and has significant environmental and public health risks if released into the environment (Figure 2). Historically, cyanide spills have killed many fish, contaminated drinking water, and damaged agricultural lands. Cyanide is a nasty and dangerous chemical to expose to our environment, making this method unsustainable.

To solve this increasing problem, students at Flinders University, led by Professor Justin Chalker, have developed a new, sustainable and cheap strategy to extract gold from electronic waste (Figure 3). Their patented process involves using a sulphur and polymer compound and trichloroisocyanuric acid. This acid is used to decontaminate water and can also dissolve gold, as well as many other metals.

Figure 2: Cyanide polluted land

The first step in the process is to use a low-cost, safe chemical compound (trichloroisocyanuric acid) to dissolve the gold. This compound is then isolated by binding it to the team's unique sulphur-rich polymer. The polymer–gold complex can be filtered out of the solution. The gold is then released from the polymer by triggering it to 'unmake' itself back into the monomers, which can be reused for future gold extractions.

This low-cost, effective way of recycling gold from e-waste will cause a decrease in the demand for gold ore (mined from the ground), decrease the need to extract gold using toxic chemicals such as cyanide and provide a cheaper, more sustainable process for gold extraction across the world.

Figure 3: Teams sort e waste for gold extraction

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Can do!

Recycling aluminium can save up to 95% of the energy used when making it from raw ore.

Magnetic confinement in a tokamak reactor

Words by Charles Tang (Year 10)

Is Science Sustainable?

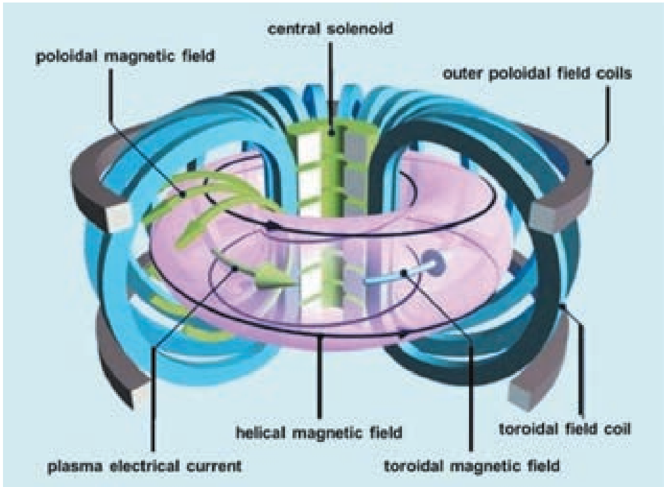

Figure 1: Basic components of a tokamak reactor

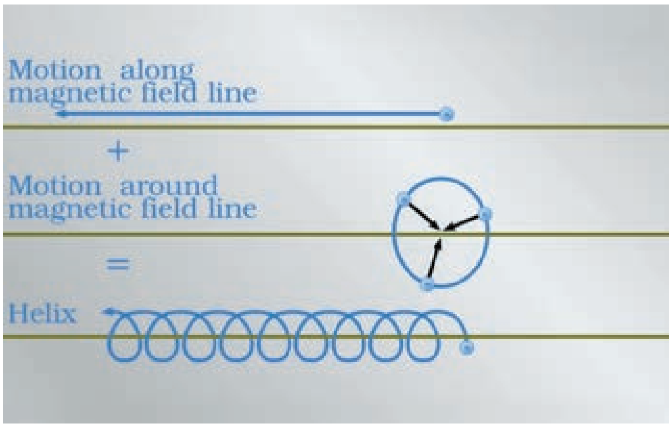

Figure 2: Movement of particles around a magnetic field

The search for cheap, reliable and abundant energy underpins our society. However, fossil fuels can only be continued to be used at the cost of increased greenhouse gas emissions and global warming. Our urgent need to develop and adopt carbon free energy sources to solve the issue of climate change only increases the urgency of this search. As well as this, the demand for energy will grow with the increasing global population, industrialization and new energy hungry industries such as Artificial Intelligence (AI). Nuclear fusion technology holds the tantalising potential to play a critical role in solving these issues.

In essence nuclear fusion aims to combine smaller nuclei to form one new, larger nucleus which releases large amounts of energy. Due to a comparatively low activation energy and high energy output, this reaction generally uses deuterium and tritium as fuel which combine to form one helium-4 atom and a neutron carrying 80% of the energy from the reaction as kinetic energy. This can be expressed as . However, overcoming the electromagnetic force of repulsion between the atoms requires inputting tremendous amounts of energy. Nuclear fusion on the Earth requires the hydrogen isotopes to be in a plasma state so that magnetic fields can control the charged particles and then exert extreme pressure and temperatures onto the clouds. Among the many techniques to achieve nuclear fusion, tokamak reactors use magnetic fields to achieve this.

A tokamak reactor is a machine confining plasma into a donut shaped vacuum chamber referred to as a torus. The plasma needs to be contained since it reaches temperatures exceeding 150 million °C, enough melt the walls on contact and any solid material on Earth. The plasma is confined through a helical magnetic field created through toroidal and poloidal field coils, and various other coils to stabilise and maintain the plasma (see figure 1).

The magnetic force is always perpendicular to the direction of motion, so a charged particle moving around at a right angle to a magnetic field will orbit around it in a circle. A particle moving parallel to or along the field will experience no force and so be free to move how it likes. A particle will generally have a combination of these two motions resulting in a helical spiral around a given magnetic field line, see Figure 2.

Based on this, fusion can occur if the particles have sufficient energy so that when they collide, they fuse.

But various issues must be avoided so that the plasma does not collide into the walls of the reactor. Drift occurs due to variations in magnetic field strength or other forces such as gravity. Drift is when the orbiting particle's position changes as it orbits around a magnetic field with unequal forces and in a nuclear fusion reactor, leading to instability.

An early approach to avoid drift was to use a magnetic mirror. This was achieved through a pair of magnetic coils some distance apart creating a cylindrical magnetic field bulging out in the middle, see Figure 3. Particles in the mirror will be strongest in the centre so particles in the outer layers would become trapped in the centre. As this occurs, the particles experience a force that opposes the direction of motion causing the particles to slow down and eventually reverse the direction of motion along the field line. The location at which the particle turns and resumes this motion in the opposite direction is called the mirror point.

Fusion with this type of reactor is limited due to its confinement of plasma being magneto hydrodynamically

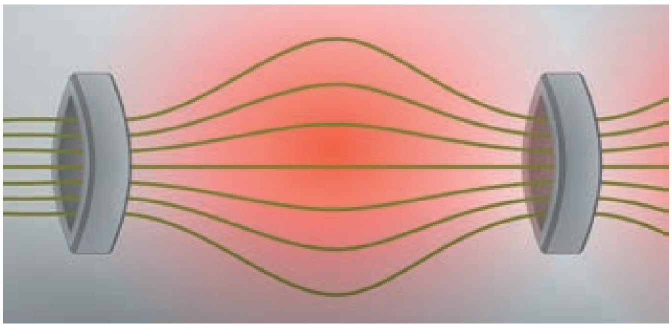

Figure 3

unstable. Every single particle moving in a circle acts like an individual dipole. The field of individual electrons is not significant but for fusion to occur, greater densities are preferred. This causes the magnetic fields to be "frozen in" to the plasma meaning a blob of plasma is like a bead on a chain and the magnetic field line is like string. The bead can move freely along the string but cannot move sideways unless it drags the string with it or vice versa. This means that high pressure can cause a blob of plasma to move out of the magnetic field line and so the rest of the plasma on that field line could also leak out. In a magnetic mirror, the outer fields between two magnets will tend to balloon outwards, dragging out the field lines and degrading confinement.

By curving the mirror back in on itself, a torus could be created to negate end losses associated with magnetic mirrors. However the strength of the magnetic fields of the torus vary as the circumference of the field increases at the outside, the field is weaker. This leads to ions and electrons drifting and it becomes unstable. Because of this, magnetic field lines need to be twisted such that part of the field line is on the outside of the torus whilst the other half inside so that half the time, the particles would drift one way one half of the time and the opposite at the other half, cancelling out the drifts.

A tokamak approaches this issue using a combination of the plasma in the toroidal shape and current being passed around the middle of it. This is done through the poloidal field system that acts like a Z-pinch, creating an additional component to the magnetic field in circles and further stabilising it. This combination causes the magnetic field to be twisted.

However, for a tokamak reactor to be our primary source of energy, it is necessary for the reactor to be a steady state device. The Ohmic (OH) transformer limits this due to it inherently being pulsed to hold the plasma in equilibrium. Another limitation is disruptions which are a sudden and catastrophic loss of plasma, causing significant damage to the reactor. Disruption mitigation systems such as massive gas injection mitigate some damage. Parameter based transfer learning for models predicting disruptions does help, however, is limited by a lack of data and further discoveries of physical mechanisms in plasma will contribute to an improved model. Further discoveries of materials and plasma's behaviour will help to overcome issues that tokamak reactors currently face.

The ITER project is a collaborative project of 35 nations that aims to confine five times the amount of plasma than any other operating machine today at 830m3 in a tokamak machine in France. To control this much plasma, the magnet system will be the largest and most integrated superconducting magnet system ever built. Ten thousand tonnes of niobium-tin (Nb3Sn) or niobium-titanium (Nb-Ti) superconducting magnets will be used in the toroidal and poloidal field system, a central solenoid, correction coils, magnet feeders, and in-vessel coils.

ITER utilises high-performance internally cooled cable-in-conduit superconductors. This allows for greater current to be carried and a magnetic field stronger than conventional counterparts to be produced. To become superconducting, the magnets need to be cooled by supercritical helium in the range of 4 Kelvin (-296 °C). The most difficult raw material to source, the niobium tin (Nb3Sn) required a large ramp-up in large-scale industrial effort of global production capacity. It took global production capacity from 15 metric tons/year to 100 metric tons/year and the introduction of three new strand suppliers from 2008 to 2015. The All-Russian Research Institute for Cable Industry, JSC VNIIKP produced 120 tonnes of material and through various processes was able to further optimise this process. The process for creating cables can be separated into three stages: preparation, cabling and jacketing.

Preparation requires processing equipment for chemical and electrochemical pre-treatment of copper wire and superconducting Nb – S and Nb – Ti. Further research and development determined that for the best quality, highly precise controls for the thickness of coating, cohesion, and dimensional tolerance needed to be achieved. The rate of production ranged from 3-5 km per hour and produced less than of the100 L of distilled water used per 14-hour workday, there were no leakages or discharge to the main drain. A major innovation in the preparation stages was to produce a production line capable of serial cable production with a central spiral, see Figure 4.

A 5-stage process was developed to optimise cabling. High-speed tubular standing machines for the first and second stage of cabling and on both stages of copper core production. Whereas planetary type cabling machines were used for stages 3 and 4. Cabling the sub-cables around the central spiral while maintaining extremely strict requirements on the local

Figure 4: Central spiral

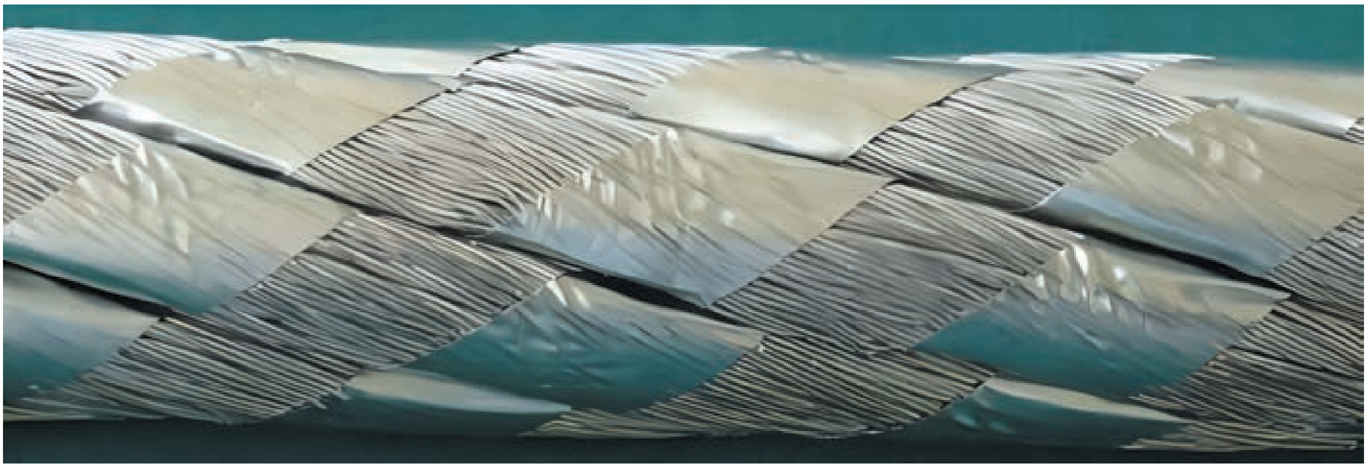

Figure 5: Spiralling of cables after compaction

void fraction (<30%) (see Figure 5) caused various technical challenges. To solve this, a planetary machine was fitted with specially developed devices to compact and two-coordinate laser measuring instruments to confirm the finished product's diameter aligned with the very tight tolerances required.

Completed and tested cables can then be transported to the jacketing line which involves various processes including welding and assembling stainless steel jackets. The whole length jacket (10-12m) is assembled using automatic buttwelding in an inert gas (argon) atmosphere. Following this, the welded joint is transferred in the control zone where the appearance of each weld undergoes various quality controls including radiographic and helium leak detectors are conducted. A conveyor belt then transfers sound welds and inserts them into a full-length welded jacket through means of steel rope and force winch to be compacted to reach the required diameter, see Figure 6.

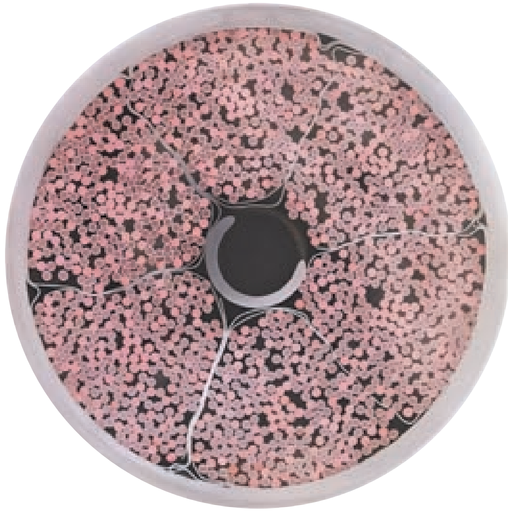

Figure 6: Cross section of superconducting conductor

In conclusion, nuclear fusion promises to solve many of the issues we face today but achieving an economically feasible reactor poses difficulties. Although the tokamak reactors have reached various milestones such as superconducting magnet manufacturing and plasma confinement, various problems remain such as disruptions which limit a tokamak's ability to be a steady state device. Continued improvements in predictive modelling and reactor control systems will be vital for fusion to be a viable energy source in the future.

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The utilisation of metal-organic frameworks for sustainable lithium extraction

Words by Ivan Sharma (Year 12)

Is Science Sustainable?

The application of lithium metal in the electronics industry has soared because of societies growing desire for a more sustainable Earth. As such, the market for technologies such as electronic vehicles (EVs) and renewable energy systems have experienced substantial growth in sales. Consequently, lithium ores are being mined limitlessly, and due to inefficient extraction and recycling methods, the global supply of lithium is rapidly diminishing. To satisfy the growing demand for lithium-reliant technologies (Figure 1), an efficient and sustainable extraction method is required. The ocean consists of approximately 200 billion metric tons of lithium, a significant quantity in contrast to the 21 million metric tons available via land extraction. However, lithium in ocean reserves are at significantly low concentrations, ranging between 0.1-0.2 ppm. Whilst standard practices for lithium extraction are not economically viable for seawater extractions, recently developed metal-organic frameworks (MOFs) indicate promising results for efficient lithium extraction, due to their exceptionally efficient selectivity of lithium ions.

Over 70% of the Earth's surface area is covered by seawater, a multifaceted combination of approximately 96.5% water, 2.5% dissolved salts, and minor amounts of other particles including dissolved materials and gases. Although a trivial proportion, salts are a significant resource, where ions of sodium, chloride, magnesium, calcium, potassium, and lithium are readily available. However, lithium isolation is especially challenging, as chemically similar and highly reactive metal cations such as Mg^{2+}, Na^+, and K^+, are abundant in seawater.

As per preferential discharge theory, lithium cannot undergo aqueous electrolysis due to its significantly high reactivity, thus water will be preferentially reduced at the cathode (Figure 2). Hence, a process of molten salt electrolysis must be conducted to efficiently generate pure lithium metal, requiring a significant input of thermal energy between 420 °C – 550 °C, thus being economically unviable.

MOFs are organic, crystalline materials composed of metal ions that are covalently bonded to organic ligands, producing networks of pores at sub-nanometre depths, and hence amplifying the frameworks overall surface area (Figure 2). These compounds typically consist of negatively charged hydroxyl/carboxyl or sulfonate functional groups, which selectively adsorb lithium ions in seawater via structural binding sites. Here, Li^+ is preferentially adsorbed as metallic

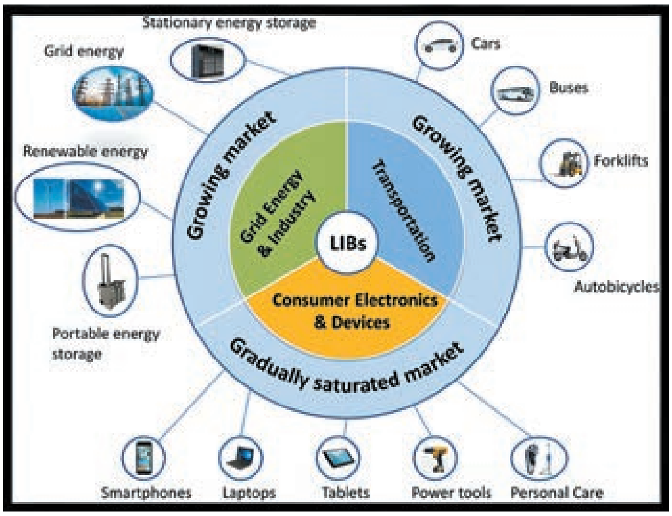

Figure 1: Lithium battery applications in different industries

ions are sieved in preference of ascending ionic radii (Li^+ > Na^+ > K^+). Subsequent to this process, lithium ions undergo desorption, being separated from the membrane and stored for future applications.

Of relevant MOFs, changes in pore size alone demonstrate minimal correlation to the selectivity of lithium ions (Figure 3). Yet, membranes consisting of carboxyl (-COOH/COO^-) or sulfonate (-SO_3^-) functional groups provide enhanced selectivity of Li^+ / Mg^{2+} ions from seawater, particularly ZIF-8-SSP membranes which exhibited significant Li^+ / Mg^{2+} ion selectivity of 4913. This can be directly attributed to the sulfonate functional group present within its membrane, prompting an overall negative surface charge which promotes the permeability of lithium cations. In contrast to other metal ions in seawater, lithium experiences greater charge density than sodium and potassium, and a smaller ionic radius than calcium (0.68Å<1.97Å). Thus, the specific pore sizes and negative charge of the ZIF-8-SSP membrane promotes the extraction of lithium ions, as Li^+ is favoured over Na^+ and K^+ due to charge density, and over Ca^{2+} as per atomic size.

The global demand for lithium-ion batteries has risen exponentially in response to the continuous development of electric vehicles (Figure 4). To assist in reaching net zero emissions within the transport sector, approximately 1.6 billion EVs would need to be in use, and thus a corresponding number of lithium-ion batteries. Whilst each battery requires an approximate 8kg of lithium, an overall 12.8 billion kilograms would be required to power all EVs and thus eradicate exhaust emissions. As per the growing demand for EVs, lithium has been extensively oversupplied, and a deficit is estimated by 2030. Thus, the universal desire for green transportation, particularly EVs, serves as a major influence for additional lithium supply, and hence incentivises sustainable extraction practices. These considerations have further influenced studies regarding environmentally viable lithium extraction, particularly

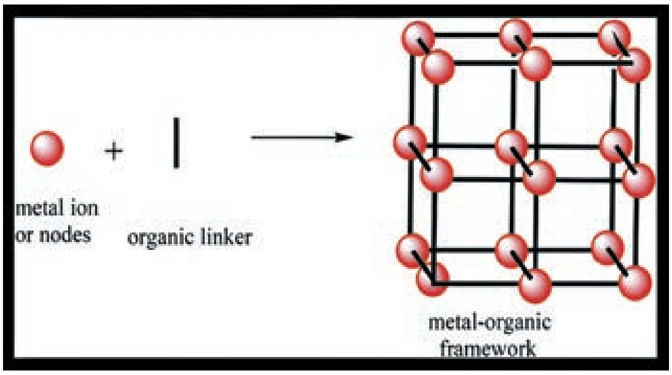

Figure 2: Standard structure of an MOF

evident through subsidised collaborative research between the CSIRO, Monash University, University of Austin, and Australian National University, which led to the development of highly selective MOFs, specific to lithium extraction.

In comparison to MOFs, current lithium extraction practises are much more detrimental to the environment. Land reserves of lithium are extracted through a water-intensive process of hard-ore mining, resulting in ecosystem disturbance, habitat loss, and water contamination (Figure 5). These polluted waterbodies can be purified through an energy-intensive process of reverse osmosis, whereby each cubic metre of water requires an input of 2.5-3.5 kwH to overcome osmotic pressure and remove undesirable molecules from the solution. These significant energy requirements induce further reliance on fossil fuels, thus contributing to the Enhanced Greenhouse Effect. Consequently, lithium producers are negatively impacted, as these energy-intensive processes increase their costs of production. Thus, such methods of extraction and refinement are economically unviable, contributing to further environmental degradation.

In contrast, MOFs provide an economically viable resolution to this problem, as lithium isolation is achieved without requiring numerous refinement steps or significant energy inputs. Utilising these frameworks increases the rate at which lithium is refined into pure metal, whilst also optimising its overall yield, thus being a major economical influence for lithium manufacturers. Costs of lithium production are directly reduced, thus minimising the costs of lithium reliant technologies such as EVs, and further increasing their accessibility to the general population.

Due to their sustainability, rapid adsorption–desorption rate, and economic viability, MOFs indicate potential superiority in lithium-ion extraction from seawater. Unlike conventional lithium extraction methods like hard-ore mining, MOFs have minimal reliance on fossil fuels for lithium isolation and can be regenerated through a sustainable process of sunlight irradiation. As such, wide-scale application of MOFs would assist in reducing the Enhanced Greenhouse Effect, whilst allowing finite resources to be reallocated elsewhere.

Furthermore, collaboration between universities and government institutes have exemplified the MOFs rapid and highly selective isolation of lithium ions from seawater reserves. These structures demonstrate a prompt adsorption-desorption rate, highlighting an increased rate of lithium refinement, and thus allowing producers to save costs by reducing their resource requirements, such as labour and capital. Moreover, MOFs are specifically designed to extract lithium ions from low-concentration solutions such as seawater. Current extraction practises are economically unviable to undergo such processes, and thus lithium reserves remain abundant in the ocean. Consequently, the successful application of MOFs in seawater would drastically increase the global supply of lithium, further decreasing its market price and promoting competition between firms in the industry, both of which promote consumer welfare.

Nevertheless, certain limitations are associated with the wide-scale utilisation of MOFs for lithium extraction, particularly due to their poor stability, toxicity of production, and limited scalability of manufacturing. Primarily, the chemical, hydrothermal, and mechanical properties of certain MOFs are susceptible to reduced stability, particularly due to the presence of weak covalent bonds between metal ions and ligands. Consequently, these materials are vulnerable to the intrusion of unwanted guest molecules which can hydrolyse

MOF membranes	Pore Size [Å]	Functional Group	Charge Type	Membrane Type	Ion Selectivity			
					Li^+/Mg^{2+}	Na^+/Mg^{2+}	K^+/Mg^{2+}	Li^+/K^+
ZIF-7	2.9	—	Neutral	MOFC	—	—	—	—
ZIF-8	3.4	—	Neutral	PMOF	3.87	4.0	4.49	0.86
ZIF-8	3.4	—	Neutral	PMOF	—		—	2.18
ZIF-8-SSP	3.4	$-SO_3^-$	Negative	PMOF	4913	64	44	112
ZIF-8@PVC	3.4	—	Neutral	MMM	2.02	1.51	1.71	1.18
UiO-66	6	—	Neutral	MOFC	—	—	—	1.58
UiO-66@PVC	6	—	Neutral	MMM	1.30	1.55	1.83	0.71
UiO-66-NH_2	6	$-NH_2$	Positive	PMOF (LLM)	>60	—	—	—
UiO-66-SO_3H	6	$-SO_3^-$	Negative	PMOF (LLM)	1.88	—	5.31	0.35
UiO-66-SO_3H@PVC	6	$-SO_3^-$	Negative	MMM	4.79	5.15	5.99	0.80
UiO-66(Zr/Ti)-NH_2@Polyamide	6	—	—	MMM	11.38	13.44	—	—
UiO-66-$(COOH)_2$	6	$-COOH/COO^-$	Negative	MOFC	1590	3230	4948	0.32
UiO-66-COOH	6	$-COOH/COO^-$	Negative	MOFC	~200	—	1554.9	—
HKUST-1-PSS	9	$-SO_3^-$	Negative	PMOF	1815	52	27	67
HKUST-1@PVC	9	—	Neutral	MMM	1.27	1.59	2.00	0.64
MOF-808-SO_4@PVC	12	$-SO_4$	—	MMM	1.06	1.20	1.51	0.70
MOF-808@PVC	12.9	—	Neutral	MMM	0.79	1.04	1.32	0.60

Figure 3: Chart representing ion selectivity for various MOFs

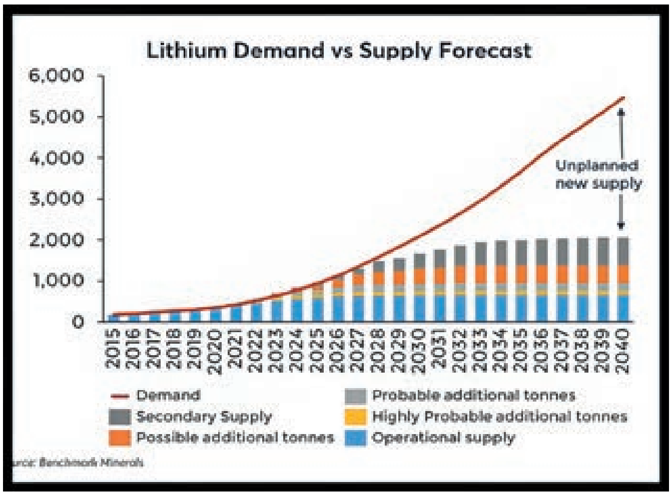

Figure 4: Future Lithium Demand vs Supply Graph

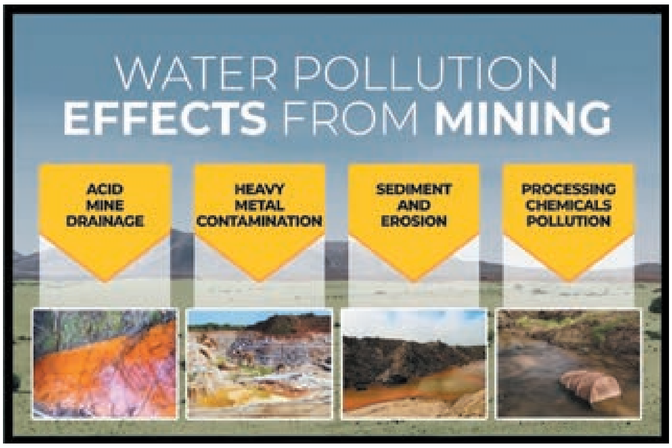

Figure 5: Environmental repercussions of hard-ore mining

the covalent bonds, corrupting its structural integrity. Thus, given water is inevitably present in seawater lithium extractions, this represents a major limitation of the process.

Moreover, MOFs must undergo crystallisation during their synthesis, necessitating a liquid state which simultaneously allows metal ions and ligands to remain dissolved. This process typically occurs between temperatures of 60-150 °C, and therefore is reliant on organic, high-boiling point solvents such as dimethylformamide (DMF) and diethylformamide (DEF). Laboratory workers are therefore at great risk, as these substances release fumes which instigate health effects such as nausea, abdominal pain, and liver toxicity. Furthermore, due to being a contemporary discovery, MOFs have only demonstrated high efficiency in laboratory settings. As such, developing a cost-effective, sustainable, and chemically stable MOF must be considered before applying it in wide-scale lithium extractions.

The recently uncovered applicability of MOFs for lithium extraction from seawater can potentially transform the lithium production industry. Influenced by both societal and economic considerations, industrial utilisation of this technology may assist in decelerating climate change whilst also prompting the affordability of lithium-reliant technologies. Nonetheless, before being applied in wide-scale lithium extractions, current methods of MOF synthesis must be developed to ensure minimal health repercussions and enhanced chemical stability.

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Sun-powered planet

In just 90 minutes, enough sunlight hits Earth to power the world for an entire year.

Is non-thermal plasma a sustainable source of energy?

Words by Jake Nykiel (Year 12)

Is Science Sustainable?

Yearly 4.53 billion tons of crude oil are consumed, over 2 billion tons of waste is generated, and 50 billion tonnes of emissions are released into the atmosphere. Since the rise of anthropogenic sources of greenhouse gases its damaging effect has compounded, causing global temperatures to rise by 1.5 degrees. This promotes rising sea levels and extreme weather patterns that threaten life. Now more than ever humanity needs to embrace renewable sources of energy and materials to prolong Earth's prosperity and minimise the damage caused by climate change.

Many developments have been made in turning waste products into valuable commodities. One such innovation is non-thermal plasma generation that allows for waste emissions like carbon dioxide and methane gas to be upcycled and converted into renewable resources that benefit society by reducing environmental damage and produce a lasting resource with universal applications.

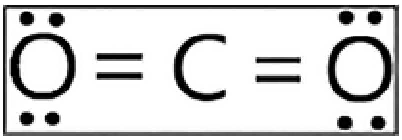

Figure 1: Structure of carbon dioxide gas

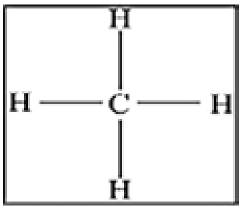

Figure 2: Structure of methane gas

Biogases, comprised mainly of carbon dioxide and methane (Figures 1 and 2) are formed through the anerobic digestion of organic matter and municipal waste by a chain of microorganisms called methanogens. The production of these gases drastically rise in low oxygen, high-heat, and high-pressure environments such as landfill which produces approximately 14% of methane emissions in the USA alone. These gases can store infrared radiation re-emitted by the earth within their bonds, increasing their kinetic energy, which is later discharged back into the atmosphere, and hence the earth, increasing global temperatures and exacerbating the effects of climate change. However, the biogas' chemical composition, energy density, flammability, and replenishing supply make them an ideal source of renewable energy. Biogas can be extracted from landfills using a network of wells drilled into waste deposits, then using compressors to feed a collection tank. These gases are then filtered and converted into valuable products. Biogas has typically been purified to increase the concentration of methane and used as a clean, renewable, combustible fuel to generate electricity, often referred to as "biomethane". Alternatively, biogas may be liquefied and combined with gasoline to produce biodiesel for use in transportation.

Non-thermal plasma differs as it utilises both constituents of biogas in varying ratios to produce organic compounds such as aldehydes, ketones, alcohols, and hydrocarbons with varying chain lengths. A non-thermal plasma generator functions by introducing gas to an electric field, causing their electrons to excite and become volatile, leading to changes in their properties. This plasma occurs at standard environmental conditions, being discharged within bubbles accompanied by carbon dioxide and methane, undergoing one of the three main proposed reactionary pathways depicted in Figure 3.

Non-thermal plasma generation provides new opportunities for salvaging biogas through a process of upcycling that boasts reduced costs, increased sustainability, and broader applications across industries, reducing their ecological footprint. The greatest advantage of non-thermal plasma is that unlike traditional methods that produce biodiesel and biomethane, it can be operated at room temperature and standard atmospheric pressure. This reduces energy demand, making sustainable sources such as wind or solar viable for driving the process. In-turn, biogas upcycling becomes a profitable venture with a positive ecological impact by reducing the release of methane into the environment which retains 28 times more heat than carbon dioxide. Furthermore, the use of renewable energy may result in prices lower than traditional fuels due to the decreased synthesising costs relative to those of extraction. Sustainably upcycled biogas could be used to reduce the environmental toll of sectors that lack an ecologically friendly alternative. Particularly, aviation where jet fuel and its variations remain the leading propellants owing to their energy density and practicality for refuelling. Aviation accounts for 1.9 percent of the world's emissions, comparable to that attributed to landfill (Figure 4).

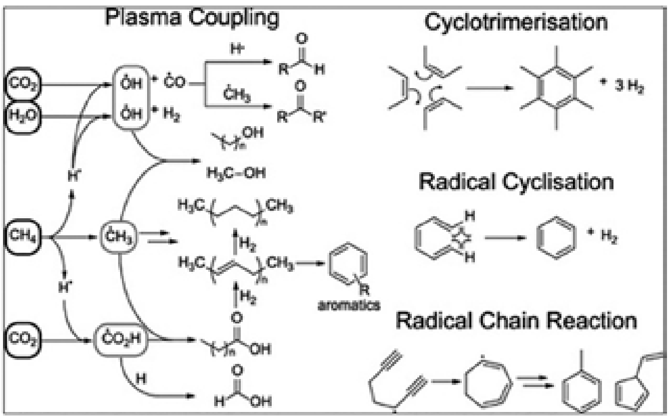

Figure 3: Proposed reaction pathways

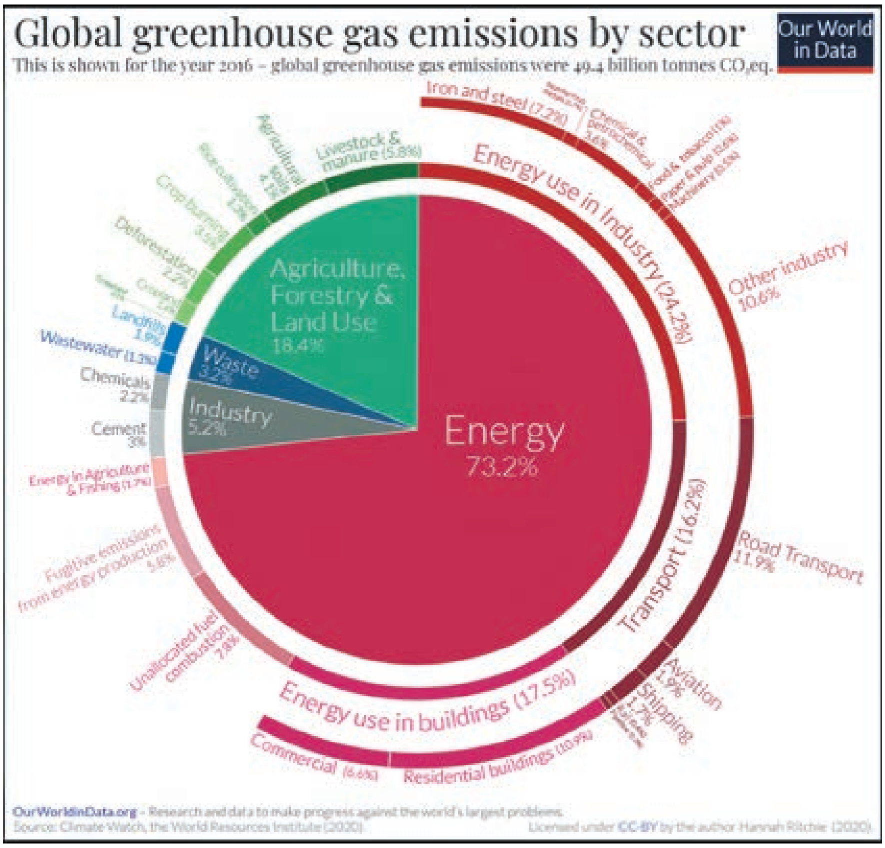

Figure 4: Emission statistics

This overlap presents an opportunity to reduce global emissions by converting landfill's unproductive gases into jet fuel constituents, thereby preventing additional pollutants from feedstock-derived petroleum fuels without reducing productivity.

Non-thermal plasma biogas upcycling presents several economic, ecological, and civil advantages. Its ability to generate valuable products in an environmentally damaging sector incentivises both governments and companies to improve their waste management programs so they may capitalize on the cheap production of a high demand commodity. An example of this is Veolia who offer landfill methane management and extraction to produce sustainable energy. Consequently, other countries who suffer from underdeveloped waste infrastructure may see this as an opportunity to bolster their independent economic and ecological capabilities whilst also improving the quality of life for their citizens. The process of upcycling biogas through non-thermal plasma generation yields materials that are widely used within the cosmetics and pharmaceutical industries. These materials are typically derived from petroleum feedstocks that are finite in nature whereas those derived from upcycled biogas are sustainable. As the population increases, so will the consumption of goods and the volume of waste sent to landfill, thus spawning a renewable supply of biogas to convert into hydrocarbons. As landfills are used globally, upcycled biogas will improve the reliability of access to fuel compared to extracted petroleum which occurs in specific geographic areas dominated by a small number of countries and conglomerates. Tests of non-thermal plasma have also produced a substance theorised to be highly crosslinked that may find use within fabrication, spawning greater possibilities of plasma polymers and their characteristics.

Whilst biogas upcycled via non-thermal plasma has many appealing qualities it remains plagued by issues such as immature technologies, low precision, and safety hazards. One of the predominant issues with non-thermal plasma upcycling is its experimental nature with the operation of the generators being of limited scale thus far. Furthermore, the process is yet to be fully explored, including how changes to the generator may impact products. The reliability of synthesis of specific products is a major shortcoming within the process. This is attributed to the short reaction period and the vast number of excited species that may be produced as a result of plasma coupling. This leads to the issue of requiring external refinement to make desirable products such as the aforementioned jet fuel. Consequently, the appeal felt by industry towards adopting such technology is reduced as such issues can harm both profit margins, and sustainability. Safety is also a weak point of biogas as it is both highly flammable and toxic. Containment of these gases can be expensive and dangerous, incurring greater costs for the equipment and training required to prevent harm.

Another limitation to upcycled biogas is the logistical component that determines the viability of a technology including the price, availability, and implementation. Cost is a large factor in a product's success; airlines, manufactures, and pharmaceutical companies typically make deals based on established dependability and price. Upcycled biogas and its derivatives would initially struggle to compete with the prices of traditional petroleum products that have benefited from the economy of scale. Furthermore, companies often avoid the risk of change, as it may cause unintended side effects within their product, or they might face issues with changing suppliers. This is another substantial weakness of biogas products, to remain competitive a large and constant supply must be maintained, otherwise it is unlikely to be adopted and society wont heed the benefits of its renewable nature.

Unfortunately, whilst the environment for extracting biogas is widely available, the method's yield is quite small due to landfill wells covering a small area. Additionally, the production of biogas depends on the continual production of waste whereas ideally society will reduce the volume that they produce. Finally, biogas products are profoundly limited by their implementation. Whilst they see use within grid energy, they are becoming increasingly outperformed by greener and faster-improving sources such as traditional renewables. This extends to personal applications such as transportation where electricity and hydrogen are being implemented to a greater success than those which utilize biogas or conventional petroleum.

The promise of a renewable future is closer than ever with the proposal of converting waste emissions into commodities that impact society as a whole. Whilst non-thermal plasma and biogas extraction suffer from small yields, high initial costs, and specific viable implementations further research will lessen these issues. Conversely, the adoption of non-thermal plasma generation offers jobs, a sustainable source of fuel and energy, better living conditions, and a healthier planet that suffers less from climate change. Whilst non-thermal plasma requires much development, it has potential to change the actions of humanity from negatives to positives if society takes a collective leap into the world of renewables.

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Enzymatic recycling: revolutionising plastic recycling and waste management for a more sustainable future

Words by Isaac Yu (Year 11)

Is Science Sustainable?

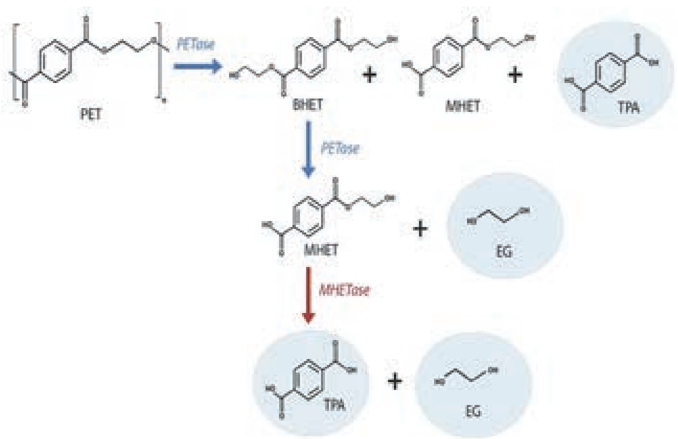

Figure 1: Diagram of PET polymer being depolymerised by PETase and MHETase and the corresponding monomers which are formed being Terephthalic Acid (TPA) and Ethylene Glycol (EG)

In a world of continual advancements, the use of and reliance upon plastics in a multitude of industrial purposes have continued to rise, leading to an increase in plastic pollution globally, contributing 19-23 million tonnes of plastic waste yearly. With the imminent need for sustainable and long-term solutions to plastic pollution, scientists are constantly researching and experimenting with new innovations. One innovation is enzymatic recycling which has the potential to revolutionise plastic waste management to create a more circular economy reducing environmental impacts to benefit society.

Plastics are a type of material characterised by their capacity to be shaped when soft and harden to maintain shape. In chemical terms plastics are polymers which are a type of substance that is made up of repeating units called monomers. Polyethylene terephthalate (PET) is one type of plastic that is commonly used in bottles and food packaging. The monomers that form PET are terephthalic acid (TPA) and ethylene glycol (EG). Traditional methods of recycling PET, involve a process called Pyrolysis where the plastics are heated in the absence of oxygen to break it down into smaller molecules. Whilst this process can result in new usable liquids such as for fuel or for new plastics there are several limitations and challenges that arise. Firstly, this process often results in incomplete decomposition resulting in 20% of PET residue to remain. Furthermore, unwanted chemicals and corrosive substances such as terephthalic acid and benzoic acid are also formed. This can degrade the quality of the usable substance and be harmful to both humans and the environment. Subsequently, the use of new chemical processes involving enzymes have been considered. An enzyme is a biological catalyst that aids in speeding up the rate of a biochemical reaction. Enzymatic recycling in terms of PET, involves the use of specific enzymes that work to depolymerise the polymer chains into the usable monomers, TPA and EG (Figure 1). The enzymes that can break down PET can be classified as PETase and MHETase enzymes. The enzymatic process allows for contaminated plastics to be recycled as the chemical reaction is specific to the desired molecules. As enzymes work by lowering activation energy, their use can decrease energy costs compared to that required to power mechanical processes and can reduce additional costs by the reusability of the enzymes. Thus, when the plastics are repolymerised they can maintain quality improving their lifespan and usability.

With an increasingly high demand for plastic use, societal and environmental factors have influenced the need for scientific advancements to meet society's needs. Through technological advancements, scientific understanding involving chemical recycling processes and enzymatic recycling have advanced, allowing for the development of recycling methods that are more efficient and effective. Furthermore, with the estimated 350 million tonnes of plastic being produced annually, more than 50% of these plastics will end up in landfill with approximately 20% of these plastics being PET. The environmental considerations have influenced the need for more efficient and effective recycling, with enzymatic recycling being a suitable alternative. Through the depolymerisation into usable monomers, a greater number of high-quality plastics can be recycled, reducing the reliance on production of new plastics and thus decreasing the environmental impact of production and conventional recycling methods. An increase in regulations being placed on companies by the European Union of including 30% of recycled content in single-use plastics has influenced the need for companies to obtain more recycled plastic materials to fulfill ethical obligations. These laws aim to limit the impact of single use plastics and prompt greater use of recycled material to decrease the impact on the environment. Furthermore, companies such as Coca-Cola and other food packaging companies require high quality food grade plastics, which with mechanical recycling methods is very difficult. Consequently, this has influenced the need for a recycling process that enables high quality plastics to be formed repeatedly, being enzymatic recycling.

Through the advancement in scientific innovation of enzymes, the use of enzymatic recycling for plastics has a plethora of applications benefiting society. Conventional techniques of plastic recycling such as pyrolysis are limited in their range of plastic recycling ability. Through the chemical use of specific enzymes, the range of recyclable material increases as enzymes are generally unaffected by paper or metal materials present. This increases the number of applications of plastic recycling, helping to reduce the plastic pollution and benefiting the environment. Furthermore, the application of enzymatic recycling can enable previously difficult to recycle plastics due to contamination from going to landfill. With the utilisation of enzymatic recycling, which has specialised enzymes that can selectively break down the PET polymers, it can bypass the need for extra decontamination reducing costs and environmental impact in running cleaning machines.

On the other hand, there are several limitations of enzymatic recycling which can constrain its use to benefit society. Firstly, whilst enzymatic recycling has proven successful in the recycling of PET, further scientific research and advancements are still to be made for other plastics such as PU and other polymers. This limits the applicability of enzymatic recycling until the potential enzymes are found which requires time and therefore the impacts on the environment and society will persist. Furthermore, despite the cost effectiveness of the enzymatic recycling process, the production costs of the enzymes are quite high, and adopting this process on a wider scale will result in high costs compared to cheaper production costs of virgin plastics, therefore limiting the use and acceptance of this process more widely in society.

Despite the multiple benefits of enzymatic recycling, it is not yet available on an industrial level, and hence, advancements to make this process more widely available are being researched. Several organisations such as Carbios, Samsara Eco and Loop industries, are already working towards expanding the use of enzymatic recycling. The regulatory pressures continue to influence the widespread use of enzymatic recycling, where the its proposed use enables cheaper production costs, an increase in usable enzymes and greater production to meet rising demands. Moreover, there are additional positives with its usage, including the integration of current recycling infrastructure to maximise industrial capabilities, further collaborations between organisations and academic institutions to advance scientific knowledge and promote a circular economy reducing environmental impacts and benefiting society.

The need for enzymatic recycling has been influenced by the greater demand of social and environmental considerations, in which more suitable plastic recycling methods are needed. Enzymatic recycling, in particular the depolymerisation of PET has many beneficial applications that aids in reducing environmental impacts, however, can be limited by the cost of production, and enzymes available. Ultimately, despite potential limitations, scientific advancements are being undertaken to make improvements to benefit society and the environment.

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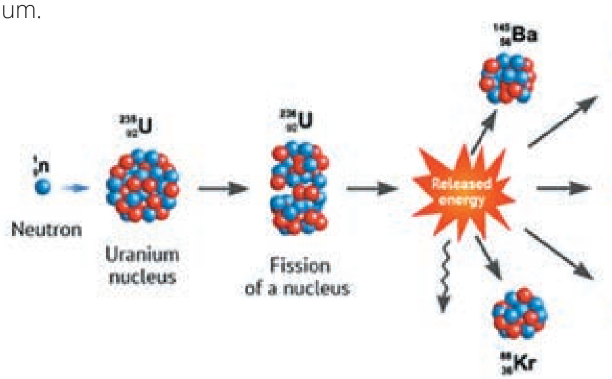
The future of nuclear power

Words by Josh Wang (Year 8)

Is Science Sustainable?

Nuclear power is a relatively new concept, emerging in the 20th century with the development of the Chicago Pile-1, a key component of the Manhattan Project. Traditionally, uranium-235 is used in these reactions because it is a fissile isotope of uranium that can initiate a chain reaction to produce energy (Figure 1). However, uranium comprises a scarce fraction of the Earth's crust, making up 0.00028%, with only a small percentage of this being usable for nuclear reactors.

Moreover, it is also relatively dangerous compared to alternative substances, as it not only produces hazardous substances such as radon from decay products, but also has waste that stays radioactive for approximately 10000 years before returning to normal levels of radioactivity. Thorium solves all these issues, as it isn't fissile by itself but is considered fertile, indicating it is still able to undergo fission reactions with a catalyst while being three times as abundant as uranium, comprising approximately 0.00105% of Earth's crust. So with most natural thorium being the ideal isotope to be used in nuclear reactors and producing similar amounts of energy in theoretical calculations, thorium is a more readily available and abundant material for fission compared to uranium.



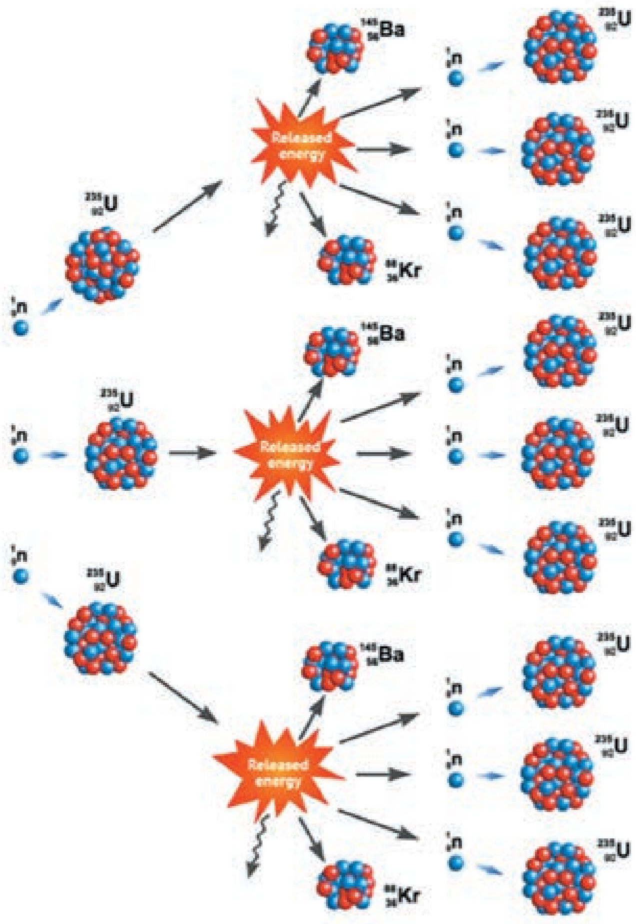


Figure 1: Diagram of chained nuclear fission

However, thorium will not work in the standard commercial nuclear reactors of today. This is because thorium is not fissile but fertile, meaning it needs to be 'bred' into a fissile element. By bombarding thorium with neutrons from a fissile element such as U-233, U-235 or P-239, it will produce T-233, which quickly decays into Pa-233, which has 91 protons, or one more than thorium. It is then separated from the thorium sample and left to naturally decay into U-233 (Figure 2), which is a fissile isotope of uranium and can be used to continue the breeding reaction. A successful thorium reactor will have to produce more fissile material than it creates. The ratio in which this material is produced is called the fissile conversion ratio and needs to be higher than 1.

However, this method poses a question: 'If thorium is converted to uranium, how is it more effective to use this method rather than directly using uranium?' Thorium is not intended to be used in standard nuclear reactors that utilise uranium, but is instead most suitable for a new experimental reactor named the 'Molten Salt Reactor' (MSR) (Figure 3). This type of reactor has two different types of fuel: solid and liquid fuel. Solid fuel is closer to commercialisation than liquid fuel reactors, as solid fuel is already commonly used in current nuclear reactors. However, it is less flexible and crucially has a lower fuel burn-up compared to liquid fuels. Liquid fuels are commonly made of a salt mixed with fertile material and fissile material, which are held in separate circuits. In this design, the by-products resulting from the fission are ideally constantly removed, as it allows for more fuel burn-up, which indicates how much energy is extracted from the material compared to its theoretical efficiency. Constant removal of by-products also results in a lower temperature to deal with after the reactor shuts down.

Thorium is a promising element for nuclear reactors, with experimental reactors such as Moltex Energy's Stable Salt Reactor reaching a burn-up on average between 120 and 200 Giga-watt days per metric tonne of uranium (GWd/tU) where the highest end products, such as China's dual programme,

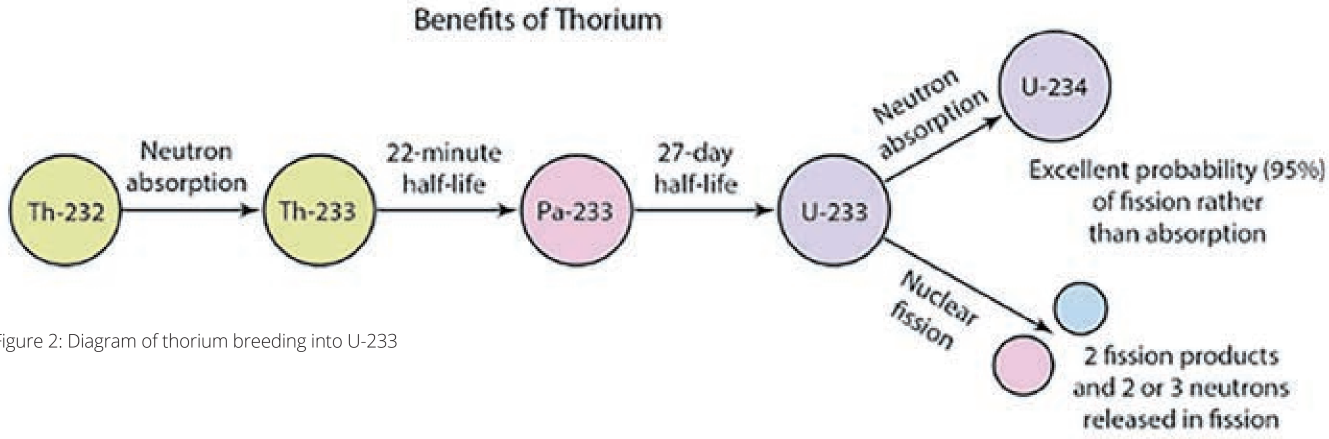


Figure 2: Diagram of thorium breeding into U-233

whose reactor can reach up to 330 GWd/tU (Figure 4). This is vastly more efficient when compared to what is commonly used in the most commercial reactor, such as Light Water Reactor, with a burn-up of only 40 to 60 GWd/tU. The available material for nuclear reactors for thorium is also much more abundant than uranium in the earth, while also being safer to mine and dispose of and safer in reactors when applying technologies such as meltable plugs which can drain fuel into chambers, thereby preventing meltdowns and catastrophic disasters such as Chernobyl.

In summary, thorium still requires many more years of development to be successfully commercialised, as it has inherent challenges with a lack of government support and international interest. Therefore, while it is unlikely that thorium and MSRs will see significant leaps forward in the next few years, it is a promising concept that will most definitely gain attention in the future when discussions on energy sustainability, particularly the utilisation of nuclear energy through fission occur.

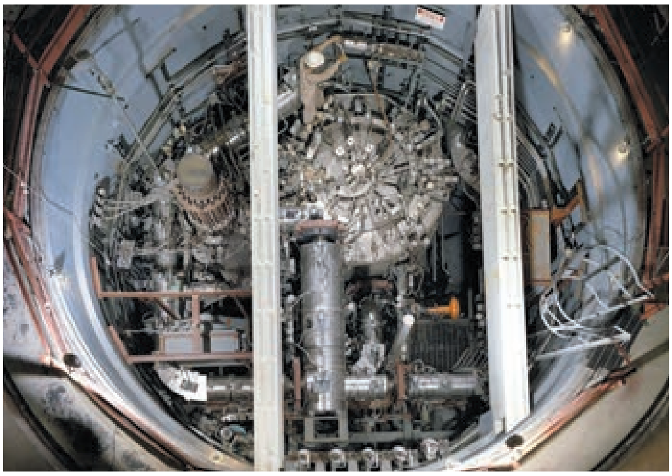


Figure 3: Top-down view of the molten salt reactor experiment at Oak Ridge National Laboratory

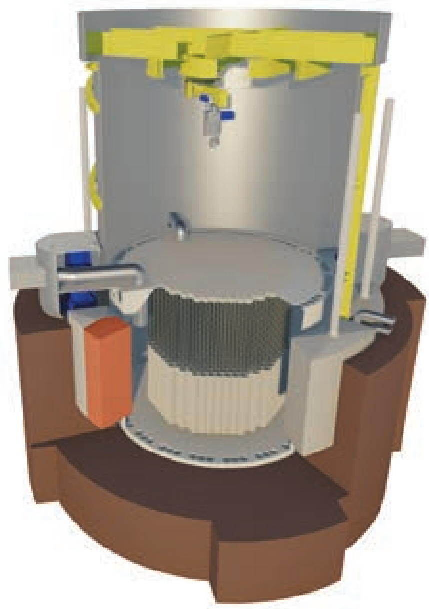


Figure 4: 3D model of Moltex Energy's Stable Salt Reactor (MSR)

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The turbocharger; widely unknown yet widely used

Words by Lucas Clayton (Year 8)

Is Science Sustainable?

For many years, turbocharging in the automotive industry has been primarily used to enhance the performance of various makes and models. But in a rapidly changing world, they are now pitched as an effective solution to improve the efficiency of vehicles without sacrificing performance. With multiple fuel-efficiency standards coming into effect, and the full force of enhanced climate change being felt across the world, turbocharging has never been so valuable whilst hybrid technology continues its development. It is therefore important to acknowledge turbocharging's valuable contribution to the automotive industry, so this article will explore the history, the clever yet simple engineering behind the turbocharger, its advantages and disadvantages, as well as the many unique variants of the turbocharger which enhance its effectiveness.

On the 16th of November 1905, Swiss engineer Dr. Alfred Büchi's design of a forced induction unit for an internal combustion engine, which would eventually become known as a turbocharger, was patented (No.204630). In 1911, Dr Alfred Büchi established a laboratory to further investigate and develop his design, and in 1918, amid World War I, the innovative forced-induction unit was fitted to some American military jets. The aim was to use the greater power delivered by the turbocharging system to improve the acceleration and top speed of the planes; crucial on the fast-changing battle ground.

The first production car to use turbocharging technology was the Oldsmobile Turbo Jetfire (Figure 1), which was available in the American market from 1962 until 1963. It produced 160kw of power at 4800rpm with its turbocharged 3.5l V8, whereas its primary competitor, the Chevrolet Monza Spider (which could be optioned with a turbocharger on the six-cylinder model), using a naturally aspirated 4.3l V8, created just 82kw. Turbocharging allowed the Oldsmobile to comfortably be the fastest in its segment – a valuable advantage in a performance and luxury focused market like America. However, the market was reluctant to accept the technology as it was expensive, and in this implication, required a special 'Turbo Rocket Fluid,' which needed to be refuelled about as frequently as the petrol tank. General Motors received multiple complaints regarding the vehicle's performance as many owners ran the car without the Turbo Rocket Fluid, as many couldn't be bothered with the additional maintenance. In 1965, General Motors offered a free downgrade to a slightly less powerful non-turbocharged model, which most owners took, making the original turbocharged model rare and valuable.

Figure 1 - The Jetfire

A turbocharger is positioned next to the engine block of an internal combustion engine, and with larger V-shaped engines, sometimes between cylinder banks. Every turbocharger has a turbine, that is spun by exhaust gasses, which then spins a compressor wheel to condense fresh air before it enters the engine. It also has other components to ensure efficiency and reliability. The turbocharging process is described below.

So that the turbocharger can obtain air, the compressor housing inlet is connected to the engine's air intake via a hose, and in some modern applications, this features a valve that can be opened or closed by the car's computer to manage the air flow. Before the air enters this hose and is compressed in the turbocharger, it passes through an air filter so that its impurities are removed, which allows for cleaner combustion and prevents unwanted particles from building up within the components.

Next, the purified air enters the turbocharger itself via the compressor housing inlet and is compressed by the compressor wheel. The compressor wheel consists of multiple blades of various sizes, which spin rapidly whilst air quickly flows through – forcing it to compress and become denser. The compressor wheel is powered by a turbine on the other side of a turbocharger, which will be discussed in greater depth later. The turbine and the compressor are mounted on the same shaft, so when the turbine spins, so does the compressor wheel.

The compressed air exits the turbocharger via the compressor housing outlet, and travels through the boost pipe, and then the intercooler. The intercooler cools the air, further increasing its density and therefore the amount of oxygen within the space. The air exits the intercooler and travels through the charge pipe towards the intake manifold.

A small yet crucial device known as a blow off valve is mounted within the boost pipe to prevent dangerously high pressure from being reached. When the throttle body is suddenly closed after being almost fully open at high rpm, it restricts air from entering the intake manifold. This is a problem as the compressor wheel continues to spin and force air into the system even after the flow of exhaust gases is drastically reduced from the turbine, due to inertia. The already dense air becomes trapped within the system and further pressurises, which can lead to dangerously high pressures being achieved, potentially damaging multiple parts. The air also wants to escape to create a homogenous pressure within the atmosphere, causing it to go back through the turbocharger's compressor, exerting significant pressure upon the turbocharger's bearings, potentially damaging them. The blow off valve opens in this scenario, to allow some air to escape the charge pipe to maintain a stable pressure within the system. This air is usually redirected back to the air intake system but can be released directly into the atmosphere. The release of pressure via the blow-off valve creates the distinct whooshing noise which is often associated with turbocharged engines.

On one side of the blow-off valve, the air in the intake manifold and a spring push against the valve, and on the other side, the air of equal pressure (equal when the throttle is open) in the charge pipe also applies force to the valve. This creates a slightly imbalanced force when the throttle is open, (as the force of the spring and the air are combined on one side) pushing the valve down, ensuring the blow-off valve remains closed and preventing the compressed air from escaping (Figure 2). When the throttle body closes, the air of greater pressure in the charge pipe exerts much more force upon the valve than the air and the spring in the intake manifold, forcing it to open by pushing it up, which allows air to escape (Figure 3).

At this stage, the fresh air passes through the same components as a non-turbocharged engine; through the throttle body, and intake manifold, and when the intake valve of a cylinder opens, the air rushes in and is reacted in the engine, usually in the 4-stroke cycle.

This is where turbochargers deliver their primary benefit: as the air that enters the engine is denser than in a non-turbocharged car due to the compression of the air, it contains more oxygen, so more fuel can be injected and combusted; producing more energy. This results in a greater power and torque output.

The turbocharging process is not complete; the exhaust gases are needed to power the compressor. As with a non-turbocharged engine, the exhaust gases exit via the exhaust manifold, but before the gases reach other components of the exhaust system, the gases enter the turbine housing. The exhaust gases flow through a small turbine within the housing which is connected to the compressor wheel by a shaft to provide it with kinetic energy. The fast flow of exhaust gases and the build-up of pressure within the relatively small exhaust system pushes the gases through the turbine and applies substantial force to it. When a greater quantity of exhaust gases is being produced, such as at high rpm or when a lot of fuel is being injected into the engine, the turbine will spin faster because the flow of exhaust gases is more abundant, and more force is therefore exerted upon its blades. Due to the pressure and the fast flow of the exhaust gases, most turbines can reach a maximum speed of approximately 250,000rpm.

Turbochargers also feature a wastegate, which is a small component mounted within the exhaust manifold or the turbine housing. This component is quite similar to the blow-off valve, as it opens or closes to release exhaust gases, by allowing the exhaust gases to bypass the turbine and directly enter the exhaust pipe. The wastegate is fully closed at low engine speeds and opens at high rpm when there is an

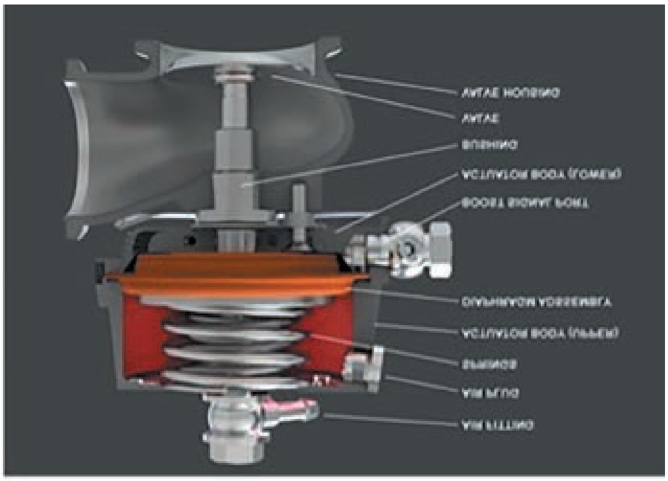

Figure 2 - An external wastegate

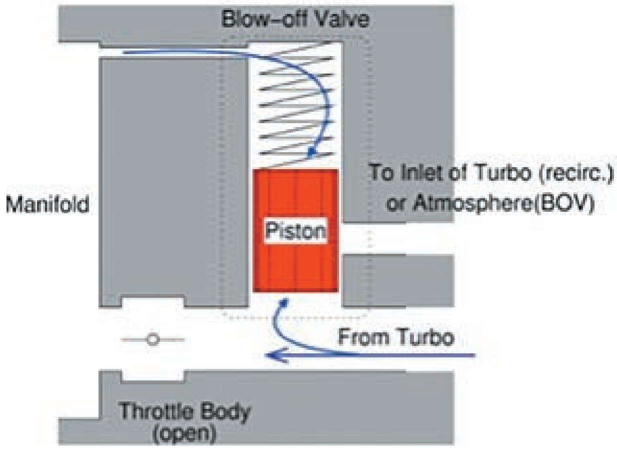

Figure 3

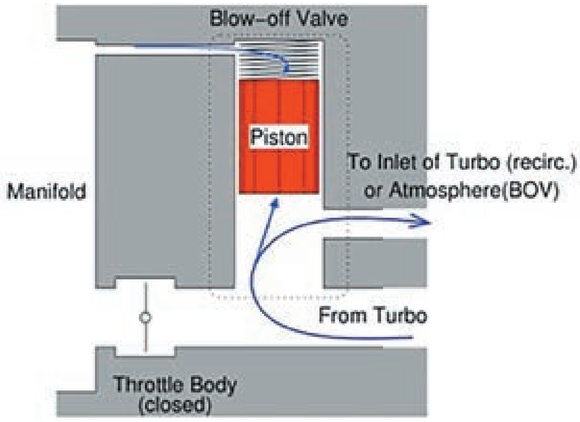

Figure 4

abundant flow of exhaust gases to prevent too much pressure from building up within the exhaust manifold. Releasing exhaust gases also prevents the turbine and compressor wheel from spinning so quickly that the turbocharger compresses so much air that the engine cannot use all of it, which can cause a dangerous build-up of pressure in the intake manifold or compressor surge.

There are two types of wastegates: external and internal wastegates. The valve of an external wastegate is held close by a spring (see Figure 4), and when the force of the exhaust gases acting upon the valve is greater than that of the spring, the valve is forced to open, allowing some exhaust gases to flow through it.

Similarly, the internal wastegate features a valve which is installed within the turbine housing, which is connected to a spring via an actuator, and once the force of the exhaust gases exceeds that of the spring, it will open and release pressure. Internal wastegates are more common than external wastegate in production vehicles, as they are built into the turbine housing, lowering production costs.

Finally, the exhaust gases travel down the exhaust pipe to the catalytic convertor, where some gases, such as carbon monoxide (CO) are converted into less harmful gases, such as carbon dioxide (CO_2). Lastly, just like any modern production car, the gases exit through the muffler, reducing the level of noise produced by the vehicle.

Turbocharging has its fair share of advantages. As It adds significant power to engines, smaller, more efficient engines can achieve the same power output as larger capacity non-turbocharged engines. This allows manufacturers to fit these smaller, more efficient engines to vehicles whilst still providing the vehicle with a level of performance usually achieved by larger capacity non-turbocharged engines. For example, a Hyundai Tucson optioned with the larger, non-turbocharged 2.0 litre four-cylinder engine produces 110kw of power and requires 8.1l/100km, whereas the version using a 1.6 litre turbocharged four-cylinder produces 132kw and uses 6.7l/100km. The significantly better fuel economy of small, turbocharged engines over equally powerful larger capacity engines is clear.

Smaller engines are more fuel efficient than larger engines, as their components require less energy and therefore less fuel to move as they have less mass and inertia. Additionally, smaller turbocharged engines are generally lighter than equally powerful larger capacity engine that they replace, so less energy is required to overcome the inertia of the entire vehicle when accelerating, further enhancing fuel efficiency.

However, when the engine is under stress, fuel efficiency is worse, because more fuel is injected into the cylinders than a larger engine (depending on capacity) to produce more power, as the air is denser. In most conditions, where the vehicle is idling or gently cruising a smaller turbocharged engine is considerably more fuel efficient than a larger non-turbocharged engine. Consequently, less carbon dioxide and other harmful greenhouse gases are released into the atmosphere during the vehicle's operation reducing its contribution to global warming as well as its impact to the nearby environment. Furthermore, this saves the owners of turbocharged cars money.

Turbochargers allow the engine to produce peak torque and perform well at low engine speeds, whereas a non-turbocharged engine would struggle. As small turbochargers (which most typical production cars use) provide a strong supply of compressed air at low engine speeds, compressing the air up to 2.5x (depending on the size), a lot of fuel can be injected; producing a large force. In comparison, the same engine without a turbocharger would produce a lot less energy at the same rpm, as less oxygen would be entering the cylinders so less fuel could be reacted.

Unfortunately, there are a few difficulties and downsides with turbocharging.

Turbochargers contain many fragile and fast-moving components which must be assembled with a high degree of precision so that they operate smoothly and reliably. Consequently, turbocharged engines require more labour and time to assemble, adding to the cost of production and the sale price.

Larger turbines possess more mass and therefore more inertia than smaller turbines. Consequently, the turbines of larger turbochargers accelerate more slowly than smaller turbochargers, so they take longer to begin providing boost to the engine, and struggle to provide boost at low rpm. Smaller turbochargers have little inertia and the force of the exhaust gases at low engine speeds is enough to spin the turbocharger at a substantial speed. Smaller turbochargers still take time to begin providing boost, albeit much less than a larger turbocharger, whilst a larger capacity non-turbocharged engine would provide its power almost instantly. Larger turbochargers struggle to operate at low rpm as the limited and slow flow of exhaust gases doesn't exert enough force upon the turbine blades to overcome enough inertia to accelerate it to a speed where it creates useable boost. At high rpm, a larger turbocharger would be spinning quickly and easily, as the fast flow of exhaust gases provides plentiful force to the turbine, although it would still take longer to accelerate up to speed than a smaller turbocharger. In these conditions, a larger turbocharger would be preferred over a smaller turbocharger as it can compress more air once it has accelerated and allows more fuel to be injected. No matter the engine speed, a turbocharger's turbine needs time to spin up to provide power whereas an equally powerful non-turbocharged engine would deliver power instantly. The variants of turbochargers described below have unique designs to mitigate these problems to deliver power instantaneously.

There are multiple variants of turbochargers, for example, the twin-scroll turbocharger. It is essentially the same as a normal turbocharger, but the exhaust gases which spin the turbine are separated in the exhaust manifold until they enter the turbine housing. The exhaust manifold, which transports the exhaust gases to the turbocharger is split in two (Figure 5), and the positioning of the cylinders within the engine determines which half a cylinder feeds. For example, cylinders 2 and 3 in a common 4-cylinder engine provide exhaust gases to one half, and cylinders 1 and 4, the other. In more exotic (and usually more powerful) V-shaped engines, one cylinder bank provides exhaust gases to one half of the exhaust manifold and the opposite bank, the other. The division of exhaust gases prevents the paths of flow of the exhaust gases from disrupting each other and intersecting; especially when the gases are rushing under substantial acceleration. Although the exhaust gases still intersect in the divided manifold, there are fewer pathways of exhaust gases (as there are fewer gases in a half) interrupting each other, whereas the gases in a normal turbocharger would cause all intersect, slowing them down more. As the flow is faster and more direct, the turbine spins up faster and too a greater maximum speed than the turbine of a standard turbocharger, allowing for a greater boost pressure in all conditions. In summary, the twin scroll turbocharger, optimises the flow of exhaust gases, improving engine performance at all engines speeds.

There is also the variable geometry turbocharger, which is also known as the variable nozzle turbocharger, uses information from the engine control unit (ECU) to optimise the flow of exhaust gases. This is achieved by the many small 'vanes' which surround the turbine (Figure 6), which are opened or closed

Figure 5 - Twin scroll turbocharger

Figure 6 - A variable geometry turbocharger

by the ECU to pressurise the exhaust gases as they enter the turbine housing, to spin the turbine faster. When these vanes are fully closed, which is often when the flow of exhaust gases is minimal, the airflow to the turbine is restricted, increasing the pressure of the exhaust gases. This causes the turbine to accelerate more quickly and to a faster speed, as the further pressurised exhaust gases contain greater potential energy than in a standard turbocharger which is released as greater kinetic energy upon the turbine's blades. Consequently, at low engine speeds, the variable-geometry turbocharger provides more compressed air and stronger performance than a standard turbocharger. As the flow of exhaust gases increases, the vanes slightly open to continue pressurising the exhaust gases, whilst not fully closing to prevent unwanted pressures from being reached. When the throttle is fully open and the engine is at high rpm, the vanes will fully open as the energy exerted upon the turbine blades from the very fast flow of exhaust gases allows for plentiful turbine speed. In summary the variable geometry turbocharger pressurises exhaust gases by restricting the flow of exhaust gases; allowing the turbine to accelerate more quickly and to a greater speed; particularly at low engine speeds.

The electric turbocharger has a simple design, yet it still provides engines with strong performance. An electric motor is mounted on the shaft shared by the compressor wheel and the turbine, which engages when required to accelerate the compressor wheel instantly (Figure 7); virtually eliminating turbo lag. When any quantity of power is demanded, the computer mounted within the electric turbocharger deciphers how fast the electric motor must spin the compressor. The electric motor only spins the compressor wheel for a few seconds, usually while the turbine is accelerating to its required speed, and then the electric motor reduces the force it applies to the compressor and hands majority of the load to the turbine. The electric motor draws power from what is usually a 48-volt battery, as these turbochargers are quite new and generally feature in hybrid vehicles. The compressor can accelerate very quickly and reach its maximum speed and therefore maximum boost at any engine speed, so engines with these turbochargers feature very strong performance in all conditions. As the electric motor within the turbocharger applies a great force to the compressor wheel in any conditions; spinning it up to its required speed almost instantly, larger turbochargers which can provide greater boost pressure but experience significant turbo lag when powered exclusively by exhaust gasses can be implemented. The electric turbocharger spins the compressor up to speed instantly due to its inbuilt electric motor, allowing for strong performance at all engine speeds and for larger turbochargers to be fitted.

Most high-performance vehicles with large engines often feature twin-turbocharging technology. Most Utes also use two turbochargers, and some high-performance cars even feature three or four, but five is unheard of. In a basic twin-turbo system, one turbocharger provides compressed air to one half of the engine, and the other turbocharger, the other half. A V6 engine featuring this set-up has one turbocharger per cylinder bank, and an inline engine is split so that each turbocharger receives the same amount of exhaust gases.

Sequential turbocharging can only be applied to twin-turbocharged engines, as it requires two different turbochargers to function. Sequentially turbocharged engines feature one large turbocharger and one small turbocharger.

When power is demanded at low engine rpm, the car's computer shuts off the larger turbocharger by closing its Boost Pressure Control Valve (BPCV); a valve located in front of the turbine inlet which controls the flow of exhaust gases into the turbocharger. The minimal flow of exhaust gases is directed entirely to the small turbocharger, which spins up quickly as it features little mass and therefore little inertia. It also reaches a high speed and provides near instant boost pressure to the engine and therefore decent power as well as response, bestowing the engine with strong low-speed performance.

As the revs increase, often at around 3,000 rpm, the BPCV of the larger turbocharger gradually begins to open, and the valve of the smaller turbocharger begins to close. This process begins to accelerate the larger turbine, and as the flow of exhaust gases further increases, the BPCV of the larger turbocharger opens more, whilst the BPCV of the smaller turbocharger begins to close. Once the larger turbine has sufficiently accelerated, often at high rpm, the BPCV of the larger turbocharger opens as much as required, whilst the BPCV of the smaller turbocharger partially closes to prioritise air flow to the larger turbocharger which creates greater boost pressure than the smaller turbo.

The sequential turbocharger combines the benefits of a small turbocharger and large turbocharger, providing strong performance at low rpm whilst providing lots of power at high rpm.

Compound turbocharging is a unique variation of twin turbocharging, as one turbocharger compresses air which then directly enters the compressor inlet of the other turbocharger (Figure 8). When acceleration is required, the fresh air first

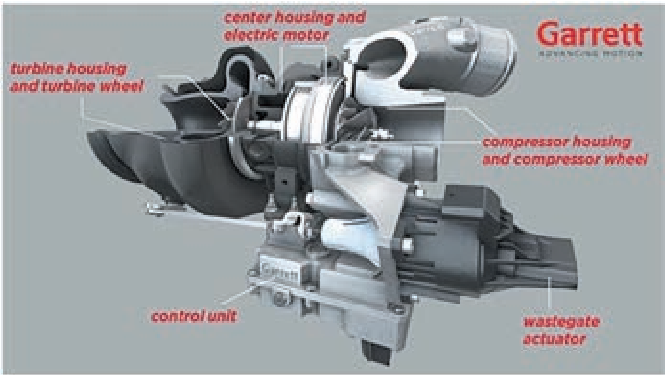

Figure 7 - The electric turbocharger

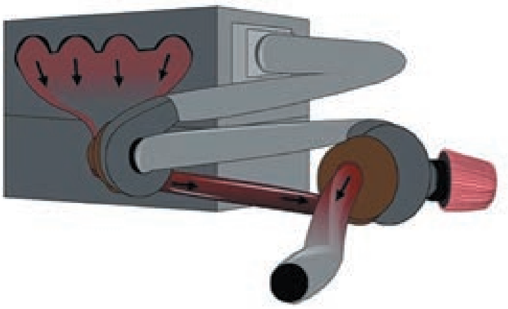
Figure 8 - The exhaust gases in some sequential turbocharging systems drive both turbines before exiting the car.

enters the larger turbocharger, which won't create meaningful boost at low engine speeds, and then flows to the smaller, more responsive turbocharger which will sufficiently compress the air and produce decent boost pressure at low rpm. The exhaust gases flow through the smaller turbo's turbine before entering the larger one, so that it spools up as quickly as possible to quickly provide boost. Both turbochargers usually feature their own pressure controlling waste gates to ensure reliability and an optimal flow of air. At high rpm, when the larger turbocharger is engaged, the smaller turbocharger's role is to further compresses the air, so the two turbochargers begin to act as one. Consequently, air delivered to the engine by the compound turbocharging systems is significantly denser than the air delivered by a normal twin-turbocharged system. This allows the engine to inject more fuel and release more energy. Compound turbocharging systems are rare in production vehicles because these systems are more expensive than other variants of twin-turbocharging. The compound turbocharging system, similarly, to a sequential turbocharging system, allows for quick response and power at low engine speeds, as well as high power at high rpm due to the heavily compressed air delivered to the engine when both turbochargers are engaged.

In conclusion, the turbocharger has greatly contributed to the automotive industry by allowing manufacturers to produce quick and efficient vehicles. The turbocharger is significantly reducing the emissions of the automotive industry whilst hybrid and EV technologies continue to develop. By providing strong performance and minimising the impact of vehicles on the environment whilst saving consumers money, the turbocharger has undoubtedly contributed greatly to modern society.

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Microwave-aided hydrogen synthesis; what are its applications?

Words by Luke Economos (Year 12)

Is Science Sustainable?

Global temperatures have reached the highest yearly average in recorded history, with an average surface temperature of 15.1˚C. Global warming has been accelerated by the Greenhouse Effect, where greenhouse gases reflect thermal energy back down onto the earth. As the burning of fossil fuels is a key contributor to greenhouse gas emissions, the need for alternatives to fossil fuels is rapidly growing. In the last decade, significant developments in material chemistry have allowed for the production of hydrogen gas as a consistent source of fuel. However, the high energy cost of hydrogen production has reduced its practical usage. Recently, scientists have developed a new method of synthesizing hydrogen gas using microwave technology.

Hydrogen gas rarely appears naturally, such as in volcanic gases or hydrothermal vents. Instead, it has to be synthesised through chemical processes. These include steam methane reforming, alkaline water electrolysis and solid oxide water electrolysis. Currently, over 95% of all hydrogen gas is produced from natural gas through the process of steam methane reforming. This process involves using high temperatures, up to 1000˚C, to cause a redox reaction between water and methane to produce hydrogen gas. Redox reactions involve the transfer of electrons. In this reaction, hydrogen in methane is reduced thereby gaining electrons to form hydrogen gas as seen below.

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Simultaneously, the carbon monoxide biproduct reacts with steam in a water-gas shift reaction to produce even more hydrogen as well as carbon dioxide. This can be seen in the following equation:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Hydrogen gas can also be made through the alkaline electrolysis of water. In this process, water is split by an electrical current into hydrogen and oxygen gases in an electrolyser. At the anode, water is oxidised producing oxygen gas. At the cathode water is reduced, producing hydrogen gas. This is illustrated in the equations below that represent the half equations for oxidation at the anode and reduction at the cathode respectively.

$$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

Another method of hydrogen production is solid oxide water electrolysis. This uses a solid electrolyte to split water under high temperatures into hydrogen and oxygen. At the anode, oxygen ions are oxidised, while at the cathode, water is reduced, as seen below.

$$2O^{2-} \rightarrow O_2 + 4e^-$$

$$H_2O + 2e^- \rightarrow H_2 + O^{2-}$$

This method requires more energy to create a high temperature environment but has a higher output of hydrogen. Due to its high energy requirements, solid oxide water electrolysis is very rarely used. Recently, an alternative process to supply the high energy requirements for solid oxide water electrolysis has been developed using microwaves. Microwaves are focused onto the solid oxide electrolyte to supply thermal energy. This also reduces the activation energy of reduction. The focused energy creates oxygen vacancies, (defects in the structure of water) that allow oxygen and hydrogen ions to detach themselves and form their respective gases. This can be seen in Figure 1, where oxygen production rises as microwaves are applied.

Climate change has driven the need for the development of new processes for green energy production. Climate change has caused large scale economic and social damage, such as damage to ecosystems, loss of biodiversity and water scarcity. The industrial burning of fossil fuels, (a key cause of climate change) releases greenhouse gases such as carbon dioxide into the atmosphere, which then traps heat within the atmosphere and warms the planet. To counteract this, governments have incentivised businesses to switch to alternative fuel sources. Since both electrolysis to produce hydrogen and it's subsequent combustion generates no carbon dioxide, governments are willing to provide research funding for hydrogen production. This can be seen in the Korean Ministry of Trade, Industry, and Energy's investment into Pohang University's study on the use of microwaves in hydrogen synthesis. By driving government investment into research for green energy, climate change has influenced the development of microwave hydrogen synthesis.

The development of microwave electrolysis has been influenced by current problems with hydrogen production. The most common form of hydrogen production, steam methane reforming, releases carbon dioxide into the atmosphere and requires the natural gas methane. Like fossil fuel combustion, this contributes to the greenhouse effect and accelerates climate change. Since methane is a natural gas, it needs to be mined and extracted from the earth. This requires the use of heavy machinery that also release greenhouse gases into the atmosphere. Additionally, to extract methane, land needs to be cleared for excavation, potentially damaging local ecosystems and destroying vegetation that would otherwise offset carbon emissions by reabsorbing carbon dioxide. Although hydrogen

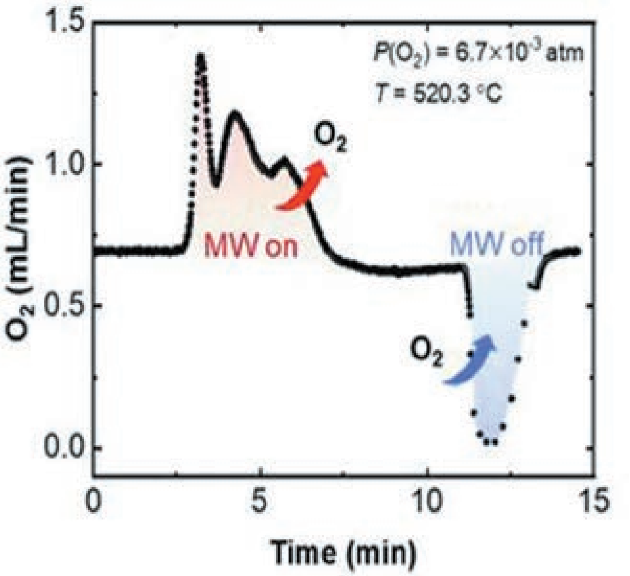

Figure 1: The targeted use of microwaves to create oxygen vacancies

can be produced through renewable means, close to 99% of all hydrogen produced globally is synthesized using fossil fuels. As demand for carbon free "green hydrogen" is predicted to increase by over 1000% in the next decade, researchers are incentivised to develop cleaner forms of hydrogen production, such as through research into electrolysis.

Global demand for hydrogen gas has influenced the development of new methods of production. Hydrogen gas has a variety of uses but is mostly used for the creation of fuel as well as being used in farming. Approximately 50% of all global hydrogen production is used for the creation of nitrogenous fertiliser, while another 25% is used for the conversion of oil into fuel for transport. As these industries expand, strain will be put on the hydrogen industry to match their growth. With global annual demand for hydrogen rising above 100 Megatons, businesses have begun to invest in research on more efficient hydrogen production to meet this rising demand. This can be seen in the Circle Foundation's support for the study into the microwave method stating that "microwaved base hydrogen synthesis can reduce the cost of production and allow for the reuse of hydrogen rich waste".

The use of microwave technology in hydrogen synthesis has the potential to reduce the cost of hydrogen production. The current process of hydrogen gas synthesis is costly and slow due to the high temperatures and long production period that are required for steam methane reforming. The use of microwaves in solid water electrolysis can decrease the activation energy by over 60%, as well as fulfilling 75% of the heat requirement. This could significantly decrease the energy cost of hydrogen production. Additionally, the process creates oxygen vacancies at a far faster rate than traditional methods. Although oxygen vacancies can take hours to form under high temperatures, Figure 1 shows this process can create vacancies in periods as short as fifteen minutes, increasing the rate at which hydrogen can be produced industrially. A lower cost of production and higher production capacity could potentially reduce the market price of hydrogen gas. Since hydrogen is used in the production of fertiliser and as fuel for transport, a lower price of hydrogen could have effects on these other markets, potentially reducing the price of food and transport in the future.

Additionally, the new microwave-assisted process of creating hydrogen could allow for the reuse of hydrogen-rich waste. Since microwaves lower the activation energy needed for redox reactions, hydrogen-rich materials which are more resistant to reduction are then able to be recycled. Seawater, plastic waste, biomass and low carbon alcohols have all been found to be a new possible source of hydrogen. This could eliminate much of the requirement for water, making the process less expensive while also being possible in areas which do not have an abundance of water. The potential use of hydrogen-rich waste products could have a positive effect on the environment, as waste that is used for hydrogen production will not be discarded into the ocean or landfill.

A key limitation in microwave driven hydrogen synthesis is the effect that microwaves can have on catalysts. When microwaves are applied to a chemical reaction, uneven areas of intense heat are created. These 'hot spots' can damage solid metal catalysts through overheating. Since most catalysts used in solid water electrolysis are rare metals, such as platinum and iridium, having to replace them often will make this method more expensive, thus reducing its potential for wider use.

Overall, the use of microwaves in solid oxide water electrolysis has the potential to reduce the price of hydrogen gas, as well as allowing for the recycling of waste for hydrogen production. However, it is limited by the damage that microwaves can cause to catalysts. This research has been influenced by the pressing problems involved in combatting climate change, rising global demand for hydrogen and issues with the current forms of hydrogen synthesis.

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Algae energy

An acre of algae can churn out up to 20,000 litres of biofuel annually — far more than corn or soy.

Is selective extraction the answer to more sustainable cobalt extraction?

Words by Owen Chen (Year 12)

Is Science Sustainable?

Cobalt is utilised in various industries such as battery and technology production, hence, 230,000 metric tons of cobalt is produced annually across the world. However, current methods used to extract cobalt from ores such as electrolysis, froth flotation, and acid leaching damage the environment and require large energy expenditure. A new cobalt extraction technique using selective precipitation has been developed by researchers at the University of Pennsylvania, and it may be more energy efficient and environmentally friendly compared to current methods. This article will discuss the factors influencing this technique, as well as its applications and limitations.

Cobalt is a moderately reactive metal, so it is usually found naturally in compound form. In order to use cobalt to make alloys with specific properties (e.g., high melting points), cobalt must be extracted from compounds and purified. This often involves separating it from nickel, another naturally occurring metal that is commonly found absorbed into the same ore deposits as cobalt. Separating nickel and cobalt is difficult due to them having similar chemical properties.
The extraction technique utilises selective precipitation, which relies on the fact that ionic compounds containing nickel or cobalt form a precipitate at different concentrations, depending on their solubility product constant (K_{sp}). The lower the compound's K_{sp} value, the lower its solubility (Ismail). If the compound's K_{sp} value is more than two orders of magnitude (10^2) greater than another compound in the same solution, then almost all the less soluble compound (lower K_{sp} value) will precipitate before the more soluble compound does. At 25°C, the researchers discovered that reacting nickel with carbonate produces nickel(II) carbonate with a K_{sp} value of 6.6×10^{-9}, while reacting cobalt with carbonate produces cobalt(II) carbonate with a K_{sp} value of 1.4×10^{-13}. As the difference in K_{sp} values (4.71×10^4) is far larger than two order of magnitude, meaning almost all of the cobalt(II) carbonate (lower K_{sp} value) in a solution will precipitate well before the nickel(II) carbonate.

This extraction technique involves reacting and dissolving ores containing both cobalt and nickel into nitric acid, producing soluble cobalt and nickel salts (See Figure 1 and Equations 1,2).

Sodium carbonate is then added to the solution, allowing the cobalt ions to form a cobalt (II) carbonate precipitate (highlighted in orange) while the nickel cations remain in aqueous form (See Figure 2 and Equations 3,4).

Eq 1: $Co_{(s)} + 2HNO_{3(aq)} \rightarrow Co(NO_3)_{2(aq)} + H_{2(g)}$

Eq 2: $Ni_{(s)} + 2HNO_{3(aq)} \rightarrow Ni(NO_3)_{2(aq)} + H_{2(g)}$

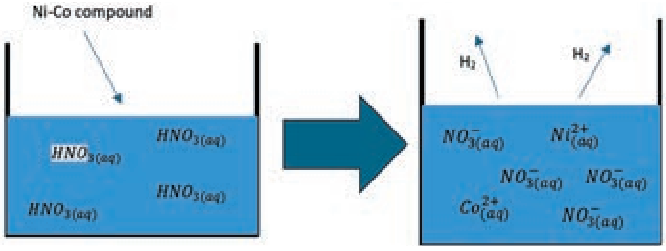

Figure 1: A diagram showing compounds containing nickel and cobalt being dissolved in nitric acid.

The cobalt(II) carbonate can then be physically separated from the mixture using filtration and processed separately to the nickel(II) carbonate.

Eq 3: $Co(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CoCO_{3(s)} + 2NaNO_{3(aq)}$

Eq 4: $Ni(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow NiCO_{3(aq)} + 2NaNO_{3(aq)}$

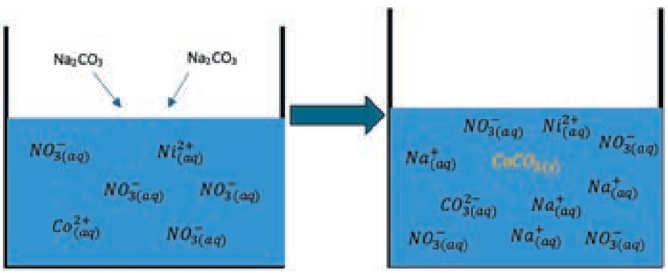

Figure 2: Adding sodium carbonate to the mixture results in cobalt being precipitated.

Societal needs have driven the research which has led to the development of this extraction technique. Cobalt is used extensively across multiple areas of society, including electric vehicle manufacturing, smartphone making, and battery production. The high demand for cobalt is causing an increase in its scarcity because it is being used at a faster rate than that at which it is being mined and processed. Efforts to harvest cobalt will only become more costly as ores deposits are used up, forcing mining companies to dig further underground or in less accessible regions to find new deposits. A 2024 report by the International Energy Agency projected that future cobalt production will not be able to keep up with consumer demand. Consequently, there would be a shortage of products such as batteries, which would then detriment technology production. Members of society would not be able to purchase technology such as phones and laptops, depriving them of the communication and rapid access to information these devices provide. Federal government agencies such as Life Sciences PA, who act in the best interest of the public, are motivated to fund research into more efficient and cost-effective cobalt extraction processes to prevent this decline from happening. This includes the new extraction technique, which is how the research team from the University of Pennsylvania was able to acquire the capital necessary to research this extraction technique for cobalt and nickel. As such, society's need for cobalt in many daily applications influenced the funding of research and experimentation, leading to the development of this process.

Political factors were another influence driving the development of this extraction technique. Many countries other than Congo have large cobalt reserves but lack the infrastructure to mine it. As of now, most cobalt mines that the United States rely on are owned by China or the Democratic Republic of Congo. From the American government's perspective, this is problematic because breakdowns in diplomatic relations between the U.S. and either of these countries could result in a trade conflict and cobalt deprivation to the U.S. This would be devastating to a technology reliant society such as the U.S., as cobalt is an essential component of many digital products. Subsequently, the U.S. government is interested in having its own domestic cobalt production. However, this has been previously quite difficult to do, since cobalt mining and extraction requires costly specialised infrastructure such as excavators and leaching tanks. There was a need for more accessible method of mining cobalt, and so this became the focal point for some American research groups from institutions such as Northwestern University and Inderscience Publishers, eventually leading to a group in Pennsylvania developing this extraction technique. Hence, political risk has compelled scientists from America into developing this extraction technique as a way of protecting American technology production.

The extraction technique has multiple applications owing to its low cost and minimal environmental impact. As there is a sufficiently large difference in K_{sp} values between cobalt(II) carbonate and nickel(II) carbonate for selective precipitation to occur at 25°C, this means the reaction requires minimal heating to occur. As such, a lower amount of money is needed to heat the reactants in contrast to methods such as electrolysis, which requires high energy expenditure due to constant electrical energy usage. Furthermore, the extraction technique does not need highly specialised equipment, as it only requires the tanks containing the solution to be acid proof. This makes it cheaper than other techniques such as froth flotation, which requires the purchase and maintenance of specialised equipment such as flotation cells and induction motors. Hence, the overall cost of the extraction technique is much lower than that of other methods.

Another advantage of the extraction technique is its minimal impact on the environment. As shown in the Equations 3 and 4, the precipitation reaction does not produce any gases that could cause pollution or global warming. This makes the production process more environmentally sustainable compared to current methods such as froth flotation, which produces environmentally harmful greenhouse gases such as carbon dioxide.

Furthermore, the sodium nitrate produced in the reaction could be sold by manufacturers to other industries that might require them, such as the food industry for meat preservation. This means the extraction technique could potentially have no waste products, resulting in minimal environmental damage as no substances would be disposed of.

While the extraction technique has various applications, it may be limited by the processes it uses which reduces its efficiency and reliability. As the precipitation reaction progresses, reactants are increasingly used up and converted to products. Consequently, the concentration of the reactants decreases over time, slowing down the rate of reaction. This means precipitating the last moles of cobalt cations out of the solution will take an unproportionately long time relative to its yield. Manufacturers will have to decide between cutting the reaction short and leaving some cobalt unprecipitated or waiting an extended period for the reaction to finish. Either way, the yield of cobalt using this technique will be diminished.

Another possible drawback of the extraction technique is that it requires constant monitoring. If too much sodium carbonate is added to the solution, all the cobalt will be reacted resulting in the unwanted precipitation of nickel. This would negate the chemical purpose of the technique, so the number of moles of cobalt(II) nitrate would need to be continuously tracked to avoid too much sodium carbonate being added. Otherwise, the manufacturers would be forced to re-dissolve the precipitation, costing additional time and money. While careful monitoring and management may prevent this error, the sensitive nature of the reaction means there is a substantial chance of it occurring which limits the technique's commercial viability.

To summarise, selective precipitation is an emerging cobalt extraction technique that appears better than all current alternative extraction methods. It was influenced by social, ethical, and political factors, and its strengths lies in its lower cost and environmental impact. While the extraction technique is currently limited in its efficiency and reliability, it still has significant potential to become the leading cobalt extraction method in the future.

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Busy city bees

Bees in cities often produce more honey than country bees, thanks to greater flower variety.

Nuclear fusion – is it the answer?

Words by Tate Symons (Year 8)

Is Science Sustainable?

Nuclear fusion is undeniably a potent form of energy. However, it is also much less known and understood than its sibling, nuclear fission. This information report covers the process used to generate energy from the reaction, its environmental impact and much more.

Nuclear fusion is the polar opposite of nuclear fission. Instead of separating an atom into 2 smaller atoms, nuclear fusion merges 2 atoms into a larger one. This feat is much harder to achieve than splitting an atom, however, it also creates significantly more energy. The primary reason nuclear fusion is considered to be much more difficult is due to the electrostatic force between the two atoms, the Coulomb force. Because the neutrons that cause nuclear fission don't need to overcome this force, much less extreme conditions are necessary for nuclear fission to occur. In nuclear fusion, the particles must overcome the Coulomb force and join together to fuse. Once the atoms are close enough, the nuclear force, the force that holds the nucleons together, will overpower the Coulomb force. This causes the particles to merge, creating a new atom.

During fusion, something called a "mass defect" occurs. During the reaction, a certain amount of mass (m) is lost and converted into energy (E), as per the equation $E=mc^2$ (where c = the speed of light). This energy is then transferred into kinetic energy in the biproducts of the reactants. Since heat is just the movement of atoms, the increase in kinetic energy causes an increase in heat.

Before I discuss the types of reactors, I first must talk about the fuel that they use. A key hurdle for nuclear reactors is net energy. Fusion requires significant amounts of energy to even start to heat up the fuel so that it can fuse and overpower Coulomb's force. An important aspect of making nuclear fusion viable is creating a reactor that can achieve a large, cost-effective net power. Net energy has been achieved several times, from both main types of reactors. To decrease the amount of energy needed, lighter atoms are used in fusion, as opposed to the atoms used in fission. The reason these lighter elements are used comes back to Coulomb's force. Coulomb's force, in more complex wording, is the attraction between oppositely charged particles and the repulsion between identically charged particles. In this case, the relevant particles are protons. Because larger atoms have more protons, the Coulomb force is stronger, meaning that more heat is required to start the fusion reaction. This, in turn, makes the reactor require more energy, making net power even more difficult.

This is the main reason why deuterium and tritium, the main fuels used in nuclear fusion, are used. They are both isotopes of hydrogen, meaning they both have one proton (Figure 1). This is ideal for the nuclear fusion reaction. Deuterium and tritium each have 2 or 3 more neutrons than normal hydrogen, respectively. These 2 isotopes are the heaviest isotopes capable of being used as fusion fuel as hydrogen 4 and above are incredibly unstable and only found in a laboratory setting. This makes deuterium and tritium ideal fusion fuels, as the extra mass enables the fusion reaction to produce more energy than it would with lighter isotopes. The deuterium-tritium reaction does have one main flaw, however: rarity and sustainability. Deuterium is very common, being found in heavy water, but tritium is the larger issue. Tritium is a very rare resource, there being only 20kg on Earth, most of which is used in thermonuclear weapons, and it is a radioactive isotope with a low half-life of 12 years.

There are currently are two ways to overcome the rareity of tritium – tritium breeding and helium-3. Tritium breeding is when a special panelling is added to a fusion chamber. This panelling contains an isotope of lithium. As seen in Figure 2, the Deuterium tritium reaction makes an extra electron. When this electron interacts with these panels, it creates tritium. This allows us to create a completely self-sustaining source of tritium. The main issue with this design, is that the isotope of lithium used is difficult to enrich with current technology. Helium 3 is a stable fusion fuel alternative to tritium. Helium 3 is not much less rare on Earth than tritium is, but the main advantage of helium 3 is that it can be found in large quantities on the moon due to it being constantly bombarded with solar wind from the sun. The idea behind using helium 3 as an alternative is that it can be

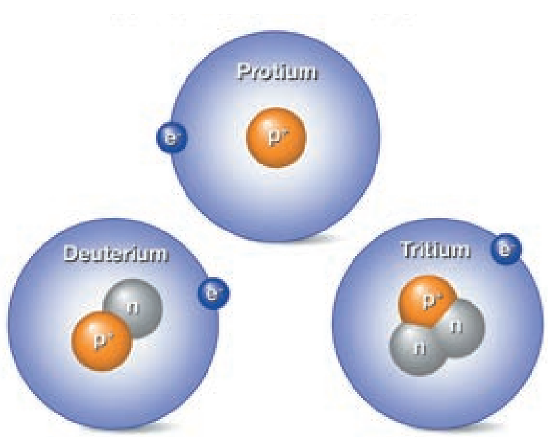

Figure 1: Isotopes of hydrogen

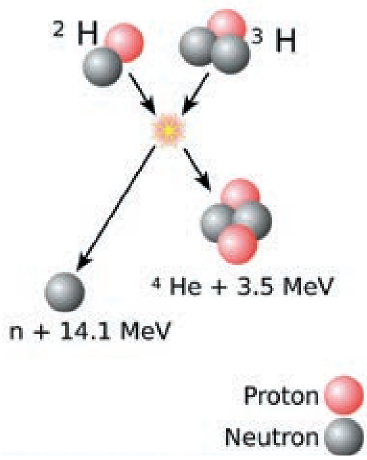

Figure 3: Deuterium + Tritium fusion reaction

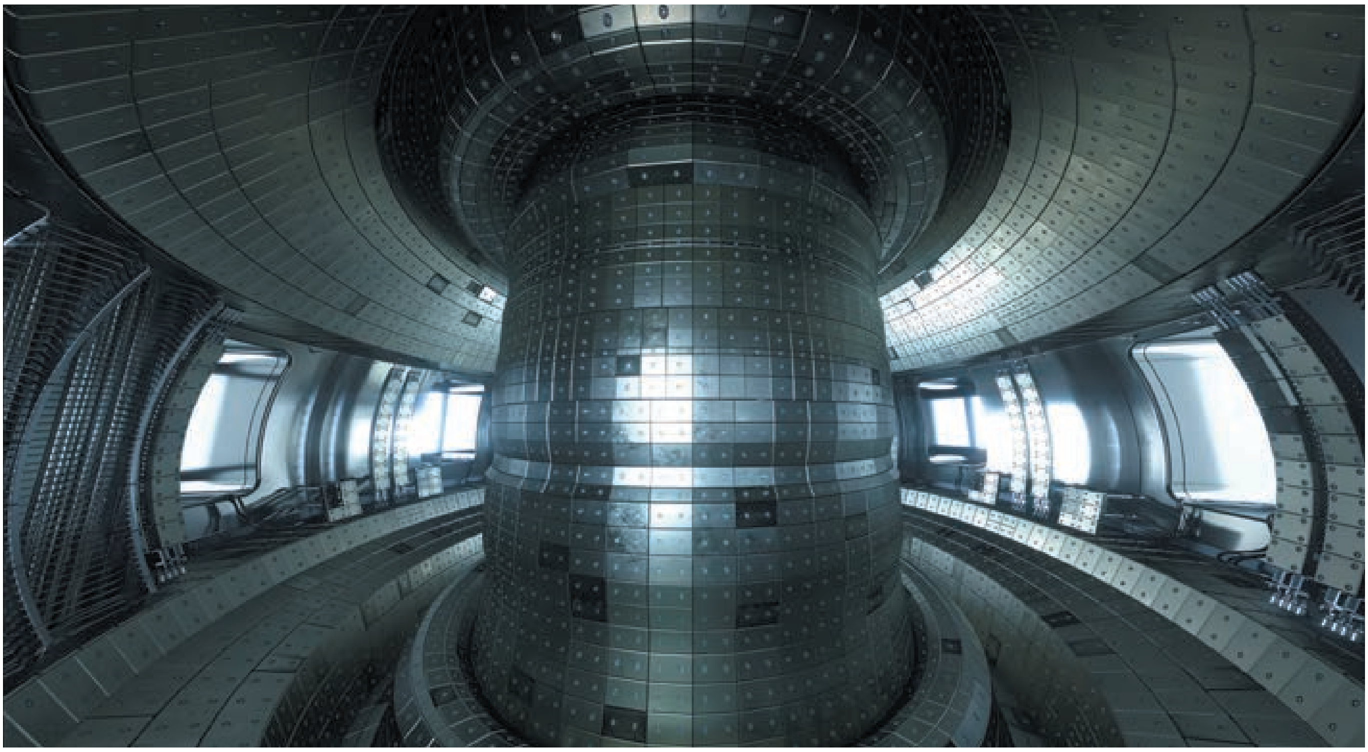

Figure 3: 3D Model of a tokamak reactor

mined from the moon, where there will be plenty of it, making it a more sustainable option.

Nuclear reactors harness the energy created by fusion to create electricity. There are several types of reactors, but the two main viable forms are tokamak reactors and inertial confinement reactors. Each has its own way of causing a fusion reaction, but they both use the previously mentioned fuels. In addition they both harness heat the heat created during the reaction, creating steam that turns a tubine.

Tokamak reactors are the most proven reactors today with the the largest and most successful version called the ITER (Figure 3). It works by heating the fuel into a plasma of 150 million ^{o}C (10 times the temperature of the Sun's core). This superheated plasma is contained using superconducting magnets. Tokamak reactors were developed during the late Cold War by the Soviets, when a race to develop power from fusion. The American equivalent is the stellarator, which has a very similar design, but the tokamak was considered to be superior internationally.

Inertial confinement reactors use a completely separate concept to achieve nuclear fusion: lasers. The fusion fuel is put into a fuel pellet and then shot with a high-power laser, creating the heat necessary for fusion to occur. The largest example of one of these reactors is the NIF.

Nuclear fusion, when used in a controlled environment, is incredibly safe. Unlike fission, fusion won't cause a major nuclear meltdown if something goes wrong. If, for example, a hole is punctured in a tokamak reactor while it's running, the plasma would cool down immediately, not harming a single person. The waste that nuclear fusion reactors create, mainly helium 4, is non-radioactive and stable, unlike the products of fission.

While it's unlikely that nuclear fusion will arrive in the immediate future (there is a joke that it's "always 30 years away"); it has significant of potential to become an energy source of the future which is sustainable and environmentally friendly. Given it can theoretically generate near-infinite amounts of fuel, it has the potential to solve all of humanity's energy needs.

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Interview with Dr Kerrigan, Senior School Physics teacher ; Prince Alfred College

Geoengineering – stratospheric aerosol injection to slow down climate change

Words by Veer Poredi (Year 8)

Is Science Sustainable?

A few decades from now, in a time where climate change and human behaviour would have wreaked havoc on the Earth, people could suffer from countless droughts, heatwaves, floods or even wars amongst themselves for necessities. In a desperate attempt to prevent extinction, the remaining powers of the world would investigate geoengineering and form an alliance to act on the problem at hand.

Hopefully, we will not have to experience such a grim era in our near future, but with climate changing rapidly taking its toll on the Earth and many governments failing to effectively deal with the problem, it is in the scope of possibility.

The question comes to mind, what exactly is geoengineering? The definition of geoengineering is that it is a large scale manipulation or intervention of a climate process in an attempt to reverse the damage of human activities on Earth.

The reason why this is important is because stopping greenhouse gas emissions is not enough to stop the effects of global warming instantaneously. If humanity wanted to increase the health of Earth, we need geoengineering.

There are multiple types of geoengineering (Figure 1), and one of the most well-known ones is Stratospheric Aerosol Injection (SAI). In 1974, Mikhail Ivanovich Budyko, a climatologist from Russia, introduced the idea of injecting sulphate aerosols into the stratosphere (Figure 2). It developed further as climatologists observed how large volcanic eruptions threw the Earth into a global cooling for 1 or 2 years. A notable example of this is the Mount Pinatubo eruption in 1991, after which there was an increase in cool weather over most of the globe. SAI is supposed to mimic this, but instead of volcanic eruptions, sulphate aerosols are released into the atmosphere by jet aeroplanes.

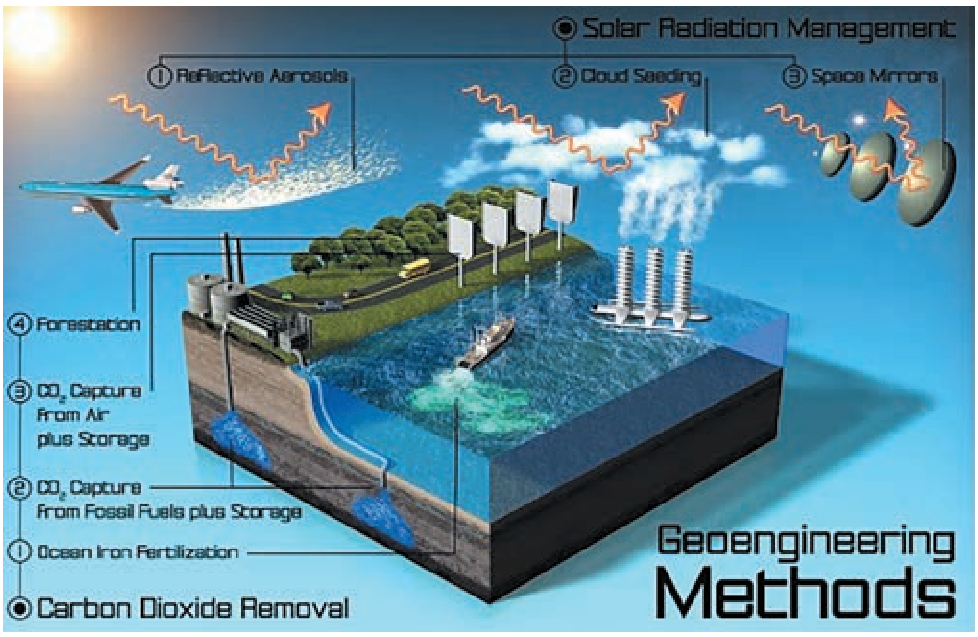

Figure 1: Various Geoengineering Methods

Furthermore, this tactic is very practical. It could be implemented in a short amount of time, and this strategy is highly cost-effective. Although sulphate aerosols will eventually fall down to the surface, SAI is considered relatively safe because nature has been doing the same thing for aeons, through volcanic eruptions and there are numerous methods in the sulphur biogeochemical cycle for the biosphere to dissolve these materials. As mentioned earlier, due to the fact aerosols don't stay in the stratosphere forever, they would have to be deployed on a recurring basis for as long as it is needed to cool the planet down.

Unfortunately, there are downsides with injecting aerosols into the stratosphere, as they may cause unwanted effects such as less rainfall. In some parts of the world, this effect would be greater, impacting fresh water access and crop growth severely, leading to many problems including a rise in starvation rates and potentially deaths in these regions. To increase viability, we would need to create safety measures and plans to protect civilians affected by the side-effects.

In addition to that, there are more risks with SAI. Sulphuric acid could very negatively affect the ozone layer. Scientists have tried to investigate different types of materials that would not harm the ozone layer as much as the sulphate aerosol. It could also create a false sense of security and the switch to environment friendly sources of energy may be delayed, meaning more carbon dioxide would be released, the oceans would become more acidic causing coral reefs to keep suffering.

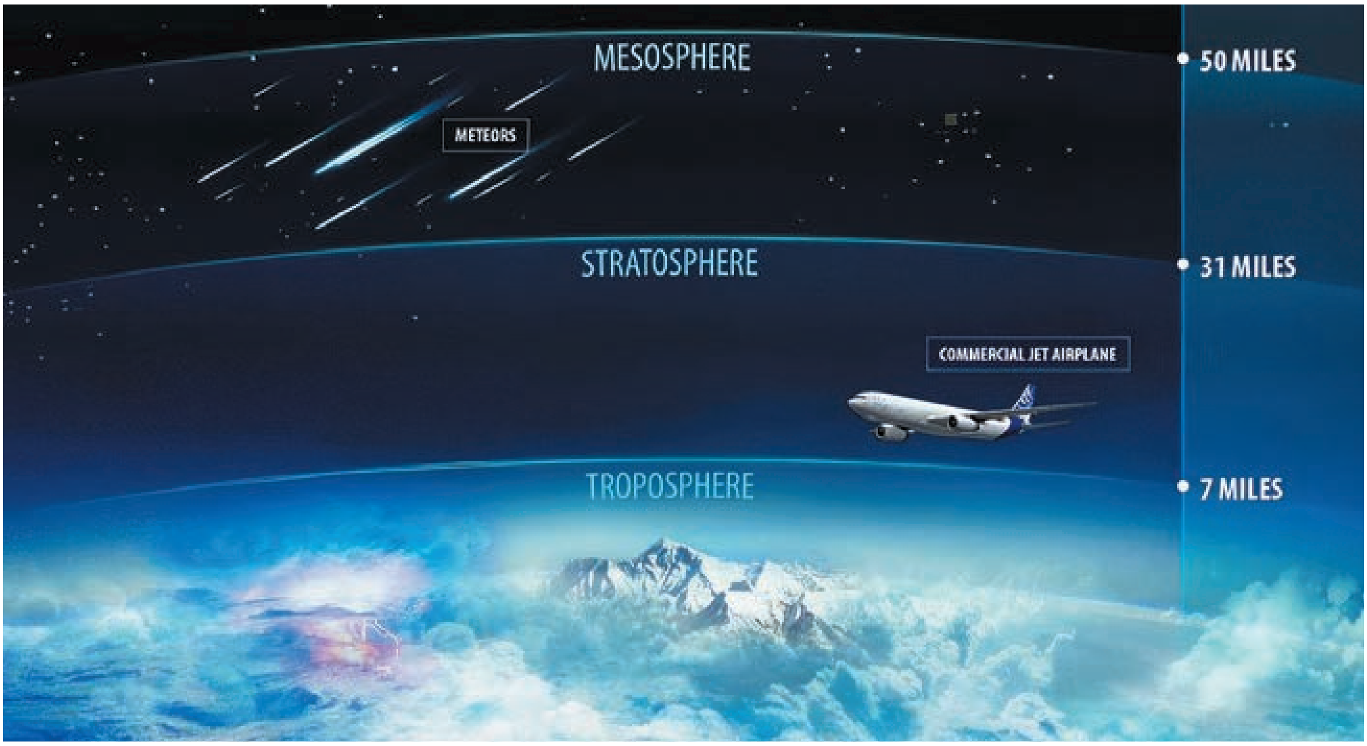

Figure 2: Where the aerosol would be injected

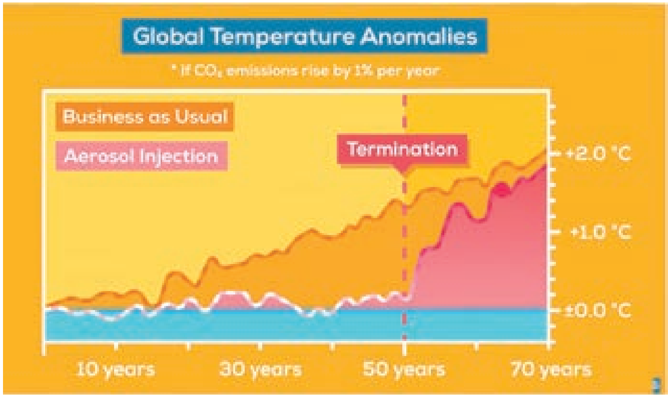

Figure 3: A graph about what would happen if we suddenly stopped SAI

Considering a worst-case scenario that this does happen, we would be forced to continue the aerosol injection for as long as possible. If we stopped, the CO_2 content in the atmosphere would cause a drastic increase in temperature that we would not be prepared to deal with (Figure 3). Although it may not be as bad if we never did any aerosol injection in the first place, such a sudden change could cause a lot more problems as ecosystems may not be able to adapt and survive, causing the world to be a hostile and unforgiving, lifeless landscape.

However, that is the worst-case scenario. In a more optimistic take, if humanity is well versed on the potential dangers that lie ahead if we are careless, we can use geoengineering as a tool to buy time instead of riskily trying to use it as a permanent solution. The world can use the time to minimalize CO_2 emissions, switch to renewable energy sources and handle any economic, political or social crisis that might be caused by a changing a fundamental part of our entire civilisation. We can move forward in technologies that would help us speed up the removal of excess CO_2, there are even methods in the field of geoengineering that could do so.

To conclude, although Stratospheric Aerosol Injection sounds incredibly useful, we must note that it is by no means a permanent solution to global warming or climate change. Instead, it, and other forms of geoengineering, are tools that we can use to help us change our ways while taking our time with any problems that we may encounter along the way.

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Investigating the creation of a method to upcycle carbon fibre reinforced polymers

Words by Noah Varghese (Year 12)

Is Science Sustainable?

Carbon fibre reinforced polymers (CFRPs) are composite materials and are an essential part of society today, used in various areas including the automotive, construction and aerospace industries. Recycling CFRPs are desirable as waste is currently sent to landfill, or incinerated. The recycling of this waste would not only reduce the need for large areas of land that are becoming increasingly expensive but would also avoid the high energy costs and conserve raw materials needed to produce new CFRPs. However, these materials are difficult to recycle, largely due to their composite nature and the cross-linking present in thermosetting polymers meaning they are unable to be melted or rebound. This newly developed method enables the re-use of the carbon fibres as the resin that holds the fibres are broken down. Additionally, a fungus called *Aspergillus nidulans*, is used to help convert the polymer matrix (Figure 1). This report will investigate the factors that influenced its creation, and the potential applications in society, and its limitations.

CFRPs are a composite material and consist of a polymer acting as a matrix, and carbon fibres which act as reinforcement (Figure 2). Carbon fibre is made up of crystalline filaments of carbon which are twisted together to create a strong yet lightweight material with high tensile strength. The polymer matrix acts as a binder to hold the carbon fibres together, this could be either thermosetting or thermoplastic polymers such as epoxy, polyester, or polystyrene.

Potential applications in society include wind turbine construction, and in transport such as in the aerospace, marine and automotive industries, due to their lightweight and strong design. With the around 80% CFRPs having thermosetting polymers as a matrix, the material is able to possess high mechanical strength and thermal resistance. It is also durabile due to the cross-links between the chains of the polymer. However, this also means that the polymer is unable to be melted and reformed, as high energy is needed to overcome the strong covalent bonds between chains leading to the polymer combusting before melting. As they cannot be melted and rebound, it is difficult to recycle them, leading obsolete CFRPs being discarded, and building up in landfill.

The polymer investigated in this report was polystyrene and the first step in this method, is to incubate the composite material in tripotassium phosphate trihydrate ($K_3PO_4 \cdot 3H2O$), and benzyl alcohol ($C_6H_5CH_2OH$) at 180°C for 24 hours. This

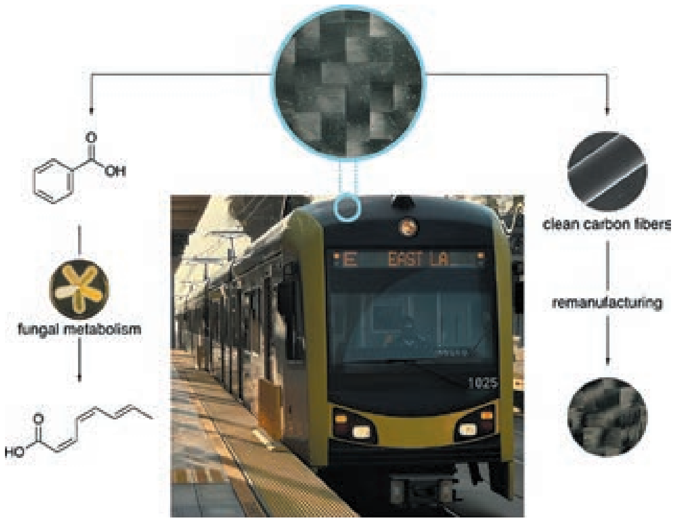

Figure 1: Example of CFRPs use and recycling method

cleaves the polyester cross-links, causing the composite to swell, which is beneficial as it allows reagents added in the following steps to have an improved insertion. The product is then digested with manganese (II) nitrate ($Mn(NO_3)_2 \cdot 4H_2O$) and cobalt nitrate ($Co(NO_3)_2 \cdot 6H_2O$), producing oligomers, benzoic acid (C_6H_5COOH) and phthalic acid ($C_8H_6O_4$). This allows the carbon fibres to be separated from the matrix with minimal damage allowing them to be re-used in other materials. These reactions are summarised in Figure 3 below.

A major difference in this method to those formally used is that biotechnology has been used recycle the polymer matrix that is usually damaged and therefore cannot be recycled in previous methods. The products then undergo purification steps involving filtrations, extractions, and crystallisations to remove the phthalic acid and the oligomers leaving only the benzoic acid. Then, using the fungal organism, *Aspergillus nidulans*, which utilises the benzoic acid as a food source, producing octa-2,4,6-trienoic acid or OTA. This can then be used to manufacture medications and drugs that can be used in healthcare.

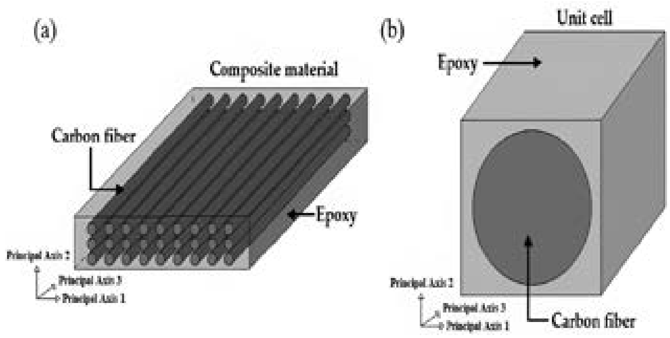

Figure 2: Diagram of CFRPs

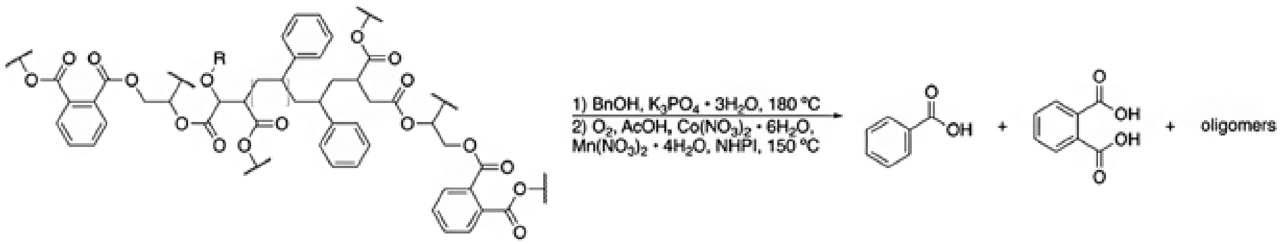

Figure 3: Process of recycling the polymer matrix

The development of this new method to upcycle CFRPs has been influenced by the issues with the current methods of CFRPs recycling. The current method to recycle CFRPs is mechanical, which breaks the material into smaller pieces, impacting its mechanical properties and mean the continuous carbon fibres cannot be recovered. Another recycling method is through the process of pyrolysis, which is not only energy intensive but the polymer matrix is destroyed, and the carbon fibres have lower strength and purity. The final method is from newly developing chemical processes which can recycle the matrix and maintain the fibre structure, but has drawbacks around a large reagent consumption, expensive equipment, and the harsh reaction conditions. The lack of a sufficient and environmentally friendly method to recycle CFRPs was a major influence in the development of this new method that is able to successfully reuse both the carbon fibre structure, and the polymer matrix with minimal drawbacks.

Environmental factors have also been a key influence in the creation of this new recycling method. Projections show that by 2030, 6000-8000 aircraft using CFRP materials will be retired, and by 2050, wind turbines using CFRPs will be retired generating 483,000 tons of waste, a large proportion of this being end of life materials. This waste will be disposed of either through landfill or by incineration. To prevent air pollution from incineration, and to reduce land needed to contain landfill, the creation and establishment of effective methods of recycling these materials is needed. The increasing global awareness of the impact on the Earth from pollution by landfill, led to the establishment of regulations by the European Commission, which outline sustainability goals to ultimately reduce the volume of waste that goes to landfill. Manufacturers and companies, obligated by these laws, investigated ways in recycling these materials, influencing research into this area and therefore, the creation of this method.

Furthermore, the ever-growing demand for CFRPs in several industries is a major influence in the application of this recycling method. Due to their favourable properties, the demand for CFRPs is expected to reach 285kt in 2025. This is due its use expanding into industries where it was previously not used, such as in the wind turbine and construction industry. The need to meet growing demand for CFRPs, influenced the creation and establishment of a method that allows CFRPs to be recycled. This reduced the need to produce virgin CFRPs.

The creation of this method to not only recycle carbon fibre, but also the polymer matrix of CFRPs will greatly benefit society. The production of new carbon fibres has been found to require over 500 megajoules of energy per kilogram, while this new upcycling method consumes less than 50 megajoules per kilogram, with the total cost of upcycling techniques only being a fifth of that to produce new ones. This would benefit manufacturers that need CFRPs in their products, as it is more economically viable for them to use recycled CFRPs. Moreover, as the upcycled fibres are lightweight and strong, they can be utilised in the aerospace and automotive industries, as the lighter weight leads to less fuel being consumed, saving costs for companies. The recycling of the polymer matrix into OTA holds several medical applications, as OTA is needed in the production of asperlin, which is used to make antibiotics or anti-inflammatory preparations. However, a limitation may be that some feel that consumers will subconsciously believe that carbon fibres produced by this recycling method are inferior to those that are newly produced. This perspective could impact the establishment of this new method, as it could diminish consumer demand for recycled carbon fibre materials meaning the fibres will need to be freshly constructed.

Ultimately, this method of upcycling CFRPs is a major breakthrough in obtaining value from this material and demonstrates how science can be influenced by other areas of society.

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Zooming ahead

Electric cars convert 70–80% of their energy into motion, while petrol cars only manage 20–30%.

The impact of PFAS removal techniques on sustainable water treatment

Words by Samuel Commons (Year 12)

Is Science Sustainable?

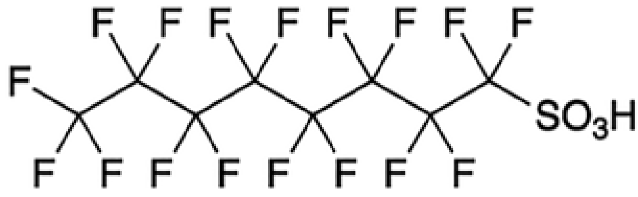

Figure 1: perfluorooctane sulfonate molecule (PFOS)

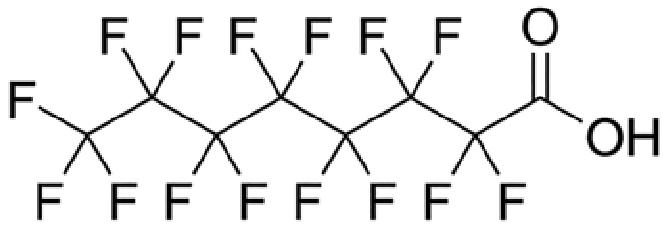

Figure 2: perfluorooctanoic acid molecule (PFOA)

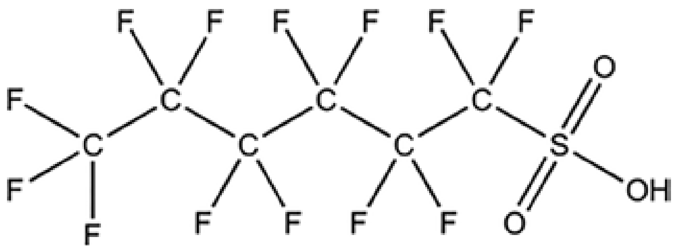

Figure 3: perfluorohexane sulfonate molecule (PFHxS)

Perfluoroalkyl and Polyfluoroalkyl substances (PFAS) have become a major concern in water treatment in recent years due to evidence suggesting that exposure could lead to health risks, including cancer. The maturity of various PFAS removal techniques, including Granular Activated Carbon (GAC) and ion exchange resin (IEX) technologies, has shown promise in reducing the PFAS concentration in drinking water sources. Although these methods have proven to be effective, they are still limited by high operational costs and the need for frequent replacement. Efforts are being made to optimise water purification using these techniques while enhancing the sustainability of these sources through improved energy efficiency and waste reduction. Governments worldwide are implementing these solutions, such as the New South Wales Government, which is introducing a mobile PFAS treatment station utilising GAC and IEX to ensure safer drinking water supplies.

PFAS, known colloquially as "forever chemicals", are a large group of complex synthetic polymers that are used in consumer products worldwide. PFAS substances are widely used in industrial and consumer products due to their physical and chemical properties, which provide resistance to oil, water, and stains, making them ideal for creating water and grease-resistant materials.

The unique properties of PFAS are attributed to their chemical structure, which consists of a carbon-fluorine backbone that is highly stable and resistant to degradation. This structure can be represented as below, with R representing the functional group and *n* representing the number of carbon atoms in the chain:

$$\text{Structure} = R - C_nF_{2n+1}$$

There are 2 types of PFAS: long-chain and short-chain. The most prevalent PFAS types in Australian water sources include perfluorooctane sulfonate (PFOS) (see Figure 1), perfluorooctanoic acid (PFOA) (see Figure 2), and perfluorohexane sulfonate (PFHxS) (see Figure 3).

According to the Organisation for Economic Co-operation and Development, there is estimated to be around 4,700 PFAS chemicals, and the National Library of Medicine, existing within the US National Institute of Health, lists approximately 6 million PFAS chemicals. There are various methods for treating water to reduce the concentration of PFAS, including GAC and IEX. The concentration of PFAS in water sources can vary between cities, due to factors such as proximity to industrial sites, military bases, and areas where firefighting foam containing PFAS has been extensively used, leading to higher contamination levels in certain communities. GAC is characterised by its extremely porous surface, which gives it a large surface area to aid with adsorption. PFAS molecules in water are attracted to and adhere to the surface of GAC particles due to hydrophobic interactions in which water is repelled from the long-fluorinated carbon chains, causing them to bind with GAC's non-polar surfaces, making it an effective method for removing these contaminants from water. IEX technologies are effective in removing PFAS from water by relying on electrostatic attractions and equilibrium principles. Most PFAS compounds are negatively charged in neutral pH conditions due to the loss of their H^+ on their carboxylic or sulfonic functional group, whilst IEX have positively charged functional groups that attract and adsorb the negatively charged PFAS molecules as their concentration in the solution is higher.

The NSW Government has recently acknowledged the issue of PFAS contamination and introduced a multi-million-dollar mobile PFAS treatment station at the Cascade Water Filtration Plant (see Figure 4) to address contamination in local water sources. The system combines various filtration technologies, such as GAC and IEX, to remove PFAS, resulting in safer, higher-quality drinking water for communities. The scientific knowledge that PFAS adsorption efficiency depends on chain length, functional groups and electrostatic interactions has enabled scientists to develop a solution to create an effective treatment process that significantly reduces the concentration of PFAS in water. In 2019, the Australian Government stated that PFAS has not been shown to cause disease in humans and "probably has minimal impact on human health". However, scientists at the EPA, and experts from other federal agencies, academia and industry continue to research PFAS amid rising concerns about its potential health risks. The EPA has collected soil and water samples for analysis, and there has been evidence suggesting that exposure to certain levels of PFAS could be linked to health concerns, particularly an increased risk of cancers such as prostate, kidney, and testicular cancer. With the scientific understanding that exposure to PFAS could be linked to major health concerns, scientists have now been able to develop a solution to remove PFAS from water sources via methods such as GAC and IEX. The implementation of these methods of purification is still relatively new, with the future implications unknown at this stage, indicating these systems will require monitoring, assessment, and evaluation of risk over the coming years.

Although the implementation of GAC and IEX technologies into the water purification process has shown promising results, there are still limitations to these technologies, including high maintenance expenses, public concerns and adverse environmental impacts. A limitation of using GAC technology is that it is almost 5 times more expensive than the conventional treatment process. While GAC is effective at removing long-chain PFAS compounds, its efficiency decreases when targeting short-chain PFAS compounds, which presents a limitation. Similarly, although IEX technologies can be less expensive for initial costs, the operational costs over time can make it more expensive than other processes. These economic challenges highlight the need for scientific innovation to develop more cost-effective solutions, to reduce the unexpected economic consequences.

There are also various environmental impacts created by the production of GAC, including the use of fossil fuels for production, which results in carbon dioxide emissions and the sourcing of materials, which can contribute to deforestation. The production of 0.5 kilograms of virgin GAC emits approximately 3.86 kilograms of carbon, and more recent studies show that producing 1kg of activated carbon from coal releases approximately 18.28kg of greenhouse gases. Furthermore, the disposal of GAC can be challenging, as PFAS takes up to 1000 years to break down. Improper disposal may cause additional environmental impacts, including contamination of soil or groundwater through leaching.

Public debate and concern over PFAS contamination have led to the installation of a treatment station at the Cascade water filtration plant. However, residents remain dissatisfied with the government's handling of the issue, particularly its delayed response and lack of transparency. Jon Dee, founder of Blue Mountains Stop PFAS Action Group, stated, "The government

Figure 4: Mobile PFAS treatment unit at Cascade Water Filtration Plant

haven't acted appropriately… they've misled the community about the safety of their drinking water,". While the installation of treatment stations is a step forward, they have not fully alleviated public concerns. Continued research, technological advancements, and effective communication between scientists, the government and society will be essential in addressing both environmental and economic challenges in treating PFAS, ensuring the long-term safety and sustainability of water sources for all communities.

The development of complex water filtration techniques, including GAC and IEX, highlights the interdisciplinary nature of scientific research and innovation. Originally developed for gas masks during World War I, GAC has since been adapted to aid in water purification and treatment. Similarly, IEX technologies evolved from early observations of ion exchange in water, to synthetic materials which can be manufactured to use in wide-ranging applications such as softening hard water, purifying lifesaving drugs and aiding with metal separation. More recently, Flinders University has been developing a new treatment method using powdered activated carbon blended with a polysulfide polymer derived from the inverse vulcanisation of canola oil. This approach is beneficial as sulphur, a common by-product of chemical reactions, is being effectively repurposed rather than wasted. These advancements were driven by interdisciplinary research, combining science with engineering and various other fields, with new technologies significantly improving the efficiency of scientific procedures and data analysis. For example, steam activation increased the porosity and surface of activated carbon, improving absorption capacity, whilst the development of ion chromatography in the 1970s increased the sensitivity of ion detection. These technological developments illustrate how new evidence and knowledge can modify and improve existing models and processes in scientific research. More recently, the development of the new mobile PFAS treatment station at the Cascade plant has shown promising early treatment results in 2024, indicating that 76-87% of the PFAS chemicals studied are expected to be cost-effectively removed by GAC filtration. There have also been scientific developments made regarding IEX technologies, with SciDev developing a proprietary IEX technology called RegenIX™, which can be implemented into treatment systems to reduce ongoing operational expenses by up to 79%.

The development of PFAS removal techniques, particularly GAC and IEX technologies, has led to significant advancements in reducing the concentration of PFAS in drinking water sources, highlighting the effectiveness of interdisciplinary research and technological innovations in tackling complex environmental issues. However, discrepancies in public opinions and economic challenges in maintaining treatment facilities limit its applicability in the future. This emphasises the need for continued scientific developments to create more sustainable long-term solutions. While progress has been made in addressing PFAS contamination issues, sustained research and innovation will be crucial in ensuring the long-term safety and sustainability of society's water sources.

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Bug engineers

Desert beetles collect drinking water from fog on their backs — a trick now inspiring new water-harvesting technology.

Science Competition Award Winners 2025

Big Science Competition High Distinctions (Year 7–10)

Billy Ang (Year 7)
Samuel Rayner (Year 7)
Hugo Mittiga (Year 8)
Veer Poredi (Year 8)
Joshua Wang (Year 8)
Aaron Liu (Year 9)
Ansh Tiwari (Year 9)
Darcy Sandow (Year 10)

International Chemistry Quiz Distinction (Year 11)

Adrian Ho
David Jia
Charles Li
Josh Penhall
Ethan Rogers
Caleb Sam-Ling
Aidan Witenden

Science Olympiads High Distinctions (Year 7-10)

Billy Ang (Year 7)
Jasper Roberts (Year 8)
Lucas Pizzino (Year 8)
James Arkwright (Year 8)
Joshua Wang (Year 8)
Harry Paholski (Year 10)
Noah Laforest (Year 10)

National Titration Competition Gold Standard (Year 11)

Rishab Tharani
Christian Smith
Charles Li
Taine Meyer

Oliphant Awards

Keshav Balachander (Year 7 Photography and Multimedia)

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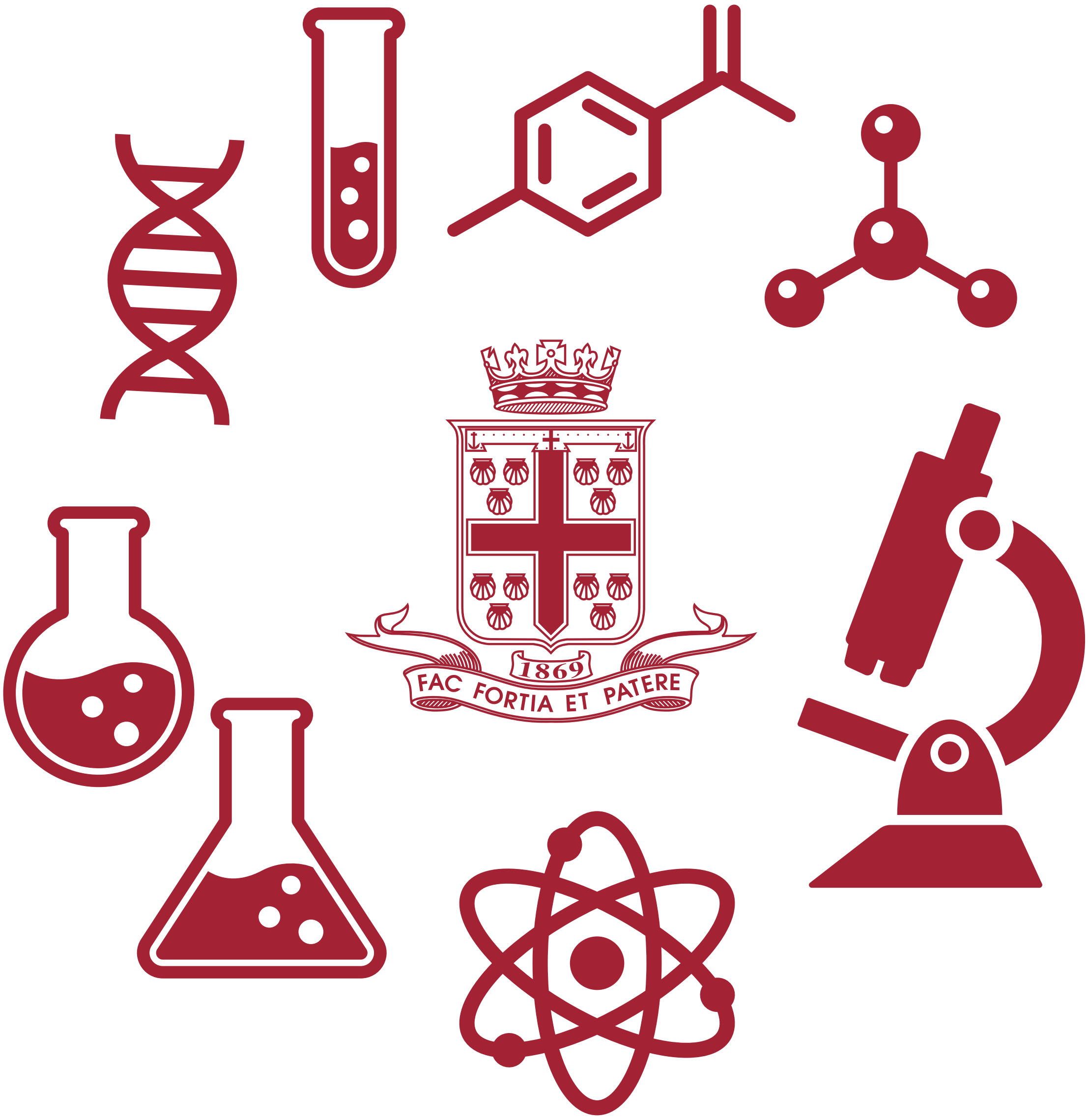
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Our future?