Economic impact study for the
Australian Research Council (ARC)
Nanocomm Hub

December 2019

pwc
Disclaimer

This report is not intended to be used by anyone other than the Australian Research Council Nanocomm Hub ('the Hub').

We prepared this report solely for the Hub’s use and benefit in accordance with and for the purpose set out in our engagement letter with the Hub dated 29 August 2019. In doing so, we acted exclusively for the Hub and considered no-one else’s interests.

We accept no responsibility, duty or liability:

- to anyone other than the Hub in connection with this report
- to the Hub for the consequences of using or relying on it for a purpose other than that referred to above.

We make no representation concerning the appropriateness of this report for anyone other than the Hub. If anyone other than the Hub chooses to use or rely on it they do so at their own risk.

This disclaimer applies:

- to the maximum extent permitted by law and, without limitation, to liability arising in negligence or under statute; and
- even if we consent to anyone other than the Hub receiving or using this report.

PricewaterhouseCoopers Consulting (Australia) Pty Limited. All rights reserved. Liability limited by a scheme approved under Professional Standards legislation.

PwC refers to PricewaterhouseCoopers Consulting (Australia) Pty Limited, and may sometimes refer to the PwC network. Each member firm is a separate legal entity. Please see www.pwc.com/structure for further details.
The Nanocomm Hub’s research is enhancing innovation in construction methods:

The Nanocomm Hub aims to develop new materials and technologies that will elevate the global competitiveness and profitability of the Australian construction sector. The Hub’s 37 active research projects span the fields of nanoscience, construction materials, green structures and asset management. These projects have potential impacts across key sectors of the Australian economy including: construction, transport, aquaculture, mining and manufacturing.

The Hub’s current research projects have the potential to enhance efficiency in the following ways:

- **Modular construction methods** that speed up construction processes
- **Low carbon, environment-friendly materials** that reduce construction costs
- **Surface damage investigation techniques** that improve road maintenance processes
- **Robotics and sensor** driven data collection to increase road maintenance efficiency and mitigate disruptions
- **Technologies for future infrastructure** using more sustainable heavy materials to extend asset lives
- **Graphene based ion exchange membranes** that reduce the water demands of mineral processing
- **Innovative mining protective structures** that prevent mine collapses improving safety and efficiency
- **Design of floating forests** that enable aquaculture farms to expand into open waters
- **Waste beneficiation and avoidance** which repurposes domestic ash, replacing ash imports

Over the next 30 years these impacts are estimated to lead to:

- **$400-1870** million in additional gross domestic product*
- **$110-490** million in additional household consumption*
- **$180-590** million in additional Australian exports*

Source: PwC analysis. *values are expressed in present value terms over the period 2020 - 2050
Executive summary

In 2017 the Australian Government’s Industrial Transformation Research Hubs scheme awarded Monash University a grant to lead a multidisciplinary team in the advancement of Australian construction materials - the ARC Nanocomm Hub (the Hub).

The ARC Nanocomm Hub

The Government's support for the Hub reflects the systemic importance of the construction industry to the Australian economy. The Hub’s vision statement is to 'develop materials and technologies that will elevate the global competitiveness and profitability of the Australian construction sector'.

The Hub currently has 37 active projects spanning four key research areas; nanoscience, construction materials, green structures and asset management.

The potential impacts of the Hub’s research

From modular construction methods that speed up construction processes to technologies for future infrastructure that reduce the impact of concrete cancer and extend asset lives; the technological innovations being developed by the Hub have the potential to materially impact the Australian economy over the next 30 years.

This report outlines the potential economic effect of a representative selection of the Hub’s innovations and technologies being utilised by industry. This analysis draws on inputs from the Hub’s management team at the Department of Civil Engineering Monash University as well as experts from the Australian Centre for Neutron Scattering and the University of Technology Sydney Concrete Engineering faculty.

Given assumptions on the likely date of market entry, commercial viability, market penetration and direct impacts on industry, two scenarios have been analysed:

- a ‘probable’ scenario, based on a more conservative estimate of eight of the Hub’s 37 projects
- a ‘possible’ scenario, based on nine of the Hub’s 37 projects with a more optimistic set of assumptions on commercial viability, market penetration and timing of market entry.

The economic benefits

Using these inputs, PwC undertook computable general equilibrium modelling to estimate the potential scale of economic benefits to Australia from the Hub’s innovations. Over the period 2020 to 2050, these benefits are forecast to be an increase in:

- gross domestic product (GDP) of $400 million and potentially up to $1,870 million
- real wages by $155 million and potentially up to $560 million
- household consumption by $110 million and potentially up to $490 million
- investment by $160 million and potentially up to $790 million
- exports by $180 million and potentially up to $590 million.

Figure A: Annual impact on GDP, 2020 - 2050 (18/19 $ millions)

Source: PwC analysis

We estimate the potential impacts of the Hub using industry specific assumptions. As with all forecasts, there is uncertainty in the magnitude and probability of the modelled outcomes occurring. The analysis takes a more conservative approach in that it considers nine the Hub’s 37 research initiatives and many of the projects could have broader applications beyond the consideration in this report.

1 One additional project (waste beneficiation and avoidance) was included in the possible scenario.
Introduction
Purpose, scope and approach
Purpose and scope

Purpose

The Australian Research Council Industrial Transformation Research Hub for Nanoscience-based Construction Material Manufacturing (the Hub), is a multidisciplinary Research Hub for the construction materials industry. Led out of Monash University in Victoria, the Hub is a network of 13 Australian and three overseas universities and 48 industry partners across Australia, New Zealand, China, Singapore and South Korea. The Hub explores the construction materials industry to inspire technological innovation throughout the sector with the overarching goal of creating lighter, more resilient materials, ultimately contributing to a more efficient, sustainable and liveable Australia.

The purpose of this report is to analyse the potential economic impact of the Hub’s research on the Australian economy over the next 30 years, if the technologies developed by its research are utilised by industry.

Scope

This analysis was prepared by PricewaterhouseCoopers Consulting (Australia) Pty Ltd (PwC) in accordance with the agreed scope with the Hub dated August 2019.

The report builds on and develops existing research and data provided by the Hub and uses a model of the Australian economy to estimate the Hub’s potential economic impact. It is important to note, this report estimates the potential future impact of the Hub’s projects being utilised by industry. It does not attempt to quantify the historic or current economic benefits of the Hub’s activities or its environmental impacts. Our approach is discussed in more detail on page 23.

As of 2018, the Hub’s 181 staff were responsible for 37 active projects. Given the breadth and diversity of the Hub’s projects, several assumptions were made to conduct the analysis in this report (see page 25 for detailed assumptions and limitations).

Key assumptions include:

- a majority of the Hub’s potential economic impacts are a result of nine of their 37 projects, as identified by the Hub
- the type and magnitude of impacts these projects have on industry were provided by the Hub and their industry partners
- the mechanisms through which these industry impacts affect the real economy were modelled by PwC.

The impacts focus on research projects with the greatest potential impacts across five key sectors of the Australian economy; construction, transport, aquaculture, mining and manufacturing.

Two separate scenarios were developed and modelled to understand the possible range in magnitude of economic impacts. The ‘probable’ scenario provides a more conservative estimate and the ‘possible’ scenario provides a more optimistic estimate of the Hub’s economic impacts.

Both scenarios were compared to the baseline forecast (i.e. what the economy would look like without the Hub’s activities), to estimate the additional economic activity which could occur as a result of the Hub’s research outputs.
Approach

The four key steps in our approach are outlined below.

1. Workshop

A workshop was conducted with the Hub to:

- understand the specifics of the Hub’s 37 research projects
- develop a short-list of projects that have the greatest potential impacts on the economy
- test the proposed mechanisms through which these projects impact the economy
- develop and agree on a set of parameters that define the ‘probable’ and ‘possible’ scenarios drawing on the Hub’s expert knowledge of the range of impacts that could be attributed to the research outcomes.

The workshop involved a range of personnel including representation from the Hub’s management team at the Department of Civil Engineering Monash University as well as experts from the Australian Centre for Neutron Scattering and the Concrete Engineering faculty at the University of Technology Sydney (UTS).

The breadth of the Hub’s research was discussed before prioritising nine projects with the potential to create the greatest impacts on the Australian economy.

2. Research

A targeted desktop literature review and consultation with industry partners was undertaken to further validate and quantify the proposed impacts that the shortlisted projects could generate and the mechanisms through which they could generate economic impacts. This step provides an additional layer of rigour to the report assumptions and validated the proposed links to the real economy.

3. Modelling

The economic impact of the Hub was estimated using the workshop and research outputs. A sophisticated macroeconomic model of the Australian economy was used to provide an estimate of the direct and indirect impacts. A detailed methodology is provided in the Economic analysis chapter.

4. Reporting

Key results of the modelling are included in this report. These include the estimated impact of the Hub’s activity on major Australian macroeconomic indicators including gross domestic product (GDP) by industry, household consumption, real wage growth, business investment and exports.

This included consideration of the:

- nature of the research project and its aims
- probability of the technology’s commercial viability
- the technology’s estimated market penetration
- impacts on industry from using the technology
- timeframe for impacts.
The Nanocomm Hub
Context, role and activities
The Australian Government, through the Australian Research Council (ARC) launched the *Industrial Transformation Research Hubs* scheme in 2013. The scheme’s objectives are to:

- encourage collaborative R&D projects between universities and organisations outside the Australian higher education sector that will solve challenging industry issues relevant to the *Industrial Transformation Priorities*
- drive growth, productivity and competitiveness within key growth sectors
- leverage national and international investment in targeted industry sectors, including from industry and other research end-users.

The scheme provides funding in cutting edge research on new technologies and economic, commercial and social transformation to support the government’s *industrial transformation priorities*. In 2017, Monash University was awarded the maximum grant of $1 million per year over 2017 - 2021 to lead a multidisciplinary team in the advancement of Australian construction materials - the Hub.

As a centralised platform, the Hub brings together experts from across disciplines with the aim of transforming the construction materials industry into an advanced manufacturing sector. It has four key research areas: nanoscience, construction materials, green structures and asset management. Figure 1 illustrates this and the Hub’s structure with its industry and research institute partnerships.

---

4 Australian Research Council (2019).
Context, role and activities

The Hub recognises the importance of the constructions material industry in Australia’s continued prosperity. It contributes approximately $12 billion to national gross domestic product and employs 18,000 Australians directly and 85,000 indirectly.

The Hub’s five primary objectives are:

- reducing energy consumption and carbon dioxide emissions in the manufacture of construction materials
- developing high performance, high-durability materials and structures
- creating materials and structures that can resist extreme conditions and terrorist attacks
- boosting the engineering capability of Australian industry with an innovative, skills-based workforce
- linking Australian companies to the infrastructure opportunities in Asia.

The analysis in this report focuses on the future benefits of technologies resulting from the Hub’s current research projects; as such, the benefits estimated in this analysis occur from 2020 onwards. In addition to the future benefits of the Hub, there are a number of factors that contribute to the Hub’s current economic footprint:

- the employment of 181 staff
- direct investment of $15 million over the 2015-2020 period: in addition to the $5 million ARC awarded grant, $10 million has been invested by universities ($3.8 million) and industry in Australia and overseas ($6.2 million)
- indirect economic impacts of the investment and jobs created at the Hub
- 34 research fellows and higher degree by research (HDR) students.
Representative current research projects

Figure 2 outlines nine of the Hub’s 37 projects that were considered as part of this analysis. They were shortlisted and identified by the Hub as currently demonstrating the greatest potential impacts on the Australian economy with respect to the technology’s commercial viability, likely market penetration and magnitude of impact on industry.

Figure 2: The nine Hub projects considered in this analysis

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Modularisation in construction</td>
<td>Use of precast concrete to increase efficiency and reduce costs in commercial construction. New-generation materials with improved durability and strength, increasing asset lives for civil engineering projects.</td>
</tr>
<tr>
<td>2. Low carbon, environment-friendly materials</td>
<td>Development of welds to optimise the surface of heavy rail tracks and prevent disruption. To collect temporal and spatial data to increase the efficiency of road maintenance budgets and mitigate disruption.</td>
</tr>
<tr>
<td>3. Surface damage investigation</td>
<td>Sustainable use of heavy construction materials in infrastructure and extension of the economic life of existing infrastructure.</td>
</tr>
<tr>
<td>4. Robotics and sensor technologies</td>
<td>Membrane used to reduce the water demands of mineral processing.</td>
</tr>
<tr>
<td>5. Technologies for future infrastructure</td>
<td>That prevent mine collapses improving safety and efficiency.</td>
</tr>
<tr>
<td>6. Graphene based ion exchange membranes</td>
<td>Mangrove-like structure used to protect fisheries and the aquaculture industry enabling farms to expand into open waters.</td>
</tr>
<tr>
<td>7. Innovative protective structures for Continuous Miners</td>
<td>Innovative protective structures for Continuous Miners that prevent mine collapses improving safety and efficiency.</td>
</tr>
<tr>
<td>8. Design of floating forests</td>
<td>Reuse of residuals from domestic coal mines and stockpiles to replace imports for use in concrete manufacturing.</td>
</tr>
<tr>
<td>9. Waste beneficiation and avoidance</td>
<td></td>
</tr>
</tbody>
</table>

Source: PwC analysis, Nanocomm Hub (2019)

The following pages consider each of these projects individually, outlining their: purpose, aims and innovations, observed impacts, technology readiness level and the probable industry impacts that are modelled.

Note, for the purposes of the modelling in this analysis, the impact of the three transport sector projects (surface damage investigation, robotics and sensor technology and technologies for future infrastructure) repeats. The projects were considered holistically, combined and modelled as one industry impact.

An explanation of technological readiness level is provided in Appendix C

Economic impact study for the Australian Research Council (ARC) Nanocomm Hub

PwC
Project focus 1: modularisation in construction

Purpose

The use of modular construction processes has the potential to deliver outcomes which are not possible using current processes and techniques. This includes reducing the quantity of construction materials required as inputs and broadening design possibilities by reducing the need for supporting structures.

Aims and innovations

This initiative is comprised of three distinct projects:

- Three-dimensional (3D) printed concrete: an additive manufacturing technology that does not require a mould, is fast, flexible and refined, in order to realise controllability and reproducibility of a model.

- Design development in precast engineered component application: using geopolymer concrete as a structural material. It is an environmentally friendly binder and could significantly reduce greenhouse gas emissions during production.

- Concrete confined by fibre-reinforced polymer (FRP): replacement of reinforced steel concrete with FRP composites, particularly in coastal regions to reduce the effects of corrosion.

Observed impacts

Modular construction methods, such as 3D printing and precast fabrication, have the potential to speed up construction processes and reduce construction and maintenance costs. For example, precast concrete has been demonstrated to reduce construction times, by up to 20 per cent, when compared to on-site construction.7

Technology readiness level: 8

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Commercial viability: 85 per cent
- Industry impact: 5 per cent reduction in the cost of labour and materials to the commercial construction sector as a result of increased speed and efficiency of construction.
- Market entry: 2030
- Market penetration: 15 per cent.

---

7 Lara Jaillon & C. S. Poon (2008)
Economic impact study for the Australian Research Council (ARC) Nanocomm Hub

PwC
Project focus 2: low carbon, environment friendly materials

Purpose

Cementitious composites are one of the most consumed infrastructure construction materials in the world because of abundant input resources, mature production process, and strong adaptability. However, the fabrication, construction, and application processes of cementitious composites have a large impact on resources, energy use, and the environment.8

Aims and innovations

Nanomaterials have been found to be among the most efficient reinforcing materials for cementitious composites. The Hub’s research has contributed to this from various aspects, including improving the exfoliation and dispersion of nanomaterials in cement and utilising nanomaterials to control cement at nanoscale.

Observed impacts

The addition of nanomaterial could increase the performance of cementitious composites significantly. Performance improvements which have been demonstrated to date include:

- 17 - 109 per cent increase in compressive strength9
- 7 - 88 per cent increase in flexural strength10
- 15 - 79 per cent increase in tensile strength.11

These improvements could result in equivalent or better performance of concrete with reduced of amounts of cement. This could also lead to significant environmental impacts as cement manufacturing is currently responsible for 8 - 9 per cent of global anthropogenic CO₂.12

Technology readiness level: 4

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Commercial viability: 85 per cent
- Industry impact: 20 per cent increase in the asset life of all new civil engineering assets as a result of more durable construction materials.
- Market entry: 2030
- Market penetration: 15 per cent

11 Shamsaei, de Souza, Yao, Benhelal, Akbari (2018).
12 Monteiro, Miller & Horvath (2017).
Project focus 3: surface damage investigation

Purpose

The quality and type of welds used in the production of railways is one of the key determinants of railway performance. In particular, welds on heavy haul railways are prone to surface damage which can reduce the productivity of rail assets.

Aims and innovations

This project aims to mitigate the localised surface damage of rail welds in heavy haul railways. The Hub’s research will achieve this by better understanding the formation of microstructures and the performance of different premium rail steel grades when used as rail flash-butt welds.

Flash-butt welds can be improved by modifying the wheel/rail contact points. Routine maintenance could also be better planned for by considering the cyclical deformation behaviour the materials and the fatigue initiation life of flash-butt welds.

Observed impacts

Reduction in maintenance costs of between 30 and 40 per cent have been observed. Good welding can not only reduce maintenance costs, increase the service life of the tracks and contribute to passenger comfort.

Technology readiness level: 8

Figure 5: The University of Queensland lab

Source: Nanocomm Hub (2018), Annual Report

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Commercial viability: 90 per cent
- Industry impact: 1.5 per cent increase in the asset life of all new road and rail assets as a result of the more effective use of maintenance budgets and new technologies.
- Market entry: 2025
- Market penetration: 15 per cent.

Economic impact study for the Australian Research Council (ARC) Nanocomm Hub

PwC
Project focus 4: robotics and sensor technology

Purpose

Australian governments spend more than $7 billion maintaining and renewing road infrastructure each year. This is a significant budget pressure which could be alleviated, in part, if more durable, resilient and secure infrastructure could be developed.

Aims and innovations

The aim of this project is to reduce the maintenance costs of infrastructure by developing intelligent robots. Two key projects include:

- crawler robot: a crawling robot with sensors which provide autonomous data logging over a pavement surface.
- innovative monitoring protocol: unmanned aerial vehicles (UAVs) which monitor the structural health of assets, including surface defects and subsurface delamination of bridges and other civil engineering structures.

Figure 6: A robotic transverse profiler being used on site

Observed impacts

Robotic systems which utilise artificial intelligence, developed to date, have been successful in detecting structural damage with 97.7 per cent specificity, 91.9 per cent sensitivity and 96.6 per cent accuracy. By using autonomous robotics systems and techniques, defective assets can be identified with greater accuracy allowing for more effective use of maintenance budgets and therefore longer asset lives.

- Sydney Water utilised similar technologies which resulted in a 25 per cent reduction in the annual cost of their critical water mains (CWM) renewal program.
- The use of semi-autonomous robots resulted in a 30 to 40 per cent decrease in the cost of bridge condition inspections, increased security of workers during inspections and enhanced traceability of bridges’ aging.

Technology readiness level: 8

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Commercial viability: 90 per cent
- Industry impact: 1.5 per cent increase in the asset life of all new road and rail assets as a result of the more effective use of maintenance budgets and new technologies.
- Market entry: 2040
- Market penetration: 15 per cent

Source: Nanocomm Hub (2018), Annual Report

Project focus 5: technologies for future infrastructure

**Purpose**

The choice of concrete as a common building material is primarily justified by its durability, high fire resistance, low-cost and low level of maintenance. However, concrete durability, and more specifically concrete cancer is becoming a growing concern. Aggressive environments may lead to premature degradation of concrete and loss of structural integrity of concrete.\(^{18}\)

Alkali–silica reaction (ASR), more commonly known as concrete cancer, can lead to serious cracking in concrete, resulting in critical structural problems and the demolition of assets. ASR involving rocks and minerals containing reactive silica forms are currently considered as the cause of early deterioration of an increasing number of concrete structures.

**Aims and innovations**

The Hub is exploring the use of local aggregates in concrete to increase durability. This includes the use of:

- non-reactive aggregates
- suitable pozzolans
- lithium admixtures
- combinations of pozzolans and lithium.

**Observed impacts**

To ensure that infrastructure networks require less maintenance and can resist extreme events, concrete needs to become more durable, resilient and secure. The Hub is currently exploring how these local aggregates can reduce the incidence of concrete cancer.

**Technology readiness level: 6**

\(^{18}\)Figueira et al. (2019).

---

**Probable industry impacts**

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Industry impact: 1.5 per cent increase in the asset life of all new road and rail assets as a result of the more effective use of maintenance budgets and new technologies.
- Commercial viability: 90 per cent
- Market entry: 2022
- Market penetration: 15 per cent.
Project focus 6: graphene based ion exchange membranes

**Purpose**

Acid waste drainage is a significant environmental issue associated with mining and other large scale earth disturbance activities. The traditional methods for treating acid waste drainage usually involve:

- high maintenance costs
- high energy consumption
- significant sludge waste
- the use of hazardous chemicals

**Aims and innovations**

To address this issue, the Hub is exploring the use of graphene-polymer composite ion exchange membranes to treat acid waste water. The integration of advanced atom-thin nanomaterials, into the graphene-based material in the membrane matrix, significantly improves the overall membrane performance.

**Observed impacts**

The ultra-thin graphene-based material exhibits superior separation and acid recovery, almost four times greater than current commercial dense membranes. For example, when a nanofiltration (NF) membrane was installed at the Asarco Globe refinery, there was a 75 per cent reduction in the volume of water required to be precipitated.

**Technology readiness level: 8**

---

**Figure 8: Graphene-based membrane for acid waste water treatment**

Source: Nanocomm Hub (2018), Annual Report

---

20 DFAT (2016).
21 Lien (2002).
22 Nanocomm Hub (2019).

Economic impact study for the Australian Research Council (ARC) Nanocomm Hub

PwC
Project focus 7: protective structures for continuous miners

Purpose

Mining plays an important role in the Australian economy. The resources sector comprises over 50 per cent of Australia’s exports and over seven per cent of Australia’s GDP.23

Continuous miners, large pieces of machinery which scrape coal from seams, are widely used in underground mining due to their high productivity. However, ground control problems such as coal or rock burst, pillar spalling and roof falls can cause injuries and loss of production. There is a need to develop an effective protective structure as the last line of defence for people working on continuous miners.

Aims and innovations

This project aims to design, manufacture and implement an innovative protective structure for continuous miners in underground coal mines; where coal burst and outburst can occur, often as a result of developing roadways in highly stressed and gassy coal seams. Quasi-static and dynamic loading tests have been designed to determine the energy release and transformation during a coal burst incident. Numerical models have been developed to study the influence of coal cleat and joint systems on the dynamic failure of coals under various loading conditions.

Observed impacts

Redesigning the platform on continuous miners and bolting rigs to reduce the distances reached during drilling and bolting can reduce the prevalence of acute injuries.24

Several possible protective structures have been laboratory tested and numerically studied for the design and implementation of a protective structure on continuous miners in underground coal mines for the enhancement of construction safety.

A case study on Coal India Ltd indicated that around 12 per cent percent of coal production is lost due to ground control problems. The new technology aims to avoid that loss and unlock higher output for the mineral industry.25

Technology readiness level: 8

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Industry impact: 0.1 per cent reduction in costs to the iron ore, coal, copper and nickel mining sectors as a result of the reduced prevalence of mine collapses.
- Commercial viability: 90 per cent
- Market entry: 2025
- Market penetration: 15 per cent.

---

23 Australian Mining (2019).
Project focus 8: the ‘floating forest’

**Purpose**

The Australian coastline and offshore structures are subject to strong waves and wind and increasingly so as a result of climate change. This results in damaged structures which negatively impacts productivity in the aquaculture industry.

**Aims and innovations**

The Hub has designed a novel floating breakwater-windbreak concrete to counteract this issue. The ‘floating forest’ provides protection to fragile shorelines and port terminals against severe wind and wave actions.

Inspired by mangrove forests, the floating forest is a mega structure which adopts an arch shape with an inclined desk to keep concrete structures under compression during strong wave action. The structure also allows for wave run-ups to produce efficient wave energy dissipation. The breakwater structure can be used in various water depths which creates a calm and protective environment.

The floating forest has the ability to help control coastline erosion, protect fish farms, marinas, port terminals, employees in the aquaculture industry and other large floating structures.

**Observed impacts**

A feasibility study has been undertaken to prove the scientific and engineering concepts. Other research currently underway includes the study of:

- the viscous effect
- various design parameters
- a floating forest model.

**Technology readiness level: 6**

---

**Probable industry impacts**

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Industry impact: a $26 million increase in output in the seafood industry as a result of improved protection for fish farms and expansion of their operational space. The seafood sector is expected to exceed $5 billion by 2040; innovation from the Hub is assumed to contribute 1 per cent of the increase from current output levels ($26 million).
- Market entry: 2025
- Market penetration: not required as this is implied in the industry impact
- Commercial viability: 55 per cent.

---

Economic impact study for the Australian Research Council (ARC) Nanocomm Hub
PwC
Purpose

As a by-product of coal production, Australia produces over 12 million tonnes of fly ash each year. This adds to existing domestic stockpiles which exceed 100 million tonnes. The majority of this is stored in ponds or sent to landfill, resulting in negative environmental impacts such as groundwater contamination.27 Despite this, Australia is still a net importer of coal ash. This is because a majority of fly ash produced domestically is brown coal ash, unlike imported black coal ash which can be used as an input to cement production.

Aims and innovations

To address this issue, the Hub are developing technologies that enable the extraction of minerals and residuals from brown coal ash for use in the manufacture of construction materials.

Specifically, the Hub is researching the role of geopolymers as environmentally friendly alternatives to Portland cement. These geopolymers are made by reacting materials containing aluminate and silicate with a highly alkaline activator. Materials used include combustion products such as coal fly ash and slag.

Observed impacts

Several new technologies are being commercialised in the areas of fly ash beneficiation and utilisation. Usage applications include:

- the partial replacement of cement, reducing cost of construction and reducing the carbon footprint during cement manufacturing
- the replacement of clay bricks, for example in underground mine stoppings and dams
- the stabilisation of soil slopes and roads - using pozzolanic nature to provide strength to slopes at low cost in comparison to traditional cement like binders.28

Technology readiness level: 6

Probable industry impacts

The economic impact of this project was estimated using the following parameters. These parameters were formulated in the workshop drawing on the Hub’s expertise and the available academic research:

- Industry impact: a $16.5 million reduction in imports as a result of domestic fly ash production and existing stockpiles replacing fly ash imports. $16.5 million is equivalent to Australia's current imports of fly ash; 150,000 tonnes of per annum worth $90 - 130 per tonne on average.29
- Market entry: 2030
- Market penetration: not required as this is implied in the industry impact
- Commercial viability: 60 per cent.
Economic analysis
Methodology, inputs, assumptions & limitations
Methodology

The purpose of this report is to estimate the potential economic impact of the Hub’s innovations. More specifically, this report estimates the possible economic benefits resulting from the technologies currently being developed in the Hub’s projects if utilised by industry.

It is important to note the analysis does not attempt to quantify the following:

- Historic or current economic impacts of the Hub’s activities: the economic activity which the Hub currently generates (including 181 staff currently employed and direct investment of $15 million outlined in the preceding chapter).
- Environmental impacts: a majority of the Hub’s current projects have the potential to reduce energy consumption and greenhouse gas emissions in comparison to incumbent technologies.
- More broad, sector-agnostic impacts: the modelling undertaken was conservative, in that it assumes the technologies being developed are utilised as per their assumed industry applications. In reality, many of these technologies could have roles in industries beyond the industry in which they were developed.

**Modelling inputs**

To develop appropriate inputs to the model, it was important to understand for each of the nine shortlisted projects the:

- research and its aims
- timeframe for market entry
- direct impacts on industry from using the technology.

All nine projects are at varying stages of the research and development lifecycle and as such, the potential benefits to industry have varying probabilities of occurring. This uncertainty comes from two main sources:

- commercial viability: the likelihood that the research successfully results in a technology that is able to be produced profitability and at scale
- market penetration: the likelihood that the technology is used by industry and whether it can replace incumbent technologies.

To account for these two factors, the potential industry benefits were scaled down using probability parameters representative of the likelihood of commercial viability and market penetration. This approach is similar to the modelling approach of the Cooperative Research Centre’s (CRC) Impact Tool.30

A description of the projects and the type, timing and magnitude of their assumed direct impacts are outlined in the following pages. The inputs to the model are primarily based on information and data provided by the Hub and their industry partners.

**The model**

To assess the direct and indirect economic impacts simultaneously, a computable general equilibrium (CGE) model was used (more details are provided in Appendix A). CGE models use actual economic data and economic theory to estimate how the economy might react to changes in external factors; in this case, the Hub’s technological innovations.

Once the research projects and their industry impacts were outlined, these impacts were translated to inputs appropriate for the CGE model. The modelling timeframe is the 30 year period of 2020 to 2050. This helps capture the long timeframes often required for innovations to complete the research and development life cycle and make it to market.

---

30 Department of Industry, Innovation and Science (2019). Economic impact study for the Australian Research Council (ARC) Nanocomm Hub
Methodology

The probable and possible scenarios

Two distinct scenarios were modelled; a more conservative estimate - the ‘probable’ scenario - and a more optimistic scenario - the ‘possible’ scenario. Table 1 outlines how the probable and possible scenarios were differentiated.

Table 1: Probable and possible scenario assumptions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Probable scenario</th>
<th>Possible Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial viability</td>
<td>Defined on a project by project basis, as per pages 13 - 21.</td>
<td>100%. (i.e. it is assumed all technologies make it to market and there is no risk that technologies are not commercially viable).</td>
</tr>
<tr>
<td>Market penetration</td>
<td>15%</td>
<td>30%</td>
</tr>
<tr>
<td>Industry impact</td>
<td>Defined on a project by project basis, as per pages 13 - 21.</td>
<td>50% greater magnitude than the probable scenario.</td>
</tr>
<tr>
<td>Market entry</td>
<td>Defined on a project by project basis, as per pages 13 - 21.</td>
<td>Projects with market entry in 2030 or later, have a market entry 5 years earlier than the probable scenario. (i.e. a probable market entry in 2030 has a possible market entry in 2025).</td>
</tr>
<tr>
<td>Waste beneficiation and avoidance project</td>
<td>Included</td>
<td>Non included</td>
</tr>
</tbody>
</table>

Source: Scenario assumptions were confirmed by Nanocomm Hub and PwC analysis
Assumptions and limitations

Assumptions

Differentiating economic activity transfer and new economic activity

A common challenge of economic impact modelling is accurately identifying new economic activity net of existing economic activity that may have shifted from elsewhere within the economy. Economic activity can and does shift across jurisdictional borders, sectors or within sectors.

The CGE model is able to estimate changes in output and input prices across industries in order to reflect changes in economic activity. The re-allocation of resources in a constrained economy is why some sectors may see minor negative impacts.

This goes some way to negating the effect of shifting economic activity within the economy. In any case, CGE modelling is a conservative approach because it requires resources be drawn from other activities by recognising the opportunity costs inherent in the economy.

Modelling inputs

The inputs to the model are primarily based on information and data provided by the Hub; regarding the aims, timing and industry impacts of each of the Hub’s nine projects. There is a level of uncertainty inherent in any forecasting exercise and particularly so with research and development. Projects with seemingly low potential at the outset of research and development can have large economic impacts and vice versa. The estimates provided by the Hub are conservative in nature and have been scaled down further to account for commercial and market penetration risks.

Limitations

Opportunity cost

The economic impacts presented in the key findings do not consider the opportunity cost of funding the Hub. It is possible if the ARC and other funding partners did not fund the Hub, other beneficial innovations would be funded in its place.

CGE modelling limitations

Relative to more simplistic input-output modelling (IO), CGE models are preferred by governments and treasuries because they have been peer reviewed, meaning the inputs and assumptions are fully and publicly documented. In addition, CGE models feature systematic price-guided behaviour and recognise the effects of economy wide constraints. Set in recursive-dynamic mode, VURM is able to model the effects of economic shocks over a period of time, solving for industries and across regions each year. These assumptions may not hold if an economy is already at or near full capacity, or if particular labour categories face skill shortages. Wages and capital stocks can and do respond in the longer term.

It was also assumed that the national economy was not constrained by any current account balance constraints during the construction period. That is, foreign capital inflow and imports required for the additional economic activity can occur without any direct implications on the availability of capital or the national economy.

Wider benefits

The economic impacts, as defined in this analysis, may draw an artificially narrow view of benefits. All impacts have been focussed on specific sectors based on existing research, however wider possible applications and benefits have not been considered. For example; residential construction could benefit from modularisation as well commercial construction, or a reduction in water waste could have wider economic and environmental benefits not quantified in this report.
Key findings

Results of the economic analysis
The potential economic impacts associated with the Hub’s research projects are outlined below.

**Gross domestic product**

Gross domestic product (GDP), the value of the economy in terms of wages and profit in each industry, is positively impacted by the Hub’s activity. The mechanisms by which cost savings and economic activity are expected to flow through the economy is illustrated in Figure 12.

Over the period 2020 - 2050, GDP is estimated to increase, relative to the baseline in present value terms, by:
- $400 million in the probable scenario
- $1,870 million in the possible scenario.

The profile of these impacts is illustrated in Figure 13.

By 2030, the Hub is forecast to contribute an additional $15 and $165 million of economic activity annually to the Australian economy in the probable and possible scenarios respectively.

The rate of increase above the baseline is greatest between 2024 and 2034, reflecting the period when the majority of projects enter the market. GDP growth above baseline then moderates while continuing to increase to 2050.
Results
Industry value added

The distribution of the impact on GDP by industry sector is illustrated in Figure 14. The figure includes the six industries directly impacted and the next five industries that experienced the largest impacts.

Direct economic impacts

The Hub’s activity is dispersed across the economy, with a concentration on the coal mining sector. In present value terms, additional output over 2020 to 2050 in the coal mining sector is forecast to be:

- $112 million in the probable scenario
- $392 million in the possible scenario.

This is driven by reduced waste water processing costs and decreased prevalence of mine collapses increasing output in the sector. In the iron ore mining sector, additional output over 2020 to 2050 is forecast in present value terms to be:

- $88 million in the probable scenario
- $335 million in the possible scenario.

This is driven by the innovative protective structures being developed for continuous miners and reducing the prevalence of coal bursts, therefore increasing output in the sector.

The civil engineering construction sector benefits from reduced costs due to extended lives of new assets; as a result of nanoparticle materials (20 - 30 per cent increase across the sector) and robotics and sensor technology (1.5 - 2.3 per cent increase for road and rail assets specifically). This results in additional output to 2050 of:

- $27 million in the probable scenario
- $131 million in the possible scenario in present value terms.

The non-metallic mineral products sector could see output increase by $104 million by 2050. This impact was only modelled in the possible scenario, and forecasts additional domestic activity due to decreased dependency on the importing of coal ash as an input to concrete manufacturing.

Figure 14: Impact on GDP by industry, total by 2050 (present values, 18/19 $ millions, discounted at 7 per cent per year)

Source: PwC analysis
Note ‘Other’ captures all sectors in the economy not otherwise defined
Results
Industry value added

In the same period, the fifth and sixth largest impacts were seen in the mining services and construction services sectors respectively. They experienced a similar magnitude of benefits (in present value terms) in the period 2020 – 2050 of:

- $30 and $23 million in the probable scenario
- $113 and $108 million in the possible scenario.

Indirect economic impacts

The sector experiencing the third largest effects was professional, scientific and technical services; a sector not directly impacted by the Hub’s activities. This reflects the importance of the downstream effects of economic activity. Over the period 2020 to 2050, the professional, scientific and technical services sector could grow (in present value terms) by an additional:

- $27 million in the probable scenario
- $134 million in the possible scenario.

The impact on the remaining sectors of the economy is captured in ‘Other’. Output in these remaining sectors is expected to increase by $50 and $330 million in the probable and possible scenarios respectively.
Results
Gross domestic product by component

Composition of economic impacts

GDP is comprised of:

- Consumption: private consumption expenditures, or consumer spending. Consumption is the largest component of Australia’s GDP and captures goods and service bought by consumers.

- Investment: private domestic investment, or capital expenditure. This captures spending by business on their activities such as the purchasing of machinery.

- Government: government consumption and investment. This captures all government spending including infrastructure and public services.

- Exports and imports: exports are flows of money into a country from a foreign country in exchange for goods or services. Imports are flows of money out of a country in exchange for products and negatively impact GDP.

The composition of additional economic growth is similar between the possible and probable scenarios. The breakdown in 2050 is provided in Figure 15. Consumption and exports are the key drivers of additional growth; a result of higher export demand and increased wages due to productivity improvements.

Consumption (36 per cent), investment (19 per cent) and government spending (17 per cent) are the source of approximately 72 per cent of all growth. However the waste beneficiation and avoidance project, which aims to reduce Australian reliance on coal ash imports, results in a notable decrease in imports in the possible scenario. Imports consist of -4 per cent of additional GDP growth in 2050 in this scenario, compared to -19 per cent in the probable scenario.

Figure 15: Impact on GDP by component, 2050 (percentage points)

Source: PwC analysis
Results
Wages and household consumption

Wages
Economic theory suggests inflation and productivity are the key drivers of wage growth. Business cycles can cause fluctuations in the short term; however as output per worker increases, the value a worker creates increases and real wages are expected to follow in the long term.

This theory is reflected in the results below, as technological innovation by the Hub results in increased productivity and real wages.

Figure 16: Impact on national real wages, 2020 - 2050 (percentage change)

Source: PwC analysis

In 2050, real wages are forecast to have grown by an additional:
- 0.0032 per cent in the probable scenario
- 0.0116 per cent in the possible scenario.

While these figures appear modest, they are equivalent to approximately $80 and $290 million in additional wages nationally in 2050. This demonstrates the potential, tangible benefits to Australian households as a result of the Hub’s activities.

Household consumption
As outlined in Figure 12, additional economic activity has effects beyond the direct impact of increased production from industry. Downstream industries can benefit from additional orders and ultimately households stand to benefit from the employment, jobs and wages stimulated.

Household consumption is a key measure of economic welfare, evidencing households capacity to purchase and consumer goods. In the period 2020 to 2050, household consumption is forecast to increase by:
- $110 million in the probable scenario
- $490 million in the possible scenario in present value terms.

The profile of these impacts are illustrated in Figure 17.

Figure 17: Impact on household consumption, 2020 - 2050 (18/19 $ millions)

Source: PwC analysis

31 This calculation is based on the level of real wages in 2050.
Economic impact study for the Australian Research Council (ARC) Nanocomm Hub
PwC
Results
Investment and exports

**Investment**

The Hub’s innovations could result in lower costs for a range of key sectors. Lower costs, while producing the same level of output, will result in productivity gains and increased returns on investment. This makes doing business more attractive to potential investors and increases investment at the margin.

Investment has a multiplier effect through the economy, stimulating further jobs, wages and downstream investment in the economy as demonstrated in the GDP by industry results.

Figure 18 outlines how exports are forecast to increase as a result of the Hub by 2050. Exports are estimated to increase over the period 2020 to 2050 in present value terms by:

- $180 million in the probable scenario
- $590 million in the possible scenario.

Higher exports in the possible scenario are predominantly driven by the waste beneficiation and avoidance project. This research would allow domestic stockpiles of brown coal ash to be used in the production of cement, displacing more expensive imports of black coal ash.

**Exports**

Increased productivity can positively impact net exports through two mechanisms. First, it increases the relative competitiveness of Australian production in comparison with imports, decreasing imports and increasing local output. Second, it makes Australian exporters more competitive in comparison with other international export competitors, increasing exports at the margin.

These effects reflect the Hub’s aim of developing materials and technologies that will elevate the global competitiveness and profitability of the Australian construction sector.

Figure 19 outlines how exports are forecast to increase as a result of the Hub by 2050. Exports are estimated to increase over the period 2020 to 2050 in present value terms by:

- $180 million in the probable scenario
- $590 million in the possible scenario.

Higher exports in the possible scenario are predominantly driven by the waste beneficiation and avoidance project. This research would allow domestic stockpiles of brown coal ash to be used in the production of cement, displacing more expensive imports of black coal ash.

Figure 18 shows over the period 2020 to 2050, an increase (in present value terms) in investment nationally of:

- $160 million in the possible scenario
- $790 million in the probable scenario.

The rate of increase is largest in the period 2025 - 2040, when changes in productivity and costs are introduced into the economy. After this period, the increase in investment declines (but remains above baseline) as markets clear and the economy reaches a new equilibrium.

Economic impact study for the Australian Research Council (ARC) Nanocomm Hub

PwC
Appendix A

Computable general equilibrium modelling, assumptions and limitations
Background

The economic impact of the Hub, including both direct and indirect effects, were estimated using computable general equilibrium (CGE) modelling.

CGE modelling

A CGE model uses actual economic data and economic theory to estimate how an economy might react to changes in external factors such as policy, investment, or in this case, technological innovation.

CGE models are an internally-consistent, interdependent representation of an entire economy with detailed sectoral and product structure. The model captures the relationships of key economic agents (including producers, households, investors, government and the foreign sector) and shows how each responds to an external change in the economy.

Relative to more simplistic input-output modelling, this type of model is preferred by governments and treasuries because they have been peer reviewed, meaning the inputs and assumptions are fully and publicly documented.

Specifically, the Victoria University Regional Model (VURM) was used. CGE models such as VURM simulate the effects on the economy in each year caused by a new development – known as an economic shock. The VURM is a multi-regional CGE model that simulates the effects on the economy in each year, taking into account indirect and substitution effects; for example, the impact additional economic activity might have on prices or resource constraints. It models the economic behaviour in the eight states/territories of Australia using a database of 79 industries producing 83 commodities. Each industry can produce a variety of commodities and capital is both industry and region specific.

In each region, there is a single household sector and a regional government. There is also a Federal government. Finally, there are foreigners, whose behaviour is summarised by demand curves for regional international exports and supply curves for regional international imports.

In recursive-dynamic mode, VURM produces sequences of annual solutions connected by dynamic relationships such as physical capital accumulation. The model captures:

- direct effects: as a result of the Hub, largely driven by increased productivity and reduced costs for Australian industry as a result of technological innovation
- indirect effects: the flow-on impacts throughout Australia, including the impact of a change in investment in the economy as a result of more efficient production or additional output.

The VURM produces estimates of standard economic measures, which serve as indicators of changes in economic activity. These include:

- gross domestic product (GDP)
- employment
- household and government consumption.

Full technical documentation relating to the VURM is available at: https://www.copsmodels.com/ftp/workpapr/g-254.pdf
Computable general equilibrium modelling

Definitions

In our CGE analysis, we have estimated the impacts of the Hub on key macroeconomic variables. Each of these measures is described below.

- gross domestic product (GDP) – this represents the 'value added' to the economy through spending patterns. Since the GDP figure captures the difference between the value of output and the value of intermediate inputs, it represents the unduplicated total value of economic activity that has taken place. The GDP impacts in this report represent the value added to the economy as a result of the cost savings, efficiency and domestic output gains in connection with the Hub’s technological innovations.

- real wage growth – represents the rate of change in wages once the effect of inflation has been accounted for. Growth in real wages represents an increase in purchasing power for employees.

- household consumption - measures household economic well-being through the acquisition of goods and services. To the extent that consumption can be considered as a proxy for living standards, an increase in consumption implies the Australian population is better off.

Indirect or flow on impacts and total economic impacts are described below.

- indirect impacts or flow on impacts – direct spending or cost reductions will flow through the Australian economy to stimulate other industries. These flow on impacts arise from changes in activity for suppliers through the various industry supply chains. For example, these impacts include companies that provide goods or services in connection with the construction industry. An example of an indirect impact could be spending on additional office space or accounting services as a result of additional construction activity.

- total impacts – represent the sum of the gross direct and indirect economic impacts.
Appendix B

References
References


Communication with Nanocomm Hub and industry partners (2019).

Communication with the Ash Development Association of Australia (ADAA) and industry partners (2019).

Department of Agriculture (2015). Australia’s seafood trade, Canberra: Department of Agriculture.


Journal of mines, metals and fuels (2016). Role of geological discontinuities during application of continuous miner technology in underground coal mines.


Presentation by Professor Wenhui Duan, ARC Nanocomm Hub (2016)

Project descriptions were confirmed by Nanocomm Hub during workshops (2019).

Project parameters were confirmed during workshops with Nanocomm Hub (2019).


Scenario assumptions were confirmed by Nanocomm Hub and PwC analysis (2019).


The University of Wollongong (2017). A case study of the illustration of the layout and support in an Indian coal mine with difficult roof condition where continuous miner is in operation.
Appendix C
Technological readiness level (TRL) scale
Appendix C: Technological readiness level (TRL) scale

<table>
<thead>
<tr>
<th>TRL</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic Research</td>
<td>Basic principles are observed and there is a focus on the material/process</td>
</tr>
<tr>
<td>2</td>
<td>Applied Research</td>
<td>Once basic principles are observed, practical applications can be identified. Most of the work includes analytical or paper studies.</td>
</tr>
<tr>
<td>3</td>
<td>Critical Function</td>
<td>Analytical studies and laboratory-scale studies to physically validate the predictions of separate elements of the technology. No strong attempt to integrate the components into a complete system.</td>
</tr>
<tr>
<td>4</td>
<td>Laboratory Testing/Validation of Component</td>
<td>The basic technological components are integrated to establish that pieces will work together and narrow possible options in the complete system</td>
</tr>
<tr>
<td>5</td>
<td>Laboratory Testing of Integrated/Semi-Integrated System</td>
<td>The basic technological components are integrated so the system configuration is similar to the final application in almost all respects</td>
</tr>
<tr>
<td>6</td>
<td>Prototype System Verified</td>
<td>The expected technology undergoes development as an operational system and is tested in a relevant environment</td>
</tr>
<tr>
<td>7</td>
<td>Integrated Pilot System Demonstrated</td>
<td>The technology’s virtual design is complete and requires demonstration of the system prototype in a relevant environment</td>
</tr>
<tr>
<td>8</td>
<td>System Incorporated in Commercial Design</td>
<td>The technology has been proven to work in its final form and under expected conditions.</td>
</tr>
<tr>
<td>9</td>
<td>System Proven and Ready for Commercial Deployment</td>
<td>The technology is in the final form and operated under the full range of operating missions conditions.</td>
</tr>
</tbody>
</table>

Source: National Aeronautics and Space Administration