Market Validation and Commercialisation of Regenerable Activated Honeycomb Monolith Carbons Technology

Final Report to

Australian Carbon Innovation

MONASH University

Purpose

This final report is intended to fulfil the obligations for Milestone 6 under the *Variation Agreement #2 – Activated honeycomb monolith carbons*, dated 28 September, 2021, between Monash University and Australian Carbon Innovation.

Milestone 6 requires reporting on the following topics:

- Summary of outcomes of sample preparation and evaluation program
- lndicative revenue and number of jobs likely to be created by full scale manufacture in Victoria.

Background

Honeycomb monoliths (HM) carbons are premium materials in the very large and growing active carbon market. They consist of contiguous hexagonal- (or square-) shaped structures with long parallel, straight channels separated by thin walls which provide particular advantages over conventional packed-bed reactors, such as (i) a high void fraction which minimises the pressure drop when high flow rates are used, (ii) high geometric surface area which increases the contact and mass transfer rates with adsorbates or reactants, (iii) facile regenerability, as well as (iv) good thermal shock and crush resistance. These advantages can proffer monoliths with significantly higher efficiencies in separation, purification and catalytic applications. The application of these structured materials as adsorbents and catalyst supports has attracted increasing attention in recent years for a number of chemical and environmental purposes[1,2,3,4,5].

A novel efficient technology to prepare electrically conductive HM carbons directly from Victorian brown coal was recently developed at Monash University[6]. In this process, a homogenised and smooth dough with plasticine-like consistency is prepared by kneading the brown coal with additives. In the presence of moisture and relatively high oxygen functional group concentrations, the development of strong H-bonding occurs. After extrusion of the homogenous dough, these strong H-bonds develop as the extruded product dries leading to 'tightening' of the coal structure such that its integrity can be maintained throughout the drying, carbonization and activation stages.

Previously known HM carbons have mostly been derived from expensive polymer/resin precursors and, as a consequence, have achieved only a small market share. The utilisation of cheap brown coal as the raw precursor material has the potential to reduce the material cost substantially and be a ‘game-changer’, enabling substantial escalation of the HM carbon market share.

With the support of this project, Monash has been seeking to partner with industry collaborators (i) to demonstrate the utility of brown coal derived HM carbons across an increasingly diverse range of applications, (ii) to secure its intellectual property through patent completions and (iii) to develop a small scale manufacturing capability enabling larger scale demonstration so as to progress towards commercialisation of this promising technology.

Summary of outcomes of sample preparation and evaluation:

A summary of the outcomes from this project is provided below. The reader is referred to the Milestone 3, 4 and 5 Project Reports for fuller details of the activities undertaken[7,8,9].

Systematic studies of sample preparation

- Systematic investigations into the conditions used to prepare monoliths have enabled improved tailoring of the surface area, porosity, conductivity and other characteristics which are important for utilisation of these carbon monoliths.
- Applications studies have progressed demonstrating the abilities and regenerability of VBC derived carbon monoliths across a range of applications, including:
  - Removal of volatile organic hydrocarbons (VOCs) and in particular formaldehyde from air streams
  - Removal of dyes, phenols, and humic material from water streams
  - Electrodes for water electrolysis
  - Material for hydrogen storage
  - Catalyst support for chemical reactions
- Characterisation of the monoliths has continuously advanced to incorporate state-of-the-art analytical techniques such as high resolution scanning and transmission electron microscopies (SEM and HRTEM), X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), etc. The information derived through these studies has provided significant advances in our understanding of chemical and physical factors that control the behaviour of the carbon monoliths in the application areas identified above.

Commercial engagement

- A number of non-disclosure agreements (NDAs) and materials transfer agreements (MTAs) were established to facilitate engagement with local and international commercial entities with potential to commercialise the technology and/or utilise it within their own processes.
- Samples were exchanged with a number of these organisations. Although COVID-circumstances impacted most of these exchanges (there were significant delays in sample preparation, delays in courier services, delays in evaluation, and consequent delays in

feedback loops) we still obtained valuable information on the potential industrial application of VBC derived carbon monoliths in several sectors.

- During the course of the project an option to license the technology created was secured, and this eventually translated into a full commercialisation agreement with Monolith Technologies Pty Ltd (ACN 645 936 152), executed on Nov 12, 2021. This provides Monolith Technologies with an exclusive license to exploit the patent rights. The specific terms of the license are confidential.

Intellectual Property

- After securing the commercial option agreement (see above), the provisional patent, which had been lodged during the course of prior research activities, was able to be translated into a family of full patents. Currently the IP is secured across multiple jurisdictions, as detailed below:
    - Australia: AU2018273801
    - USA: US17/058928
    - China: CN 201880093808.5
    - Europe: EP18805549.5
    - India: IN 202017051119
    - Japan: JA, 2021-515251
    - Singapore: SG11202011601W
    - World: WO 201821390A1

Indicative Revenue and Number of Jobs

Monolith Technologies Pty Ltd have undertaken market evaluation, via Secondary Research, Expert Interviews and 'Markets and Markets' Analyses. Based on this information they have established commercial strategies / targets and undertaken financial forecasts. They have provided the following details:

The total market for activated carbon in SE Asia is AUD $2,182 Million. They aim for a 3% market share, equating to AUD $70 Million in sales for a full year (from 2024, approx.).

Some of the assumptions include:

- AUD 1 Million is required for equipment and setting up the facility (Loaders, hoppers, mixers/extruder/grinder/mould heads/forklifts), split between investors, bank and government grants
- Premises to be leased
- 80% of sales will be Super Carbon (powder), 20% for Carbon Block Monoliths (this may change)
- The extrusion equipment to be sourced to be capable of manufacturing up to 7 tonnes per hour
- 2 sales staff are allocated from 2023, 3 from 2024 (approx.)
- 2 finance/administration staff are allocated from 2023, 3 from 2024 (approx.).
- Technical/factory staffing of 8 staff from 2023, 11 staff from 2024 (approx.)

References:

[1] C. Moreno-Castilla, A. Pérez-Cadenas, *Carbon-based honeycomb monoliths for environmental gas-phase application*s, Materials 3(2) (2010) 1203
[2] P. Avila, M. Montes, E.E. Miró, *Monolithic reactors for environmental applications: A review on preparation technologies*, Chemical Engineering Journal 109(1–3) (2005) 11-36
[3] P. Ciambelli, V. Palma, E. Palo, *Comparison of ceramic honeycomb monolith and foam as Ni catalyst carrier for methane autothermal reforming*, Catalysis Today 155(1–2) (2010) 92-100.
[4] J.L. Williams, *Monolith structures, materials, properties and uses*, Catalysis Today 69(1–4) (2001) 3-9.
[5] M. Assebban, A.E. Kasmi, S. Harti, T. Chafik, *Intrinsic catalytic properties of extruded clay honeycomb monolith toward complete oxidation of air pollutants*, Journal of Hazardous Materials 300 (2015) 590-597.
[6] M.R. Parsa, *Investigation of spontaneous combustion behaviour of brown coal the effect of densification processes*, PhD Thesis, Monash University, Ch 7, 2016
[7] Milestone 3 Progress Report to Australian Carbon Innovation, July 1, 2021.
[8] Milestone 4 Progress Report to Australian Carbon Innovation, July 9, 2021.
[9] Milestone 5 Progress Report to Australian Carbon Innovation, December 31, 2021.