Parliamentary Submission:

PFAS Sub-Committee of the JSCFADT – Ongoing Scrutiny of PFAS Remediation

A Report on

PFAS HARVESTER

Photo of a pilot-scale version of UON's Regenerative Open Loop Calcium Cycle (ROL2C) which forms the basis of the PFAS Harvester technology.

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Executive Summary

The PFAS Sub-committee of the Joint Standing Committee on Foreign Affairs, Defence and Trade (JSCFADT) has recently invited research and industry experts, as well as key community stakeholders, to make submissions to the Sub-committee's inquiry into the Department of Defence's management of PFAS remediation under its 'National PFAS Investigation and Management Program' (*Department of Defence Annual Report 2017–2018; 2018–19).*

As part of this inquiry, Prof Behdad Moghtaderi from the University of Newcastle (UON) has received an invitation from the Sub-committee to submit a report on a thermochemical technology platform, named PFAS Harvester, which is being developed by his team for combined destruction and resource recovery from PFAS contaminated media.

Development and commercialisation of such technology requires a great deal of research efforts and importantly the capital needed to develop and demonstrate solutions at scale is typically too prohibitive for most companies and institutions. A collaborative approach provides the lowest cost and quickest pathway to meet the challenge. With this in mind, the team behind the PFAS Harvester grouped the related research and development (R&D) activities into three distinct stages, namely:

1. Stage (1) – Development and demonstration of a laboratory-scale proof-of-concept PFAS Harvester prototype.
2. Stage (2) – Development and field trial demonstration of a 2,000 L/day pilot-scale PFAS Harvester.
3. Stage (3) – Commercialisation.

Stage (1) activities were successfully completed in 2017-2018 with generous funding from UON. The encouraging results obtained from Stage (1) formed the basis of a grant proposal to the Government and industry in support of the R&D activities associated with Stage (2). More specifically, the team applied for nationally competitive funding through the Australian Research Council's Special Research Initiative on PFAS (ARC SRI-PFAS). The proposal was successful and the team secured sufficient funds to develop and demonstrate a pilot-scale version of the PFAS Harvester. The relevant activities which are jointly supported by the ARC and Evocra Pty Ltd (Evocra), are due to commence in July 2020, after the execution of relevant agreements between UON, ARC and Evocra. Upon successful completion of Stage (2), the team intends to develop and roll out a commercial version of the PFAS Harvester technology through a spin-off company and using private investment.

The report presented in this submission provides an outline of research objectives and methodology for <u>Stage (2) only</u> (i.e. the project funded by the ARC and Evocra for a pilot-scale PFAS Harvester). Preliminary results from a series of techno-economic analyses as well as experimental data from the laboratory-scale proof-of-concept prototype are also presented in this report to demonstrate the superior and unique features of the PFAS Harvester compared with conventional technologies.

Section 1

Aims and Background

1.1 Narrative

Remediation technologies for perfluoroalkyl and polyfluoroalkyl substances (PFAS) exploit chemical and physical properties of PFAS containing media to immobilise, remove and where possible destroy PFAS contaminants. Primary treatment processes which constitute the majority of conventional and emerging PFAS remediation technologies focus on immobilisation and removal, rather than destruction of PFAS contaminants. Therefore, the remediation achieved by this group is partial; requiring secondary treatment for final destruction of PFAS molecules. However, the secondary treatment processes that are in use or under development for PFAS destruction (e.g. incineration; plasma arc, etc.) suffer from a number of shortcomings, most notably: (i) high energy footprints, (ii) limited ability to treat a diverse range of PFAS contaminants or contaminated media, (iii) enhanced emission of pollutants such as dioxins and fluorocarbons as well as (iv) high treatment costs.

The PFAS remediation technology described here (i.e. PFAS Harvester) is a novel poly-generation thermal process for combined destruction and resource recovery from PFAS and/or PFAS contaminated media. This breakthrough process is a simple, cost effective and environmentally friendly alternative to incineration with far superior energy efficiency and emission profiles. It relies on a novel regenerative open loop calcium cycle (ROL2C) developed by Prof Moghtaderi and his team at the University of Newcastle (UON) for production of hydrogen enriched synthesis gas (syngas) by methane steam reforming.

The project described here seeks to further advance the understanding of the fundamental science underpinning the creation of the PFAS Harvester technology and identify operating parameters / conditions necessary to support its commercial rollout. To that end, the project will pay special attention to field testing of a pilot-scale PFAS Harvester using PFAS enriched feeds generated by our industry partner Evocra from a contaminated liquid media at an active remediation site using Evocra’s primary treatment technology “Ozofractionative Catalysed Reagent Addition (OCRA)” process.

1.2 Aims and Objectives

The principal vision in this project is to advance the technical development of the PFAS Harvester technology, thereby, facilitating its commercial deployment. To fulfil this vision the project will specifically examine the inner workings of the ROL2C process with the aim of:

- Determining the underlying science and engineering that govern the operation of the proposed PFAS Harvester and in particular the partitioning and deportment of carbon and fluorine into the gas and solid phases.
- Evaluating the performance characteristics of the PFAS Harvester and demonstrating its capabilities by field testing a 2,000 litre per day (L/d) pilot-scale version of the technology under real industry settings.

The research, in particular, will focus on the following key objectives:

- *PFAS Harvester technology assessment* – (i) gaining a fundamental understanding about the reaction properties of long and short chain PFAS species in the presence of

CaO, methane, steam and hydrogen at temperatures between 700ºC and 850ºC, (ii) exploring the influence of operating conditions such as pressure, temperature, heating rate and reacting environment, fluidisation and particle transport on the overall performance of the process, (iii) examining the microstructural rearrangements and/or morphological transformations of CaO during the carbonation stage with the view to optimise the pore structure and minimise deactivation, (iv) using the knowledge gained to identify/devise novel ways of maximising the PFAS destruction efficiency and the yield of major recoverable by-products such as syngas and limestone-rich ash/slag.

- *Feedstock supply, characterisation and optimisation* – (i) production and supply of sufficient quantities of PFAS concentrate for pilot-scale field trials, (ii) determination of typical composition and concentration of PFAS species in the OCRA's product stream, (iii) optimisation of the OCRA process to uplift its PFAS capture efficiency, thus, producing by-products with higher PFAS content for pilot-scale field trials.

1.3 Drivers

PFAS constitute a group of chemicals that have been widely used since the 1950s in the manufacture of products that resist heat, stains, grease and water/moisture. Examples include products such as fire-fighting foams, Teflon cookware, carpets, fabrics, furniture, metal plating, aviation hydraulic fluid, surfactants and fire-fighting foams. Due to their widespread use, persistence and mobility in water and soil, the release of PFAS into the environment has become a health concern since these chemicals do not break down easily in humans and animals by any natural process. The health and environmental concerns have been key drivers behind this project as well as the recent worldwide surge in the research and development (R&D) activities related to PFAS remediation technologies.

PFAS remediation technologies refer to processes and measures that allow targeted contaminants to be immobilised, removed or destroyed. Broadly speaking, the existing and emerging PFAS remediation technologies can be classified into two groups namely [1-15]: (i) primary treatment technologies for PFAS isolation and/or removal and (ii) secondary treatment technologies for PFAS destruction and/or utilisation. For a given contaminated media, the primary goal of primary treatments is to either reduce the mobility of the PFAS contaminants and thereby increase their concentration in the host media, or alternatively capture and extract the PFAS from the media. Therefore by default, the isolation and/or removal based treatment methods do not break the strong C-F bonds in PFAS molecules, although such treatments may convert some of the long-chain PFAS molecules to short-chain molecules. Because of this inherent limitation, the PFAS contaminated media, treated by primary treatment methods, requires additional remediation steps [1-3]. Examples of primary treatment technologies are: biological (e.g. fungal enzymes and microbial), isolation (e.g. capping and excavation / disposal), membrane filtration (e.g. reverse osmosis and micro, nano and ultra-filtration), precipitation / flocculation (e.g. in-situ foam fractionation, and electro-coagulation), and sorption (e.g. granular activated carbon or GAC, biochar, injected carbon and ion-exchange resins).

The PFAS secondary treatment methods focus on destroying the molecular structure of PFAS contaminants primarily by breaking the C-F bonds. While such methods are often employed in multi-step strategies as secondary remediation measures (e.g. incineration, plasma arc, high energy electron beam, ball milling), some can potentially destroy PFAS species in a single step, hence, function as both primary and secondary measures (e.g. sonolysis, redox techniques such as chemical oxidation, chemical reduction and electrochemical oxidation). Destruction methods that are also capable of utilising PFAS molecules (e.g. PFAS Harvester, vapour energy generator) are new concepts in PFAS remediation. Their primary focus is to destroy PFAS contaminants but in a manner that results in the production of a range of valuable by-products).

There are a number of factors that make PFAS remediation quite challenging [1-3]. These include: (i) characteristics of PFAS including the wide spectrum of acidity, volatility, solubility and hydrophobicity and changes in properties, mobility and structure due to past remediation or co-contaminants; (ii) technical / commercial maturity given that PFAS remediation technologies that have been demonstrated at pilot or full-scale in multiple applications are generally scarce, thus, the degree of confidence in PFAS technologies is relatively low; (iii) effectiveness noting that primary treatment methods cannot provide a complete solution and require reliable and effective secondary treatments, and (iv) social aspects including community acceptance and stakeholder engagement.

Whilst the R&D activities in the PFAS remediation space are accelerating, most developments are in their early stages of maturity and as such the race is on for developing cheaper and more effective PFAS remediation technologies. This submission outlines one such technology.

1.4 Opportunity

Generally, the concentration of PFAS species in the contaminated media is quite small. For example, according to case studies carried out by Evocra the combined concentration of all PFAS species in wastewater was found to be between 1,000 and 3,500 µg/L with an average value of 1,300 µg/L [4]. After primary treatment using Evocra's OCRA process the average concentration was increased by an impressive three orders of magnitude to about 1,300 mg/L. This is still too dilute, implying that in an incineration type secondary treatment process, much of the energy input is wasted in converting the water content of the PFAS concentrate to steam which ultimately has to be vented out of the system. In the PFAS Harvester process this massive quantity of steam together with some methane are used to produce hydrogen enriched syngas, thereby, offsetting a large proportion of the input energy. This, in turn, would allow the exergy losses (i.e. availability losses) to be minimised resulting in a much smaller energy footprint for the Harvester when compared with a conventional incinerator. Similarly, in the case of PFAS contaminated solids (e.g. GAC) the Harvester can offset a large proportion of the input energy by utilising the organic content (with makeup CH_4 and steam) for production of hydrogen enriched syngas. These features are discussed in the proceeding sections.

Section 2

Quality and Innovation

2.1 The PFAS Harvester

The PFAS Harvester is a poly-generation plant based on the ROL2C process devised at UON by Prof Moghtaderi and his team. The process is essentially a regenerative open loop calcium cycle for production of hydrogen enriched syngas by methane steam reforming (MSR). The Harvester, as shown in Figure 1, consists of two fluidised bed reactors, namely: the "Reformer" and the "Calciner". The Reformer takes a feedstock of PFAS, calcium oxide (CaO) and methane and converts them to other products at temperatures between 700-850^{o}C and a pressure of 15 bar. The Reformer's key functions are to:

(i) thermally decompose the PFAS content of the feedstock;

(ii) provide the necessary contact between the resulting steam / organic matter with the methane so that the MSR reaction and syngas production can proceed, and;

(iii) facilitate the carbonation reaction between the CaO particles and the gaseous CO_2 generated via PFAS dissociation and the water-gas-shift reaction (WGS).

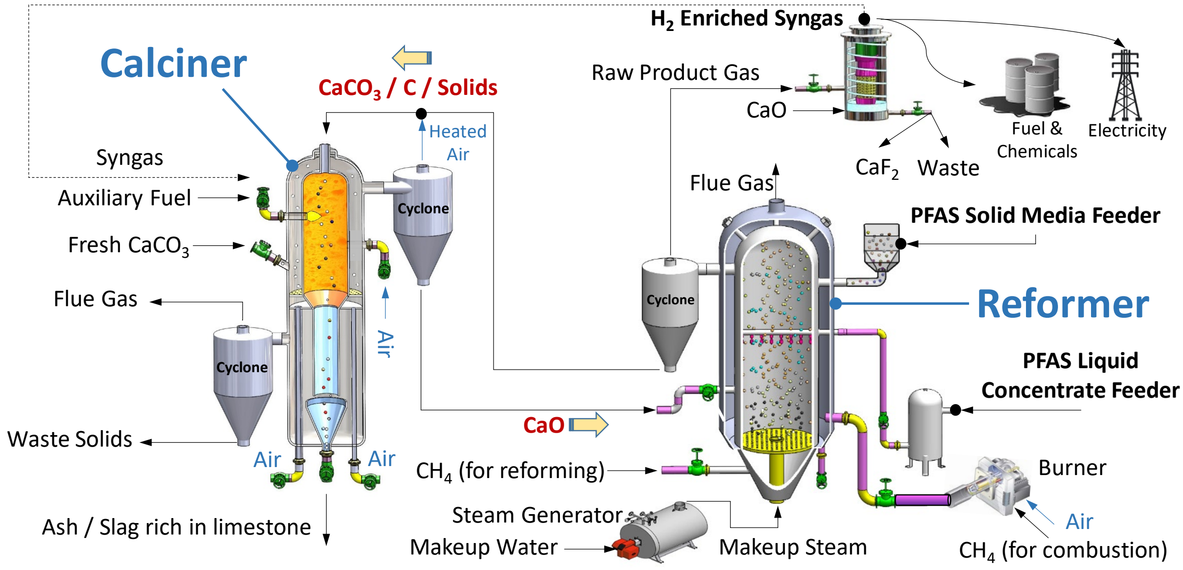

Figure 1: Infographics showing the PFAS Harvester components (*not to scale)*.

The raw gaseous products from the Reformer are directed towards a cleaning unit where in the first stage any remaining HF and CF_4 are reacted with additional CaO and converted to CaF_2. The gases are then further cleaned using a conventional wet scrubbing unit to separate and dispose of other impurities (e.g. sulphide).

Meanwhile, the carbon residues (mainly char) along with other solids (e.g. silica, sand, CaF_2, $CaCO_3$, etc.) are pneumatically transported from the Reformer to the Calciner which is a hybrid system comprising an inner core entrained flow reactor surrounded by an outer fluidised bed reactor. The sole function of the Calciner is to produce CaO required for the Reformer. This particular open loop arrangement for CaO / $CaCO_3$ has been adopted because the alternative closed loop configuration (where the incoming $CaCO_3$ particles from the Reformer are calcined and returned back to the Reformer) requires $CaCO_3$ particles to be separated from other solid residues which is an extremely difficult task at high temperatures. The role of the inner core entrained flow reactor is to fully oxidise the organic content of the hot solids transported from the Reformer extracting their heat.

As Figure 1 shows, combustion in the inner core is assisted using a combination of an auxiliary fuel such as methane and/or recycled syngas product from the Reformer. The main by-product from the inner core is a mix of ash and slag rich in calcium carbonate. This by-product is a highly sought after feedstock in the manufacturing of high temperature glass. The annulus between the inner core of the Calciner and its outer skin forms a fluidised bed reactor in which fresh limestone particles are calcined at temperatures around 900°C by indirect heating using the thermal energy provided by the inner core reactor.

2.2 Unique Features of the PFAS Harvester

- Offering a ploy-generation platform where in addition to the destruction of PFAS contaminants, valuable by-products are produced (e.g. hydrogen enriched syngas, calcium carbonate rich ash/slag, calcium fluoride, etc.).
- Ability to break C-F bonds at temperatures lower than those of other thermal processes.
- High PFAS destruction efficiency.
- Ability to deal with a wide range of PFAS contaminants and diverse forms of contaminated media.
- Small energy footprint and minimal environmental impact.
- Cost effectiveness (97% lower than incineration; comparable with average landfill costs; Section 2.3 for more details).
- Scalability and ease of reconfiguring the process for mobile applications (e.g. skid mount modular units).

2.3 Preliminary Thermodynamic Assessment and Economic Analysis

As part of Stage (1) R&D activities and in preparation for Stage (2) proposal, the research team conducted a comprehensive set of thermodynamic and economic analyses to assess the techno-economic merits of the PFAS Harvester. For this purpose, the ASPEN$^+$ software package was employed to carry out a set of detailed process simulations studies while the FactSage software package was used in parallel to gain more insight into equilibrium characteristics of reactions involved in the context of the PFAS Harvester and its operating conditions. The information collected through the above studies formed the basis of an overall mass and energy balance calculation as well as a bench-marking study comparing the Harvester with conventional incinerators and methane steam reformers. The Harvester examined in these studies was a unit capable of treating 2,000 L/d of PFAS concentrate with an average concentration of 1.3 mg/l. Heat losses were included in the calculations / analyses to ensure the results were as realistic as possible. Conservative values were used to determine the economics of the Harvester (e.g. H_2 \$8/GJ, limestone \$40/tonne, methane \$10/GJ and CaF_2 \$100/kg).

Preliminary calculations revealed that a 2,000 L/d unit roughly produced 444 kg/d of hydrogen, 148 kg/d net CO_2 (most of the CO_2 is offset through repeated carbonationcalcination cycles), 4.6 g/d of CaF_2, and 4,222 kg/d of $CaCO_3$ rich ash-slag. The unit's heat demand was ~1,500 MJ/d and it required 889 kg/d of methane for reforming, 27 kg/d of methane for combustion and 4,500 kg/d of fresh limestone for CaO generation. The unit's superior characteristics are revealed when its key attributes are compared with a conventional incinerator as summarised in Table 1.

As can be seen, the energy and emission footprints as well as the capital cost of the Harvester are much lower than those of the incinerator. Interestingly, while the Harvester registers a higher operating cost, according to Table 1, it only needs to charge 5 cents per litre (or $50/tonne) to achieve the same net income as the incinerator. This is 97% lower than the figure of $1.58 per litre (or $1,580/tonne) that an incinerator operator has to charge to achieve the same profit margin (the cost for plasma destruction can be as high as $21 per litre). Such a big margin is primarily the result of producing hydrogen by the Harvester as a value added product. Furthermore, at the above service fees the 2,000 L/d Harvester unit needs to treat about 285 m^3 of PFAS concentrate to breakeven (~142 days of operation at full capacity). However, the breakeven volume for the incinerator counterpart is 479 m^3 or approximately 240 days of operation at full capacity. The $50/tonne service fee for the Harvester is also quite competitive when it is compared with landfill costs in Australia which range between $45 and $105 per tonne.

Table 1: Bench marking of a 2,000 L/d PFAS Harvester unit against a conventional incinerator

Indicator	PFAS Harvester	Conventional Incinerator	%Reduction = [Inc–Harv]/Inc
Energy footprint (MJ/d)	1494	3797	+61%
Emission footprint (kg/d)	148	189	+22%
Capital cost ($)	360,000	606,530	+42%
Operating cost ($/d)	1,125	630	-79%
Service fees that result in the same net income	0.05 ($/L)	1.58 ($/L)	+97%

The above Harvester unit was also compared with conventional methane steam reformers to further validate its capabilities. Typically the efficiencies of conventional large-scale reformers range between 80% and 90% based on the higher heating value of methane (efficiency = Energy[out] / Energy[in]). Thermodynamic barriers prevent attaining efficiencies greater than 92% while the efficiency of small-scale reformers can be significantly lower than 80% if their exergy losses are not minimised. Fortunately, because of the unique design of the PFAS Harvester, the 2,000 L/d unit examined in the preliminary studies posted a reforming efficiency of 84.4% which is well within the above range.

The PFAS Harvester unit was also compared with a Vapour Energy Generator (VEG) system. The VEG which has been primarily developed for soil remediation has some similarities with the PFAS Harvester but is markedly different in terms of heat management. The Harvester utilises the water content of the PFAS concentrate / leachate to generate high temperature steam whereas VEG makes use of ex-situ water for steam generation. More importantly, the Harvester produces significant quantities of excess hydrogen enriched syngas whilst the little syngas produced in-situ by the VEG is all consumed internally to lower the external fuel demand. As a result, for the same output (destruction of ~2.5 g/d of PFAS) VEG features an energy footprint which is almost two times greater than that of the Harvester (2,968 MJ/d).

2.4 Preliminary Experimental Findings

Laboratory-scale experiments were conducted using the proof-of-concept PFAS Harvester on samples of PFOS (perfluorooctane sulfonate) to access the reactions underpinning the operation of the PFAS Harvester. The choice of PFOS as a representative of PFAS was due to its abundance in wastewater treatment sludge. The PFOS and CaO powders purchased from Sigma–Aldrich were used in the experiments which included thermo-gravimetric analysis (TGA) and X-ray diffraction (XRD) measurements. The TGA experiments were carried out at 600-1,000 ^{o}C and 15 bar under two reacting environments of nitrogen and methane / steam (representing MSR conditions) using a DynTHERM TGA unit (Rubotherm, Germany). The XRD analysis were completed using a High Energy Powder XRD unit (Malvern Panalytical). Powders of PFOS and CaO were mixed at different Ca/F molar ratios between 1 and 100. The upper band was to mimic the molar ratio of Ca in an actual PFAS Harvester.

To determine the destruction efficiency, the mass of PFOS (and its products of thermal decomposition) was measured before and after each test in both solid and gas phases. The product gases were collected from the TGA outlet in plastic bags and analysed by a GC/MS unit consisting of a 450-GC-Bruker gas chromatographer and a 320-MS-Bruker mass spectrometer both from Germany. The PFOS content of the solid products were measured by sub-contractors using a liquid chromatography / tandem mass spectrometry system. The mass balance obtained by combining the above measurements was typically 99.9% accurate. For a residence time of 1 min the destruction efficiency was found to vary between 67% at 600 ^{o}C to 100% at 950 ^{o}C. The destruction efficiency under the methane/steam environment was found to be generally higher than that under nitrogen. One of the key findings from the experiments under nitrogen was that by increasing the molar ratio of CaO destruction efficiencies between 98-100% could be achieved at 870 ^{o}C which is significantly lower than the temperatures used in incinerators.

Similar results have been reported in the literature in regards to reactions between $Ca(OH)_2$ and PFOS [11-12]. The key mechanism responsible for this temperature drop has been identified as the displacement of fluoride with hydroxide [11-12]. Therefore, the decomposition of PFOS with CaO may similarly start from the replacement of fluoride in PFOS by oxide; leading to the observed temperature drop. Interestingly, the experiments performed under the methane steam reforming conditions (methane / steam) showed further reductions in the temperature for full conversion of PFOS (down to about 830 ^{o}C). Given that the reactions in TGA are not limited by diffusional transport of heat and mass, a likely culprit for this additional temperature drop might be H_2 which has a very large specific heat. In addition to the impacts of CaO and hydrogen on the PFAS destruction temperature, minimisation of the exergy losses of the Harvester might lower the destruction temperature even further.

Section 3

Methodology

3.1 Approach

In-line with the key objectives outlined earlier, the research consists of two complementary programs of study; each comprising several sets of smaller investigations, namely:

- Program-1: PFAS Harvester technology assessment

  T1. Reactivity studies – Determining the reaction kinetic properties of representative PFAS species under conditions pertinent to the PFAS Harvester.

  T2. Structural studies – Examining microstructural rearrangements and/or morphological transformations of CaO particles and their impact on CaO deactivation while reacting in the Reformer and Calciner units.

  T3. Process studies – Exploring the influence of operating conditions on the performance of the Harvester and field trialling a 2,000 L/d pilot-scale prototype using actual (i.e. real) PFAS feedstock.

  T4. PFAS Harvester optimisation studies – To identify and devise novel ways of maximising the yields of major recoverable material assets using the knowledge gained in T1 to T3 and T5 to T6.

- Program-2: PFAS feedstock supply, characterisation and optimisation

  T5. PFAS supply and characterisation studies – Supply and characterise the PFAS concentrates from OCRA.

  T6. OCRA optimisation studies – Improve capture efficiency and increase the PFAS content of concentrate.

3.2 Methods and Techniques

T1 – Use of atmospheric and high-pressure TGA as well as fixed and fluidised bed reactors to determine the intrinsic reaction properties of representative samples of PFAS (e.g. PFAAs, PFCAs, PFSAs, FASAs, FTSAs, FTCAs, FTOHs, FASEs and FASAAs).

T2 – Measurements of the internal surface area by CO_2-BET and the pore size distribution and the pore volume by the mercury porosimetry; scanning Electron Microscopy (SEM) to measure the porosity and particle wall thickness; XRF measurements of fresh and reacted particles to compare the major inorganic elements that are present in each case; and XRD measurements to better understand the extent of solid-gas reactions.

T3 – Design, construct and commission a 2,000 L/d pilot-scale PFAS Harvester, and field trials of the pilot-scale unit using actual PFAS concentrate feedstock supplied by Evocra.

T4 – Use of GenOpt optimisation tool (Lawrence Berkeley National Laboratory; USA) for a comprehensive set of multi-dimensional optimisation runs which are aimed at determining a set of operating variables that result in the lowest energy footprint and the highest PFAS destruction and syngas production efficiencies.

3.3 Timetable

Tasks / Studies	**Year 1**				**Year 2**			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
T1. Reactivity studies	✓	✓	✓					
T2. Structural studies		✓	✓	✓	✓			
T3. Process studies			✓	✓	✓	✓		
T4. PFAS Harvester optimisation				✓	✓	✓	✓	✓
T5. PFAS supply and characterisation	✓	✓	✓	✓	✓			
T6. OCRA optimisation		✓	✓	✓	✓	✓	✓	

Section 4

Benefits and Expected Outcomes

4.1 Feasibility

The proposed research draws on the discipline areas of reaction and process engineering (Moghtaderi and Doroodchi), particle technology (Doroodchi), colloid and interfacial science/engineering (Nguyen) and wastewater / PFAS remediation (Dickson). All participating universities have ERAs of 5 in Chemical Engineering and Resources Engineering / Extractive Metallurgy and have attracted significant funding to establish a world class research infrastructure. The proposed project will make extensive use of this infrastructure along with the hardware and capacity already acquired through previous projects by the CIs. Consequently the project requires only modest funding for the design and construction of the 2,000 L/d pilot-scale PFAS Harvester, upgrades of an existing OCRA setup in UON and the operating and maintenance costs associated with the use of these facilities. The project also supports two full-time postdoctoral researchers and two part-time research assistants for whom salary support is requested. The combined contribution of the two industry partners is $550k ($280k cash and $270k in-kind) which represents 60% of the ~$920k funding requested from the ARC (the ARC guidelines stipulate a minimum of 20%). The cash contribution alone is $280k or 30% of the funds from the ARC; exceeding the minimum ARC requirements.

Moreover, the CIs are intimately familiar with the experimental apparatus and no technical issues are foreseen with successful completion in the specified timeframe. This combination of experience and track record, complementary skill sets of CIs, reliance on existing infrastructure, the use of proven apparatus / methodology and a modest and cost effective budget ensures the feasibility of the project. Importantly, the above combination will also provide a supportive and stimulating environment for postdoctoral training.

Given the operating principles of the PFAS Harvester, the research program has also been designed in a manner to analytically verify PFAS destruction. This is achieved by incorporating mandatory measurements of PFAS and their harmful by-products before and after each experiment. This approach which is organic to the research methodology adopted in the proposed study will ensure a robust and effective assessment of the PFAS Harvester and its capabilities.

Furthermore, the industry partner is fully committed to the project and based on their own business models see value in the successful development and deployment of the PFAS Harvester technology. As previously noted, Evocra is very much interested in a low-cost destruction process for PFAS containing water. Evocra’s activity at Hobart airport for instance requires the Company to destruct the recovered PFAS contaminant. The previously used option of plasma destruction (for concentrate generated from the Brisbane Airport activity) was $14-21/L, which is prohibitively high when compared to that of ¢5/L for the PFAS Harvester technology proposed in this application. Evocra will engage with the proposed research through its Chief Technical Officer (PI Dickson), who will lead task T5 and contribute to several other tasks.

4.2 Outcomes

The collaboration between some of the leading Australian researchers and engineers at UON, UQ and Evocra will significantly enhance Australia's research and innovation capacity in the emerging field of PFAS remediation, resource recovery and waste minimisation. Development and deployment of the PFAS Harvester process will also directly contribute to the Australian Government Research Priority "*Soil and Water*" by tackling the Practical Research Challenge of "*Minimising damage to, and developing solutions for restoration and remediation of, soil, fresh and potable water, urban catchments and marine systems*". The project will also train two PRA researchers capable of tackling problems of importance in PFAS remediation and waste utilisation. The opportunity to work with industry and CIs in their world leading laboratories at UON and UQ, will provide valuable mentorship and career development for the PRAs. More importantly, the interactions among the partner organisations will provide a great opportunity to inspire the next generation of Australian innovators and technology development companies. The proposed project will lead to a number of technical outcomes and socio-economic benefits.

- The key technical outcomes which will directly contribute to the industry partners' bottom-line include:
    - Development and advancement of a robust, effective and low-cost secondary treatment process for PFAS remediation with superior performance characteristics to conventional thermal based processes.
    - Recommended set of variables for optimised operation of the above process (i.e. PFAS Harvester).
    - Improvement in the technical and economic viability of using OCRA as a primary treatment process for PFAS remediation.
    - Improvement in the techno-economic viability of the MSR process for hydrogen enriched syngas production.
    - Establishment of research expertise and provision of research training (postdoc) in developing PFAS remediation technologies in an Australian laboratory / company.
    - New reaction kinetics data related to the interaction between PFAS species with H_2, H_2O, CH_4 and CaO.

- The socio-economic and environmental benefits of the project at national level are also significant and include:
    - Cost-effective PFAS remediation and waste utilisation.
    - Research and development of innovative technologies / processes.
    - Market creation.
    - Export potential.
    - Lower greenhouse gas (GHG) emissions and improved air quality due to improved energy and emission footprints of the PFAS Harvester process over conventional thermal based processes.
    - Enhanced institutional / industry collaborations across partner organisations.

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