CRC for
Water Sensitive Cities

Variation Agreement Project C2.1

THIS AGREEMENT is made on the day of 2017

THE CRC FOR WATER SENSITIVE CITIES, Building 74, Monash University, Clayton, Victoria, 3800 **(CRC)**

AND the parties named in Item 1 of the Schedule **(Other Parties)**

BACKGROUND:

A. CRC and the Other Parties entered into the Document named in Item 2 of the Schedule (**Document**).

B. CRC and the Other Parties wish to vary the Document in accordance with this Agreement.

IT IS AGREED AS FOLLOWS:

1. Definitions

1.1 Terms which are defined in the Document and used in this Agreement have the meaning given to them in the Document, unless stated otherwise.

2. Effective date of variation

2.1 The effective date of this Agreement is the date set out in Item 3 of the Schedule (**Effective Date**).

2.2 Clause 2.1 does not affect any right or obligation arising before the Effective Date.

3. Variation

3.1 The parties agree that from the Effective Date the Document will be varied in accordance with Item 4 of the Schedule.

3.2 Save for varying the Document as specified in this Agreement, all other provisions in the Document remain unchanged.

4. General

4.1 **Costs:** Each party remains responsible for its own costs and expenses in entering into this Agreement.

4.2 **Signatories:** The signatories to this Agreement warrant that they have the authority to enter into this Agreement on behalf of the party they are stated to represent.

4.3 **Counterparts:** This Agreement may be executed in any number of counterparts. All counterparts taken together will constitute the one Agreement.

4.4 **Electronic Signatures:** Each party may communicate its execution of this Agreement by successfully transmitting an executed copy of this Agreement by facsimile or email to each other party.

EXECUTED as an Agreement

SIGNED for and on behalf of **[CRC]**
by its authorised officer:

Signature: .....

Name: BEN FURNACE .....

Date: 14/9/17 .....

CRC for
Water Sensitive Cities

SIGNED for and on behalf of **UNIVERSITY OF WESTERN AUSTRALIA** .....
by its authorised officer:

Signature:.....

Name:.....

Date: .....

SIGNED for and on behalf of **THE UNIVERSITY OF QUEENSLAND** .....
by its authorised officer:

Signature:.....

Name:.....

Date: .....

Ian G Harris
Director, Research Partnerships
UQ Research and Innovation
The University of Queensland

31/8/17

SCHEDULE

Item	Description
1. Other Parties	**THE UNIVERSITY OF WESTERN AUSTRALIA ABN 37 882 817 280** of Crawley in the state of Western Australia (UWA). **THE UNIVERSITY OF QUEENSLAND ABN 63 942 912 684** of St Lucia in the state of Queensland (UQ).
2. Document	Project Agreement C2.1 Resource Recovery from Wastewater. Executed 29 April 2014.
3. Effective Date	01Jan2017
4. Variations	Project Agreement revised budget for FY1617 provided to: • Extend project end date from Jan 2017 to 30June17. • Release $15,000 cash from UQ project lifetime budget to UQ FY1617 budget to enable project completion. • Transfer $22,756 cash from UQ FY1617 budget to UWA FY1617 budget.

CRC for
Water Sensitive Cities

SIGNED for and on behalf of **UNIVERSITY OF WESTERN AUSTRALIA** .....
by its authorised officer:

Signature:.....

Dr Campbell Thomson
Name:.....

18 August 2017
Date: .....

SIGNED for and on behalf of **THE UNIVERSITY OF QUEENSLAND** .....
by its authorised officer:

Signature:.....

Name:.....

Date: .....

SCHEDULE

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Cooperative Research Centre for Water Sensitive Cities

Project Agreement

Project Number: C2.1

Project Name: Resource Recovery from Wastewater

Project Participants: The University of Queensland and The University of Western Australia.

Project Leader: Damien Batstone & Anas Ghadouani

An Australian Government Initiative

THIS AGREEMENT IS MADE BETWEEN

CRC FOR WATER SENSITIVE CITIES LTD ABN 19 158 409 137 of Clayton in the state of Victoria (**Company**).

AND

The Project Participants set out in Schedule 1

Recitals

A. The Company is responsible for the governance, management and co-ordination of the Centre.

B. The Project Participants are participants in the Centre.

C. The Centre's Activities include overseeing four Research Programs. Each Research Program has a designated Program Leader who is responsible for the coordination and conduct of the Research Programs.

D. Within the Research Programs, the Centre determines the general nature of the research projects to be conducted and then in conjunction with the Project Participants, develops the detailed research project C2.1 - Resource Recovery from Wastewater

E. The Centre also manages the funding of the Project.

F. The Project to which this Project Agreement relates has been approved by the Board as a Project to be carried out by the Project Participants with funding from the Company as part of the Activities of the Centre.

G. By signing this Project Agreement, the Parties acknowledge their agreement to carry out the Project in accordance with the following terms.

PROJECT DETAILS

1 Dictionary

1.1 In this Project Agreement, unless the context otherwise requires, the following definitions apply:

(a) **BIP Participant** means the Party that has made the relevant Project BIP available to the Project.

(b) **Centre** means the Cooperative Research Centre for Water Sensitive Cities.

(c) **Centre IP** means the Centre IP arising from the Project but excluding the SWF IP..

(d) **Contributed Personnel** means the persons identified in Schedule 1 as the personnel who will conduct or be involved in the Project.

(e) **Participants Agreement** means either the Essential Participants Agreement or an Other Participant Agreement, entered into by the Company and a participant in the Centre.

(f) **Parties** means the Project Participants and the Company and **Party** means any one of them.

(g) **Project** means the project set out in Schedule 1.

(h) **Project BIP** means the Background Intellectual Property of the Parties described in Schedule 1 or that is subsequently made available to the Project under the Participants Agreement.

(i) **Research Project Proposal** means the proposal for the Project attached as Annexure B.

(j) **SWF** means the fund known as the Smart Water Fund which has been established under a joint venture agreement the participants of which include, City West Water Corporation, Yarra Valley Water Corporation, Melbourne Water Corporation and The State of Victoria represented by the Department of Environment and Primary Industries.

(k) **SWF Funding Agreement** means the agreement between The University of Queensland and the SWF dated on or about 2 December 2013 entitled "*Funding Agreement*".

(l) **SWF IP** means the Intellectual Property arising from the SWF Project.

(m) **SWF Project** means the project extension, set out in Schedule 2 which is to be performed by The University of Queensland and funded by the SWF in accordance with the SWF Funding Agreement.

1.2 Words and phrases used in this Project Agreement that also appear in Schedule 1 [Definitions and Interpretation] of the Participants Agreement, and that are not specifically defined in this Project Agreement, will have the meaning given to those words and phrases in Schedule 1 of the Participants Agreement.

2 Paramountcy

If there is an inconsistency between this Project Agreement and a Participants Agreement, this Project Agreement will prevail to the extent of that inconsistency in relation to the Project.

If there is inconsistency between the SWF Project component of this Project Agreement and the Participants Agreement, in each case the SWF Funding Agreement will prevail.

3 Application of Participants Agreement

The Project Participants acknowledge and agree that:

(a) the conduct of the Project forms part of the Centre Activities;

(b) the conduct of the SWF Project does not form part of the Centre Activities and is to be conducted by The University of Queensland in accordance with the terms of the SWF Funding Agreement;

(c) all the provisions of the Participants Agreement that, expressly or by implication, apply to the conduct of Projects, will with any necessary amendment, be deemed to form part of this Project Agreement; and

(d) this Project Agreement will be read with and deemed to form part of the Participants Agreement.

4 Project

In consideration of:

(a) the payment of the Project Funds to the Project Participants by the Company; and

(b) the making available of the Project Contributions to the Project by the Parties,

the Parties will conduct the Project in accordance with this Project Agreement and the Participants Agreement.

The Parties acknowledge that The University of Queensland will separately conduct the SWF Project in accordance with the terms and conditions of the SWF Funding Agreement.

5 Term

5.1 The Project will commence on the Project Commencement Date and will be completed on the Project Completion Date unless terminated earlier or otherwise agreed by the Parties.

5.2 A Project Participant may terminate this Project Agreement upon thirty days written notice to the other Parties, if another Project Participant:

(a) abandons the Project; or

(b) fails to achieve a Milestone or deliver a Deliverable within 60 days of the time specified in this Project Agreement,

and the Project Participant seeking to terminate has fully documented the work that it has completed and for which it has been funded before it gives notice of termination to the other Parties.

5.3 The SWF Project will be conducted by the University of Queensland in accordance with the terms and conditions of the SWF Funding Agreement.

6 Payment and Project Contributions

6.1 Each Project Participant must make available to the Project, its Project Contributions in accordance with the Participants Agreement and Schedule 1.

6.2 The Company will:

(a) pay to the Project Participants the Project Funds; and

(b) distribute the Project Contributions,

in accordance with the Participants Agreement and Schedule 1.

6.3 In addition to its rights under the Participants Agreement, the Company may withhold some or all of the Project Funds and Project Contributions from a Project

Participant that has not complied with the Project Agreement or the Participants Agreement in conducting the Project.

6.4 The Parties acknowledge that the funding for the SWF Project is supplied in accordance with the SWF Funding Agreement.

7 Performance

7.1 The Responsible Participant must ensure that the Project Leader fulfils the responsibilities and duties set out in Annexure A, in addition to any obligations set out in the Participants Agreement. The Responsible Participant must notify the Company upon becoming aware that the Project Leader is unable or is likely to become unable to fulfil the requirements in Annexure A for the duration of the Project.

7.2 In addition to any obligations under the Participants Agreement, each Project Participant must, and must ensure its Contributed Personnel, cooperate with the Project Leader, act in accordance with the Participants Agreement, and carry out its part of the Project to enable the Project to be conducted in accordance with this Project Agreement.

8 Meetings

8.1 The Project Leader must attend the following minimum number of meetings for the duration of the Project and for a period of up to [6] months following the Completion Date, either in person or using technology available to the meeting:

(a) two Centre workshops (industry focus) each Financial Year;

(b) two Centre workshops (research focus) each Financial Year; and

(c) all program meetings relevant to the Research Program to which the Project relates, as scheduled by the relevant Program Leader,

provided that the Project Leader has been provided with reasonable prior notice of the meeting.

8.2 The Project Leader may be excused from attending a meeting personally if:

(a) he or she has notified the CRC Executive of the reasons why they cannot attend, and suggested a nominee to attend in his or her place; and

(b) the CRC Executive consents to the nominee attending in the Project Leader's place.

If consent is provided and the nominee attends the meeting, the Project Leader will be deemed to have attended the meeting for the purposes of clause 8.1.

8.3 The Centre may vary the number and timing of workshops specified under clause 8.1(a) or (b) by notice to the Project Leader.

8.4 Attendance by any one of the persons listed in Annexure B, Item 7 will be deemed to comply with Clause 8.1.

9 Reporting

9.1 In addition to its obligations under the Participants Agreement, the Responsible Participant must report, or ensure that the Project Leader reports:

(a) as required by Item 10 of the Research Project Proposal;

(b) to the Company when requested, in the Approved Form notified by the Company from time to time;

(c) to the Program Leader of the Research Program for the Project, in relation to any issues adversely affecting or likely to adversely affect the Project (including any matter that the Project Leader considers will, or may, affect the ability of the Project to satisfy the Milestones or deliver the Deliverables, or to be completed within the Project Budget) as soon as practicable after that matter or issue comes to the attention of the Project Leader; and

(d) to the CRC Executive or Research Advisory Sub-Committee when requested.

9.2 The Quarterly reports required under Clause 21 of the Essential Participants Agreement must also contain a summary of the research progress made and expenditure of cash and in-kind contributions for the Project.

9.3 If requested by the CRC Executive or CRC Advisory Committee, the Project Participants must provide the CRC Executive or CRC Advisory Committee with any information reasonably requested in relation to the Project.

10 Milestones and Deliverables

10.1 Subject to this clause, the Milestones must be achieved, and the Deliverables must be delivered to the Company at the times specified in this Project Agreement.

10.2 A Project Participant is not required to achieve Milestones or deliver Deliverables to the extent that its failure to do so is attributable to the acts or omissions of other Project Participants or circumstances beyond its reasonable control.

11 Project Review

11.1 The Project will be reviewed by the CRC Executive and Research Advisory Sub-Committee in accordance with the Participants Agreement.

11.2 The Board may, on the recommendation of the CRC Executive or otherwise:

(a) implement variations to the Project; or

(b) terminate the Project, if following a review, the Board reasonably forms the view that the Project will not achieve its objectives,

provided the Board acts in accordance with the Participants Agreement.

12 Intellectual Property

12.1 Each BIP Participant makes available its Project BIP to the Project in accordance with the Participants Agreement.

12.2 All Centre IP will be owned by the Company. Each Project Participant will do all things reasonably necessary, including the signing of documentation, to vest the Centre IP in the Company.

12.3 Each Project Participant will on request from the Company provide the Company with information in relation to the Centre IP created by its personnel.

12.4 For clarity, the Parties acknowledge that any SWF Project BIP made available by The University of Queensland to the SWF Project is not provided in accordance with the Participants Agreement.

12.5 The Company and each Project Participant acknowledges and agrees that the SWF IP will be owned by The University of Queensland who is then legally required to assign all of the SWF IP to the SWF pursuant to the terms of the SWF Funding Agreement. Each Party will do all things reasonably necessary, including the signing of documentation, to vest the SWF IP in The University of Queensland.

13 Commercialising Contract Material pursuant to the SWF Funding Agreement

13.1 Any defined terms in the SWF Funding Agreement are to be referred to in the interpretation of this clause 13.

13.2 The University of Queensland hereby assigns its rights and obligations under clause 14.3(b) to (f) of the SWF Funding Agreement inclusive to the Company and the Company accepts the assignment.

The University of Queensland acknowledges that the Manager may deal exclusively with the Company regarding the Commercialisation of the Contract Materials without further reference to The University of Queensland.

13.3 The Company acknowledges that any failure of the Company to comply with the terms of clause 14.3(b) to (f) of the SWF Funding Agreement will be taken as a breach of the SWF Funding Agreement by The University of Queensland and as such the Company is liable for and indemnifies The University of Queensland from and against, any loss or damage however caused in connection with any use of the Contract Material by the Company or any breach of the SWF Funding Agreement of clause 14.3(b) to (f) (inclusive) by the Company.

14 Contributed Personnel

14.1 Each Project Participant will make available its Contributed Personnel to conduct the Project in accordance with Schedule 1.

14.2 Subject to this clause, the Contributed Personnel of Project Participants remain subject to the terms and conditions of employment under which they are employed by Project Participants.

14.3 Each Project Participant will:

(a) take all reasonably practical steps to ensure that any working environment where:

(i) its Contributed Personnel work; or

(ii) the Project is conducted,

is safe and without risk; and

(b) be responsible for the health and safety of:

(i) its Contributed Personnel at all times when they are at work; and

(ii) all other persons whose health or safety may be adversely affected by the conduct of the Contributed Personnel's actions.

14.4 Each Project Participant covenants and undertakes to procure that Centre IP created by any of its Contributed Personnel will be owned and dealt with according to this Project Agreement.

15 Commonwealth Obligations

The Parties acknowledge and agree that at any reasonable time any person designated by the Commonwealth Cooperative Research Centre Program may view the progress of the Project and that the Parties will give all assistance reasonably requested by such designated person.

Executed as an Agreement

EXECUTED by **CRC FOR WATER SENSITIVE CITIES LTD ABN 19 158 409 137** by its duly authorised signatory

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~~CEO~~/COO

ROBYN McLACHLAN

Print full Name

Witness

EBONY HENDERSON

Print Full Name

29/04/2014

Date

EXECUTED by **THE UNIVERSITY OF QUEENSLAND ABN 63 942 912 684** by its authorised officer in the presence of

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18/12/13

Authorised Officer

Ian G Harris

Director, Research Partnerships
UQ Research and Innovation
The University of Queensland

Print full Name

Witness

Print Full Name

Gail Roudenko

Date

EXECUTED by **THE UNIVERSITY OF WESTERN AUSTRALIA ABN 37 882 817 280** by its authorised officer in the presence of)

Authorised Officer

Dr Campbell Thomson
Director, Research Services
The University of Western Australia

Print full Name

Witness

Christine Casey
Associate Director,
Research Grants & Finance
Research Services, M459
The University of Western Australia
35 Stirling Hwy, Crawley WA 6009

Print Full Name

17/4/14

Date

SCHEDULE 1 PROJECT DETAILS

Project Title	Item 1 of the Research Project Proposal.
Research Program (Recital B)	Item 4 of the Research Project Proposal.
Project Participants	The Company **Name:** Robyn McLachlan **Position:** Chief Operating Officer, CRC for Water Sensitive Cities Ltd **Address:** PO Box 8000, Monash University LPO, Clayton Campus VIC 3800 **Telephone:** + 61 (0) 3 9902 0542 **Mobile:** +61 (0)402 013 497 **Email:** robyn.mclachlan@crcwsc.org.au
	The University Of Queensland **Contact for notices:** Director, Research Partnerships **Address:** The University of Queensland, Brisbane, QLD 4072 **Telephone:** +61 (0) 7 3365 3559 **Email:** director.partnerships@research.uq.edu.au
	The University of Western Australia **Name:** Dr. Campbell Thomson **Position:** Director, Research Services **Address:** Registrar's Office, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 **Telephone:** +61 (0) 3 9902 9468 **Email:** campbell.thomson@uwa.edu.au
Responsible Participant (clause 9)	Item 7 of the Research Project Proposal.
Contributed Personnel (clause 13)	Item 11 of the Research Project Proposal.
Project Funds (clause 4 and 6)	See Annexure C.
Project Contributions (clause 4 and 6)	See Annexure C.
Background IP	

(clause 12)	Technology for ammonia and potassium recovery as embodied in Aus Patent #1768162 Title "Wastewater Refinery".	
Project Plan	*Project Leader* (clauses 8 and 9)	Item 7 of the Research Project Proposal.
	Project Commencement Date (clause 5)	Item 2 of the Research Project Proposal.
	Project Completion Date (clause 5)	Item 2 of the Research Project Proposal.
	Project Objectives	Items 3 and 8 of the Research Project Proposal
	Proposed strategy	Item 9 of the Research Project Proposal.
	Milestones (clause 10)	Item 10 of the Research Project Proposal.
	Deliverables (clause 10)	Item 10 of the Research Project Proposal.
	Project Budget	Item 11 of the Research Project Proposal.
	Third party contributions	Item 11 of the Research Project Proposal.
	Resources	Item 11 of the Research Project Proposal.
	Student requirements	Item 11 of the Research Project Proposal.
	New Assets or Capital Items	Item 11 of the Research Project Proposal.
	Analysis of Project risk	Item 12 of the Research Project Proposal.
	Analysis of Utilisation of Project outcomes	Items 13 & 14 of the Research project proposal

ANNEXURE A PROJECT LEADER RESPONSIBILITIES

Project Leaders have responsibility for and must fulfil the following duties in relation to the Project:

(a) Supervision of Project Activities in accordance with the Research Project Proposal.

(b) Managing the utilisation of Contributions provided by the Company and Project Participants and any other resources made available for the Project Activities.

(c) Ensuring the quality and timely delivery of Project Deliverables according to Milestones.

(d) Actively fostering and facilitating the research collaboration amongst Project Participants.

(e) Fostering integration of research outputs and insights across the Research Program and supporting the relevant Program Leader(s) in integrating research outputs across the Research Programs in the Centre.

(f) Identifying and effectively managing and mitigating Project risk and raising any risk or performance issues concerning the Project in a timely manner with the Program Leader.

(g) Attendance and active participation in Centre industry partner and research workshops.

(h) Preparation of timely quarterly reports to the CRC Executive (suitable to be shown to the Board) on Project progress and Project Budget expenditures.

(i) Identifying any Centre IP developed within the Project, maintaining proper records of the Centre IP developed and its use within the Project and notifying the Program Leader of such Centre IP and any potential future use of Centre IP within the Centre.

RESEARCH PROJECT PROPOSAL

(max. 10 pages – excluding References)

Summary Details

1. Title of research project proposal:

C2.1: Resource Recovery from Wastewater

2. Proposed Project Commencement Date: *(month/year):* Jan 2014

Project Duration *(years):* 3 years

3. Project Abstract: *(Objectives, Outputs and Outcomes)*

Wastewater treatment currently uses significant amounts of energy to remove valuable resources. This project aims to develop and demonstrate technologies suitable to recover energy, valuable elements, including phosphorous, nitrogen, and potassium, and water, such that ultimately the value of the resources in wastewater is more than the cost of extraction. The technology to be developed will be applicable in a range of situations, including supplementing existing treatment plants. The ultimate aim is to develop a suite of technologies that together can act as a complete replacement to existing wastewater treatment systems and all scales for treatment of domestic wastewater. To address this aim, the key objectives are; (i) develop technology for up-concentration of nutrients and organics in dilute streams; (ii) develop processes to effectively release nutrients and energy from concentrate streams, and (iii) develop chemical and physical processes to recover nutrients as high-value streams. Outputs by the end of the project will be complete technology packages to address these objectives, including demonstration at pilot scale.

4. Number and name of CRC research program

❑ Program A – Society	❑ Program B – Water Sensitive Urbanism
X Program C – Future Technologies	❑ Program D – Adoption Pathways

5. ANZSRC Field of Research (FoR) classification

090701 Environmental Engineering Design; 090702 Environmental Engineering Modelling; 090703 Environmental Technologies

6. **Keywords:** *(max 6)*		
Nutrient recovery	accumulation	phosphorous
algae	membranes	precipitation

7. Project Leader(s)

Name: A. Prof. Damien Batstone

Institution: The University of Queensland

Department: Advanced Water Management Centre

Name: A. Prof. Anas Ghadouani

Institution: University of Western Australia

Department: School of Environmental Systems Engineering

Research Proposal

8. Objectives and background

Objectives

The overall project aim is to provide a suite of technologies suitable for resource recovery (elements such as N, P, K, as well as chemical and thermal energy) from wastewater. The guiding principle is that wastewater treatment should occur at net positive electricity generation, with generation of agricultural fertilizer. Ultimately, wastewater should be able to be treated at net negative operating cost. Technology will be applicable at both centralized and decentralized scales.

Objectives to achieve these aims are:-

(a) Develop biological and physical processes to concentrate nutrients and energy from dilute wastewater streams.

(b) Develop biological and physical processes to release and recover nutrients and energy from concentrated streams in (a) as well as other concentrate streams.

(c) Develop chemical and physical processes to recover nutrient streams as high-value substitutes to existing commercial nutrient products.

Background

Until now, activated sludge wastewater treatment in Australia has been heavily focused on removal of nutrients to very low levels. This is normally intensive in both actual energy, for aeration, pumping, and dewatering, and embodied energy, in external carbon sources, transport, and use of chemicals. Energy costs have risen substantially as nutrient levels have become tighter.

Based on our survey work (MacGahan et al., 2010), wastewater contains approximately 5% of our current N and P resources, and approximately 3% of domestic energy consumption. While it is unlikely that wastewater treatment activities can result in substantial energy gains, energy self-reliance for wastewater activities can be readily achieved, and the nitrogen and phosphorous that can be recovered is of substantial value. In addition, this is not just applicable to the domestic wastewater industry, but can be applied across the whole waste and wastewater sector. This can achieve recoveries on the order of 20% of nitrogen and phosphorous, and can potentially replace all domestically consumed potassium (MacGahan et al., 2010). For a country

that exports almost half of the food produced, this represents a massive nutrient resource.

There has historically been resource recovery from concentrated streams, including methane generation and recovery from waste activated and primary sludges using anaerobic digesters. Nitrogen and phosphorous are also being recovered from anaerobic digester effluents (Le Corre et al., 2009) by struvite precipitation, though full-scale references are limited to a handful of plants around the world. The largest is a full-scale plant in Japan recovering 4T/d of struvite (Ueno and Fuji, 2001).

A change in wastewater paradigm to a resource recovery concept has been seriously proposed in the last 5 years (Batstone 2010; Verstraete et al., 2008). This is beyond low energy alternative mainstream processes such as main-line Anammox for nitrogen removal. However the main applications for energy and nutrient recovery technologies have been opportunistic within the current wastewater treatment framework, and are generally limited to <15% of the energy and phosphorous in the source wastewater, and <5% of the nitrogen. There are currently no technologies available for recovery of potassium. There are also no technologies available as a replacement from main-stream wastewater treatment operations, with most acting only on concentrate streams. This limits their application to centralized only applications, in conjunction with high-energy activated sludge treatment.

This project will develop technology to replace wastewater treatment at a number of scales, addressing the three major steps of concentration, release, and recovery. Long-term, it could be expected to enable replacement of existing centralized treatment plants, as an alternative to activated sludge treatment. However, in the shorter term, its scalability, modularity, and low

resource consumption will give it a very strong opportunity in the decentralized, remote, and small-scale application areas.

Apart from actual technology development, a key requirement, especially for acceptance at a decentralized scale is piloting and demonstration. This will be a key component of the research plan, showcasing the separate modules planned within this project.

Research Questions

- Identify the extent to which biological process (aerobic accumulative and algae) can accumulate nutrients (nitrogen and phosphorous) from dilute wastewater streams. Higher levels will require post-polishing.
- Identify physical based separation techniques as an alternative to biochemical based nutrient removal techniques.
- Identify the extent to which biochemical methods (principally anaerobic digestion) can release nutrients and energy from concentrate (algae and physically concentrated) streams.
- Identify physical and chemical methods to fully recover nutrients from waste streams. For phosphorous this is likely to be precipitation, but alternative, electrochemical and adsorptive based methods will be needed for ammonia and potassium.

9. Research plan *(methods, timelines and outputs – do not include annual workplans)*

The project will be operated in three sub-projects simultaneously related to the three objectives of (a) accumulation, (b) release, and (c) recovery. The project team has existing research strengths in all three areas, with the Grains Research and Development Corporation (GRDC) funding nutrient recovery technology (N, P, and K), and the MLA/Australian Meat Processors Corporation (AMPC) funding biochemical accumulation from red meat wastewaters. All of this research so far has focused on agroindustrial wastewater, which is already working on a positive net revenue basis, and the role the CRCWSC C2 project will be adapt the technology and concepts to the domestic market, and particularly for low strength high volume wastewater streams.

The Accumulate, Release, and Recovery technologies are all separate, and, applicable individually to specific wastewater streams (as is being done in the GRDC Nutrients from Waste project), it is intended that they be integrated from the start of the project for the purposes of domestic wastewater treatment at a range of scales. This will be a principal role of the postdoctoral research fellow, as well as the project leaders. They will also be responsible for identifying opportunities to apply separate technologies in a stand-alone configuration.

There are PhD student projects associated with each sub-project, and the project will be managed by a dedicated postdoctoral researcher at UQ. This researcher will also be responsible for pilot work, which will be addressed in a separate subproject.

Accumulation sub-project

The accumulation sub-project will be contributed to by both UWA and UQ, with three major aspects:-

(a) Accumulation in algal reactors. Algae will be selected and grown to assess their capacity to accumulate nutrients, as well as to incorporate readily degradable organics. It is expected that several parallel reactors will be operated, with selection under different conditions (light, loading rate, aeration, sequencing etc) to best optimize accumulation of both organics and nutrients. Because the focus is on accumulation rather than production, heterotrophic rather than autotrophic algae will be used. The strains will be selected for their ability to utilise wastewater carbon sources, and algae will be selected over bacteria through aeration control and phototrophic growth. The algal reactors will be set up in the first year in phototrophic and heterotrophic mixed mode, with a focus on accumulation of competent algae. Subsequent work will focus on optimisation to maximise carbon, phosphorous, nitrogen, and potassium uptake

with minimal energy input in terms of aeration and light. The second year will also involve application of the bioreactors and assessment of algae degradability. It should be noted that this project is focused on heterotrophic accumulation, rather than autotrophic growth, and we are not aware of other researchers working with heterotrophs for this purpose.

(b) Accumulation in activated sludge reactors. Accumulation stage activated sludge reactors will be operated with short sludge retention times in sequencing batch reactors (<2 day sludge retention time). This will further develop the popular A-stage activated sludge process that is now being used to treat industrial wastewaters with low energy input (AMPC project). This is an existing and known process that will be modified for application to domestic streams, and with enhanced nitrogen and phosphorous accumulation. Phosphorous accumulation through polyphosphate accumulating organisms is known to work at short retention times, but ammonium recovery is far more difficult, and full ammonia recovery may be impossible without the use of algae.

This aspect of the project represents risk mitigation in the case that heterotrophic algae cannot be effectively grown.

(c) A physical separation project will focus on application of membranes (and anaerobic membrane systems in sub-project 2) for direct release of nutrients in the water line. This will utilise existing anaerobic membrane bioreactor (AMBR) test assets at UQ to evaluate membrane flux rates in the presence of algal and A-stage biomass. This can then be used to determine whether the accumulation stage can be implemented in a membrane bioreactor configuration, which is able to directly produce effluent suitable for non-potable reuse.

Release sub-project

The release sub-project will take material from accumulation sub-project to evaluate nutrient release and transfer to the water line. There will be a key focus on pH management to avoid excessive precipitation of nutrients (particularly phosphorous) prior to the recovery stage.

The first stage will involve batch anaerobic digestion in serum flasks of material directly from the accumulation sub-project to assess the extent of nitrogen, phosphorous and potassium release under standard conditions, as well as serve as a platform to enhance and maintain release, as one of the major issues identified so far in the GRDC project has been phosphorous precipitation. Model materials from other resources (e.g., algal ponds, activated sludge plants, primary digesters), to establish methods, but further work will take material directly from the accumulation sub-project. Batch testing will be done in triplicate against controls and blanks using techniques for which UQ is recognized world-wide. This will provide a broad understanding of how to extract and retain both energy and nutrients. As material properties are further developed, and more material is available from the related sub-project (after year 1) continuous digesters will be operated to identify modes of operation that maximize nutrient release and avoid unintended mineral nutrient precipitation. This is likely to involve thermophilic anaerobic digestion at supressed pH (likely to be chemical free pH suppression through CO_2 cycling). Anaerobic membrane processes will be initially assessed using existing assets at UQ, and applied to the whole project if shown to be economically and practically of advantage. Certainly they offer the potential to minimise sidestream precipitation.

Recovery sub-project

The recovery sub-project will be led by UQ, and will apply outcomes from the GRDC project to evaluate phosphorous recovery by struvite, as well as nitrogen and potassium recovery through novel techniques. This will use electrodialysis for nitrogen and potassium upconcentration (10x per stage), and precipitation, stripping, and adsorption for subsequent recovery of these chemicals. While the electrodialysis process will be well developed prior to the start of the CRC C2 project, subsequent recovery techniques, and particularly application to domestic lower strength streams has not. There is also a need for development of alternative techniques to recover particularly nitrogen and potassium, particularly from domestic streams. Particularly potassium depletion is an emerging problem in Australia, and is highly relevant to Australian grain crops. This is an emerging area, and while we cannot yet conceptualise an alternative recovery technique particularly for potassium, a technology review and assessment will be done in the early stages of the project to identify alternative methods.

There are therefore three major techniques to be applied in his sub-project; (a) struvite precipitation, which is currently widely offered, though normally for anaerobic digester streameam treatment, and which needs further economic optimisation (e.g., for the use of low cost MgO rather than $MgCl_2$ and NaOH); (b) electrodialytic potassium and ammonium (and potentially phosphorous recover), which is a technique currently applied by UQ for agroindustrial streams, but is not in the field (to our knowledge, we are the only group with an active focus on potassium recovery); and (c) potential processes to be identified through an early stage discovery process. These represent varying levels of risk and innovation, with struvite carrying almost no risk or innovation, electrodialysis being only in the lab, and the potential to identify and apply as yet unknown processes. The level of research effort will also vary, with struvite precipitation being application only in pilot (no laboratory research) using the existing UQ design, most of the effort going on development of electrodialysis, and work on developmental processes depending on the opportunities and risks identified during the review. It should be noted that agricultural testing and marketing, while not part of this project is being addressed through the GRDC fertilizer from wastes project, with field tests of material from C2 being planned already in 2014 and 2015 (winter crops in WA, summer in Qld and

Pilot sub-project

The pilot demonstration subproject will be led by UQ, and will aim at rapid deployment of the technology in a pilot project in Brisbane. It will be implemented by the project postdoctoral researcher. It will initially be developed based on proven technology (biochemical accumulation, digestion, precipitation) from each laboratory sub-project, but identify and deploy higher risk, more innovative technologies (algal accumulation, single valency ion recovery) as they move from laboratory to application stages.

It is expected that the initial major units (project year 3) will include an accumulation stage (on the order of $1m^3$), separation and digestion stage (also on the order of $1m^3$), and mineral precipitation stage (on the order of 10L). Additional more innovative technologies can then be substituted for these basic stages. While funding has been allocated to this in years 3 and 4, additional industry funding will be needed to actualize the demonstration plant.

Schedule

	2013	2014	2015	2016
Project definition, personnel development etc				
Subproject 1: Accumulation				
Subproject 2: Release				
Subproject 3: Recovery				
Subproject 4: Demonstration				

10. Project Deliverables and Milestones *(list quarterly, half-year or annual milestones as appropriate)*

Project Deliverables	Milestone dates
1. Technology planning review complete and project plan completed	31/12/2013
2. Project personnel recruited and all laboratory work underway.	30/6/2014
3. Review of technologies based on laboratory results and modelling.	31/12/2014
4. Continuous versions of accumulation, release, and recovery technologies demonstrated in laboratory.	30/6/2015
5. Technology prototypes developed and in laboratory testing	31/12/2015
6. Technology prototypes transferred to field.	30/6/2016
7. Technology prototypes demonstrated in field	31/12/2016

11. Resources *(include anticipated annual cash and inkind budget over the duration of the project)*

12. Risk and Risk Management *(identify risks to the successful completion of the project and risk management measures adopted)*

Risk	Management Measures
Technology not feasible	Multiple options to be investigated for each model (accumulation, release, recovery)
Heterotrophic algae cannot be grown in wastewater	Switch to bacterial accumulation stage (existing technology), and optimise for N removal.
Technology too expensive	Identify excessive costs at technology gating stage (end of year 1)
Community, social or safety concerns around use of end-products	Identify possible safety or community concerns through technology gating stage and address as an integrated part of the project (e.g., testing prototype outputs). Identify opportunities for linkages to other appropriate projects in CRCWSC.
Lack of required expertise in project team	Address through upstream (CRCWSC) review and collaboration within CRC.

Adoption Pathways

13. Linkages to other Projects *(linkages to other research activities within the Program and across other Programs within the CRC)*

C2 is heavily linked to all other research projects in program C except for C5. Specifically, it is linked to C1 in that prediction of quality and quantity of wastewater addressed in C1 will influence process selection and optimisation in C2. Likewise, C2 will produce a variety of output wastewater streams that can be linked to C1 for fit for purpose manufacturing. C2 is linked to C3 in that recovery processes in C2 will influence discharge timing and concentration to sewer processes evaluated in C3. C3 will influence C2 in determining both characteristics of wastewater to be discharged to C2 technologies, as well as possibility to use C2 technologies for sewer mining. C2 is linked to C4 as effluent from C2 may receive further treatment through C4 processes. Resource products from C2 may enhance application of C4 technologies.

C2 is more generally linked to program A in identifying routes to promote reuse of recovered resources. It is heavily linked to program D as a technology focused project, with specific process units suitable for direct application.

14. Linkages to Adoption Pathways activities *(outline possible adoption pathways activities to disseminate and encourage industry adoption of project outputs.*

C2 is heavily focused on rapid dissemination and adoption of target technologies. There are two main methods of industry engagement. (1) CRC partners, particularly technology providers will be consulted throughout the project to assist in the technology development. Target industry clients may include precipitation specialists, chemical suppliers (particularly of ion exchange resins and adsorpents), membrane suppliers, and electrochemical equipment suppliers. (2a) The project is focused from the very start with rapid movement to field prototypes. A deliverable is that all three technology types to be developed in the project will exist in prototype, and this will be applied in the field by the end of the project. This will engage urban water suppliers and treatment organisations, as well as whole plant suppliers. (2b) The technology to be developed will be scalable and applicable across a range of applications. One example may be initial application of phosphorous and nitrogen recovery to high-concentration streams such as anaerobic digestate, followed by progressive implementation in lower strength streams (such as main-line) at the same plant. This would provide a higher level of familiarity with the technology prior to possible replacement of existing units in a greenfield application.

While preliminary opportunistic adoption is likely to be in larger treatment plants (where concentrated sidestreams are more available), application in replacement of complete treatment plants is more likely in smaller greenfield sites, where testing and discharge to a main sewer is available. This concept has been identified in discussion with water utility stakeholders.

References

15. References

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16 Resources: ANNEXURE C

The information displayed here is private and confidential.