Next generation technologies for recovery of energy, nutrient and water resources from slaughterhouse wastewater

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16th March 2016

Let’s Talk Australian Meat Processing

1. Australian red meat processing plants generate large volumes of wastewater rich in organics and nutrients.
2. The industry has a high exposure to carbon pricing due to wastewater methane emissions, and its use of coal for steam generation.
3. Until recently, there were large gaps in knowledge of wastewater sources, as well as resources available (chemical and thermal energy, carbon, nitrogen phosphorous, and other elements).
4. New technology options are emerging – focus on low cost treatment and resource recovery, but how do they fit industry requirements? and do they actually work?

Slaughterhouse Wastewater

Large Volumes of Wastewater

Organic waste: 20-40 tonnes/d = 180 – 350 GJ/d potential energy

Nitrogen: 0.5 – 1 tonnes/d

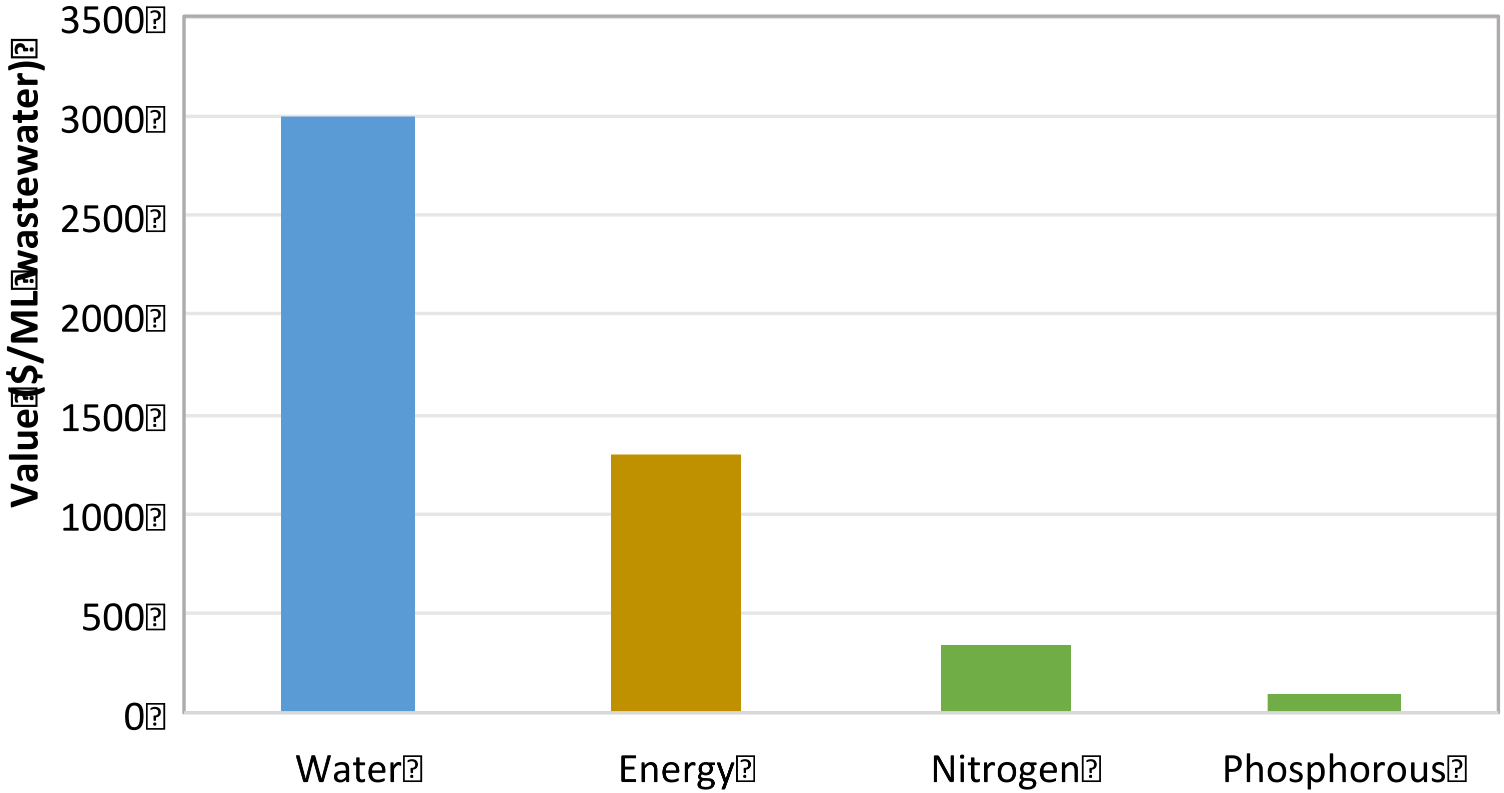
Phosphorus: 0.1-0.2 tonnes/d = > 1 t/d struvite fertilizer

	Volume $m^3\ day^{-1}$	TCOD mg L^{-1}	sCOD mg L^{-1}	TS^b mg L^{-1}	FOG mg L^{-1}	N mg L^{-1}	P mg L^{-1}
Literature Concentration	-	2,000-10,000	-	500-2,000	100-600	100-600	10-100
Site A	2420	12,893	1,724	8,396	2,332	245	53
Site B	3150	9,587	1,970	7,000	1,300	232	50
Site C	2110	10,800	890	7,530	3,350	260	30
Site D	2150	12,460	2,220	7,400	3,300	438	56
Site E	1600	12,200	1,247	6,678	2,380	292	47
Site F	167	7,170	1,257	3,806	2,258	182	27

Key Challenges

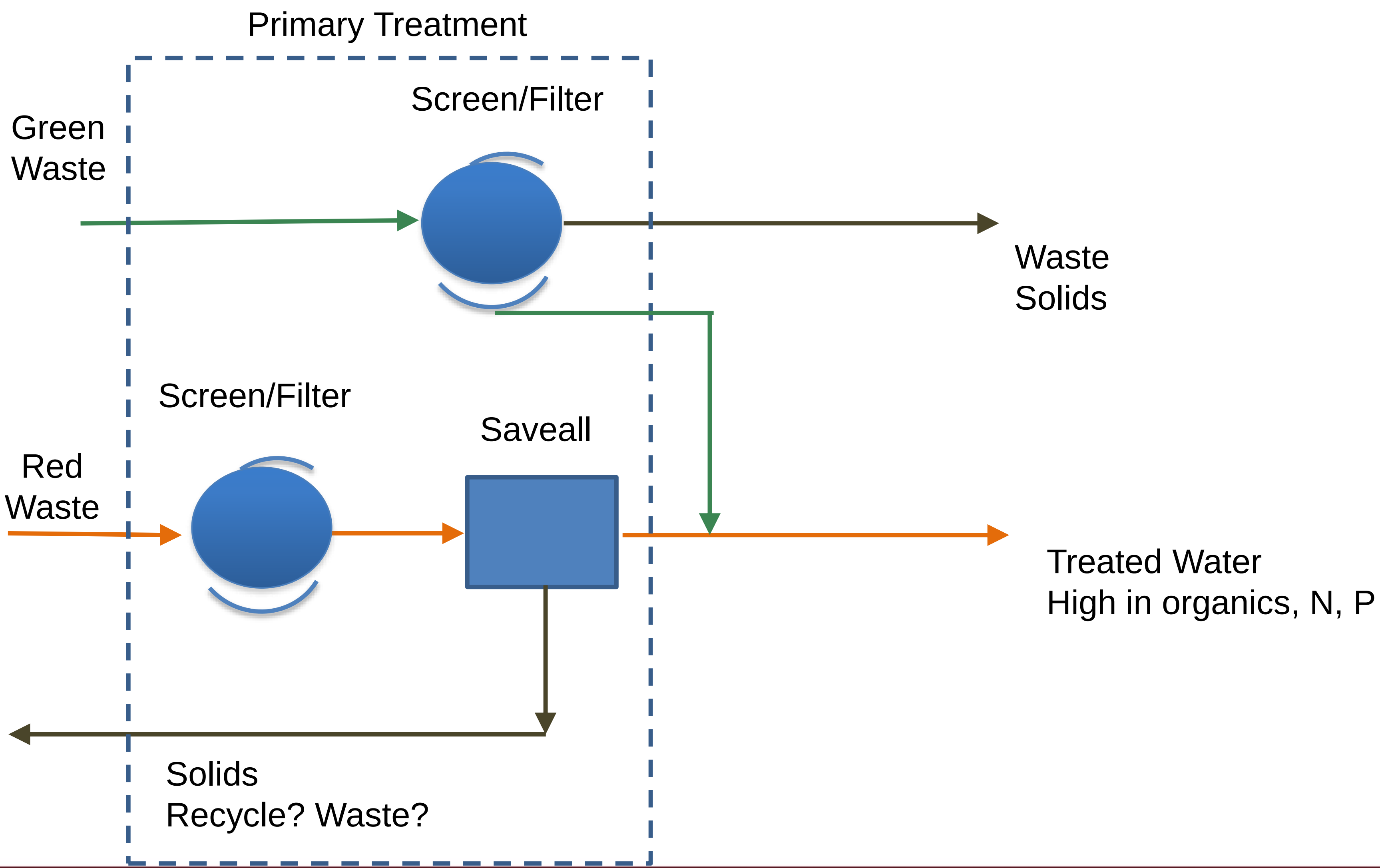
1. Oil and Grease
2. Organics
3. Phosphorous
4. Nitrogen
5. Solid Waste
6. Water Supply, Discharge, Re-use
7. Odour
8. Biosecurity and Pathogens

The Value in Wastewater



Water value at $3/kl for town supply, Energy valued at $10/GJ, Nitrogen valued at $1.20/kg and P valued at $1.50/kg

Example Waste Treatment Train



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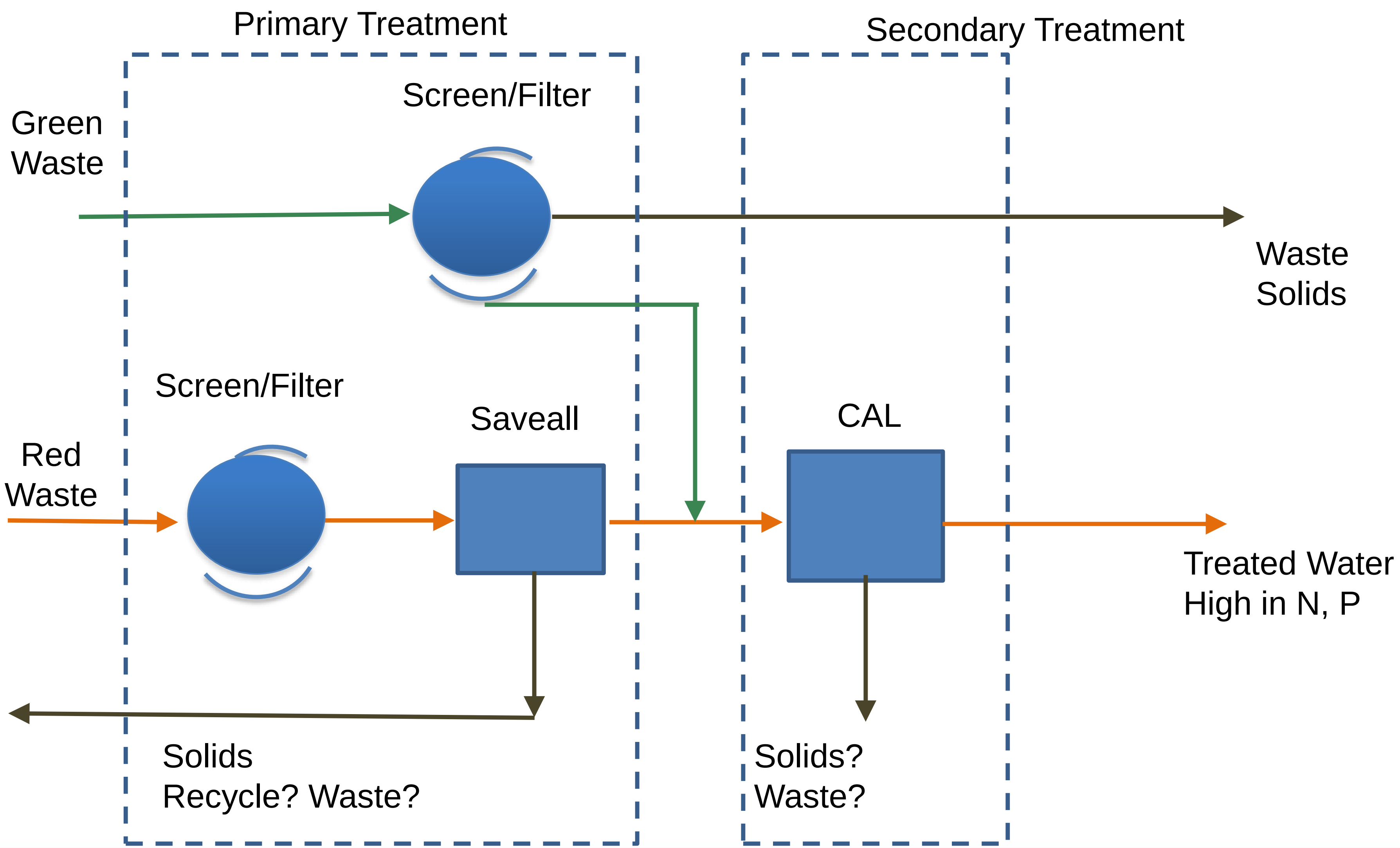

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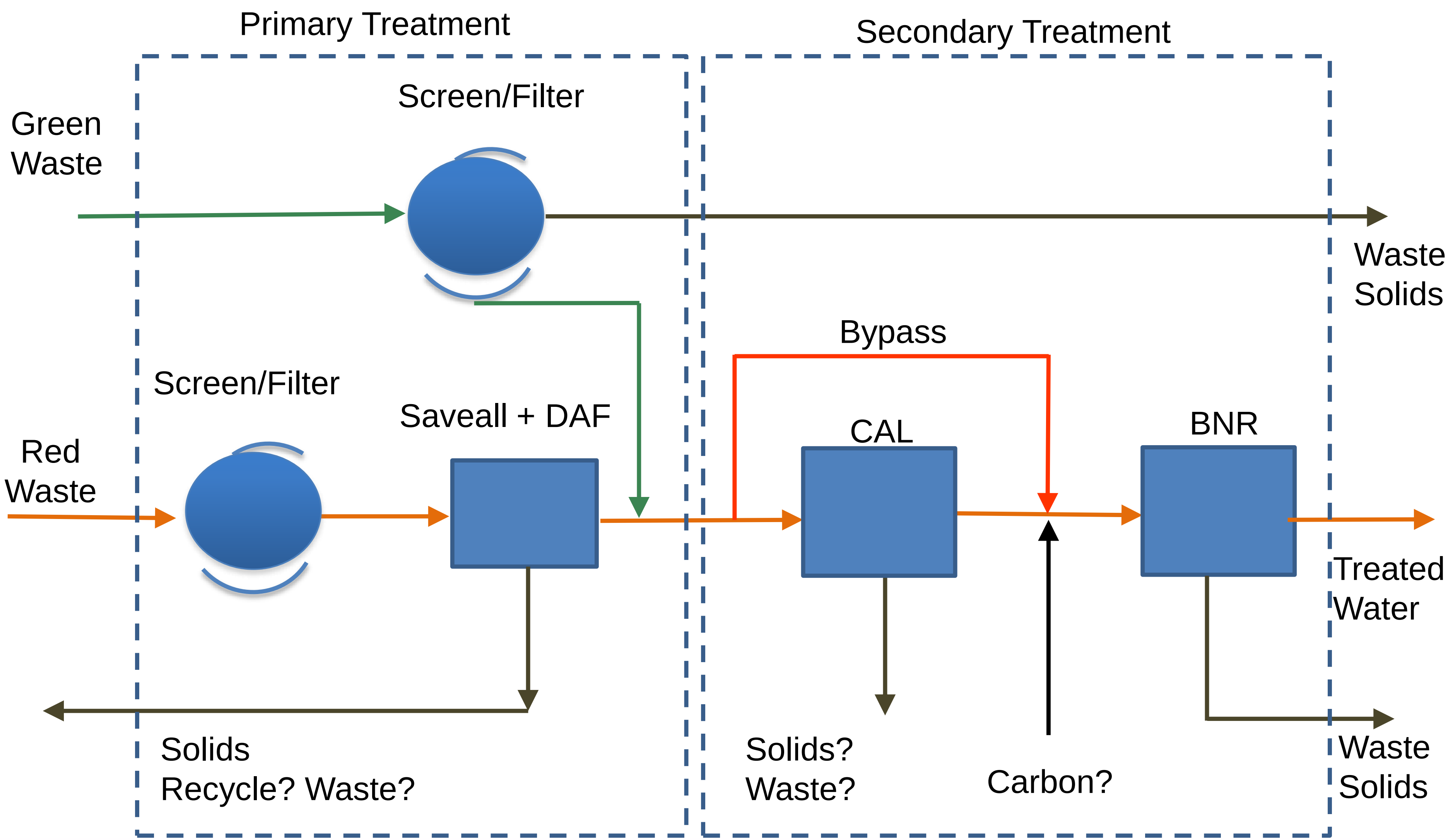

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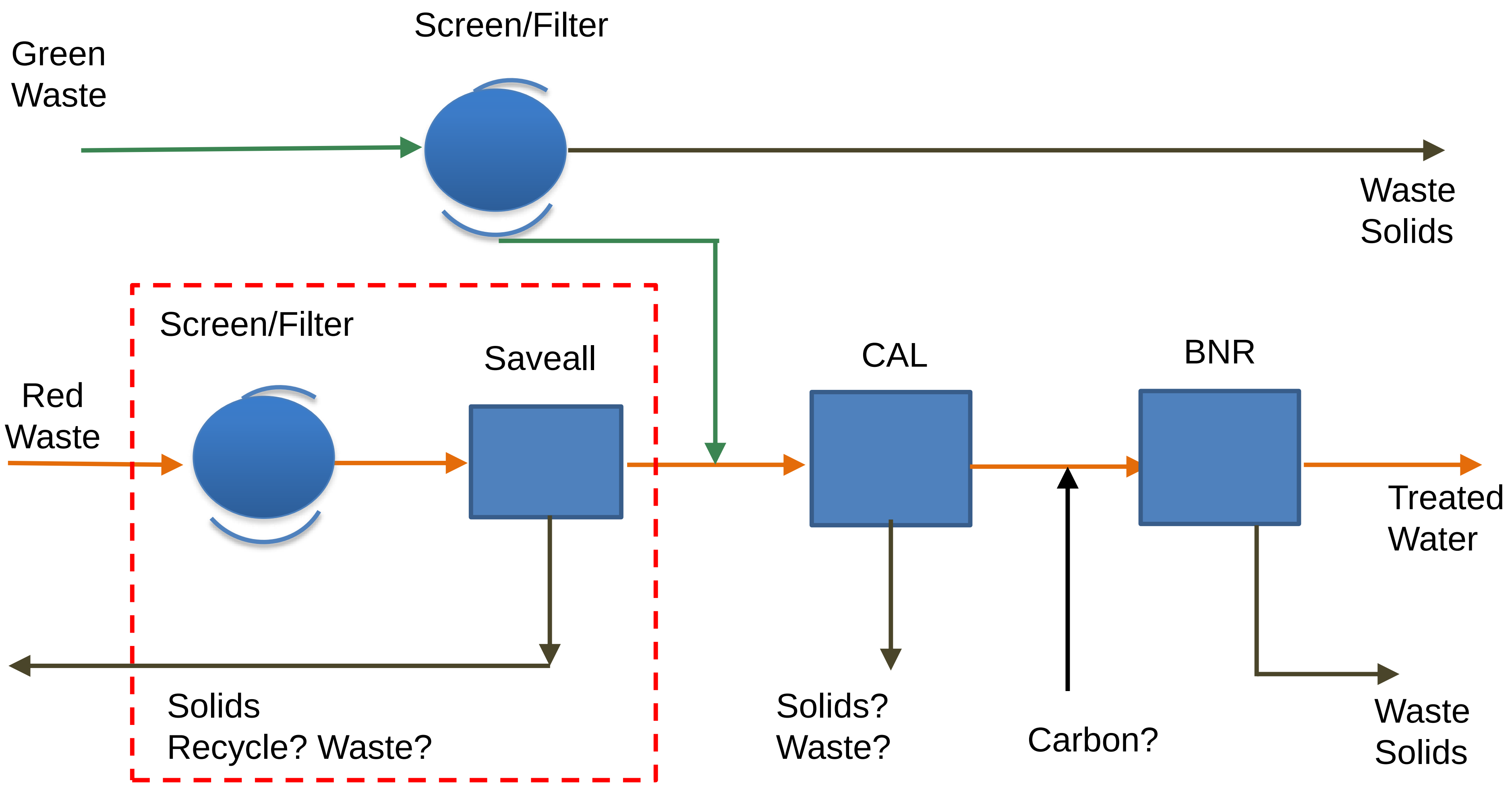
Oil and Grease Capture



Oil and Grease: The Value Proposition

Methane Yield from Fat Oil Grease:	~ 1000 m^3/tonne FOG
Energy potential from methane:	34 MJ/m^3 = 34 GJ/tonne
Energy Value from methane:	$10/GJ = $340/tonne

Value of Tallow FOG:	Top Grade:	$700 - $1,000
	Lower grade:	$300 - $500

	Volume $m^3\ day^{-1}$	TCOD mg L^{-1}	sCOD mg L^{-1}	TS[b] mg L^{-1}	FOG mg L^{-1}	N mg L^{-1}	P mg L^{-1}
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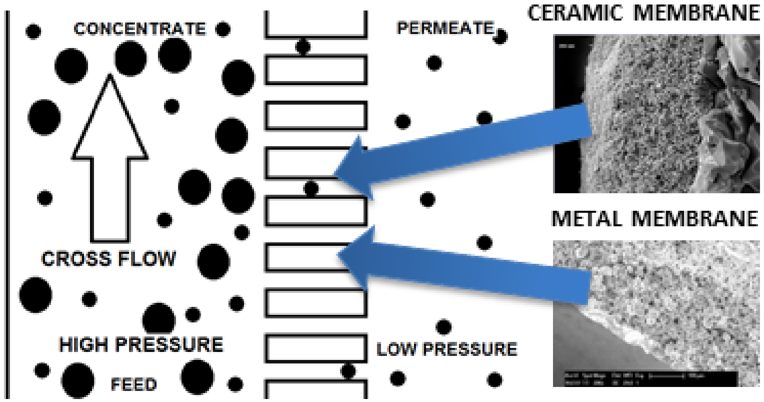
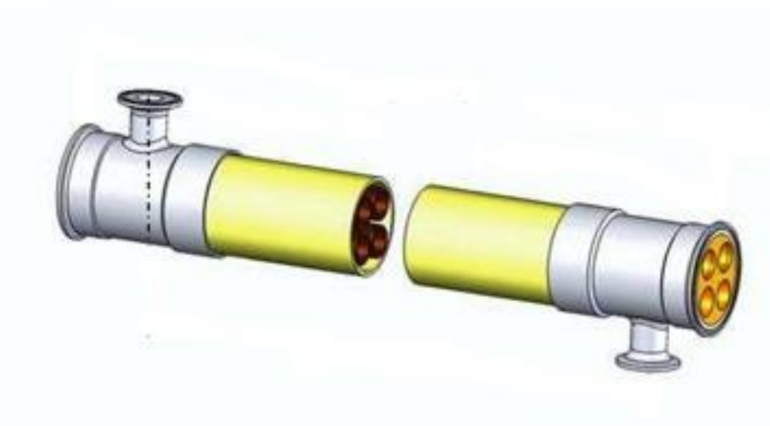
Oil and Grease: Managing Risk

- FOG is energy dense with very high methane potentials ~ 1000 L CH_4/kg VS
- FOG c
  - –
  - –
- FOG c overs
- Recov

Research Opportunity -Membranes for FOG Recovery??





Are there better options?

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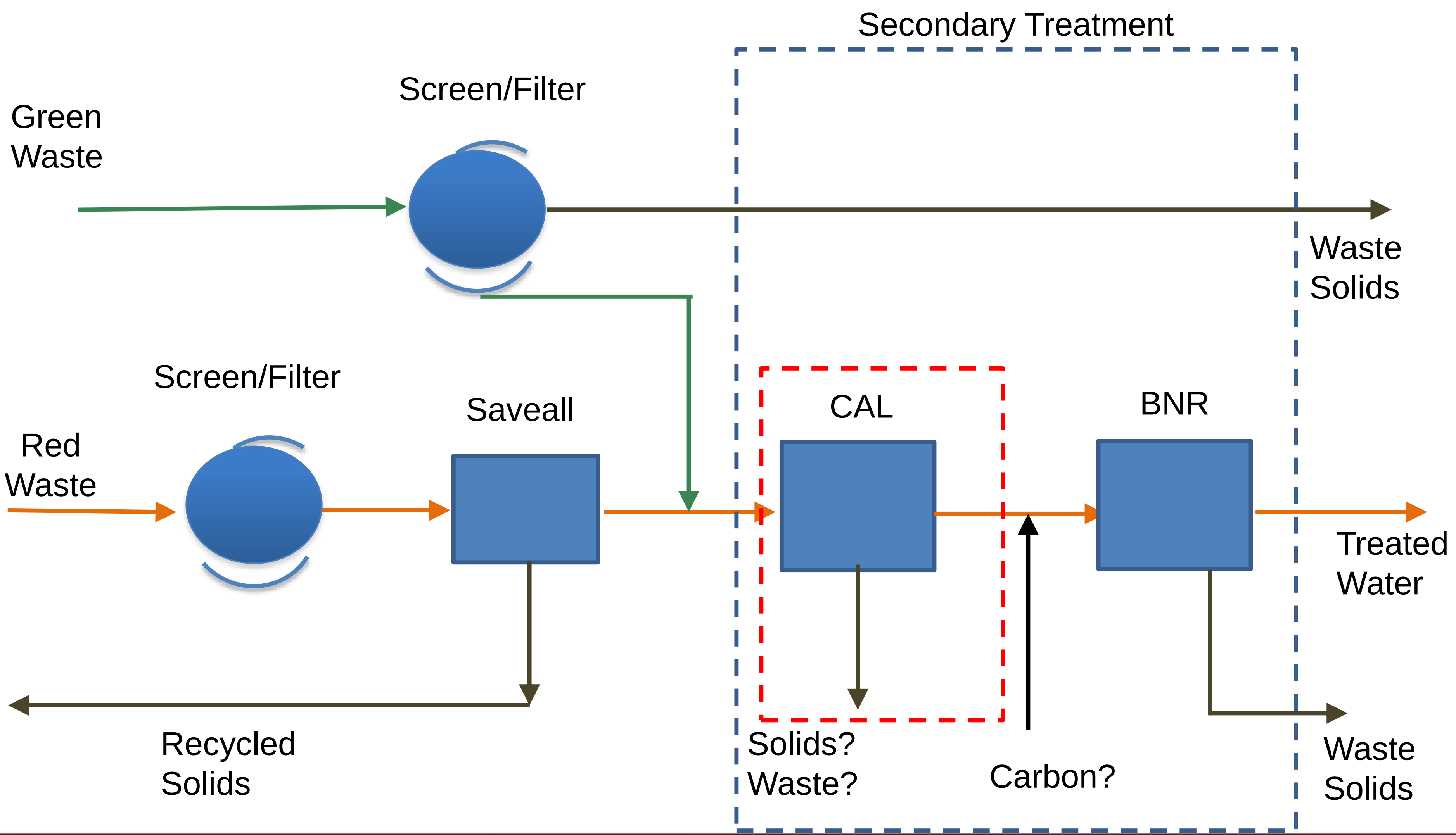
Wastewater Organics

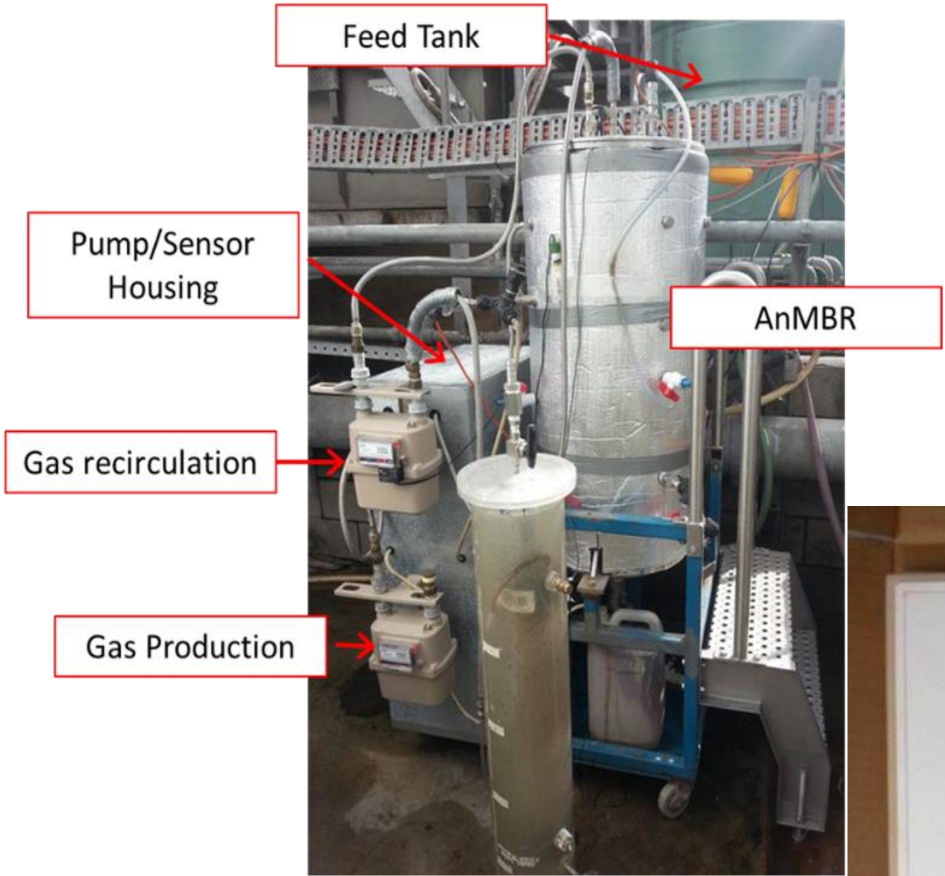


Current Approach - Anaerobic Lagoons

<u>Technology Description</u>

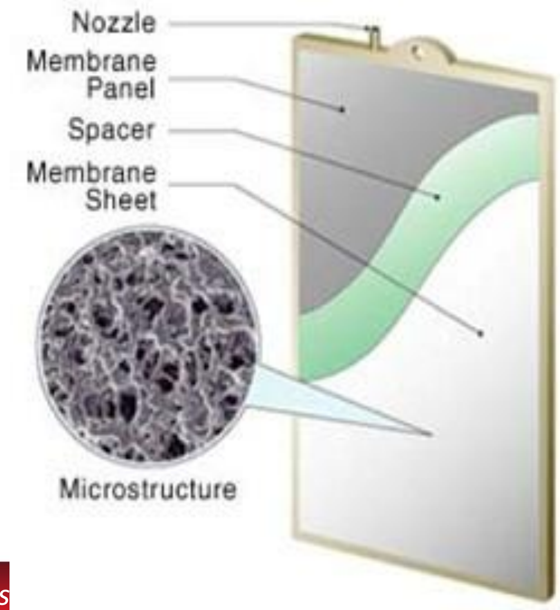
- Established technology - many successful case studies in meat processing;
- Low cost infrastructure;
- Very low operating costs;
- Very large footprints;
- Mixed gas capture/odour risks (uncovered – bad, covered is better);
- Renewable energy as biogas (if covered);
- Risks around climate variability, washout of sludge, cover damage etc.

Emerging - Anaerobic Membrane Bioreactors



Red Meat Processing Industry…..

- High strength, high solids wastewater.
- Fats oil and grease
- AMBR footprint 100x less than anaerobic lagoons
- High quality effluent
- What about membrane fouling?



AnMBR Performance

- Maximum Loading rate 3-4 kgCOD.m^{-3}.d^{-1} with a HRT of 2-4 days;
- Active biomass inventory is a key factor impacting the maximum loading rate.

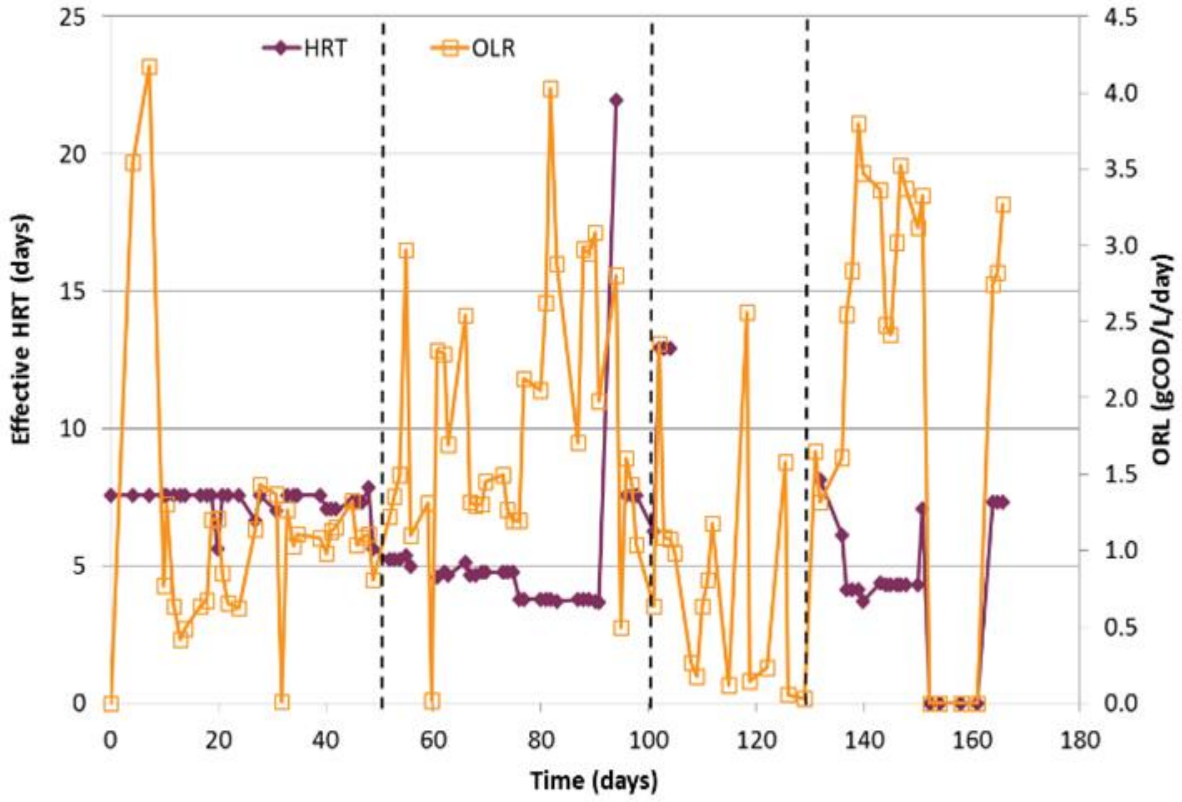


Figure: Hydraulic retention time (HRT) and Organic Loading Rate (OLR) during the pilot operation at 37° C.

AnMBR Performance

- Maximum Loading rate 3-4 $kgCOD.m^{-3}.d^{-1}$;
- Solids/Biomass inventory must be managed to control membrane fouling;
- >95% COD removal;
- 90% of N is mobilised to permeate as NH_4^+;
- 80% of P is mobilised to permeate as PO_4.

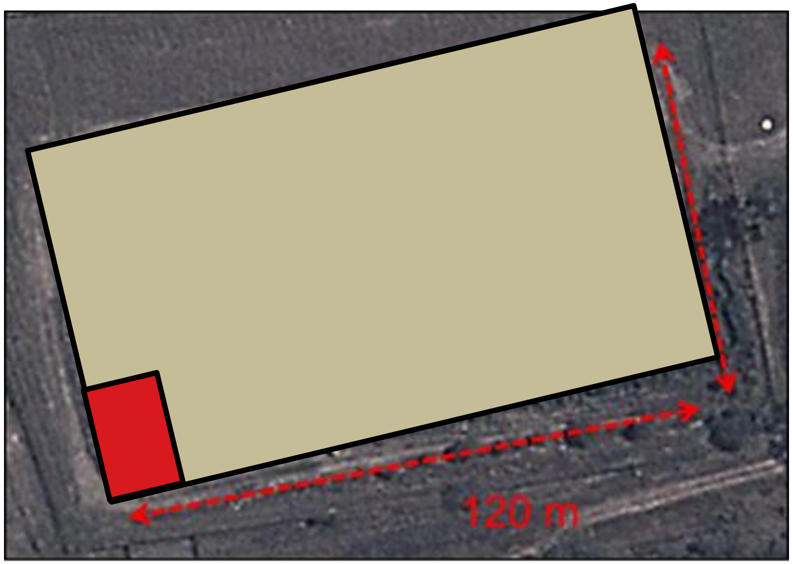
SUMMARY FEED										
	TS	VS	tCOD	sCOD	FOG	VFA	TKN	NH4	TP	PO_4
	$g.L^{-1}$	$g.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$
Minimum	2.4	2.1	4387	919	98.4	30.4	93.4	14.2	9.7	6.1
Average	5.9	5.3	11536	1908	2681.8	569.9	366.3	95.1	38.9	27.4
Maximum	18.0	16.9	29463	3799	5293.9	1329.5	816.0	318.0	177.6	128.0
SUMMARY PERMEATE										
	TS	VS	tCOD	sCOD	FOG	VFA	TKN	NH4	TP	PO_4
	$g.L^{-1}$	$g.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$
Minimum	0.00	0.00	72	72	0.0	6.0	212.4	55.8	17.8	15.9
Average	0.01	0.01	425	425	16.4	166.5	318.1	316.7	30.9	31.4
Maximum	0.01	0.01	1665	1665	39.4	1139.6	532.0	509.0	65.2	79.8

Scope to optimise process for nutrient recovery

Lagoon vs. Anaerobic Membrane Reactor

Better gas production/recovery and better effluent quality

	TS	VS	tCOD	sCOD	TKN	TP
	$g.L^{-1}$	$g.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$
Raw	5.9	5.3	11,536	1908	366	39
CAL	0.7	0.6	1,800	600	345	36
AnMBR	0.01	0.01	425	425	318	31



Smaller Footprint Required

AnMBR is viable, but needs optimisation!

Key Challenges

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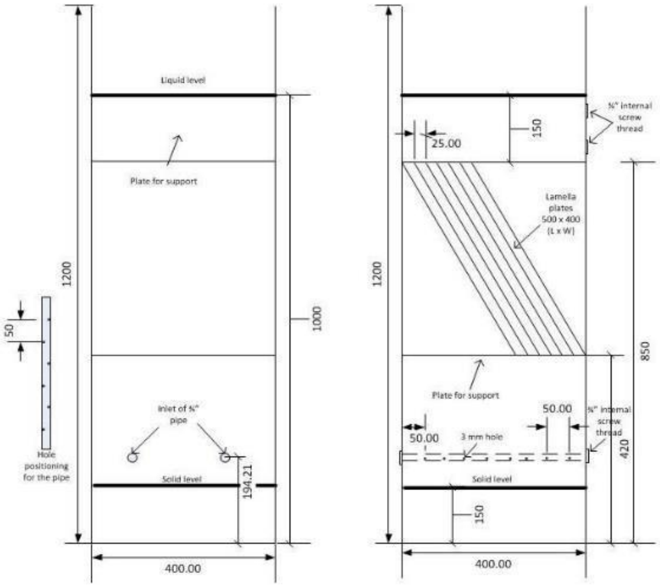
Emerging Technology – P recovery through Struvite



Stage 1 Objectives

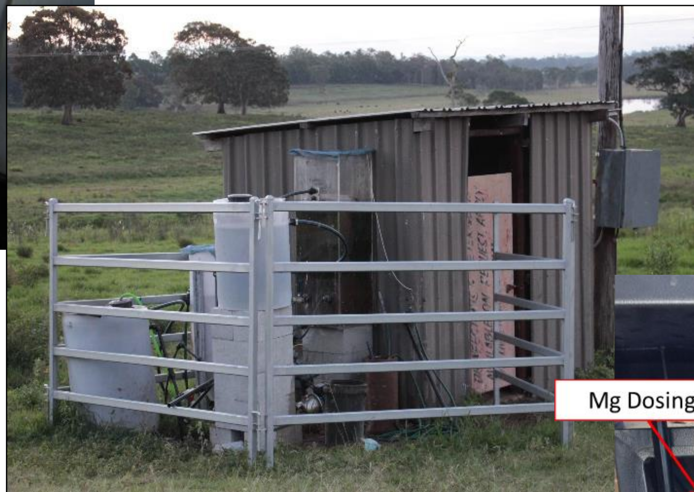
- Develop technology for nutrient recovery on digester/lagoon effluent;
- Identify lower P limit (~10 mg/L P is theoretical limit);
- Identify chemical consumption;
- Cost-benefit analysis.

Stage 2 Objectives

- Run reactor for an additional 3 months on digester/lagoon effluent;
- Implement on new site including adaptation equipment (mainly feed and holding vessel system);
- Full product analysis by microscopy and ICP-AES;
- Cost-benefit analysis for pond recovery.

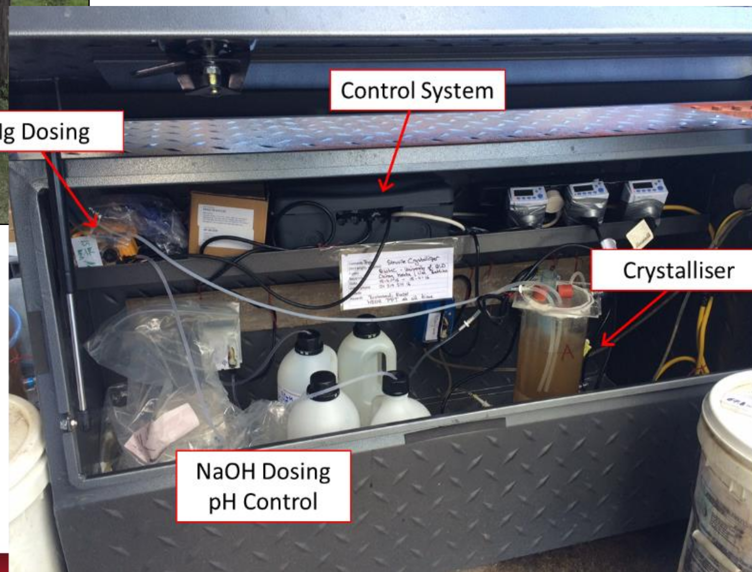
UQ/AMPC/MLA Pilot Plant Applications

Biogas Digester Effluent



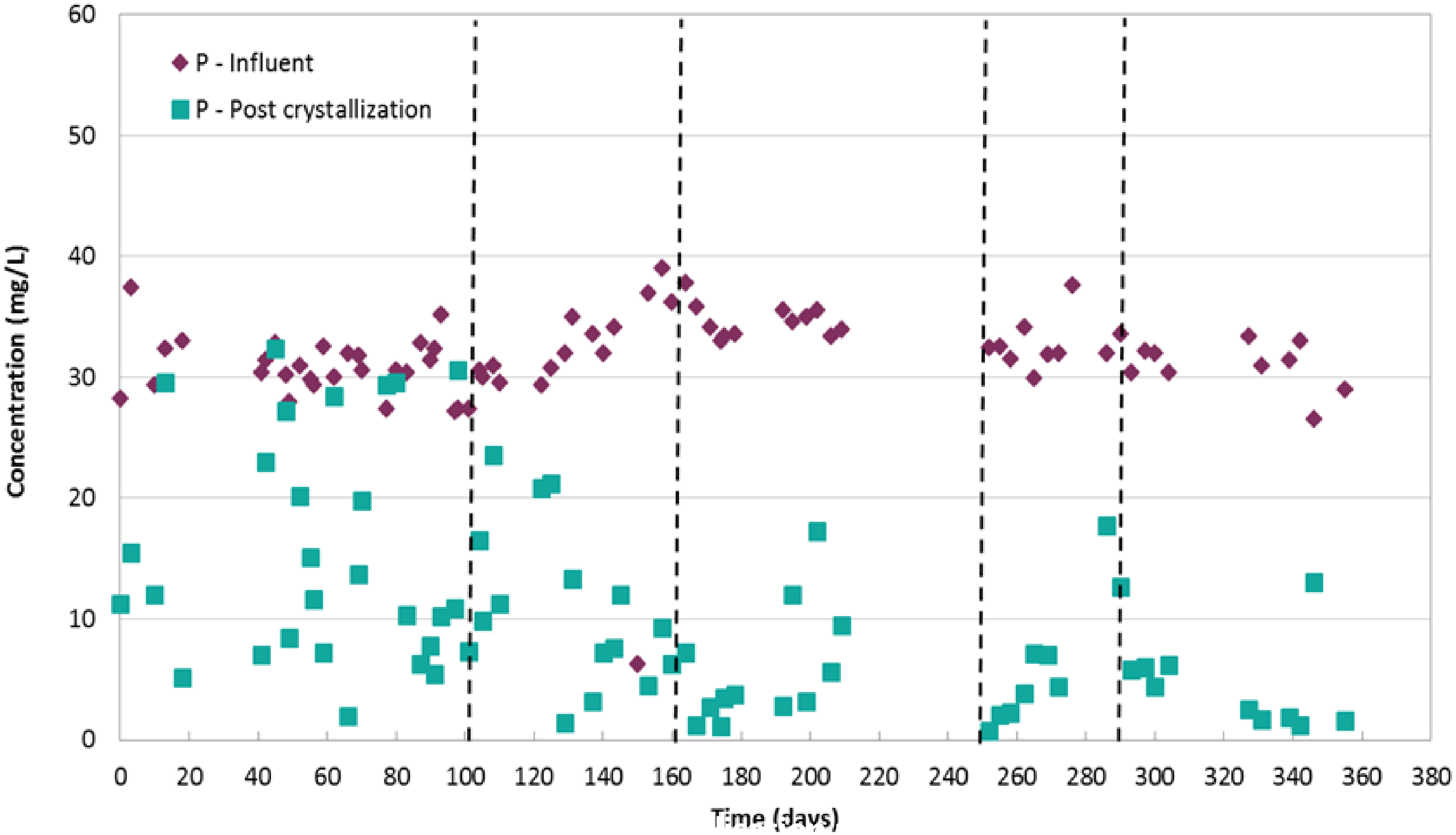
CAL Effluent

Membrane Treated Effluent



Struvite: P Recovery Performance

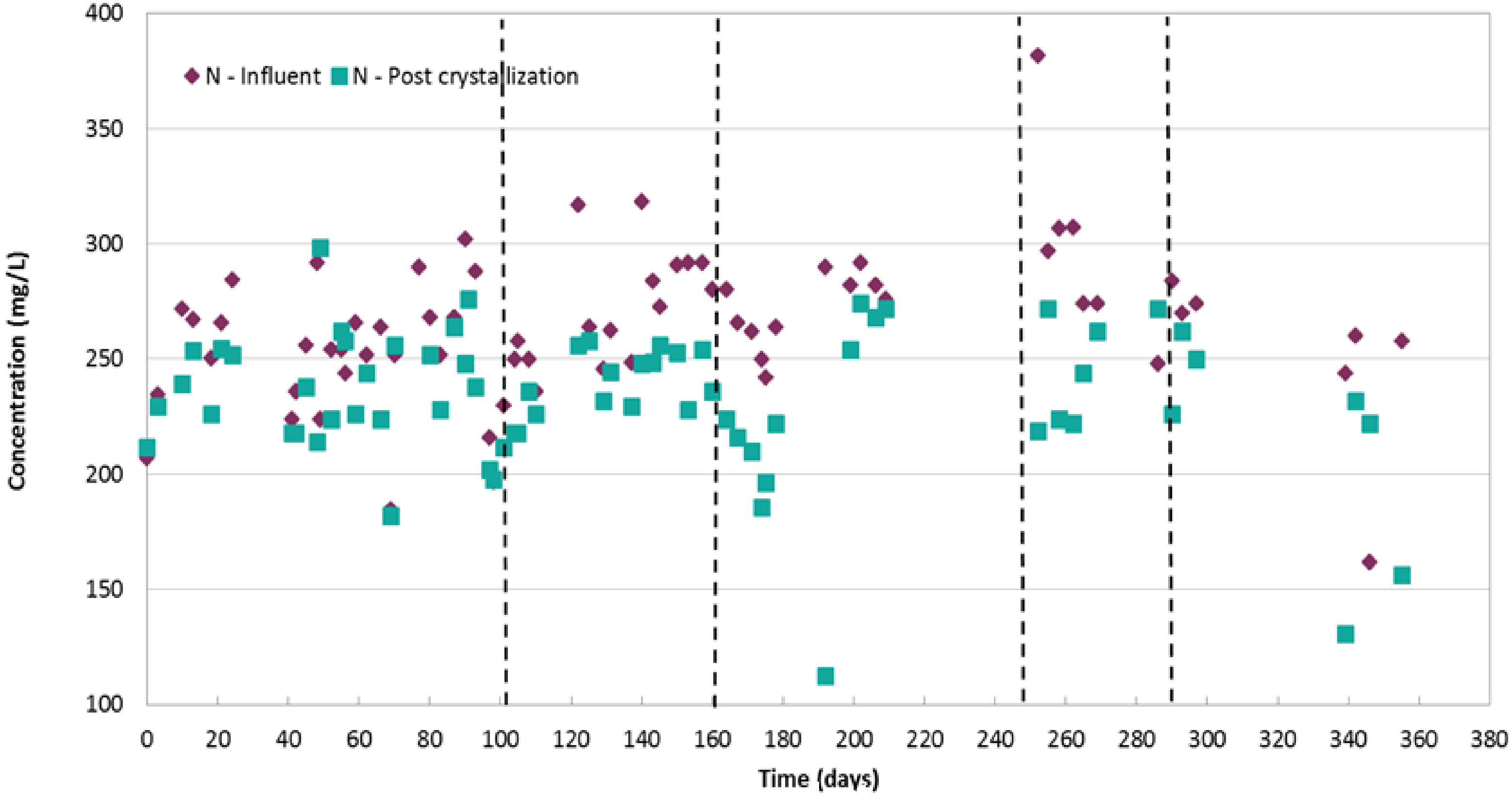
- Highly sensitive to magnesium chemical dosing
- Can be effective technology for P removal – achieving effluent P <10 mg/L



anaerobic lagoon effluent.

Struvite: N Recovery Performance

- Not suitable as a standalone process for nitrogen removal



treating anaerobic lagoon effluent.

Struvite Product Quality

Lagoon Effluent:
•Product contained 2-3% P - low compared to pure struvite (approximately 10% P);
•Nitrogen content was high – product contained organic sludge solids from CAL effluent;
•magnesium content was high – chemical dosing not yet optimised.

Membrane Treated Digester Effluent:
•Product contained 15% P – very high compared to pure struvite (approx. 10% P expected);
•No organic sludge contamination;
•Minimal excess magnesium.

Struvite Composition

	Al	Ca	Fe	K	Mg	N	Na	P	S	Zn
	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$	$g.kg^{-1}$
CAL effluent	3.37	18.43	5.95	1.90	41.01	42.23	2.29	32.46	7.50	0.44
Membrane-treated Effluent	0.02	3.6	0.13	2.8	162.5	-	21.8	157.3	0.72	0.00

Pre-treatment/screening of CAL effluent not critical – but can have substantial benefits!

Struvite Cost Comparison

- Capital costs generally low for P removal processes, while operating costs can be high;
- Chemical consumption is the primary operating cost;
- Chemical consumption based on stoichiometric dosing – higher dosing may be required;
- Struvite – cheaper, but removal limited to ~ 10 mg/L P;
- Alum dosing – expensive, but removal to < 1mg/L P can be achieved.

Struvite	
Commodity	Price
Magnesium hydroxide (90% purity – 37% Mg)	$800/tonne
Magnesium	$2100/tonne as Mg
Mass ratio required	0.8
Chemical cost per kg P removed	< $2/kg
Alum dosing	
Commodity	Price
Aluminium Sulphate (15% purity – 2% Al)	$200/tonne
Aluminium	$10,000/tonne as Al
Mass ratio required	0.9
Chemical cost per kg P removed	~ $8-10/kg

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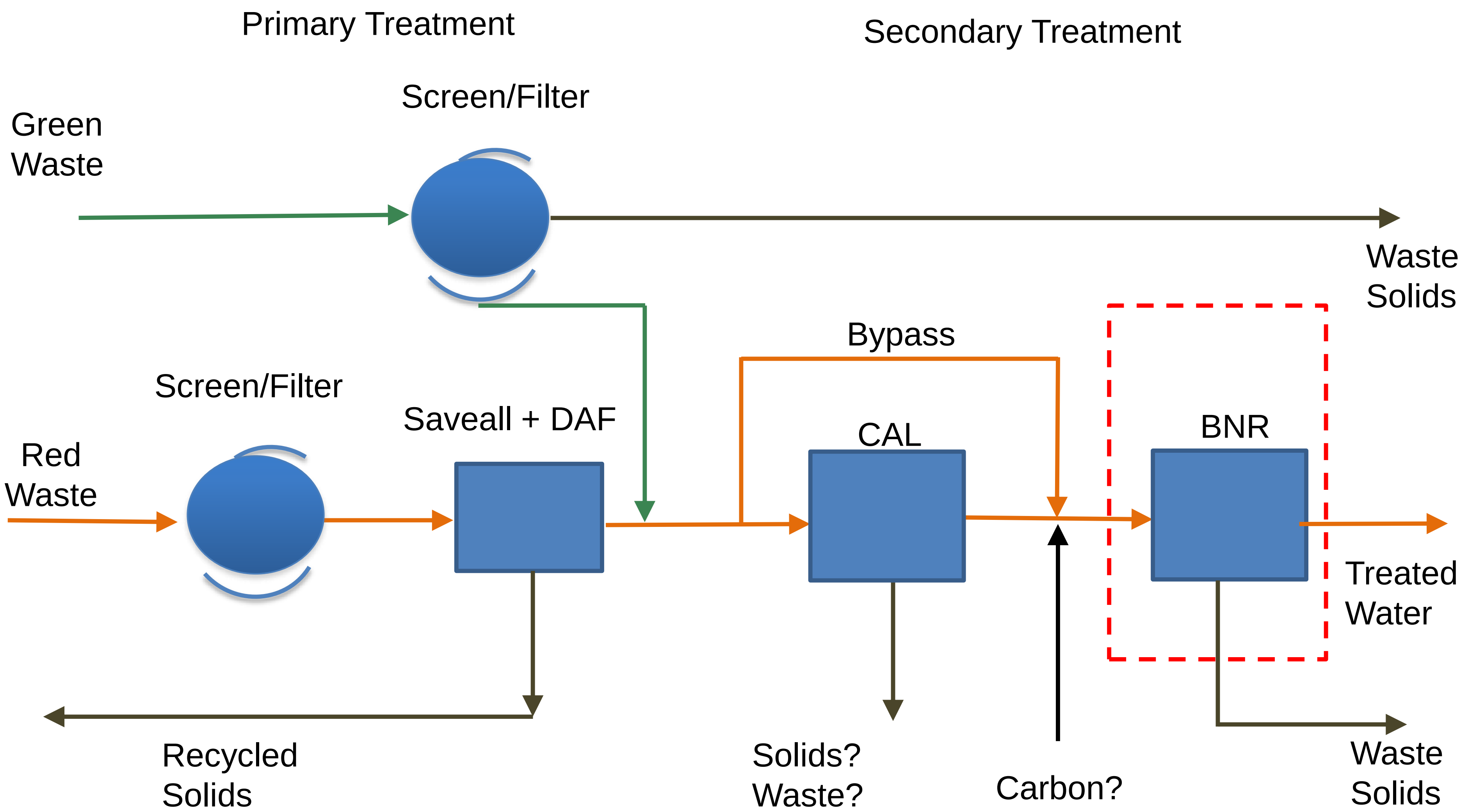
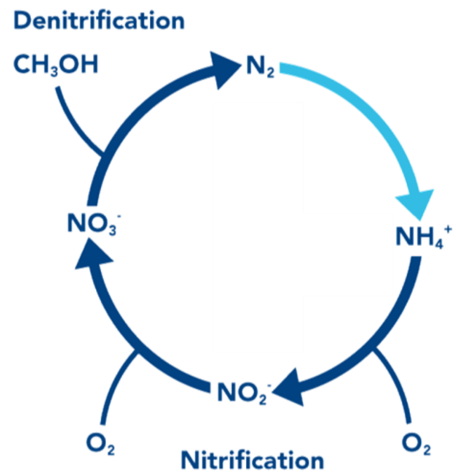
Nitrogen Removal



Current Approach - Conventional Nitrification/Denitrification (SBR or BNR)



Technology Description

•Established technology in many industries;
•Many different reactor configurations;
•Ammonium is first converted to nitrate under aerobic conditions – requires aeration;
•Nitrate is converted to N_2 gas under facultative conditions – requires carbon source;
•Waste sludge containing COD, N and P
•High COD reduced process effectiveness – COD will oxidise and consume O_2;

Short Cut Design Basis

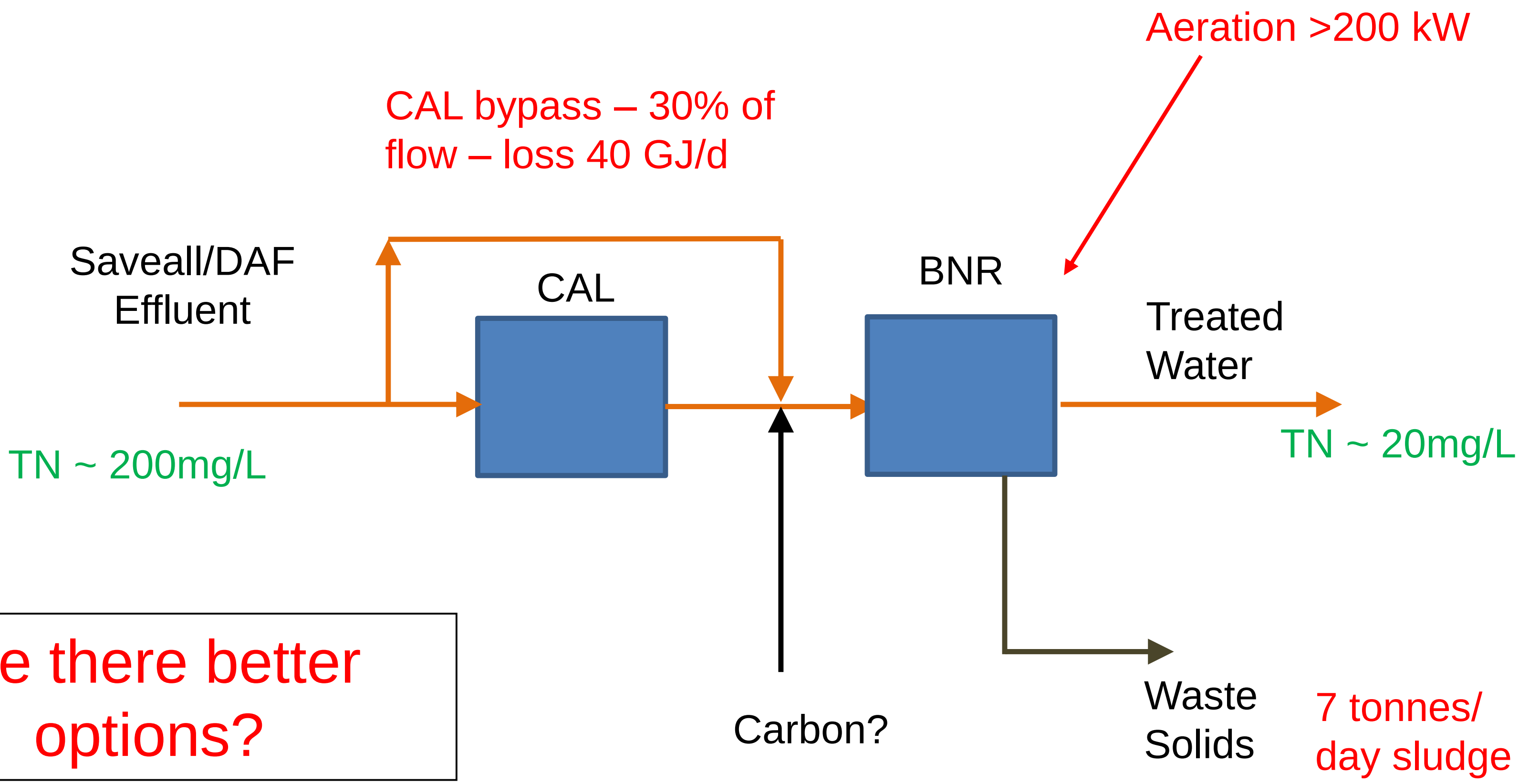
•Nitrogen loading rate: 0.3 kgN/m^3/d
•COD required: 2.86 kg COD/kg N removed
•Energy demand: 4.7 kWh/kg N removed
•N removal: 90%
•Sludge yield: 0.4

Figure adapted from: Paques, 2013

Case study: Impact of BNR on Treatment Train

Wastewater volume: 3.5 ML/ day

TN loading rate: ~ 700 kg/day



Are there better options?

Emerging Technology: Anaerobic Ammonium Removal (AAR)

Technology Description

✓Many different reactor configurations;
✓Utilises a shortcut in nitrogen cycle – partial nitrification requires 60% less aeration;
✓Very low sludge production.
×Sulphides may present inhibition risk;
×Doesn't' t achieve complete N removal;
×Limited case studies in meat processing.

Mainline AAR Project (2016-2018)

•Stage 1 – Proof of Concept
•Stage 2 – Onsite demonstration
•Stage 3 – Full-scale Implementation

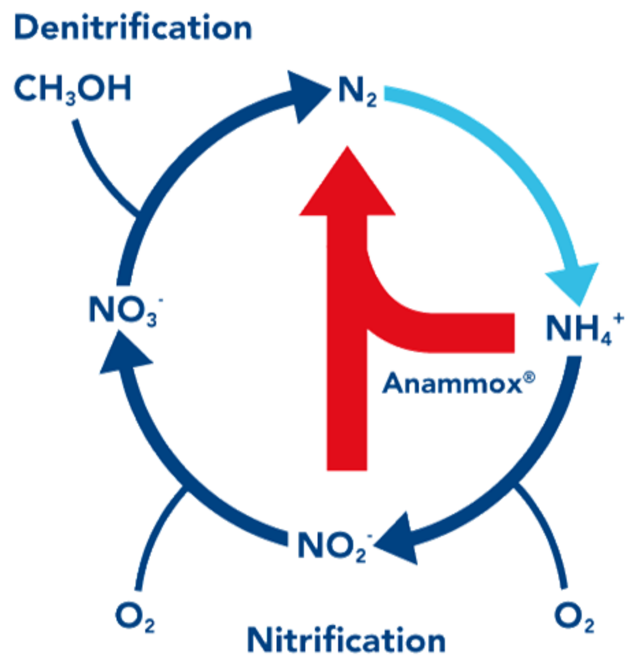


Figure Source: Paques, 2013

Other Strategies for N removal/recovery?

Electro-dialysis??

Forward Osmosis??

Stripping?

Hydrogels??

Single-Cell Protein??

Electro-chemical??

	Volume $m^3\ day^{-1}$	TCOD $mg\ L^{-1}$	sCOD $mg\ L^{-1}$	TS^b $mg\ L^{-1}$	FOG $mg\ L^{-1}$	N $mg\ L^{-1}$	P $mg\ L^{-1}$
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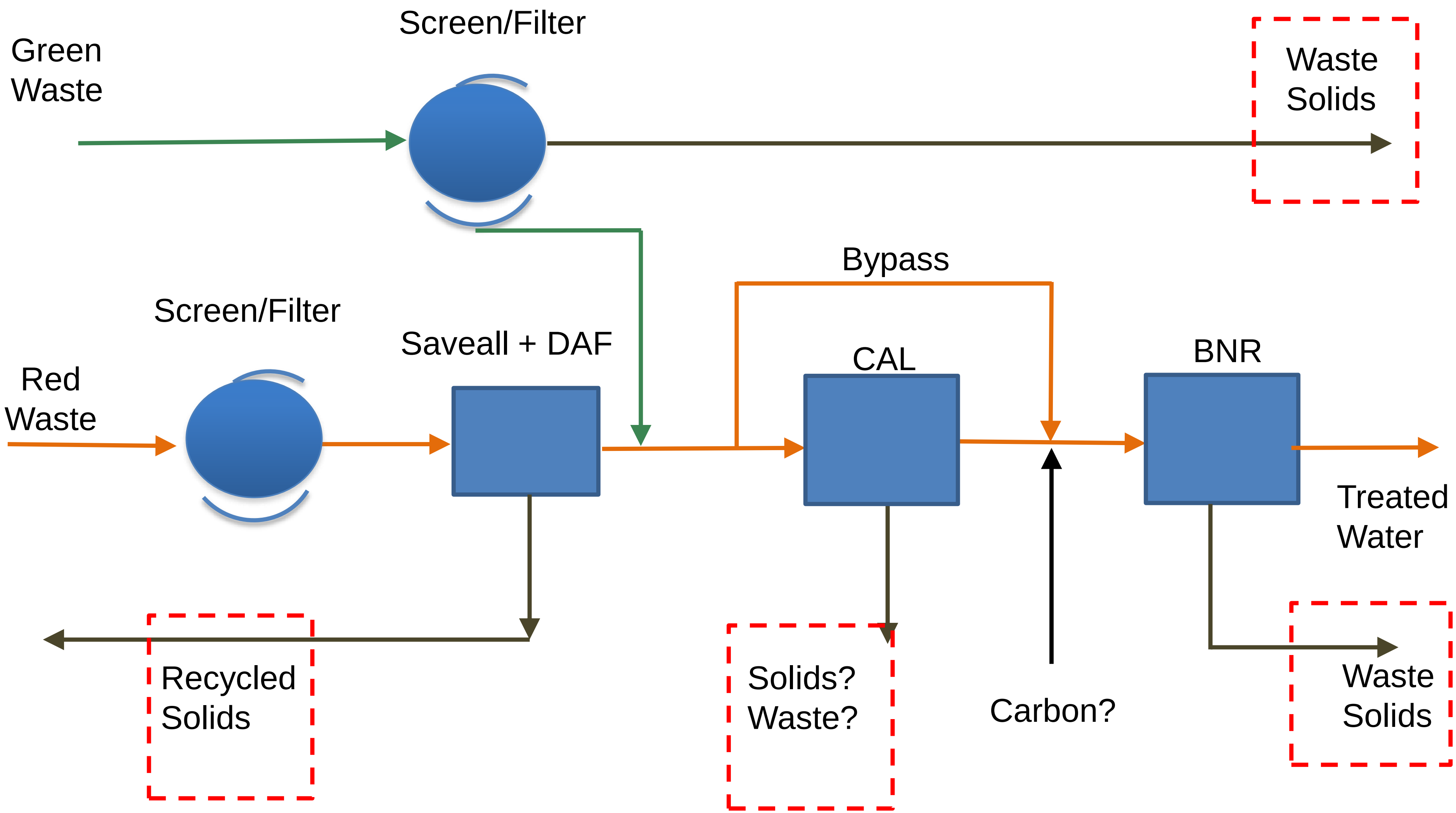
Sources of Solid Waste



Emerging Tech: In-vessel Anaerobic Digestion (IVAD)

<u>Technology Description</u>

- Established technology in numerous industries;
- Biological process that converts organic waste to biogas;
- Digestion residues – reuse as organic mulch;
- Different configuration – augment using pre-treatments.

<u>AWMC Biosolids Partnership Program</u>

- Temperature Phased AD (TPAD)
- 20 m^3 pretreatment and 100 m^3 digester
- 3-5 tonne paunch/day (wet solids)
- 20-50 kW energy recovery (heat or co-gen)
- Location: Beenleigh QLD
- Phase 1 commissioned August 2010
- Phase 2 Solids: Commissioned 2012

TPAD Outcome Highlights

- Anaerobic digestion can reduce the mass of paunch solid waste by >60%;
- Paunch waste produced ~ 200-280 L CH_4/kg VS;
- Some improvements in dewaterability;
- Materials handling is the biggest technical challenge;
- Methane yields and hydrolysis rates at the lower end of the "organic waste spectrum":
  - Requires large (expensive reactors)
  - Lower biogas revenue

Solutions exist – better solutions needed!

Other Strategies for Solid Waste

AD technologies

- Thermal hydrolysis??
- Co-digestion??
- Chemical pre-treatment??
- Thermophilic pre-treatment??
- Leach-bed digestion??
- Plug-flow digestion??

Other technologies

- Gasification??
- Composting??
- Single-Cell Protein??
- Vermiculture/Black solider flies??
- Pyrolysis/biochar??
- Combustion/incineration??
- Smouldering??

Current AWMC/UQ research areas

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Motivations for Water Recycling

- Australian slaughterhouses use large volumes of potable water and generate large volumes of wastewater (6-18 kL per ton HSCW)
- Water is a major cost:
  - Purchase price of up to $3.5/kL for potable water
  - Treatment and disposal costs of $1-2/kL volume plus possible penalties for organics and nutrients
- Water availability can be an issue during droughts – freedom to operate challenges
- Re-use through advanced water treatment to potable standards has been implemented successfully in multiple Australian applications:
  - Municipal wastewater – important as it deals with human pathogens
  - Brewery wastewater – food applications relevant to domestic and expert markets
  - Poultry Slaughterhouses – meat processing application
- But what are the technical, regulatory, social barriers for application to red meat?

AWMC Water Recycling Approach

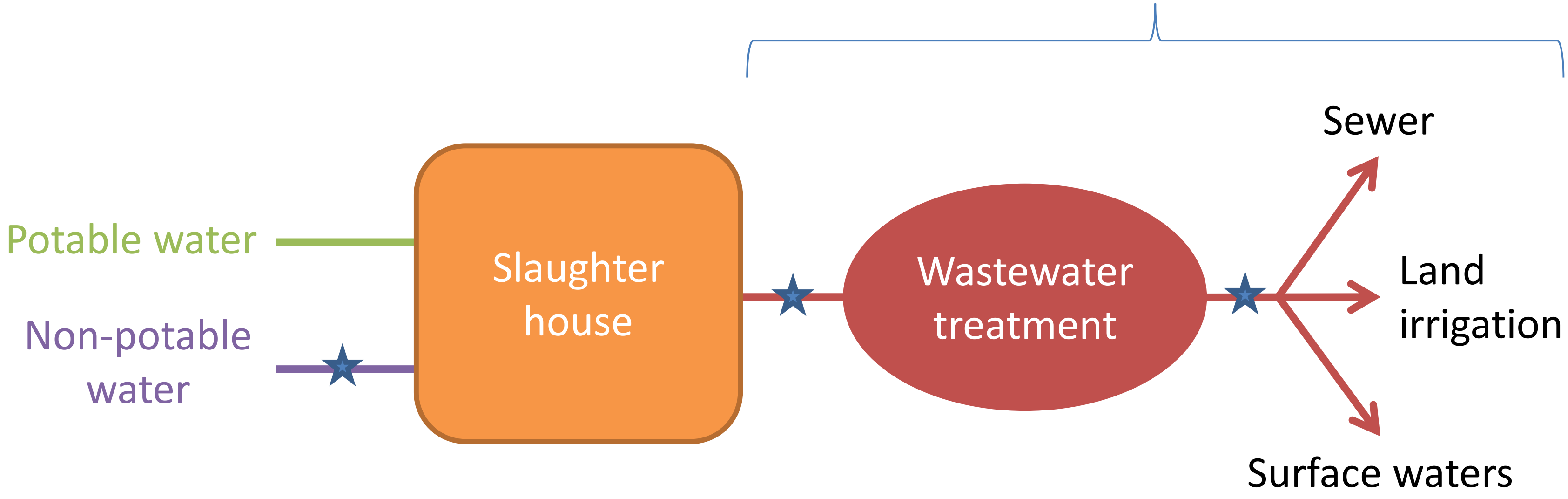
Project aims

- Develop a policy framework and benchmark targets during meat processing for a global best practice in:
  - Conservation
  - Water recycling
  - Water reuse
- Develop effective R&D strategies to reach these targets and demonstrate efficient resources management & sustainability

Methodology

- Literature review based on:
  - International peer reviewed journal (incl. case studies)
  - National & international regulation guidelines
  - AMPC research reports
- Sampling campaign at 3 abattoirs to update wastewater quality and quantity
- Assessment of industry needs, opportunities and barriers

Model Cost Benefit Analysis (Energy and Water) to treat a particular stream for a specific end-use

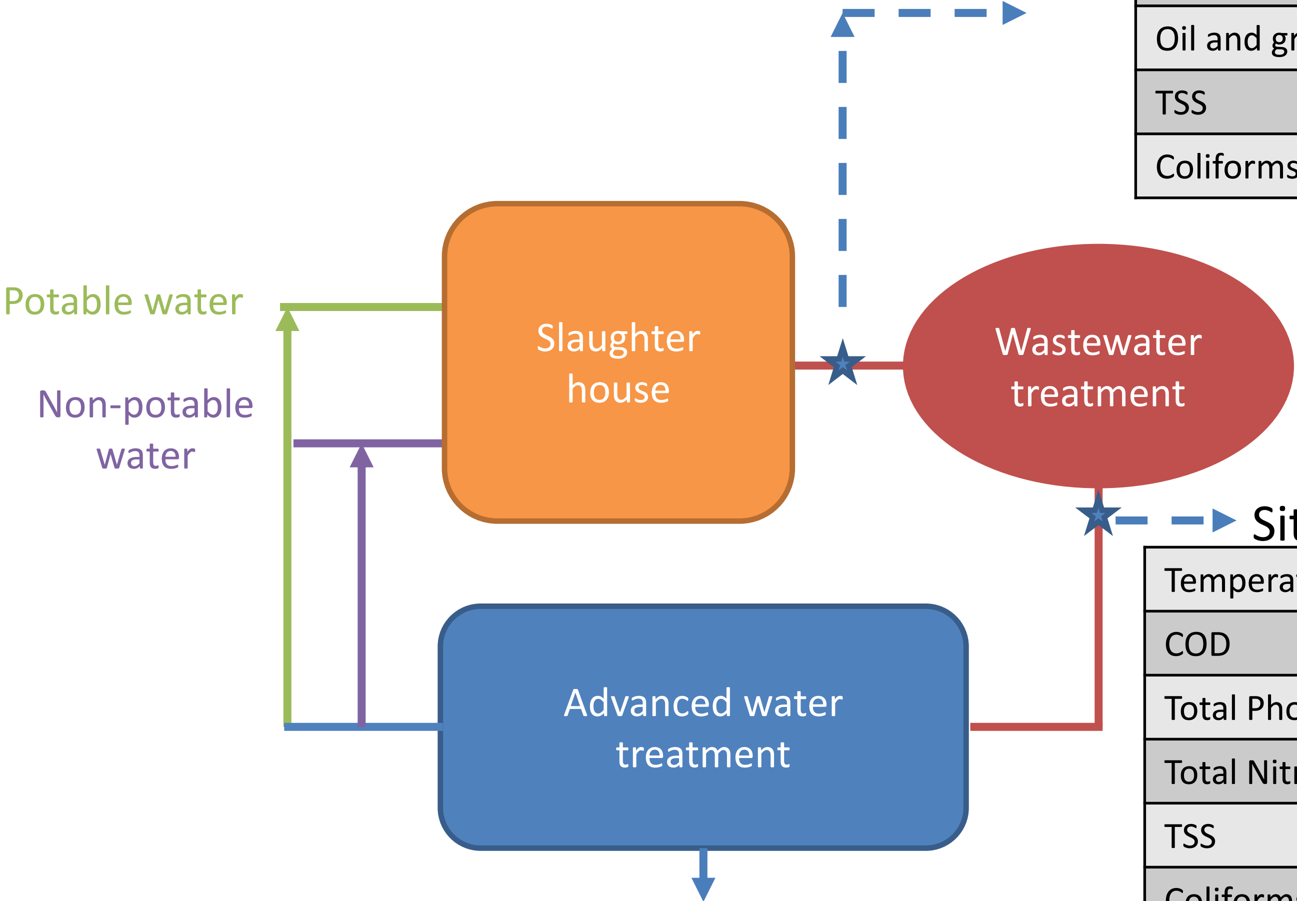


★ Sampling points project 2015/2016

Possibility to add to the model:

- Operating cost?
- Waste-to-energy opportunities?
- Greenhouse gas emissions?

Temperature	~50^{o}C
COD	10,000 mg/L
Total Phosphorus	10-100 mg/L
Total Nitrogen	100-600 mg/L
Oil and grease	100-600 mg/L
TSS	500-2,000 mg/L
Coliforms	~10^{6} CFU/100mL



Site dependant

Temperature	~40^{o}C
COD	1000 mg/L
Total Phosphorus	10 mg/L
Total Nitrogen	20 mg/L
TSS	100-400 mg/L
Coliforms	~10^{5} CFU/100mL

Conventional for IPR: MF/RO/UV-AOP → high energy cost

Alternative: Cl_2/Deep bed filters/ion exchange for TOC/ion exchange for ammonia/UV-AOP/BAC or Cl_2/Deep bed filters/ion exchange for TOC/ion exchange for NH_3/O_3/BAC/UV

Option: MBR/UV-AOP

Slaughter house

Low contaminated streams

Water consumption in abattoir

Major Areas of Water Consumption	Percent of Total Fresh Water Consumption
Stockyard (mostly wash-down)	7-24%
Slaughter, evisceration	44-60%
Boning	5-10%
Inedible & edible offal processing	7-38%
Casings processing	9-20%
Rendering	2-8%
Chillers	2%
Boiler losses	1-4%
Amenities	2-5%

Possibility to recycle 47-66%

Non-potable water purpose

What does the Advanced Water Treatment Technology Look Like?

Developing Area
What this Space!

Changing Focus of Waste Treatment Processes

20 yrs ago → Present → Next 10 yrs

Production Focused

Pros:
- Cheap Capital
- Cheap Operating
- Simple Technology

Cons:
- Very basic treatment
- Limited compliance
- No eco-efficiency
- No resource recovery
- No nutrient removal
- Angry neighbors

Compliance Focused

Pros:
- Excellent knowledge of waste
- World leading best practice
- Strong compliance
- Happier neighbors

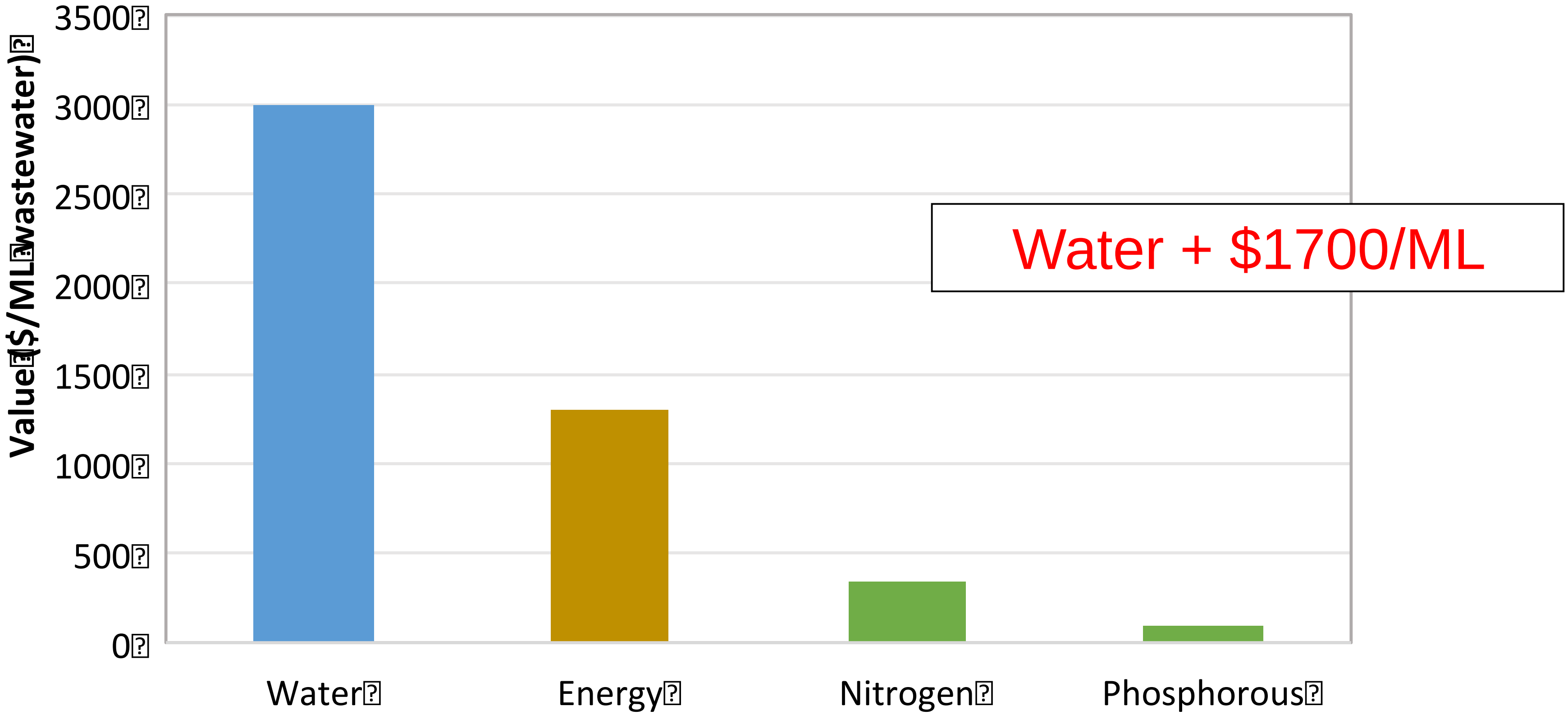
Cons:
- More expensive
- More complex to operate
- Little ROI – mostly cost mitigation
- Retrofitting technologies

Value/Resource Focused

Opportunities:
- Enhanced recovery
- Biogas capture
- Low energy nitrogen removal
- Struvite - P recovery
- Waste to protein
- Water reuse and recycling

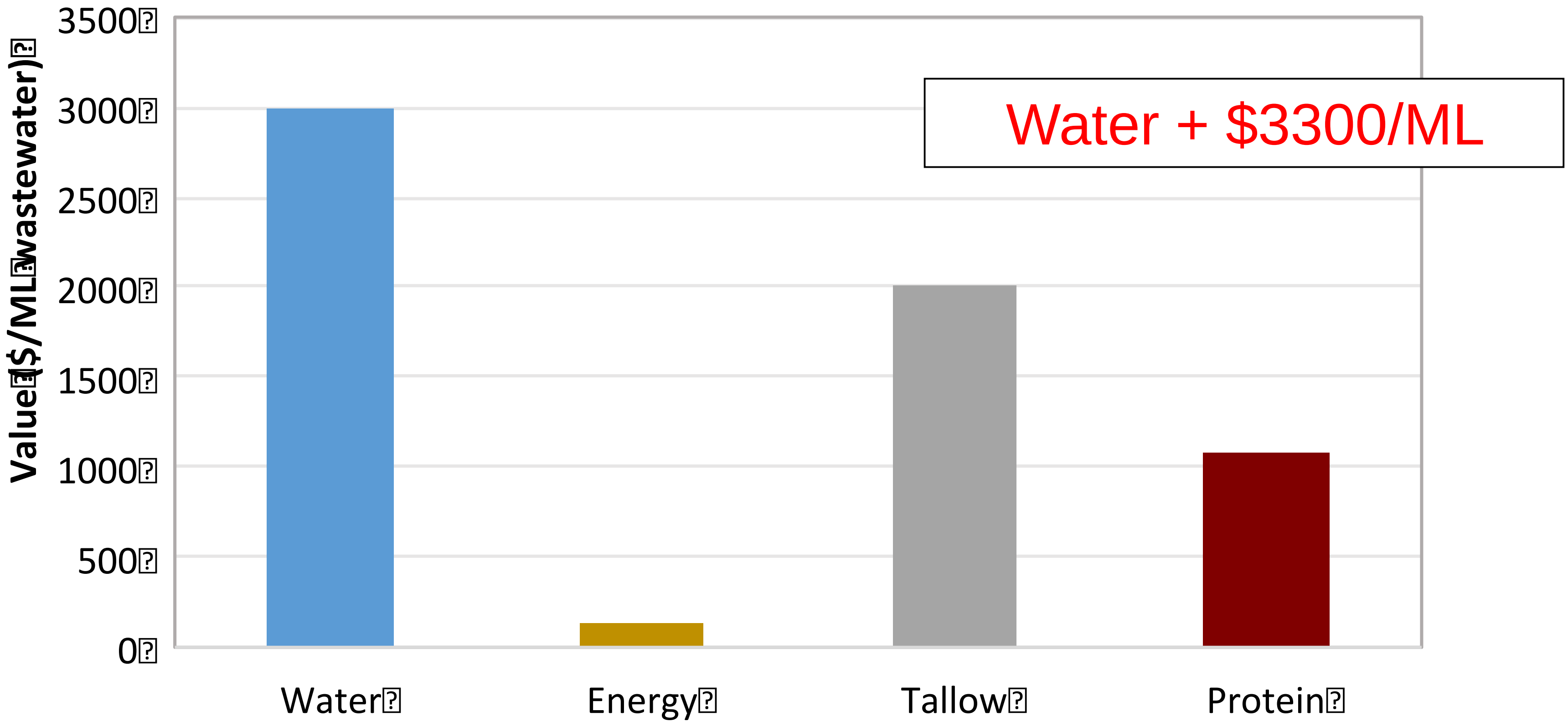
The Technologies:
- Higher initial investment – but provides return
- Low energy
- Low emission
- High level of automation

The Value in Wastewater



Water value at $3/kl for town supply, Energy valued at $10/GJ, Nitrogen valued at $1.20/kg and P valued at $1.50/kg

Future Value in Wastewater?



Water value at $3/kl for town supply, Energy valued at $10/GJ, Tallow valued at $800/tonne and Crude protein valued at $600/kg

Contact

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