Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

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CALUMET PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 2

EVALUATION OF CARBON ADDITION TECHNOLOGIES FOR THE

CALUMET WATER RECLAMATION PLANT – CALUMET WATER

RECLAMATION PLANT CARBON DEMANDS

AND POSSIBLE TECHNOLOGIES

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WATER RECLAMATION PLANT – CALUMET WATER RECLAMATION PLANT

CARBON DEMANDS AND POSSIBLE TECHNOLOGIES

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FORWARD

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) recognizes the value of phosphorus as a non-renewable resource. In an effort to optimize the sustainable removal of phosphorus from its wastewater influents and the subsequent recovery of phosphorus in various forms suitable for use as an agronomic fertilizer, the MWRD initiated a Phosphorus Removal and Recovery Task Force in 2012. The Task Force initiated a study phase at several of the MWRD's Water Reclamation Plants (WRPs) to evaluate the feasibility of implementing enhanced biological phosphorus removal and to develop operational guidelines for optimizing its effectiveness. The Task Force has created WRP specific study workgroups that are focused on each of the WRPs that have been identified to participate in this initiative. As the workgroups complete various phases of their studies and evaluations they are documenting their findings and recommendations in technical memoranda. These memoranda are written by the WRP specific workgroups and vetted by the Task Force before being published. Their purpose is to capture the state of knowledge and study findings and to make recommendations for implementation of enhanced biological phosphorus removal as they are understood at the time the memoranda are published.

DISCLAIMER

The contents of this technical memorandum constitute the state of knowledge and recommendations developed by the MWRD's Phosphorus Task Force at the time of publication, and are subject to change as additional studies are completed and experience is attained, and as the full context of the MWRD's operating environment is considered.

Evaluation of Carbon Addition Technologies for the Calumet Water Reclamation Plant

Technical Memorandum 2

Date: October 4, 2013

To: Phosphorus Task Force & Advisory Committee

From: Phosphorus Study/Planning Team

Subject: CWRP Carbon Demands and Possible Technologies

1.0   Purpose

This Technical Memorandum uses existing data to approximate the carbon deficit range the Calumet Water Reclamation Plant (CWRP) will experience when the implementation of the enhanced biological phosphorus removal (EBPR) process is full scale. The available technologies from Technical Memorandum 1 are re-evaluated within this memorandum with respect to the technology's ability to supplement and meet the carbon deficit. Based on this review, a 'short list' is developed for further evaluation including cost analysis, bench scale testing, feasibility, etc.

It should be noted that the numbers presented here are a gross estimate of the deficit of carbon expected. The calculations are based largely on ratios suggested in literature for successful phosphorus removal. However, these values are ranges and are site-specific. Tailored lab-scale experiments could provide more accurate data in the future.

2.0   Carbon Deficit

Enhanced biological phosphorus removal (EBPR) is performed by phosphate-accumulating organisms (PAOs), which are naturally occurring bacteria present in aerobic activated sludge processes. Their growth is encouraged by cycling them between anaerobic and aerobic conditions. PAOs store energy as polyphosphates. These contain high-energy bonds and function like energy storage batteries. In the absence of oxygen (O), or under anaerobic conditions, the PAO polyphosphate bonds are broken to provide the energy to uptake volatile fatty acids (VFAs) forming intercellular poly-β-hydroxyalkanoates (PHAs) and causing P release. Similar to DO, nitrate can also be used as an electron acceptor. Denitrifiers can out compete with the PAOs for the VFAs in low DO environments. As such, any nitrate in the anaerobic zone can inhibit EBPR. In the subsequent aerobic zone, or in the presence of O, PAOs obtain energy from stored PHAs and uptake large amounts of P into their cells, which they again store as polyphosphates.

In the EBPR approach at CWRP, carbon is necessary to drive both denitrification and phosphorus uptake. The mixed liquor (ML) is first subjected to anoxic conditions where nitrate is still present due to the

return activated sludge (RAS), and carbon is utilized for denitrification. The ML passes next to anaerobic conditions where the PAOs utilize the carbon.

This section presents historical data to characterize the influent, primary effluent, and aeration battery flows for the plant. Additionally, shorter term data from the EBPR demonstration projects in 2012 and 2013 are characterized. These two data sets are used to develop an estimate for the carbon deficit at the CWRP.

2.1 Flow Evaluations

2.1.1 Raw Sewage and Primary Effluent

Flow data for CWRP is divided below into two different periods. Period I has data from January 2010 – April 2012. Period II has data from May 2012 – June 2013. Period II captures the effect of the new primaries on the treatment process.

TABLE 1 – FLOWS

	PERIOD I	PERIOD II
Incoming Flow		
Average (MGD)	253	233
Min (MGD)	124	109
90% (MGD)	416	405
Incoming BOD		
Average (mg/L)	115	143
Min (mg/L)	16	17
90% (mg/L)	168	225
Primary Effluent BOD		
Average (mg/L)	84	86
Min (mg/L)	24	18
90% (mg/L)	95	121
Primary Effluent SS		
Average (mg/L)	77	76
Min (mg/L)	12	28
90% (mg/L)	120	116
Primary Effluent TP		
Average (mg/L)	5.38	6.02
Min (mg/L)	0.95	1.33
90% (mg/L)	9.07	8.68

Primary Effluent TKN		
Average (mg/L)	17.98	19.39
Min (mg/L)	5.18	4.89
90% (mg/L)	24.49	24.56

Overall primary effluent concentration data for the two periods are similar, but the flows are slightly higher for Period I. For the purposes of this memo, data cited and used in subsequent sections are from Period II, May 2012 – June 2013, as that data is from the same time as the EBPR demonstration study data collected.

In addition, EBPR systems prefer stability. Figure 1 shows the distribution curve for the primary tank effluent BOD_5 over Period II. The BOD_5 is relatively consistent, which is a benefit to the CWRP system.

FIGURE 1 – BOD_5 DISTRIBUTION
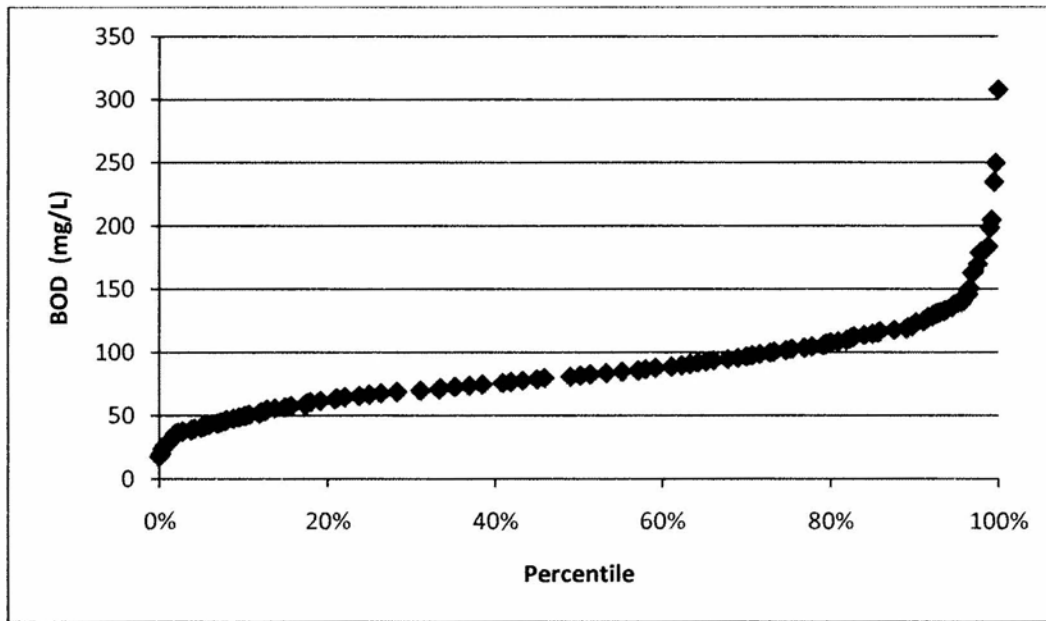
2.1.2 Aeration Tank Flow Data

TABLE 2 – PERIOD II AERATION TANK FLOW DATA

	BATT A	BATT B	BATT C	BATT E1	BATT E2
Primary Effluent Flow					
Average (MGD)	46	44	44	48	51

Min (MGD)	10	8	5	11	12
90th % (MGD)	73	73	70	91	102
RAS Flow					
Average (MGD)	40	36	33	53	48
Min (MGD)	24	27	18	30	34
90th % (MGD)	44	39	36	57	52
Average RAS/Primary Effluent	0.87	0.82	.75	1.10	0.94

2.2 EBPR Results Overview

Table 3 contains averages of data from the two EBPR studies conducted at CWRP. The first study, from May 2012 until July 2012, was conducted on Battery E1 while the second study, February 2013 to March 2013, was conducted on Battery A. In both studies, the air was turned down in the RAS, mixing, and feed channels and in the first portion of the tanks to create the anoxic and anaerobic zones cited above.

TABLE 3 – DESIGN RANGE FOR EBPR AND DATA FROM STUDIES

PARAMETER	EBPR DESIGN RANGE/TARGET	BATTERY E1 STUDY (5/2/12 – 7/31/12)	BATTERY A STUDY (2/19/13 – 6/30/13)
Primary Effluent TP (mg/L)	--	6.56	4.12
BOD:TP of PE	> 20 – 25	15.25	13.2
Primary Effluent solCOD (mg/L)	--	Not Sampled	63.4
rbCOD:TP PE	11 – 16	Not Sampled	6.0
RAS NO_3-N&NO_2-N (mg/L)	0	1.50	1.1
MLSS (mg/L)	> 3,000	2,808	2,263

RAS/PE	0.5 – 1	1.51	0.81
HRT Anaerobic Zone (min)	30 – 90	66	59
HRT Anoxic Zone (hour)	Long enough for denitrification	1.28	0.33
SRT (days)	Seasonal ~ 4 Summer ~ 10 Winter	12.77	12.0

From the data collected during the each of the studies, the BOD:TP ratio was lower than the target range for successful EBPR. Here, solCOD is a proxy for rbCOD, rather than the actual rbCOD value. While the solCOD:TP ratio does fall within the range for rbCOD:TP, it should be noted that COD:BOD ratios greater than 2:1 indicate poor biodegradability of the wastewater carbon ('Optimal Nutrient Ratios for Wastewater Treatment', Hach-Lange, 2012). COD:BOD ratios on days where both values were available ranged from 0.64 – 2.85 meaning there are days when biodegradation is severely limited at CWRP. Lastly, measurements of actual rbCOD taken later in the study showed that rbCOD:solCOD is about 0.5.

2.3   Deficit Calculation

The purpose of this section is to identify a carbon addition load that would support EBPR.

2.3.1   Assumptions Made

Literature values are available for the carbon necessary for P release and uptake as well as denitrification of the RAS and influent PE. A summary of the pertinent values is presented in Table 4. It is recognized that some of these values represent ideal conditions, and it is possible that EBPR could be operable in lower ranges.

TABLE 4 – RATIOS

BOD CALCULATION

Parameter	Value Used (Reference)
BOD:TKN	3[1]
BOD:TP	25[2]

rbCOD CALCULATION

Parameter	Value Used (Reference)
COD:solCOD	2.7[3]
COD:NO$_3$	5[4]
rbCOD:TP	11-16[5]
rbCOD:solCOD	0.52[6]

[1]: 'True Confessions of the Biological Nutrient Removal Process', Sam Jeyanayagam, <u>Florida Water Resource Journal</u>, January 2005.

[2]: 'Nutrient Removal, WEF Manual of Practice No. 34', Water Environment Federation, 2011.

[3]: Average from daily COD:solCOD ratios from Stickney. Although this value is site specific and variable from season to season, there is no current COD:solCOD data from CWRP. As this ratio is only used when calculating carbon demand from nitrate, this shall be used as a proxy.

[4]: 'Optimal Nutrient Ratios for Wastewater Treatment', Hach-Lange, 2012.

[5]: 'Biological Nutrient Removal: Where We Have Been, Where Are We Going?', Barnard, J.L., WEFTEC 2006. It should also be noted that 11 is the minimum of the range; SWRP, however, has a functioning EBPR system with values closer to 11 indicating that a lower amount may be acceptable.

[6]: Average from rbCOD at CWRP work performed by Dr. Qin.

From these values, the general equation used to estimate the carbon deficit is as follows:

$$\text{EQUATION 1:} \quad \textbf{\textit{Carbon Deficit,}} \frac{\textit{lbBOD or rbCOD}}{\textit{day}} =$$

$$[C_{PE}](Q_{PE})(8.34) - \{[NOX_{RAS}](Q_{RAS}) + [NOX_{PE}](Q_{PE})\}(C\text{:}NOX\ Ratio)(8.34)$$
$$- \{[TP_{PE}](Q_{PE})\}(C\text{:}TP\ Ratio)(8.34)$$

where   C: Carbon parameter, either BOD or rbCOD, dependent upon the calculation, mg/L
                  $[NO_X]$: Combined nitrite and nitrate concentration, mg/L
                  [TP]: Total Phosphorus concentration, mg/L
                  Q: Flow, MGD
                  PE: Primary Effluent
                  RAS: Return Activated Sludge

2.3.2 Summary of Results

For the carbon deficit analysis, rbCOD was chosen as a more viable parameter over BOD or total COD. According to the 'Nutrient Removal: Manual of Practice' issued by WEF, it is the most accurate of the substrate measurements. In addition, throughout the duration of the EBPR studies at SWRP and CWRP, it became evident that there is also a portion of solCOD which is not readily bioavailable for the bacteria. In looking at the CWRP data from the 2013 study, average solCOD concentrations from the primary effluent, just before entering the anaerobic zone, and at the end of the anaerobic zone are 68 mg/L, 36 mg/L, and 35 mg/L, respectively. The rbCOD should more adequately capture the fact that there is recalcitrant BOD, COD, and solCOD that cannot be used through the process.

TABLE 5 – rbCOD DEFICIT RANGE FROM 2013 EBPR STUDY[1]

	Average of days where deficit calculated	Maximum deficit seen over study data	Average of all days, whether deficit or excess calculated
rbCOD Deficit for Battery A (lb/day)	(9,685)-(18,330) Represents 48/52 days	(18,996)-(33,921)	(8,585)-(18,330)

[1]: Range shown here represents the difference when using the range of rbCOD:TP from Table 4.

For the 2013 data, these parameters were collected at the same points and on the same days for analysis. These averages represent data from February – June 2013; more data can be added as the study progresses. It should be noted that these data were collected over different seasons; there is generally a higher carbon demand in the warmer months. Also of note is that the theoretical rbCOD demand was calculated for 52 days. Using an rbCOD:TP ratio of 11, 48 of those 52 days show that there is a deficit, or roughly 92% of the time the system is carbon limited; with an rbCOD:TP ratio of 16, the system is carbon limited all of the time.

For the sake of this initial report, an average daily rbCOD deficit range of 10,000 – 20,000 lb/day is used for Battery A; this range is representative of the range of rbCOD:TP ratios used. Assuming the same deficit exists for all 5 batteries, the technologies are examined with respect to a plant-wide deficit range of 50,000 – 100,000 lb/day.

3.0 Preliminary Design Engineering for Available Technologies

In this section, each of the technologies from the short list in Technical Memorandum 1 is evaluated for its carbon addition potential. For the fermentation technologies, tankage requirements for flows are also estimated to give an idea of capital costs and operating equipment. Estimated energy requirements are calculated, when values are available, for comparison of the disintegration technologies.

The short-listed technologies from Technical Memorandum 1 are:

- Primary Sludge Fermentation
- RAS Fermentation
- Focused-Pulse
- UltraSound
- Chemical Addition
- Imported Wastes

3.1 Biological Sludge Fermentation

One option at CWRP is to use the old primary tanks as fermentation tanks. There are 25 unused rectangular primary tanks which have been gutted and left with the concrete in place. The dimensions of these tanks are as follows:

TABLE 6 – OLD PRIMARY TANK DIMENSIONS

	TYPE I TANKS	TYPE II TANKS
Number of Units	18	7
Type	2-bay	4-bay
Width	15' 6"	15' 6"
Length	100'	100'

Height	9' 6"	10' 8"
Volume/Unit	29,450 ft^3	66,133 ft^3

In addition to tankage, equipment that would need to be installed includes pumping, sludge mixing, sludge collector mechanisms, scum removal, fermented sludge pumping, fermentate pumping and transmission, covers, corrosion control linings, and odor control.

### 3.1.1 Primary Sludge Fermentation

Technology

Although there are a variety of configurations that would accomplish adding primary sludge fermentate to the EBPR process, all rely on holding the sludge until the bacteria breakdown and release volatile fatty acids (VFAs).

Theoretical Production of Carbon

Preliminary experiments have been conducted to determine the VFA and solCOD production from holding primary sludge in the laboratory. Primary sludge samples were taken in the morning on the selected days. The sludge was then held in a bucket and samples were taken over a period of 3 or 4 days. Thirty minutes prior to the sample being collected, the sludge was stirred to release the VFAs trapped in the sludge. Both VFA and solCOD concentrations were measured for three trials. Average VFA concentration was 344 mg/L while solCOD concentration averaged 600 mg/L after 72 hours.

Correlations between the initial volatile suspended solids values (VSS) and solCOD production are also necessary to standardize the anticipated carbon load produced. Figure 2 shows the carbon production after 72 hours from the CWRP sludge in terms of both VFA and solCOD averaged by the VSS. As a conservative estimate, averaging out only the last two trials, the mg solCOD/mg VSS ratio is 0.09 while mg VFA/mg VSS is 0.06, which is in the lower range of literature values for primary sludge; expected yields ranged from 0.05 – 0.3 mg VFA/mg VSS ('Fermenters for Biological Phosphorus Removal Carbon Augmentation', Issued by WERF August 9, 2011).

FIGURE 2 – NORMALIZED VFA & solCOD PRODUCTION
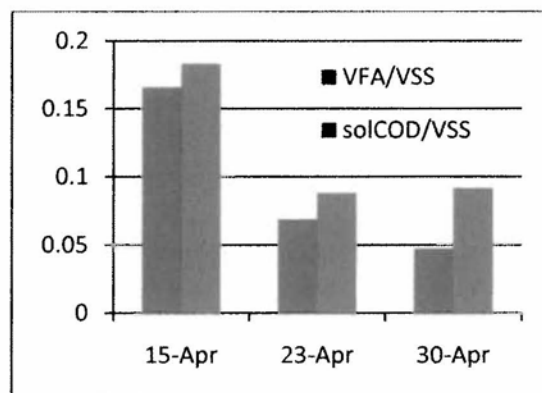
Estimate of Carbon Production Potential

Table 7 presents the data for primary sludge flows as well as the suspended solids concentration.

TABLE 7 – PRIMARY SLUDGE FLOWS

	PRIMARY SLUDGE FLOW	PRIMARY SLUDGE % SOLIDS
Average (MGD)	1.67	1.24
Min (MGD)	0.47	.09
90th % (MGD)	2.98	2.51

Using average values for primary sludge percent solids, solCOD/VSS production potential seen in bench scale experiments, and a VSS/TSS ratio of 0.64 (from CWRP primary sludge data), the following can be calculated in Equation 2:

$$\textbf{EQUATION 2:} \quad 0.09 \, \frac{\text{mg solCOD}}{\text{mg VSS}} \cdot 0.64 \, \frac{\text{VSS}}{\text{TSS}} \cdot 12{,}400 \, \frac{\text{mg TSS}}{\text{L}} \cdot 1.67 \, \text{MGD} \cdot 8.34 = 9{,}948 \, \frac{\text{lb solCOD}}{\text{day}}$$

The estimate of the load in Equation 2 shows that primary sludge fermentation alone is not enough to satisfy the carbon deficit for all five of the batteries, even at the lower end of the estimated deficit range; perhaps the Battery A deficit at the lower end could be met through primary fermentation of all of the primary sludge. As there is considerable infrastructure in place, however, this could help to offset the demand with a relatively low cost. In addition to using the existing primary tanks as fermenters, there is also the option that the existing gravity concentration tanks (GCTs) could function in this capacity. This would require the addition of a pump station near the GCT building, piping, and any necessary recycle pumping.

It should also be noted that operations at CWRP lead to variable retention times for primary sludge in these existing GCTs which, in effect, has caused some primary sludge fermentation. From January 2013 through October 2013, the average VFA concentration as measured from the GCT overflow is 217 mg/L, ranging from less than 5 mg/L 22% of the time to above 322 mg/L 25% of the time. However, the supernatant is returned to the head of the plant under current operations. As the process is still carbon limited even with the additional VFAs from the GCTs, investigation into a better location to feed the GCT overflow would be necessary.

Other Considerations

The most important parameter governing the design of primary sludge fermentation tanks is the solids retention time, or SRT. The hydraulic retention time, HRT, can be used to fine tune the process. For primary sludge fermentation, design should be for an SRT of 4 – 8 days in the winter months and 3 – 5 days during the summer months. If the tank is heated, the SRT for winter can also be for 3 – 5 days. Table 8 uses the average flow rate for primary sludge from Period II, a design SRT of 5 days to allow for a buffer, and no internal recycle for simplicity in design. The number of tanks that would need to be utilized under varying wastage rates is shown in the Table 8.

TABLE 8 – TANK UTILIZATION FOR PRIMARY SLUDGE FERMENTATION

WASTED SLUDGE (MGD)	TYPE I TANKS	TYPE II TANKS
0.1	4	2
0.2	7	3
0.3	9	4
0.4	11	5

3.1.2   Return Activated Sludge Fermentation

Technology

The principles of return activated sludge (RAS) fermentation are similar to primary sludge fermentation involving the disintegration of bacteria and carbon release. However, with RAS fermentation, significant nutrients can be returned to the treatment stream.

Theoretical Production of Carbon

Studies specific to CWRP have yet to be performed on the RAS VFA formation potential. However, studies by others have shown the following correlations (from 'Fermenters for Biological Phosphorus Removal Carbon Augmentation', Issued by WERF August 9, 2011):

- Fermenting RAS from a plant with primary clarifiers is expected to have a lower VFA yield than a plant without primary clarifiers.

- Fermenting RAS from a BNR process with a longer SRT is expected to have a lower VFA yield than a shorter SRT BNR process.
- Typical yields for RAS is 0.09 – 0.14 mass VFA/mass bCOD and 0.09 mass VFA/mass VSS.

As CWRP does operate with primary clarifiers and with longer SRTs, the yield is taken from the lower end of the range, 0.09 mass VFA/mass bCOD and 0.09 mass VFA/mass VSS.

Estimate of Carbon Production Potential

There is data available for the MLVSS/MLSS ratio in each of the batteries which can be used as a basis for VSS/TSS in the sludge. A conservative, rough estimate from the last year's worth of data puts this ratio around 0.7. Using a yield of 0.09 mg VFA/mg VSS and an average percent solids of 0.54 (also from CWRP Battery data), Equation 3 shows the flow of RAS necessary to generate 50,000 – 100,000 lb/day.

EQUATION 3: $\quad 50,000 \, \frac{\text{lb solCOD}}{\text{day}} \div \left(8.34 \cdot 5,400 \, \frac{\text{mg TSS}}{\text{L}} \cdot 0.7 \, \frac{\text{VSS}}{\text{TSS}} \cdot 0.09 \, \frac{\text{mgVFA}}{\text{mgVSS}} \right) = 17.6 \text{ MGD}$

$$100,000 \, \frac{\text{lb solCOD}}{\text{day}} \div \left(8.34 \cdot 5,400 \, \frac{\text{mg TSS}}{\text{L}} \cdot 0.7 \, \frac{\text{VSS}}{\text{TSS}} \cdot 0.09 \, \frac{\text{mgVFA}}{\text{mgVSS}} \right) = 35.2 \text{ MGD}$$

Equation 3 shows, on initial analysis, that about 17.6 MGD of RAS/WAS flow total would need to be fermented to satisfy the carbon demand, 35 MGD of RAS/WAS flow would be needed to meet the higher end of the deficit. However, as noted in Technical Memorandum No. 1, the fermentation of RAS would likely release orthoP back into the stream; the balance between the increase in solCOD and orthoP would need to be further studied.

Other Considerations

Similar to the fermentation of primary sludge, the most important design parameter for RAS fermentation is the SRT. For a full scale operation, the SRTs are kept between 3 and 4 days, but can operate as low as 1 to 2 days. Additionally, it is typical for only a portion of the RAS flow to go through a fermenter; literature values suggest 15% - 30% of total RAS flow. This would mean that 17.6-35.2 MGD of RAS would need to be diverted from the aeration tank system. The RAS is typically reintroduced into the system following fermentation, but the implications of this upon the biomass would need further evaluation as the fermented RAS could affect the health and settle-ability. However, this technology is capable of meeting the necessary flow demands to generate the carbon needed.

3.2   Focused Pulse Treatment of WAS/Open Cel Lysis

Technology

Focused Pulse treatment sends pulses of electricity to break down cell membranes of RAS and, hence, accelerate lysis. As discussed in the previous technical memoranda, the major advantage of focused pulse technology over fermentation is that a much smaller footprint is needed. Additionally, given the low reaction time, design could be such that a recycle channel or pipe could be constructed, rather than the tankage necessary for RAS fermentation.

Theoretical Production of Carbon

Research has shown that the lysis of cells through Open-Cel or focused pulse technology can increase the solCOD by 26 times ('Feasibility of Focused-Pulsed Treated Waste Activated Sludge as a Supplemental Electron Donor for Denitrification', Lee, Parameswaran, Alder, Rittmann; Water Environment Research, 2010).

Estimate of Carbon Production Potential

The solCOD in the RAS at CWRP has been measured 17 times during the 2013 study; 40% of the time, the solCOD value was below detectable limits. The remaining 60% of the time, the average concentration was approximately 30 mg/L (excluding one uncharacteristically high day and non-detects). Assuming the same increase as the literature, the solCOD concentration for focused-pulse treated WAS would be 780 mg/L.

To fully meet the estimated solCOD deficit for the plant of 50,000 – 100,000 lb/day, the focused pulse technology would need to treat

EQUATION 4: $\quad 50,000 \frac{lb\ solCOD}{day} \cdot 453,592 \frac{mg}{lb} \cdot \frac{L}{780\ mg} \cdot \frac{MG}{3,780,000\ L} = 7.7\ MGD\ RAS$

$\quad\quad\quad 100,000 \frac{lb\ solCOD}{day} \cdot 453,592 \frac{mg}{lb} \cdot \frac{L}{780\ mg} \cdot \frac{MG}{3,780,000\ L} = 15.4\ MGD\ RAS$

As RAS flows are well over 15.4 MGD, it seems feasible that the technology could produce the required additional solCOD. For comparison purposes, the volume necessary to meet an HRT on the order of microseconds is negligible.

Other Considerations

Another parameter that can be found in the literature involves the energy usage. From the Open-Cel website, 300 kwh/dry ton is necessary for treatment. The RAS solids average is 0.542 % solids for all 5 batteries. Using this value and considering the carbon deficit range,

EQUATION 5:

$$\frac{7.7\ MG}{day} \cdot \frac{3,780,000\ L}{MG} \cdot \frac{5,420\ mg}{L} \cdot \frac{lb}{453,592\ mg} \cdot \frac{ton}{2,000\ lb} \cdot \frac{300\ kwh}{dry\ ton} = 52,168 \frac{kwh}{day}$$

$$\frac{15.4\ MG}{day} \cdot \frac{3,780,000\ L}{MG} \cdot \frac{5,420\ mg}{L} \cdot \frac{lb}{453,592\ mg} \cdot \frac{ton}{2,000\ lb} \cdot \frac{300\ kwh}{dry\ ton} = 104,336 \frac{kwh}{day}$$

The additional benefit mentioned in the focused-pulse technology papers is that the denitrification rate is better than methanol when used as a carbon source. For our purposes, this would mean that if treated RAS were added to the beginning of the anoxic zone, the anoxic zone could potentially be shorter. Over the course of the profile sampling at SWRP, it has become clear that denitrification is not complete until the end of what is being defined as the anaerobic zone. As seen in Table 3 above, the HRTs for what is designed as the anoxic zones for Battery E1 and Battery A differ considerably, with Battery A having a relatively short average HRT. Batteries B and C are similar to Battery A while Battery E2 mimics Battery E1. As the time for denitrification is limited to the RAS, mixing, and influent channels, it could

be beneficial to provide a carbon source with that can produce higher denitrification rate to accelerate the process and allow it to fit into the time alloted by the current infrastructure.

Although the denitrification rates may not be an issue, construction costs for the focused-pulse method would be considerably less than the other options and, at first glance, solCOD added to the process from this technology has the potential to meet the solCOD needs. However, the additional P and NO_3 released from the treated RAS as well as the additional energy burden on the plant would both need further evaluation. Given that this is a fairly new technology, it would also be prudent to conduct bench-scale lab tests in conjunction with the company before proceeding.

3.3   Ultrasound

Technology

Similar to Focused Pulse technology, ultrasound breaks down the RAS particles using ultrasound waves.

Theoretical Production of Carbon

Much less information was available for ultrasound technology, especially with respect to phosphorus removal. In one study, the solCOD was increased by 50 times with UV equipment of 400 W treating 100 mL of WAS for 40 minutes. Using the same approximated RAS solCOD values from the CWRP study of 30 mg/L and the same increase as in the literature, the solCOD concentration for ultrasound treated WAS would be around 1,500 mg/L.

Estimate of Carbon Production Potential

To fully meet the estimated solCOD deficit for the plant of 50,000-100,000 lb/day, the ultrasound technology would need to treat

$$\textbf{EQUATION 6:} \quad 50{,}000\ \frac{lb\ solCOD}{day} \cdot 453{,}592\ \frac{mg}{lb} \cdot \frac{L}{1{,}500\ mg} \cdot \frac{MG}{3{,}780{,}000\ L} = 4.0\ MGD\ RAS$$

$$100{,}000\ \frac{lb\ solCOD}{day} \cdot 453{,}592\ \frac{mg}{lb} \cdot \frac{L}{1{,}500\ mg} \cdot \frac{MG}{3{,}780{,}000\ L} = 8.0\ MGD\ RAS$$

From a flow standpoint, it seems feasible that the technology could produce the sufficient solCOD. Because less RAS is required, pumping and piping requirements would also be reduced.

Other Considerations

To achieve 50 times the initial concentration, a 40 minute detention time was used. Because of the volume, this would require some tankage for the technology, but significantly less than RAS or primary sludge fermentation.

Another parameter that can be found in the literature for ultrasound is the energy usage. From the same study, 400 watts/0.1 L was necessary for treatment. Although this initial scale-up is likely an overestimate as it is based on a lab scale experiment, using this value for the carbon deficit range,

$$\textbf{EQUATION 7:} \quad \frac{0.4\ kW}{0.1\ L} \cdot \frac{3{,}780{,}000\ L}{MG} \cdot \frac{4.0\ MG}{day} \cdot \frac{day}{24\ hours} = 2{,}520{,}000\ kwh/day$$

$$\frac{0.4\ kW}{0.1\ L} \cdot \frac{3{,}780{,}000\ L}{MG} \cdot \frac{8.0\ MG}{day} \cdot \frac{day}{24\ hours} = 5{,}040{,}000\ kwh/day$$

Given that additional tankage would be necessary, the initial energy demands are much larger than focused-pulse technologies, and the disadvantages of ultrasound are similar to other RAS treatment, it does not seem worthwhile to pursue ultrasound technologies.

3.4   Chemical Addition

The most versatile chemical to be added would be one that could be utilized for both denitrification and P removal as both may be occurring with the same feed, dependent upon the feed point. The chemicals from Technical Memorandum No. 1 chosen were based upon safety and practical concerns as well as their ability to denitrify and supplement phosphorus removal. In addition, QLF, a molasses-based carbon source, was recently found as a carbon source and added to this table.

TABLE 9 – FLOW OF CHEMICAL NECESSARY TO MEET DEMAND RANGE

Substrate	COD (mg/L)	k_D (mg N/g VSS·h)	Flow Needed to Satisfy Average solCOD Deficit Range	Cost (S/gal)	Cost (Million S/yr)
Acetic Acid, 20%	219,000[1]	5.4[4]	27,400 – 54,800 gal/day	0.79[5]	$7.9 – $15.8
Propionic Acid	1,494,900[2]	1.7-2.1[4]	4,020 – 8,030 gal/day	9.17[6]	$13.4 – $26.8
Sucrose 20 Brix	274,000[1]	--	21,900 – 43,800 gal/day	0.64[5]	$5.1 – $10.2
MicroC2000	1,040,000[7]	4.7-6.37[4]	5,770 – 11,540 gal/day	1.5[7]	$3.2 – $6.4
QLF	920,000[3]	--	6,520 – 13,040 gal/day	2[3]	$4.8 – $9.5

[1]: 'Got Carbon?: Widespread biological nutrient removal is increasing the demand for supplemental sources'; deBarbadillo, C., Barnard, J., Tarallo, S., and Steichen, M., WE&T, January 2008.

[2]: 'A review of characterization requirements for in-line preferementers, Paper 1: Wastewater characterisation', Rossle, W.H., and Pretorius, W.A., Water SA, July 2001.

[3]: From QLF Representative. Cost could be lower if chemical ordered in bulk.

[4]: 'Comparisons of Organic Sources for Denitrification: Biodegradability, Denitrification Rates, Kinetic Constants and Practical Implication for Their Application in WWTPs'; Onnis-Hayden, A., Gu, A., WEFTEC, 2008.

[5]: 'Alternative Carbon Sources for Achieving Biological Nutrient Removal at Municipal Wastewater Treatment Plants'; Fiss, E., Fiss, E, and Rebodos, R., NC AWWA-WEA Conference Paper, 2010.

[6]: Web estimate – cost from manufacturer required for further cost analysis.

[7]: From MicroC Representative.

3.5 Imported Organics or Food Waste

Alternative carbon sources, such as food or drink wastes, can provide considerable cost savings. The challenge would be in finding a source able to meet the flows required by CWRP. As seen in Table 10 below, considerable flows would be necessary to provide the projected daily carbon load; to find a source with that amount of waste would be difficult.

TABLE 10 – FLOW OF FOOD WASTE NECESSARY TO MEET DEMAND RANGE

Substrate	COD (mg/L)	k_D (mg N/g VSS·h)	Flow Needed to Satisfy Average solCOD Deficit Range (MGD)
Brewery Waste[1]	1,250 – 3,000	8.18	2 – 9.6
Dairy Waste[1]	5,000 – 11,000	6.21	0.55 – 2.4
Winery Waste[1]	230,000	--	0.03 – 0.05
Soft Drink Waste[2]	68,500	--	0.1 – 0.2

[1]: 'Comparisons of Organic Sources for Denitrification: Biodegradability, Denitrification Rates, Kinetic Constants and Practical Implication for Their Application in WWTPs'; Onnis-Hayden, A., Gu, A., WEFTEC, 2008.

[2]: 'Alternative Carbon Sources for Achieving Biological Nutrient Removal at Municipal Wastewater Treatment Plants'; Fiss, E., Fiss, E, and Rebodos, R., NC AWWA-WEA Conference Paper, 2010.

4.0 Summary and Short List of Carbon Supplementation Technologies

Based upon literature ratios, the carbon deficit at CWRP is quite significant, ranging from 50,000 – 100,000 lb/day, dependent upon the rbCOD:TP ratio. Studies to develop a plant specific rbCOD:TP ratio capable of maintaining successful EBPR specific to CWRP will be completed by the Phosphorus Task Force.

Because of the magnitude of this deficit, it is highly likely that an external carbon source will need to be added. However, each of the technologies are summarized below with respect to their ability to meet at least part of the carbon deficit.

Primary Sludge Fermentation

While the initial estimate of production does not seem that it is adequate to meet the carbon deficit demand, it is worth further investigation as there are tanks available to operate in this manner. Potentially, fermentation from primary sludge could meet about 10-20% of the total demand.

RAS Fermentation

There is a much larger RAS flow than primary sludge, giving this technology a much higher potential load. There is sufficient flow to ferment and potentially meet the carbon deficit at both ends of the range. Similar to primary sludge fermentation, there is infrastructure in place to offset the capital cost involved with fermentation, but P release may occur.

Focused-Pulse

The technology is capable of meeting the deficit and lowering the amount of activated sludge that would require treatment. This could prove to be a benefit in the end when balanced against maintenance of infrastructure for RAS fermentation only.

UltraSound

While the technology is capable of meeting the carbon deficit, given the initial estimate of energy usage and the lack of data supporting use for EBPR, it does not seem worthwhile to pursue.

Chemical Addition

The most dependable of all the options considered is chemical addition. Although the cost of the chemicals is quite high if used to meet the carbon deficit entirely on their own, it might be necessary to have the dependability of a chemical as part of an overall system.

Imported Wastes

These wastes certainly have the potential to supplement the carbon demand, but finding a source as the sole carbon provider could prove to be difficult. However, the technology is environmentally friendly, benefits industry by saving on pre-treatment, and could be combined with a primary or RAS fermentation process. Capital cost involved in adding imported wastes to a process is minimal; hence, it is advisable to continue to pursue this technology and search for local industries to partner with.