Review of Conceptual Leachate Treatment Scoping Study

New England Waste Services of Vermont (NEWSVT)
Coventry, Vermont

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1.0 EXECUTIVE SUMMARY

The Vermont Department of Environmental Conservation (DEC) issued a Solid Waste Facility Certification to New England Waste Services of Vermont (NEWSVT) on October 12, 2018 for the continued operation of a landfill facility located in Coventry, Vermont and the ability to expand that facility for future operations. The presence of per- and polyfluoroalkyl substances (PFAS) compounds were included in the NEWSVT Certification issued to NEWSVT. The presence of PFAS prompted DEC to request NEWSVT to conceptually evaluate two on-site and two off-site treatment and pretreatment technologies for removing PFAS compounds at the landfill. The evaluation also required an economic analysis for each of the four treatment and pretreatment technologies.

NEWSVT contracted with Brown and Caldwell Environmental Services (BC) to perform the conceptual evaluation for treating PFAS-laden leachate and providing an economic analysis of the costs for implementing the four recommended technologies. On October 15, 2019, NEWSVT submitted the BC report titled “Conceptual Leachate Treatment Scoping Study for New England Waste Services of Vermont (NEWSVT) Landfill,” dated October 11, 2019.
The report provides an evaluation of commercially available PFAS treatment technologies and recommends two on-site and two off-site treatment and pretreatment technologies for the removal of PFAS compounds as required. The report also includes an estimation of the costs (capital and operational) for implementing the recommended on-site and off-site treatment and disposal options.

DEC contracted with Civil & Environmental Consultants, Inc. (CEC) to comment on the BC report. DEC requested that CEC opine by the end of April 2020 including a review and written comment on the BC submittal including:

1. Determination if any treatment options presented are more or less feasible than presented by the report;
2. Assessment of whether there are any additional, feasible leachate treatment options that were not presented; and

3. Evaluation of the Class 5 cost estimates associated with report, including a review of the reasonableness of the selected vendors that these cost estimates were based.

The documents reviewed in the BC report include the process descriptions and evaluation criteria, cost opinions presented and details as available, leachate concentrations, and design parameters for both the Newport and Montpelier Vermont public owned treatment works (POTWs). Attachments to the BC report were also reviewed, and they included:

- Leachate Characterization (Appendix A);
- Regulatory Review (Appendix B);
- Leachate Strategy Review (Ranking; weighted economic, environmental, technology factors), (Appendix C);
- GAC and IX Resin Isotherm Testing of POTW Effluents (Appendix D);
- Capacity Evaluation for Leachate Treatment of Montpelier POTW (Appendix E); and
- Capacity Evaluation for Leachate Treatment of Newport POTW (Appendix F).

CEC finds that BC options evaluation and criteria selection is appropriate and well developed. We find that a number of cost line items and considerations were incorporated in process descriptions or summaries of costs but could not be individually identified. Therefore, CEC used experience and engineering judgment to approximate each line item of cost or other item. In addition, subsequent identification of air emissions criteria and approaches to meet requirements should be further researched. Definition of solids fixation and stabilization methods and criteria require delineation. For example, flyash is mentioned as a solidification agent, but further stabilization may be required for either PFAS, ammonia, or other constituents from residuals of the options discussed when placed back in the landfill.

CEC has included Option 1a-2 to reflect documented performance of Rochem's PFAS removal capability with a two pass reverse osmosis system. In the period between the preparation of the BC report and this review, an option to treat the PFAS constituents by the HTX electrocoagulation-based system has become available and appears to meet the needs and is included as Option 1a-3 and Option 2d.

BC reported that the highest rated approach is Option 1a. CEC recommends that further consideration be given to each of the three options in Option 1a, 1a-2, and 1a-3, as ratings and overall costs are reasonably similar at this stage of evaluation.

2.0 BASELINE PARAMETERS

The review of the BC report and attachments provided the following baseline conditions for raw leachate parameters, as well as opinion of the surface water discharge parameters.

The raw leachate constituents were assumed to be untreated if discharged to either the Newport or Montpelier POTWs. In our evaluation, CEC reviewed and evaluated leachate and POTW characteristics including constituent concentrations and flow variations. A summary of the concentrations reported in the BC Report for pre-2019 average raw; 95% percentile strength, indirect discharge to local POTWs, and direct discharge to the Black River surface discharge are shown below in Table 1, and a more complete analysis is shown in Appendix A. Recent data from 2019 is also included in Table 1 for selected constituents for maximum concentrations observed in that period.

One of the primary concerns is Vermont's drinking water regulations for PFAS constituents is 20 ppt (parts per trillion) for the combination of five PFAS (PFOA, PFOS, PFHxS (perfluorohexane sulfonic acid), PFHpA (perfluoroheptanoic acid) and PFNA (perfluorononanoic acid)). This standard was used as a basis for the direct discharge option. Other treatment discharge standards were based on speculative discharge limits to the Black River that VTDEC reports as a Class B waterway, allowing dilution and a mixing zone credit. This is a lower Black River classification than reported by BC. Other discharge locations, including Lake Memphremagog are possible, but were not evaluated. Options for hauling to Newport and Montpelier POTWs were based on PFAS concentration removals applied to those entire plant design flows. Although the contaminant 1,4-dioxane may be removed from leachate in the options described, the focus of this report is limited to PFAS constituents.

Table 1. Selected Parameters

	Influent Criteria			Effluent Criteria	
	Average Pre 2019 Concentration[4]	95th Percentile Pre 2019 Concentration[4]	2019 95% Percentile or Max Concentration	Indirect Discharge (POTW)[5]	Direct Discharge to Black River, Monthly Average [6]
Parameter	mg/L				
Design Flow (Hydraulic Capacity = 50,000 gpd)					
BOD_5	3,138	4,425	5,200	834 lbs/day	37[1]; 10 [6]
COD	3,138	4,425			
Total Chloride	1,831	2,700			N/A
Total Kjeldahl Nitrogen	1,157	1,675			N/A
Total Sodium	1,588	2,025	2,100		N/A
Alkalinity (as $CaCO_3$)[3]	6,870				N/A
Total Suspended Solids			170		27
Total Dissolved Solids[3]	6,280				N/A
Ammonia Nitrogen[1,3]	1,200				5.0
Total Kjeldahl Nitrogen			1,400		5.0
pH[1]	8.0	8.6			6 to 9
Parameter	Metal (ug/L)				
Arsenic	664	1,173			10
Zinc	249	548		6.07	110[1]
Parameter	Organics (ug/L)				
Tetrachloroethene	2.5	2.5			0.69
Toluene	27.6	46.0			1,300
Total Cresol	525.0	1,092.0			25
a-Terpineol[1]					16
Benzoic acid[1]					71
Total cresol	2,050.0				25
p-cresol[1]					14
3&4 Methylphenol	516.0	1,072.0	2,040		25
Phenol[1]	111.0	208.0			26
Parameter	PFAS (ng/L)				
Total 5 PFAS (PFOA, PFOA, PFHxS, PFHpA, PFNA)	3,364		3,418		20[2]
PFOA/PFOS	2,094		1,982		20[2]

Reference Notes:

D - Diluted Sample

[1] EPA Final Effluent Limitation Guideline and Standards for Landfill Point Source Category

[2] Total PFAS (sum of 5 PFAS Compound) limit is 20 ppt

[3] Only one sampling event results provided

[4] Results as of 1/31/2019

[5] Indirect (POTW) limit reported by Brown & Caldwell

[6] Speculative Limits based on the Black River as a Class B water body.

[7] Effluent Limitation guideline 40CFR445.21

[8] Vermont Water supply rule, Chapter 21 MCL

3.0 IDENTIFIED TREATMENT OPTION

CEC reviewed the treatment options presented in the BC report. The goal included evaluating the suitability of the options considered and the recommendation process for narrowing the alternatives with a numerical ranking to meet the following objectives both at the NEWSVT landfill and at the Montpelier and Newport POTWs:

- Treatability;
- Technical competency;
- Robustness;
- Constructability;
- Operability;
- Power and chemical requirements;
- Residuals;
- Land use requirements;
- Visual, odor, noise concerns;
- Biosolids management; and
- Other similar parameters.

The alternatives presented are a fair representation of approaches to meeting leachate management for the NEWSVT site. The graphics and text descriptions in the BC report remain essentially unchanged and are not repeated in the review. BC identified several scenarios, each of which contained several options.

- Scenario 1 identified options for direct discharge to surface waters;
- Scenario 2 is pretreatment prior to discharge to POTWs;
- Scenario 3 is Zero Liquid Discharge; and
- Scenario 4 is transport and disposal of untreated leachate at either the Newport or Montpelier POTWs and adding treatment enhancements and PFAS removal capabilities at their discharge.

CEC reviewed the alternatives presented for the appropriate numerical assignment of how each alternative meets the requirements and the importance of each criteria were developed and compared with the Brown and Caldwell submittal. The evaluative criteria is discussed in subsequent sections.

3.1 SCENARIO 1 OPTIONS (DIRECT DISCHARGE TO SURFACE WATER)

Scenario 1 options consisted of:

- Option 1a: Standalone RO with GAC (and/or IX) with or without leachate concentrate volume reduction;
- Option 1b: MBR plus RO and IX, with or without leachate concentrate volume reduction; and
- Option 1c: EO plus UF, RO, and IX, with or without leachate concentrate volume reduction.

Detailed descriptions for the options identified by Brown and Caldwell are contained in the text of the BC report. The selected option 1a was retained by BC for further evaluation for treating the NEWSVT leachate technologies.

CEC reviewed if other alternatives are more or less feasible than presented by the Report. CEC has included two additional options that are presented in Table 2. Option 1a-2 eliminated GAC following RO. Option 1a-3 added an electrocoagulation process followed by GAC.

3.1.1 Option 1a-2: RO + Mineralization with Concentrator

CEC evaluated a variation of Option 1a (RO + GAC + Remineralization + Concentrator + Emissions Control) using a three-stage Rochem reverse osmosis system and removing GAC. There will be sufficient PFAS removal to provide a discharge with less than 20 ppt of the 5 PFAS constituents regulated by Vermont. This approach was documented by a Rochem RO test performance showing 99.5% removal in each stage that would result in a PFAS concentration below 20 ppt.[1] Costs for an emissions control unit were not identified in the BC report.

As a note, BC identified that the emissions control included an oxidizing step for odor control after the Heartland evaporative concentrator. There is a question of the amount of PFAS constituents that would be emitted from the concentrator air stream, and if further treatment would be required. Should there be quantities of PFAS in the concentrator air emissions that require control, temperatures in excess of 1,000 degrees C may be required for demineralization.[2],[3] Other references report possible PFAS transformations at lower temperatures.[4] Literature information suggests that may be the case, but research in that area is being developed. Costs associated with thermal oxidation above 1,000 degrees C is not included in either the BC report nor in this review.

3.1.2 Option 1a-3: MBR + Electrocoagulation + Filtration + Activated Carbon

One technology not investigated further by BC includes an electrocoagulation treatment train, as developed by HTX Technologies. In the time since the BC report was prepared, HTX has piloted and installed leachate treatment for PFAS that produced effluent quality water. The process train includes the following steps:

- pH adjustment to 8.6;
- Coarse filtration;
- Biological treatment in a MBR process including nitrification;
- Dewatering excess MBR solids;
- pH adjustment to 4 and air stripping to remove residual alkalinity;

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[1] Stanford, P "Leachate Treatment Technologies for PFAS", New York Federal Annual Conference, May 2019

[2] EPA Technical Brief, Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams, Sept 30, 2019

[3] PFAS Incineration: EPA Activities and Research, by Jeff Ryan, EUEPA Office of Research and Development at State/EPA Region 5 Air Toxics Risk Assessment Meeting Nov 13, 2019, Chicago, IL

[4] Solo-Gabriele, H, "Waste type, incineration, and aeration are associated with per- and polyfluoroalkyl levels in landfill leachate" Waste Management, Vol. 102, 15 April 2020, pages 191-200

- Electrocoagulation;
- Dissolved air flotation (DAF) for liquids solids separation and dewatering solids;
- Ultrafiltration with solids reject returned to MBR process;
- GAC polishing units;
- Discharge to Black River; and
- Residual solids from above processes solidified for placement in the landfill.

The process does not include TDS or chlorides removal. If RO is included, process components and costs may be a portion what is included in option 1a-2. At this point, the process options assume that TDS removal will not be required.

3.2 SCENARIO 2 OPTIONS (PRETREATMENT FOR POTW DISPOSAL)

Scenario 2 options prepared by BC included three options to partially treat leachate to reduce approximately 50% of the leachate PFAS concentrations for further treatment at POTWs. The pretreatment would occur either at the NEWSVT Landfill or at the POTWs. The options presented included:

- Option 2a: Standalone RO with or without leachate concentrate volume reduction;
- Option 2b: EO plus UF and RO with or without leachate concentrate volume reduction;
- Option 2c: MBR plus GAC; and
- Option 2d: HTX plus GAC.

Detailed descriptions of these processes are contained in the BC Report. Option 2a was retained for further evaluation. CEC identified an additional option for this scenario using the HTX process (option 2d).

3.2.1 Option 2d: MBR + Electrocoagulation + Filtration + Activated Carbon

Option 2d includes most of the components of Option 1a-3 but eliminates the MBR process. Following the effluent of the DAF, the HTX Treated Leachate is pumped to a cartridge filter for final filtration prior to being transferred to the polishing feed tanks. The flow will be sampled. If the sum of the 5 PFAS compounds is less than 50% of the 5 PFAS compounds in the raw leachate, then the HTX Treated Leachate is pumped to two day tanks before disposal at an off-site treatment. If the sum of the 5 PFAS compounds of interest is greater than 50% of the 5 PFAS compounds in the raw leachate then all, or a portion, of the HTX Treated Leachate is pumped to an included Lead/Lag GAC Unit, and subsequently disposed off-site.

3.3 SCENARIO 3 OPTION (ZERO LIQUID DISCHARGE)

BC identified one option (Option 3a) for Zero Liquid Discharge (ZLD) using a Heartland Evaporative Concentrator to reduce the leachate volume to approximately 3% of the raw leachate flow. The residual would require stabilization and solidification prior to placement of the resultant solids and other constituents not evaporated back in the landfill. A detailed description of the process is contained in the BC Report. The BC report noted that thermal oxidation is included in the process description, but CAPEX and OPEX for a high temperature thermal oxidizer, if required, are not included in the BC evaluation, nor presented in this review, No additional ZLD options were identified by CEC for this Scenario.

3.4 SCENARIO 4 OPTIONS (POTW ENHANCEMENTS)

This scenario included hauling untreated leachate to the Newport POTW where leachate storage for equalization, additional aeration basin and blower capacity, disc filtration, and GAC would be added (Option 4a), Another option is hauling untreated leachate a further distance to the Montpelier POTW, where leachate storage for equalization, aeration blower capacity, rotating disc filtration, and GAC prior to discharge. CEC also added a change in the disinfection process from UV to peracetic acid to prevent the leachate from decreasing the UV transmittance causing effluent disinfection reduction.

A detailed description of these options is contained in the BC report, and both options 4a and 4b were retained by BC for further evaluation.

A summary of the options retained by BC and the option added by CEC are shown in the table below:

Table 2. Options Identified by Brown and Caldwell plus Options Identified by CEC

Technology	Description
No Action	
Option 1a On-Site: Discharge to Surface Water	RO + GAC + Remineralization with Concentrator + Emissions Control
Option 1a-2 CEC Revision On-Site: Discharge to Surface Water	RO + Remineralization with Concentrator - No Activated Carbon
Option 1a-3 HTX CEC Revision On-Site: Discharge to Surface Water	Air Strip + Electrocoagulation + Filtration + Activated Carbon + Concentrator
Option 3a On-Site: Zero Liquid Discharge (ZLD)	Concentrator + Emissions Control
Option 2a Off-Site: Pretreatment at NEWSVT/POTW (50% Reduction)	RO at NEWSVT/POTW with Concentrator (at NEWSVT)
Option 2d Off-Site: Pretreatment at NEWSVT/POTW (50% PFAS Reduction_	HTX with Activated Carbon at NEWSVT
Option 4a –Off-Site: POTW Enhancements 3,4 Newport	Filtration + GAC at POTW (Newport)
Option 4b - Off-Site: POTW Enhancements 3,4 Montpelier	Filtration + GAC at POTW (Montpelier)

4.0 ALTERNATIVE TECHNOLOGIES

CEC reviewed the options considered and evaluated in the BC Report to determine if there are additional, feasible leachate treatment options that were not presented. CEC assessed the feasibility of innovative technologies that may be appropriate at the landfill or at the Montpelier and Newport POTW sites. This review included those technologies beyond conventional leachate treatment technologies (following or in lieu of biological treatment) associated with PFAS (Activated Carbon, Reverse Osmosis, and to a lesser extent ion exchange or deep well injection). These innovative technologies included those identified by BC in various stages of bench and pilot testing, include:

- Biochar adsorption - Less effective than GAC or resins, non-regenerable;
- Direct treatment with IX resins - Resin fouling and premature breakthrough;
- Boron-Doped Diamond (BDD) anode EO - Not demonstrated with leachate nor at full scale; Anode production challenges;
- Titanium Dioxide anode EO - Not demonstrated with leachate nor at full scale; Anode production challenges;
- Electrocoagulation – BC reported that PFAS removal not demonstrated with leachate; however, a pilot test at the Brainerd, MN landfill reported nondetect PFAS concentrations at pilot scale[5];
- Sonolysis - Not demonstrated with leachate nor at full scale;
- AOP - Not applicable due to high concentrations of competing oxidizable organic material in leachate coupled with limited proven effectiveness on PFAS compounds; By-product formation such as perchlorate and bromate;
- Reductive defluorination - Not applicable due to high concentrations of competing organic material in leachate coupled with limited proven effectiveness on PFAS compounds;

5 https://www.prnewswire.com/news-releases/htx-solutions-produces-groundbreaking-results-and-solves-major-challenge-in-perfluorocarbons-pfcs-treatment-and-landfill-leachate-by-taking-contaminants-to-non-detectable-levels-300779020.html

- Anaerobic defluorination - Not demonstrated with leachate or proven to be effective with PFAS compounds;
- Carbon nanotubes - Not proven with leachate and not commercially available;
- Thermal distillation - Not proven with leachate or for PFAS removal;
- Plasma arc thermal destruction - High energy, not suitable for high volumes, not commercially proven;
- Incineration - Not feasible for significant volumes of leachate. Air emission issues; Hydrofluoric acid and other by-products formation in emissions; Requires up to 30-minute contact time at >1,000 degrees Celsius for destruction; and
- Electrodialysis - Not demonstrated with leachate for PFAS removal.

Other technologies exist that may be subcategories of the above or individual processes not listed for PFAS removal in various media including groundwater and potable water. Nevertheless, the universe of alternative technologies are not appropriate for leachate treatment either alone or as components of a treatment train. This evaluation is based elimination of these processes based on insufficient process experience, time, temperature, or other parameters. These additional technologies include:

- ferric and alum or other coagulation technologies;
- granular/micro-/ultrafiltration;
- aeration[6];
- heterogeneously catalyzed ozonation[7];
- Ozofractionation[8];
- UV scenarios (UV photolysis; UV with nanoscale materials; UV oxidation including fenton's reagent, persulfate, periodate, UV reduction);

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[6] WRF 4949-PFAS, Water Research Foundation, 2020

[7] Removal of per-and polyfluoroalkyl substances (PFASs) from tap water using heterogeneously catalyzed ozonation, Frankel,v et al, Environ Sci Water Res Technol. 2019, 5, 1887

[8] Remediation of Poly-and Perfluoro Alkyl Substances: New Remediation Technologies for Emerging Challenges, Arcadis

- Nanoscale technologies (zero-valent iron coated Mg aminoclay; Nano scale zero-valent nickel and iron coated on activated carbon);
- Oxidation including heat activated persulfate, permanganate activated persulfate (ScisorR®), and Peroxone activated persulfate Oxyzone®[9]; and
- Other adsorptive technologies that have been used for PFAS control in groundwater that may be substituted for activated carbon. They may include CycloPure; Rembind; MatCare; Plumestop, Perfluoraidl Polydadmac; Fluoro-sorb; and other zeolites. None of these have documented performance on leachate.

CEC added Option 1a-3 that include the innovative HTX electrocoagulation based system followed by granulated active carbon prior to surface water discharge. The HTX electrochemical reactor is based on advanced electrocoagulation and is configured and operated in a specific and proprietary way that enables HTX to extract long chain PFAS compounds from the leachate into a separate concentrated PFAS stream. The PFAS concentrated stream is removed from the HTX electrochemical reactor using vacuum. During bench testing of another site's raw leachate containing similar PFAS concentrations, HTX system achieved 75% removal of 6 PFAS compounds (PFDA, PFHpA, PFHxS, PFNA, PFOS, and PFOA) from the treated leachate, with similar removals reported in the literature.[10, 11, 12] HTX expects to be able to achieve similar removal results during commercial operation. Achieving the 20 ng/L total in the HTX process treated leachate; final polishing of the HTX treated leachate by GAC is required to achieve the

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[9] Overview of Remediation Technologies for PFAS-Contaminated Groundwater, Costanza, J., NGWA Innovating to Address Emerging Issues for Groundwater Resources, 2017

[10] Chunhui Zhang Yi Peng Ke Ning Xiameng Niu Shuhui Tan Peidong Su, " Remediation of Perfluoroalkyl Substances in Landfill Leachates by Electrocoagulation" First published:04 November 2013 Highly efficient removal of perfluorooctanoic acid from aqueous solution by H2O2-enhanced electrocoagulation-electroflotation techniquehttps://doi.org/10.1016/j.emcon.2016.04.001tps://doi.org/10.1002/clen.201300563

[11] BoYangaYanniHanaYunpanDengaYingyingLiaQiongfangZhuobJinhuaWuc, "Highly efficient removal of perfluorooctanoic acid from aqueous solution by H2O2-enhanced electrocoagulation-electroflotation technique", https://doi.org/10.1016/j.emcon.2016.04.001tps://doi.org/10.1002/clen.201300563

[12] Lin, Hui, et al. "Efficient sorption and removal of perfluoroalkyl acids (PFAAs) from aque 49.17 (2015): 10562-10569ous solution by metal hydroxides generated in situ by electrocoagulation." Environmental Science & Technology, 49.17 (2015): 10562-10569

target. In addition to removing PFAS compounds, the HTX electrochemical reactor also removes some of the organic contaminants from the leachate that compete for adsorption sites on granular activated carbon thereby extending the life of the media in the final polishing step to achieve the PFAS target. The volume of granular activated carbon consumed to achieve the target is therefore assumed as a multiple of the activated carbon consumption in Option 1a., The per gallon service charge includes the capital cost for the duplex GAC unit, But the service fee for Operation and Maintenance does not include the GAC media and a separate carbon usage line item is included in addition to the per gallon fee. Ammonia removal by either biological nitrification or air stripping would be considered. Should the HTX option appear attractive, bench and pilot testing is recommended for this option.

Evaluation of the Class 5 cost estimates CEC reviewed BC reported vendor quotes, engineering considerations, and associated design parameters for adequacy and completeness, and contacted vendors to verify questions. Vendors contacted by CEC included Rochem reverse osmosis, Heartland Technology (concentrator), Calgon Corporation (Activated Carbon), Clark Technologies (Leachbuster®), and HTX Technologies (electrocoagulation systems). Costs for capital and operation and maintenance were either confirmed or updated. Details for the cost opinions are included in the Appendix.

CEC prepared an independent Class 5 cost estimate based on the equipment type and capacity proposed in the referenced report. A Class 5 cost estimate can be used for alternatives analysis and initial viability and expects to have an accuracy range of -20% (low) and +100% (high). CEC evaluated operation and maintenance financial consideration according to similar criteria.

CEC prepared the independent evaluation of the alternatives presented. In addition, CEC also modified Alternative 1a (the onsite treatment alternative with direct discharge including a two stage reverse osmosis; reject concentration; evaporative concentrator and emissions control followed by activated carbon and recarbonization. CEC prepared an alternative, termed 1a-2 that eliminated the activated carbon polishing. The approach incorporates Rochem data that shows removal of 99.5% of PFAS constituents in each stage. Therefore, a 2,000 ppt raw leachate PFAS concentration of the five identified PFAS constituents would be reduced to 100 ppt in stage 1 and further reduced to 5 ppt in stage 2. Therefore, this alternative shows the CAPEX and OPEX considerations with the elimination of activated carbon.

CAPEX and OPEX cost opinions for option 1a-3 was prepared for the HTX alternative described above. The financial model is based on a per gallon charge that amortizes equipment and also include operation and labor as the system is operated by HTX. Although HTX provides CAPEX and OPEX as a service on a per gallon rate, several items are excluded from the rate, and are included in separate line items. The delineation of CAPEX incorporated in the per gallon fee is shown to allow a calculation for the line items of electric supply, instrumentation, process piping, contractor and engineering design and management fee, and contingency. The CAPEX for the costs for the HTX provided items was then removed from the summation of capital costs for consistency with the per gallon charge. Capital costs not included in the per gallon charge and power is excluded in the per gallon rate.

Alternatives 4a and 4b the provided financial opinions for transport and disposal to Montpelier and Newport that were also modified. The costs present an opinion of Montpelier costs for effluent filtration with a rotating disk filter unit and activated carbon. As Montpelier currently uses UV disinfection, CEC's experience is as little as 0.5% to 2 % of leachate addition to a POTW will reduce UV transmission to well below 65%. The design leachate flow of 50,000 gpd to the Montpelier annual average flow of 2 mgd results in a 2.5% flow based contribution. The design leachate flow compared to a diurnal low flow in the Montpelier POTW would result in a higher percentage of leachate during those times. Therefore, CEC included the CAPEX for use of a peracetic acid disinfection system in lieu of the UV system. Although the discontinuation of the UV system would reduce power costs, that reduction was not considered. The chemical cost for the operation of Peracetic acid disinfection was included. Other modifications to both Newport and Montpelier were confirmed, and the cost opinions for CAPEX and OPEX were revised.

The cost opinions show the low, mid, and high CAPEX and CEC's opinion of annual OPEX costs. The financial evaluation also includes a life cycle amortization of CAPEX and annualized OPEX costs over a 20 year life at a 6 percent discount rate to achieve a combined amortized CAPEX and summarized annual OPEX that we will term a "life cycle cost". The transport and disposal fee for options 4a and 4b were included in those alternatives to arrive at a comparative cost per gallon for each of the alternatives presented.

The cost opinions included the following considerations, similar to those proposed by BC with minor modifications. Many of the same or similar cost criteria used by BC were incorporated in this evaluation, due to the level of detail and accuracy appropriate at this stage of evaluation, and is presented by a Class 5 cost opinion with the following assumptions contained in the appendix.

Table 3 provides a summary of the CAPEX and OPEX cost opinions for each of the options. Detailed individual costs evaluations, and are shown in the appendix.

Table 3. Cost Opinions

NEWSVT PFAS Landfill Leachate Treatment System - Cost Summary

	CAPEX Range											
Technology	Low CAPEX Less 20%	Mid - Opinion	High CAPEX Plus 100%	OPEX	Treatment System Life Cycle Cost - Present Worth	Mid opinion annual Capital Recovery Factor (CRF) = 0.087185	Combined Annualized Cost, CRF + OPEX	Treatment Cost/Gal	Annual I Transport & Disposal (T&D)	Total Annual Treatment and Hauling/Disposal Cost	Present Worth Treatment System and T&D	Overall Cost/Gallon
No Action	0	0	0	$0	0	0	0	0	$1,572,000	$1,572,000.00	$18,030,840	$0.07
Option 1a On-Site: Discharge to Surface Water	$13,163,000	$16,454,000	$32,908,000	$961,000	$27,500,000	$1,435,000	$2,396,000	$0.1313	$0	$2,396,000	$27,482,120	$0.1313
Option 1a-2 CEC Revision On-Site: Discharge to Surface Water	$12,354,000	$15,443,000	$30,886,000	$921,000	$26,000,000	$1,346,000	$2,267,000	$0.1242	$0	$2,267,000	$26,002,490	$0.1242
Option 1a-3 HTX CEC Revision On-Site: Discharge to Surface Water	$2,152,000	$2,690,000	$5,380,000	$2,640,000	$33,000,000	$235,000	$2,875,000	$0.1575	$0	$2,875,000	$32,976,250	$0.1575
Option 3a On-Site: Zero Liquid Discharge (ZLD)	$10,927,000	$13,659,000	$27,318,000	$7,142,000	$95,600,000	$1,191,000	$8,333,000	$0.4566	$0	$8,333,000	$95,579,510	$0.4566
Option 2a Off-Site: Pretreatment at POTW (50% Reduction)	$7,140,000	$8,925,000	$17,850,000	$835,000	$18,500,000	$778,000	$1,613,000	$0.0884	$1,572,000	$3,185,000	$36,531,950	$0.1745
Option 2d: Offsite HTX Pretreatment at POTW/NEWSVT (50% Reduction)	$2,381,000	$2,976,000	$5,952,000	$2,001,000	$25,900,000	$259,000	$2,260,000	$0.1238	$1,572,001	$3,832,001	$43,953,051	$0.2100
Option 4a –Off-Site: POTW Enhancements Newport	$5,031,000	$6,289,000	$12,578,000	$954,000	$17,200,000	$548,000	$1,502,000	$0.0823	$1,154,000	$2,656,000	$30,464,320	$0.1455
Option 4b - Off-Site: POTW Enhancements Montpelier	$4,645,000	$5,806,000	$11,612,000	$1,085,000	$18,300,000	$506,000	$1,591,000	$0.0872	$1,572,000	$3,163,000	$36,279,610	$0.1733

5.0 LEACHATE MANAGEMENT RATING OF OPTIONS

We evaluated the treatment options delineated by BC and the CEC additional options for managing the NEWSVT landfill leachate. CEC independently developed a list of criteria that would constitute project success. In general, evaluations of alternatives should be performed to determine the treatment configuration and processes that will most cost effectively meet the requirements identified in the design basis. The analysis to determine cost effectiveness integrated with consideration of subjective parameters in this section. Along with an evaluation of the treatment alternatives to meet leachate PFAS management, this approach also considers solids treatment processes for handling and disposing of residuals.

Evaluation using non-monetary evaluation criteria is largely subjective, and non-monetary criteria can be weighted, and each alternative can be ranked for a total non-monetary ranking. The following presents a list of Non-Monetary Evaluation Criteria:

- Ability to Remove PFAS;
- Operability – Ease of operation minimizes operator attention/expertise required to ensure successful process performance;
- Ease of maintenance – Maintenance requirements not excessive and do not require special expertise; facilities and equipment readily accessible;
- Operator familiarity – Staff familiarity and ability to use staff experience from existing facilities;
- Reliability/Process robustness – Demonstrated performance; proven process/technology to meet treatment criteria reliably; Not subject to upset from inadvertent operational changes, toxic slugs;
- Hydraulic sensitivity – Capability to handle variations in hydraulic loads with minimal process impacts;
- Waste loading sensitivity – Capability to handle variations in waste loads with minimal process impacts;
- Additional waste products – technology or process produces new non-hazardous or hazardous waste;

- Flexibility – Capability for changes in process operations to handle differing waste load conditions and to meet differing treatment objectives for different effluent requirements; Consideration for POTW to reject loads;
- Environmental Effects – Minimize potential for odors; sustainability;
- Noise – Minimize potential for noise;
- Footprint – Minimizes footprint and disruption to site, including removal of trees;
- Expandability – Footprint maximizes area available for expansion; and
- Construction Timing – Time to implement facility, including permit, design, construction, commissioning.

6.0 FATAL FLAW ANALYSIS

These considerations were evaluated for each of the criteria to identify if a fatal flaw existed that would render an alternative not feasible for this application. If a technology exhibits a Fatal Flaw, then that technology will be eliminated from further consideration. The results of the Fatal Flaw Analysis are presented in Table 4. We included the “No Action” alternative as a comparison, with the understanding that there is risk that untreated leachate disposal may not be feasible in the near future. The No Action alternative is the only option that fails in the Fatal Flaw Analysis.

Table 4 – Results of Fatal Flaw Analysis

OPTION	Ability to Remove PFAS	Operability/Ease of Maintenance	Operator Familiarity	Reliability /Process Robustness	Hydraulic Sensitivity	Waste Load Sensitivity	Additional Waste Products	Odor/ Offsite Enviro. Impacts	Noise	Footprint	Expandability	Construction Timing
No Action	**F**	**A**	**A**	**A**	**A**	**A**	**A**	**C**	**D**	**A**	**F**	**A**
Option 1a On-Site: Discharge to Surface Water	**A**	**C**	**C**	**A**	**B**	**C**	**B**	**B**	**A**	**C**	**C**	**C**
Option 1a-2 CEC Revision On-Site: Discharge to Surface Water	**B**	**C**	**C**	**B**	**B**	**C**	**B**	**B**	**A**	**B**	**C**	**C**
Option 1a-3 HTX CEC Revision On-Site: Discharge to Surface Water	**B**	**A**	**B**	**C**	**C**	**C**	**C**	**C**	**A**	**C**	**C**	**C**
Option 1b: MBR plus RO and IX, with or without leachate concentrate volume reduction	**B**	**D**	**D**	**C**	**C**	**C**	**D**	**B**	**C**	**C**	**C**	**C**
Option 1c: EO plus UF, RO, and IX, with or without leachate concentrate volume reduction	C	**D**	**D**	**C**	**C**	**C**	**D**	**B**	**C**	**C**	**D**	**D**
Option 3a On-Site: Zero Liquid Discharge (ZLD)	**B**	**C**	**C**	**C**	**D**	**B**	**C**	**C**	**C**	**B**	**C**	**C**
Option 2a Off-Site: Pretreatment at POTW (50% Reduction)	**C**	**B**	**C**	**C**	**C**	**C**	**D**	**C**	**C**	**D**	**C**	**C**

Option 2b: EO plus UF and RO (50% PFAS Reduction)	**D**	**D**	**D**	**C**	**C**	**C**	**D**	**B**	**C**	**C**	**D**	**D**
Option 2c: MBR plus GAC (50% PFAS Reduction)	**B**	**D**	**D**	**C**	**C**	**C**	**D**	**B**	**C**	**C**	**C**	**D**
Option 2 d: Off-Site; HTX Pretreatment (50% PFAS Reduction)	**B**	**A**	**B**	**C**	**C**	**C**	**C**	**C**	**A**	**C**	**C**	**C**
Option 4a –Off-Site: POTW Enhancements 3,4 Newport	**B**	**B**	**C**	**D**	**C**	**C**	**B**	**B**	**B**	**D**	**C**	**D**
Option 4b - Off-Site: POTW Enhancements 3,4 Montpelier	**B**	**C**	**C**	**C**	**C**	**C**	**B**	**B**	**B**	**C**	**C**	**D**

F = Fatal Flaw; A= Excellent; B=Good; C= Acceptable, D=Poor, N/A= not applicable

6.2 ELIMINATED TECHNOLOGIES

The No Action Alternative is considered to be non-responsive to the NEWSVT landfill needs, as termination of the leachate disposal may occur without warning, leaving the landfill in a precarious position without the ability to dispose of collected leachate.

Other options not further considered are consistent with the lower BC report ratings, and include options 1b, 1c, 2b, and 2c due to complexity and operations considerations. These elimination considerations are confirmed by the overall ranking presented in subsequent table.

6.3 RECOMMENDED TECHNOLOGIES

Based on the Fatal Flaw Analysis, the No Action option was eliminated because of the inability to meet leachate management needs. The next step in this structured analysis assigned rankings and relative multiplier to the alternatives that passed the Fatal Flaw Analysis (shown in Table 4).

The following Table 5 lists a multiplier as the first step in the ranking of the alternatives. Each parameter is given a relative number for the importance of that parameter. A subjective rating of that ranking is applied to provide a weight of that ranking. This rating was developed absent of input from Casella Waste Services, and should be modified based on their input. Then finally, the numerical weights of the rankings are compared one against another to provide a priority of the options to consider for meeting effluent criteria.

Table 5 - Multiplier Weightings for Ranking Evaluation

Heading	Multiplier	Comment
Ability to Remove PFAS	10	Fundamental
Operability/Ease of Maintenance	10	Equipment Delivery and Construction
Operator Familiarity	8	Operator training and familiarity, ease to operate
Reliability /Process Robustness	5	Includes Commercialization
Hydraulic Sensitivity	5	Feed tank should buffer this
Waste Load Sensitivity	7	Able to manage changes in waste loads
Additional Waste Products	6	Secondary waste created? If so, what is the difficulty and cost to manage?
Odor	7	Offsite odor complaints
Noise	4	Impact to surroundings
Footprint (small)	3	Can be a critical criteria based on a site.
Expandability	3	Accommodation for increases/ stages
Construction Timing	3	Permitting, design, construction
Capital Cost (low)	8	Initial funding issue
O&M Cost (low)	9	Can override capital over a long period of operation

The next step is a relative ranking of how each consideration meets the intent that category. The rankings in each consideration are assigned a numerical value of 1 to 5, with 5 means that the consideration meets the needs, where a ranking of 1 show significant deficiencies.

Table 6- Rating of How Each Option Meets Criteria

OPTION	Ability to Remove PFAS	Operability/Ease of Maintenance	Operator Familiarity	Reliability /Process Robustness	Hydraulic Sensitivity	Waste Load Sensitivity	Additional Waste Products	Odor/ Offsite Enviro. Impacts	Noise	Footprint	Expandability	Construction Timing	Capital Cost	Operation and Maintenance Cost
Option 1a On-Site: Discharge to Surface Water	5	3	3	5	4	3	4	4	5	3	3	3	3	4
Option 1a-2 CEC Revision On-Site: Discharge to Surface Water	4	3	3	4	4	3	4	4	5	4	3	3	3	4
Option 1a-3 HTX CEC Revision On-Site: Discharge to Surface Water	4	5	4	3	3	3	3	3	5	3	3	3	5	1
Option 1b: MBR plus RO and IX	4	1	1	3	3	3	1	4	3	3	3	3	1	1
Option 1c: EO plus UF, RO, and IX	3	1	1	3	3	3	1	4	3	3	1	1	1	1
Option 3a On-Site: Zero Liquid Discharge (ZLD)	4	3	3	3	1	4	3	3	3	4	3	3	3	2
Option 2a Off-Site: Pretreatment at POTW (50% Reduction)	3	4	3	3	3	3	1	3	3	1	3	3	4	2
Option 2b: Off-site EO plus UF and RO (50% Reduction)	1	1	1	3	3	3	1	4	3	3	1	1	2	2
Option 2c: Off-site MBR plus GAC (50% Reduction)	4	1	1	3	3	3	1	4	3	3	3	1	1	1
Option 2d: Off-site HTX (50% PFAS Reduction)	4	5	4	3	3	3	3	3	5	3	3	3	5	1
Option 4a –Off-Site: POTW Enhancements Newport POTW	4	4	3	1	3	3	4	4	4	1	3	1	4	3
Option 4b - Off-Site: POTW Enhancements Montpelier POTW	4	3	3	3	3	3	4	4	4	3	3	1	4	3

Each of the processes were further rated based on criteria outlined in Table 7 The multipliers assigned to each criterion aim to reflect the most important aspects of a treatment plant installation or upgrade. Table 7 presents the calculated results of the numerical ranking of the options for landfill leachate management at the NEWSVT site. For interest in evaluations, we included a number of lesser ranked options to identify where we project they may lie on the scoring continuum, even though they may have been eliminated for other reasons. Table 4 shows the ability of each option to meet the identified criteria and the importance of meeting that criteria Then the multiplication of meeting the criteria times the importance of that criteria is shown in the cells. The summary to the right of each row is the net score of each alternative in terms of the desirability of each alternative in the Summation Score column.

Table 7 – Option Ranking Based on Criteria and Multiplier

OPTION	Ability to Remove PFAS	Operability/Ease of Maintenance	Operator Familiarity	Reliability /Process Robustness	Hydraulic Sensitivity	Waste Load Sensitivity	Additional Waste Products	Odor/ Offsite Enviro. Impacts	Noise	Footprint	Expandability	Construction Timing	Capital Cost	Operation and Maintenance Cost	Summary Score	Rank
Multiplier	10	10	8	5	5	7	6	7	4	7	3	3	8	9		
Option 1a On-Site: Discharge to Surface Water	50	30	24	25	20	21	24	28	20	21	9	9	24	36	341	1
Option 1a-2 CEC Revision On-Site: Discharge to Surface Water	40	30	24	20	20	21	24	28	20	28	9	9	24	36	333	2
Option 1a-3 HTX CEC Revision On-Site: Discharge to Surface Water	40	50	32	15	15	21	18	21	20	21	9	9	40	9	320	3
Option 1b: MBR plus RO and IX	40	10	8	15	15	21	6	28	12	21	9	9	8	9	211	9
Option 1c: EO plus UF, RO, and IX	30	10	8	15	15	21	6	28	12	21	3	3	8	9	189	11
Option 3a On-Site: Zero Liquid Discharge (ZLD)	40	30	24	15	5	28	18	21	12	28	9	9	24	18	281	7
Option 2a Off-Site: Pretreatment at POTW (50% Reduction)	30	40	24	15	15	21	6	21	12	7	9	9	32	18	259	8
Option 2b:Off-Site EO plus UF and RO	10	10	8	15	15	21	6	28	12	21	3	3	16	18	186	12
Option 2c: Off-Site MBR plus GAC	40	10	8	15	15	21	6	28	12	21	9	3	8	9	205	10
Option 2d: Off-site HTX (50% PFAS Reduction)	40	50	32	15	15	21	18	21	20	21	9	9	40	9	320	3
Option 4a –Off-Site: POTW Enhancements at Newport POTW	40	40	24	5	15	21	24	28	16	7	9	3	32	27	291	6
Option 4b - Off-Site: POTW Enhancements Montpelier POTW	40	30	24	15	15	21	24	28	16	21	9	3	32	27	305	5

The leachate treatment options presented above are compared for the considerations listed. Other considerations not addressed, and may be more site specific include including solids disposal and air emissions, cost effectiveness with increased volume treated, among other considerations that Casella may deem important. Thus customization of this approach to identify an objective ranking of many subjective considerations can be adjusted based on stakeholder input.

The following Table 8 shows a more comprehensive listing of the summarized raw leachate characteristics and speculative discharge limits for direct surface water discharge for option 1 alternatives.

Table 8. Leachate Parameters

		Influent Criteria		Effluent Criteria	
	Average Pre 2019 Concentration[4]	95th Percentile Pre 2019 Concentration[4]	2019 95% Percentile or Max Concentration	Indirect Discharge (POTW)[5]	Direct Discharge to Black River, Monthly Average [6]
Parameter			mg/L		
Design Flow (Hydraulic Capacity = 50,000 gpd)					
BOD_5	**3,138**	**4,425**	**5,200**	**834 lbs/day**	**37[1]; 10 [6]**
COD	**3,138**	**4,425**			
Total Chloride	**1,831**	**2,700**			**N/A**
Total Kjedahl Nitrogen	**1,157**	**1,675**			**N/A**
Total Sodium	**1,588**	**2,025**	**2,100**		**N/A**
Alkalinity (as $CaCO_3$)[3]	**6,870**				**N/A**
Total Suspended Solids			**170**		**27**
Total Dissolved Solids[3]	**6,280**				**N/A**
Ammonia Nitrogen[1,3]	**1,200**				**5.0**
Total Kjedahl Nitrogen			**1,400**		**5.0**

Total Phosphorous			6.8		
Ortho-phosphate[3]	**1.8**				
pH[1]	**8.0**	**8.6**			**pH6 to pH9**
Specific Conductance	**14,164**	**18,415**			
Temperature	**17.1**	**24**			
Parameter			**Metal (ug/L)**		
Aluminum			**460**		
Antimony	**22.4**	**41.5**			**5.6**
Arsenic	**664**	**1,173**			**0.02**
Barium	**196**	**223**			**1**
Boron			**20,000**		
Beryllium	**6.6**	**10**			
Cadmium	**14.5**	**25.0**		**120**	
Chromium	**313**	**498**			
Cobalt	**136**	**200**			
Copper	**145**	**250**		**12,000**	
Cyanide			**0.015**		**140**
Iron	**22,300**	**46,700**	**59,000**		**300**
Lead	**71**	**250**		**2,710**	
Manganese	**1,823**	**3,570**	**26,000**		
Mercury	**0.41**	**2.00**			
Molybdenum	**133**	**250**			
Nickel	**471**	**658**		**5,370**	**610**
Selenium	**13.3**	**20.0**			
Silver	**119**	**200**		**7,900**	
Strontium[3]	**0.85**				
Thallium	**9**	**16.5**			
Vanadium	**119**	**200**			
Zinc	**249**	**548**		**6.07**	**110[1]**

Parameter			Organics (ug/L)		
Acetone	2,632	3,541			
Benzene	3.50	4.40			2.2
t-Butanol	1,762	2,587			
2-Butanone (MEK)	3,977	4,076			
Diethyl Ether	32.8	42.0			
1,2 Dichloroethane	3.4	3.9			0.38
Ethyl Benzene	12.0	14.8			530
2-Hexanone	57.0	57.3			
4-Isopropyl toluene	6.0	7.0			
4-Methyl 2-Pentanone	78.0	101.0			
Naphthalene	18.5	22.4			
Tetrachloroethene	2.5	2.5			0.69
tetrahydrofuran	2,022.0	2,381.0			
1,2,4 Trimethyl benzene	5.9	6.5			
Toluene	27.6	46.0			1,300
Total Xylenes	29.6	37.9			
Unidentified	7.6	10.0			
Total Cresol	525.0	1,092.0			
a-Terpineol(1)					16
Benzoic acid(1)					71
p-cresol(1)					14
2 Methyl Phenol	18.3	24.3			
3&4 Methylphenol	516.0	1,072.0	2,040		
Naphthalene	10.4	14.3			
Phenol(1)	111.0	208.0			15
Unidentified Peaks	10.0	10.0			
Parameter			**Trace Elements/Anions/Cations (mg/L)**		
Calcium(3)	110				
Fluoride(3)	<0.10				

Magnesium			150		
Potassium(3)	590				
Sulfate			15		
Sulfide(3)	16				
Silicate (SiO_2)					
Parameter			**PFAS (ng/L)**		
Perfluorobutanoic acid (PFBA)	**10,300**		**2,352**		
Perfluoropentanoic acid (PFPeA)	**2,020**		**1,476**		
Perfluorohexanoic acid (PFHxA)	**2,890**		**2,565**		**20(2)**
Perfluoroheptanoic acid (PFHpA)	**748**		**828**		**20(2)**
Perfluorooctanoic acid (PFOA)	**1,850**		**1,743**	**120,000**	**20(2)**
Perfluorononanoic (PFNA)	**125**		**102**		**20(2)**
Perfluorodecanoic acid (PFDA)	**129**		**68**		
Perfluoroundecanoic acid (PFUnA)	**16.0**				
Perfluorododecanoic acid (PFDoA)	**17.0**				
Perfluorotridecanoic acid (PFTrDA)	**3.36**				
Perfluorotetradecanoic acid (FTeDA)	**3.12**				
Perfluorobutanesulfonic acid (PFBS)	**3,520**		**3,058**		
Perfluoropentanesulfonic acid (PFPeS)	**50**		**58**		
Perfluorohexanesulfonic acid (PFHxS)	**397**		**52**		
Perfluoroheptanesulfonic acid (PFHpS)	**ND (<6.93)**				

Perfluorooctanesulfonic acid (PFOS)	**244**		**186**	**1,000**	**20(2)**
Perfluorononanesulfoic acid (PFNS)	**ND (<1.85)**				
Perfluorodecanesulfonic acid (PFDS)	**ND (<4.97)**				
Perfluorododecane sulfonic acid (PFDoS)	**ND (<1.85)**				
4:2FTS	**NQ**				
6:2FTS	**2,090D**		**2,577**		
8:2FTS	**122**		**74.81**		
Perfluorooctanesulfonamide (PFOSA)	**14.9**				
N-Methylperfluorooctanesulfonamide (N-MeFOSA)	**9.5**				
N-EtFOSA	**34.3**		**65.30**		
MeFOSAA	**82.0**		**98.31**		
EtFOSAA	**49**				
N-MeFOSA	**287**				
N-EtFOSE	**110**				
Total 5 PFAS (PFOA, PFOA, PFHxS, PFHpA, PFNA)	**3,364**		**3,418**		**20(2)**
PFOA/PFOS	**2,094**		**1,982**		

Legend:

D - Diluted Sample

1. EPA Final Effluent Limitation Guideline and Standards for Landfill Point Source Category

2 - Total PFAS (sum of 5 PFAS Compound) limit is 20 ppt

3. Only one sampling event results provided

4. Results as of 1/31/2019

5. Indirect (POTW) limit reported by Brown & Caldwell

6. Speculative Limits based on the Black River as a Class B water body.

7. Effluent Limitation guideline 40CFR445.21

8. Vermont Water supply rule, Chapter 21 MCL

Appendix A

Description of HTX Process for Option 1a-2

The raw leachate, at pH 8.6 standard units (s.u.) and 24 degrees C, will be pumped from NEWSVT's above ground Raw Leachate Tank (438,000-gallon capacity) and sent to a self-cleaning strainer for coarse filtration and removal of large suspended solids. Backwash solids from the strainer will be periodically returned to the landfill for disposal. After coarse filtration, the leachate flows to a MBR/ultrafiltration (UF) Unit (design basis is 60,000 gpd at 25 °C leachate temperature) for biological treatment to remove ammonia/ammonium, nitrite and nitrates, BOD, COD and alkalinity. The external tubular MBR incorporates am ultrafilter for liquids/solids separation, including an anoxic basin and.an aeration tank. The biological treatment tanks are anticipated to be sized at 50,000 gallons for the anoxic tank and 100,000 gallons for the Oxic/Aeration Tank. Liquids/solids separation system includes a UF (ultrafiltration) membrane unit, blowers, associated pumps and control panel and membrane cleaning system. There will be a solids separation flow will either be returned to the aeration tank or dewatered by a Rotary Press. Resultant liquids will be returned to the MBR system. The dewatered solids will be disposed into the landfill. The biological process will consume some of the alkalinity that reduced electrocoagulation unit foaming, critical for PFAS removal.

The ultrafilter flow will enter two intermediate tanks where air stripping will first remove residual ammonia, then the flow will enter a second tank for pH adjustment by addition of H2SO4 (reduction to ~pH 4) and air stripping occurs to remove residual alkalinity to prevent foaming in the HTX electrochemical reactor unit. The decarbonated leachate is then pH adjusted by addition of NaOH (increase to ~pH 8) and sent to HTX Feed Tanks (2 off, 20,000-gallon capacity each). The flow is then pumped to the containerized HTX Unit. The unit includes electrocoagulation reactor and a screw press for further treatment. Long chain PFAS compounds are removed from the leachate into a separate concentrated PFAS stream, reducing the 5 Vermont PFAS compounds by 75%. The HTX electrochemical reactor will also convert some of the soluble leachate contaminants, including organic contaminants that will compete for activated carbon adsorption sites, into insoluble contaminants for removal.

The flow is then pumped to a Dissolved Air Flotation (DAF) Unit where dissolved air is used to float the insoluble contaminants allowing them to be separated. The wet sludge removed from the DAF unit will contain insoluble organics, metals, as well as a portion of the PFAS compounds not removed from the HTX electrochemical reactor. The DAF resultant solids will be dewatered using either a Membrane Filter Press or a Rotary Press. The dry solids from the press will contain PFAS compounds and should be stabilized or can be encapsulated using HTX's proprietary encapsulation technology. The recovered liquids from the Press will contain a portion of the PFAS compounds and will be routed to the front end of the process, or combined with the concentrated PFAS liquid and encapsulated using HTX's proprietary encapsulation technology.

Should the technology use HTX's proprietary encapsulation technology, the result is a non-leachable solid form (bricks) that can be disposed. Encapsulation of the above waste streams have not been included, and solidification with flyash is initially anticipated pending further technology evaluation.

Following the DAF, the flow enters an Ultra Filtration Unit (UF) for further removal of suspended particles. This solids laden liquid reject stream (approximately 5% or 2500 gpd) that will be returned to the MBR waste slurry Rotary Press for removal of solids and recovery of liquid. The flow then enters two Polishing Feed Tanks to a Lead/Lag GAC unit for removal of remaining PFAS compounds. The spent activated carbon can be disposed of in HTX's sequestration and encapsulation process reducing costs associated with regeneration of spent activated carbon or regenerated offsite. To further reduce costs, CAS can purchase regenerated activated carbon vs using fresh in the Lead/Lag GAC Unit.

Appendix B – Cost Evaluation Assumptions

- Additional characterization and treatability testing are required to refine and validate treatment process performance and economics.
- Engineering Design is beyond the scope of this review for the options presented. As design of an individual option develops, significant cost changes may occur.
- Each option was based on a leachate flow of 50,000 gpd. Option 4a and 4b included costs for treating the entire POTW flows for effluent PFAS removal. Flows are based on additional equalization tank, aeration basin and blower installation, rotating disc filtration, and granulated activated carbon at Newport (0.6 mgd). The Montpelier option 4b includes equalization tank, blower addition, rotating disc filtration, granulated activated carbon, and UV replacement with peracetic acid for disinfection. Additional solids management the result of leachate addition is not considered, as it would be incorporated in the disposal fee.
- Calculations and opinions of probable costs presented herein are conceptual level estimates prepared without benefit of a thorough engineering evaluation and include an allocation for repair and replacement costs over a 20 yr. period at a 6 percent discount rate. As such, this information should not be considered definitive and should be validated after proper engineering evaluations are completed.
- In accordance with the Association for the Advancement of Cost Engineering International (AACE) criteria, this is a Class 5 estimate. A Class 5 estimate is defined as a Conceptual Level or Project Viability Estimate. Engineering, bonding, and legal costs are assumed at 3 percent of construction. Class 5 estimates are used to prepare planning level cost scopes or evaluation of alternative schemes, long range capital outlay planning and can also form the base work for the Class 4 Planning Level or Design Technical Feasibility Estimate. The expected accuracy for this Class 5 estimate is -20 percent to +100 percent. In unusual circumstances, ranges could exceed those shown.
- Construction cost estimates, financial analyses, and feasibility projections are subject to many influences including, but not limited to, price of labor and materials, unknown or latent conditions of existing equipment or structures, and time or quality of performance by third parties. Such influences may not be precisely forecasted and are beyond the control of this review Actual costs incurred may vary from the estimate prepared by BC and as

modified by CEC, and are based on these conditions and influences beyond BC or CEC's control, and neither warrants or guarantee the accuracy of construction or development cost estimates.

- Major equipment budgetary costs were verified with equipment vendors or based on prior experience at other sites or were developed based on engineering experience.
- The location for proposed equipment does not require significant site preparation (e.g., major earthwork, blasting, dewatering, or stormwater management) and has sufficient structural integrity to accommodate the proposed equipment (e.g., no piling or special subsurface improvements required). Minimal geotechnical and site preparation costs are included.
- The facility has adequate space for construction of the proposed equipment.
- Option 3a annual OPEX includes approx. $5.7M in propane gas annual usage costs for the concentrator thermal oxidizer; Propane gas cost based on $2.50 per gallon, as reported by BC
- The cost opinions include a 25% equipment line item for power distribution for each alternative; however, the facility is assumed to have sufficient electrical power for new process equipment. Option a-3 percentages were reduced to reflect the HTX transfer of responsibility to their per gallon service charge.
- Standby or spare blowers are not included in addition to those that the facility may already have these units.
- The existing aeration pipe size is adequate for increased air flow rate in options 4a and 4b.
- Aeration grid upgrade includes demolition of existing aeration diffusers, lateral and header piping in option 4a
- A building or structure to house the proposed equipment is included.
- Site and civil improvements are not required for the proposed equipment; and service utilities such as potable water, instrument air, plant air, and electricity are not required.
- Purchased equipment installation allows 25% of equipment cost
- Each alternative includes a 30%t contingency.
- Contractor overhead and profit of 15% is included in each construction and equipment line item.

- Instrumentation and controls equipment and installation is shown at 25% of total equipment cost, other than option 1a-3.
- Process piping is shown at 25 percent of total equipment cost, other than option 1a-3.
- Electrical systems and installation is shown at 25percent of total equipment cost.
- Structural costs are shown for concrete additions, whereas other structural components are included in the contingency line of each alternative.
- POTW transport and disposal (T&D) costs provided by Casella as incorporated in the BC report.