H2Ohio Technology Assessment Program (TAP)

Final Report

Assessment of Agricultural Nutrient Management Technology Submission

Solugen Inc. AcquaCore™ (previously identified as BioChelate™ Pro)

January 2022

TETRA TECH

EXECUTIVE SUMMARY

Solugen Inc. (Solugen) of Houston, Texas has submitted a technology proposal for AcquaCore™ (previously identified as BioChelate™ in original proposal submittal) and AcquaCoreX™ (BioChelate Pro™) to the Ohio Environmental Protection Agency's (Ohio EPA's) H2Ohio Technology Assessment Program (TAP) for the purpose of addressing the Lake Erie algal blooms and associated nutrient loading. Both of these technologies were recently rebranded, but the formulations remain the same. The technology evaluation focus was on the AcquaCore™ technology as it is a more developed technology, with only certain aspects of the AcquaCoreX™ technology mentioned in this report where relevant to address the TAP objective in reducing nutrient loading to rivers, streams, and lakes. Studies completed to date have shown that the AcquaCore™ technology can reduce the phosphorus content in formulations for traditional phosphorus-based scale control and corrosion inhibitor products. The AcquaCoreX™ technology is Solugen's phosphorus-free product that has a high potential for significantly reducing nutrient loading, but more research and development is required to support Solugen's claims.

Solugen suggests and Tetra Tech concurs that AcquaCore™ offers potential to improve water quality in the Lake Erie watershed that is cost-effective, sustainable, using domestically produced feedstock that can improve the effectiveness and efficiency of industrial scale and corrosion inhibition treatment. An added benefit of this technology, although not considered an TAP objective, is that Solugen's new BioForge™ processing facility is considered to be carbon negative and the biobased materials used in AcquaCore™ have a much lower environmental footprint than other commonly used corrosion and scale control treatment systems that have been demonstrated through 3rd party testing.

The Solugen AcquaCore™ technology is a proprietary enzyme-based chemical that is produced by converting domestically grown United States corn sugar with no dependence on overseas suppliers. The technology is a replacement for traditional chemical phosphorus-based corrosion and scale inhibitor products commonly used by industrial water treatment end users. The technology has been demonstrated through multiple small-scale laboratory studies with one utilizing synthetic waters that are expected to be representative of waters located within the Lake Erie watershed. There will be no work needed to deploy Solugen's technology for the H2Ohio program as it is designed to be a "drop-in" replacement to traditional systems that are commonly used by end users today. AcquaCore™ is currently used by some Association of Water Technologies companies in their scale and corrosion control product formulations and recently reported favorable results to Solugen at a conference in September 2021 that are referenced throughout this report. Processing for the H2Ohio project would occur at Solugen's newly constructed, 20,000 square feet BioForge™ processing plant located in Houston, Texas. The BioForge™ facility is scheduled to be operating this year and can produce up to 10,000 metric tons of chemicals per year that can meet or exceed the feedstock demands for this project.

This report evaluates AcquaCore™ against a suite of criteria identified by the TAP using information provided by Solugen and obtained elsewhere. Tetra Tech determined that AcquaCore™ is very likely to be effective at reducing nutrient loading to the Lake Erie watershed but needs to be demonstrated on a larger scale. Tetra Tech did not identify any negative impacts associated with scalability, supply chain limitations, environmental risks, community perception, or waste management. AcquaCore™ is cost effective, based on the two scenarios

provided by Solugen for a large industrial user and small industrial user. However, an evaluation of longevity of the product should be further evaluated in comparison to conventional treatment systems for long-term cost implications. Equivalent costs of $2.00/pound (dry) on average for AcquaCore™ products compared to traditional phosphorus-based products were reported and further cost efficiencies could potentially be found through an evaluation of other cost factors, such as (1) optimization of chemical selection and feedstock control; (2) reduction of operation and maintenance costs associated with equipment fouling; (3) reduction of overall regulatory costs; (4) water quality trading cost differentials; and (5) energy savings for processing compared to traditional systems. Industrial end user willingness is a potential barrier due to upfront deployment costs, which could be addressed through financial support provided by the H2Ohio Initiative. A demonstration project targeting widespread adoption of AcquaCore™ within the Lake Erie watershed could evaluate the ability of financial incentives to spur end users to use this technology and also provide more detailed data about nutrient load reduction, scale and corrosion inhibition performance, and potential constraints to using the technology within the Lake Erie watershed.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
$/sq. foot	Dollars per square foot
AWT	Association of Water Technologies
BD	Blow Down
BTU	British Thermal Units
BTU/hr	BTU per hour
BTU/sq. foot	BTU per square foot
ECHA	European Chemicals Agency
ECOSAR	Ecological Structure Activity Relationships Program
GPD	gallons per day
GPM	Gallons per minute
HAB	Harmful algal bloom
HCA	Hydrophilic carboxylic acid
HDA	Hydrophilic dicarboxylic acid
HEDP	Hydroxyethylidene diphosphonic acid
HVAC	Heating, ventilation, and air conditioning
Hx	Heat Exchanger
mg/L	Milligrams per liter
mg/L P	P in milligrams per liter
Million P/year	Million pounds of water per year
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
Ohio EPA	Ohio Environmental Protection Agency
P	Phosphorus
P/year	Pounds per year for treatment consumption
PBTC	Phosophonobutane-1,2,4-tricarboxylic acid
PMN	Pre-manufacture notice
POTW	Publicly-owned treatment works
PPE	Personal Protective Equipment
ppm	parts per million

QAPP	Quality Assurance Project Plan
RL	Readiness level
RO	Reverse osmosis
TAP	Technology Assessment Program
Tetra Tech	Tetra Tech, Inc.
TSCA	Toxic Substances Control Act
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
USD	U.S. Dollars
USD/P	USD per pound of product or phosphorus
USD/year	USD per year
WELB	Western Lake Erie Basin

1.0 INTRODUCTION AND BACKGROUND

H2Ohio (http://h2.ohio.gov) is Ohio Governor Mike DeWine's comprehensive, data-driven water quality plan to reduce Harmful Algal Blooms (HABs), improve wastewater infrastructure, and prevent lead contamination. Governor DeWine's H2Ohio plan is an investment in targeted solutions such as :

- Reducing phosphorus runoff through increased implementation of agricultural best management practices and the restoration of wetlands;
- Improving wastewater infrastructure;
- Replacing failing home septic systems; and
- Preventing lead contamination in high-risk daycare centers and schools.

HABs have been a concern in Lake Erie for decades, and the State of Ohio has a long history of developing solutions to address them. In support of these efforts, state agencies are often presented with new approaches for addressing HABs. These approaches often involve technologies and products that are typically innovative, can be proprietary, and span multiple scientific disciplines. To evaluate these proposals for their efficacy and feasibility, the Ohio Environmental Protection Agency (Ohio EPA) worked with the Ohio Lake Erie Commission to create a public advisory council—the Technology Assessment Program (TAP) Team. The H2Ohio TAP Team is comprised of representatives from the private sector, public sector, trade associations, and non-profit companies. The H2Ohio TAP team is conducting an evaluation of technologies designed to treat, control, and reduce HABs in the Lake Erie watershed. H2Ohio initiated the TAP to solicit and evaluate technologies that support one or more of the following five goals:

1. Reduction of nutrient loading to rivers, streams, and lakes;
2. Removal of nutrients from rivers, streams, and lakes;
3. Reduction of the intensity or toxicity of algal blooms;
4. Recovery of nutrients from animal waste; and
5. Improvement of nutrient removal in wastewater treatment systems.

The H2Ohio TAP Team worked to solicit and prioritize technology proposals for further review. A Request for Technologies (RFT) was developed and issued by Ohio EPA in November 2020 (H2Ohio TAP, 2020). The H2Ohio TAP conducted a thorough evaluation of the 40+ proposals received in response to the RFT and selected 10 technologies for further evaluation. The developers of these 10 technologies were given an opportunity to provide additional information and supporting data to allow an independent evaluation of their technology by a third party, Tetra Tech.

As a contractor to the Ohio EPA, Tetra Tech conducted an independent third-party evaluation of the 10 technologies selected by the H2Ohio TAP team. The goal of the evaluation was to provide a general assessment of the potential effectiveness, implementability, readiness, and cost of deploying each technology. Select technologies may eventually be demonstrated in the field under future H2Ohio programs.

2.0 PURPOSE

The primary purpose of the technology assessment and evaluations was to conduct a comprehensive scientific evaluation of the selected technologies to determine if and how they could be utilized to address HABs in Lake Erie.

Based on input from Ohio EPA and the H2Ohio TAP team, Tetra Tech established primary (P1 & P2) and secondary (S1 & S2) objectives for the third-party evaluation program. The primary objectives are critical to the technology evaluation and involve conclusions regarding technology performance that are based on quantitative and semi-quantitative data. The primary objectives for the evaluations of the participating technologies are as follows:

- P1: Effectively assess the performance, cost-effectiveness, and reliability data gathered from each vendor with regard to one or more of the 5 H2Ohio goals:
    - Reduce nutrient loading to rivers, streams, and lakes:
    - Remove nutrients from rivers, streams, and lakes:
    - Reduce the intensity or toxicity of algal blooms
    - Recover nutrients from animal waste:
    - Improve nutrient removal in wastewater treatment systems, specifically with small (e.g. lagoon) and decentralized systems
- P2: Ensure that the evaluations are completed by appropriate personnel using a documented, consistent approach and level of detail, to include:
    - Proof of concept review
    - Fatal flaw analysis
    - Review of previous implementation of the technology or similar technologies
    - Review of data quality objectives
    - Review of quality assurance/quality control procedures and reports
    - Evaluation of scalability
    - Information gap evaluation
    - Evaluation of cost; both total and by unit, such as nutrient reduced/removed
    - Feasibility review for a proposed demonstration project
    - Feasibility review for full scale implementation
    - Statement of probability of success

The secondary objectives pertain to Tetra Tech's approach to assessing and presenting the information and thus support the primary objectives.

The secondary objectives for Tetra Tech's evaluation are as follows:

- S1: Prepare Comprehensive Scientific Assessment and Recommendations Reports for each technology that will support potential users' ability to make sound judgements on the applicability of the technology to a specific site and to compare the technology to alternatives.

- S2: Ensure that project deliverables follow consistent format and similar levels of detail. Each report will contain:
    - A summary of the technology and results of past uses of the technology;
    - Results of conceptual model review, fatal flaw analysis, and information gap evaluation;
    - A statement of probability of success and scalability of the project;
    - Verification of cost estimates at various implementation levels;
    - Results of the feasibility review for a potential demonstration project and full-scale implementation of the technology;
    - Verification of claims made by applicants.

The technology evaluation consisted of the (1) collection; (2) evaluation; and (3) summarizing and reporting of data on the performance and cost of each technology. These data provided the basis for meeting the primary objectives.

Most data supporting these evaluations were provided by the technology developers and Tetra Tech attempted to verify it using independent sources, when available. Tetra Tech focused its verification efforts on key aspects of the technology (e.g., effectiveness, cost) as well as any claims that seemed questionable. Otherwise, Tetra Tech assumed information provided by the vendor to be accurate. Instances where Tetra Tech is unsure of a claim being made by the vendor are noted in the report. In some cases, information was also obtained from the peer-reviewed scientific literature. Tetra Tech worked with each developer to obtain the data necessary to meet the primary and secondary evaluation objectives.

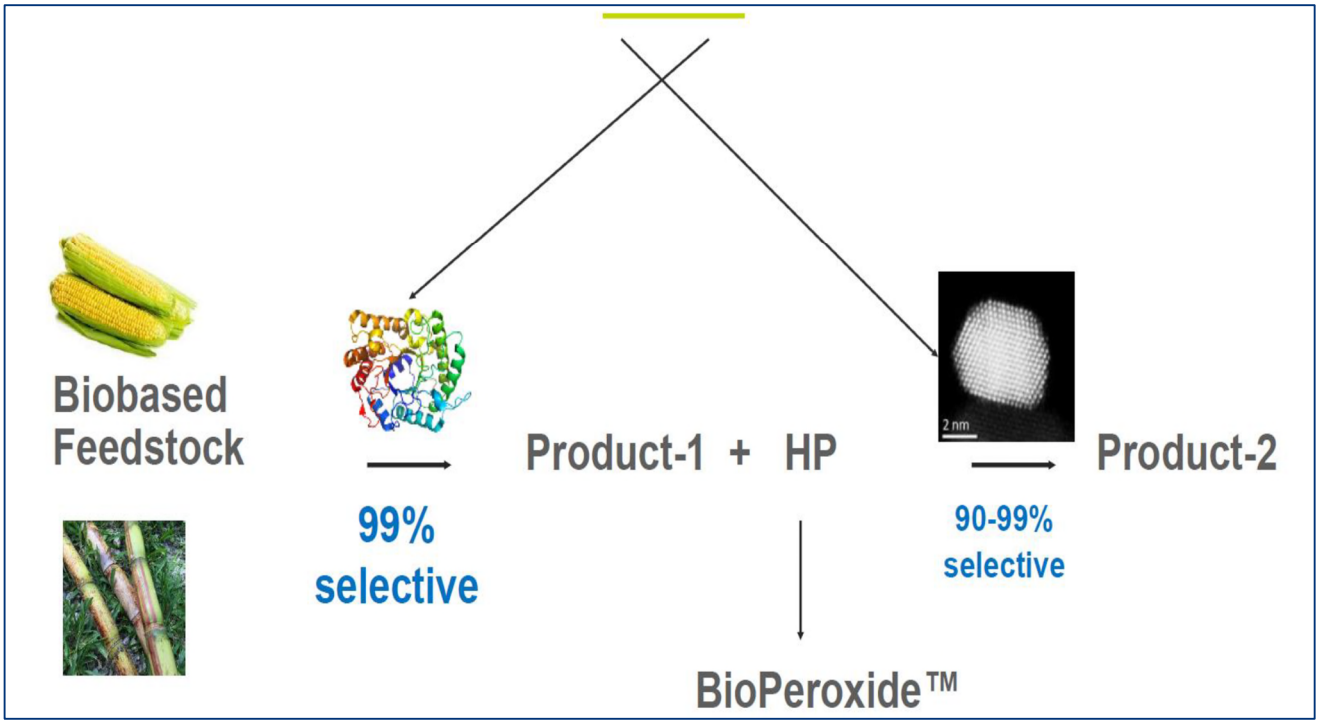
Tetra Tech then completed an independent evaluation of the data provided by each developer and prepared separate reports for each technology evaluation, following a consistent report format. Please note that since the initial grant proposal was submitted to H2Ohio TAP, Solugen has developed a revised analysis based on recently validated test data that is highlighted throughout this report. The products previously identified as BioChelate™ and BioChelate Pro™ in their proposal were recently rebranded and are now identified as AcquaCore™ and AcquaCoreX™, respectively. However, the formulations remain the same. This report provides a summary of our review of the AcquaCore™ technology since it is a more mature technology as indicated by Solugen. Some aspects of the AcquaCoreX™ technology are also mentioned in the report when it is relevant.

3.0 TECHNOLOGY OVERVIEW

Solugen Inc. (Solugen) of Houston, Texas developed the AcquaCore™ technology using a patented chemoenzymatic process by converting domestically grown U.S. corn sugar through a patented enzyme and catalysis chemical process that produces phosphorus-free and zinc-free corrosion and scale inhibitor products for water treatment customers as shown in Figure 1 (Solugen, 2021). Specifically, this process uses enzymes and novel metal catalysts to produce organic acid products and hydrogen peroxide from sustainable and domestically produced bio-based feedstocks identified as hydrophilic carboxylic acid (HCA) and hydrophilic dicarboxylic acid (HDA). This

technology was designed by Solugen to satisfy the need for greener technologies to address the scaling, fouling, and corrosion problems associated with industrial cooling systems.

Figure 1 - Solugen's Chemoenzymatic Process



Solugen's AcquaCore™ provides an alternative green technology for cooling systems and industrial end-users that is bio-based and phosphorus-free. The technology is a drop-in replacement to traditional phosphorus-based corrosion and scale inhibitors that are primarily used by large industrial end-users that utilize water treatment chemistry, such as Proctor and Gamble located in Cincinnati, Ohio, Hanging Rock Energy Power Plant located in Lawrence County, Ohio, or Collins Park Water Treatment Plant located in Toledo, Ohio. Specifically, these traditional water treatment programs commonly utilize phosphorus-based corrosion and scale control products, such as hydroxyethylidene diphosphonic acid (HEDP) and phosophonobutane-1,2,4-tricarboxylic acid (PBTC). These commonly used phosphorus-based inhibitors increase nutrient loading, and lead to HABs in surrounding lakes, rivers, and wetlands. In general, one pound of phosphorus in the waterways typically generates about 500 pounds of wet algae (SePRO, 2021). This eutrophication has been documented to cost the United States (U.S.) over $2 billion annually (Dodds et al., 2009). Solugen's AcquaCore™ products enables high-quality chemical passivation and corrosion protection for its end users, as well as increasing the efficacy of incumbent products.

Solugen indicates that the bio-based corrosion and scale water treatment technology, AcquaCore™ is highly effective in providing corrosion protection and scaling control in a variety of cooling water conditions. In addition, the technology is considered by Solugen to be a green chemistry that is non-toxic to aquatic life, phosphorus-free, zinc-free, and bio-based that can improve water quality index.

Although not considered a part of the evaluation criteria for the H2Ohio TAP project objectives, Solugen's AcquaCore™ bio-based product was also certified to be carbon-negative by an independent 3rd party through completion of a life cycle assessment. The 3rd party life cycle assessment is provided in Attachment 1 of this report (Solugen, n.d.).

4.0 TECHNOLOGY EVALUATION

This section of the report addresses each of the criteria identified by Ohio EPA to be included in the independent evaluation process.

4.1 CONCEPTUAL MODEL REVIEW

Solugen did not provide a conceptual model for review but have been researching and developing commercialized green chemistry scaling and corrosion inhibitors since 2016, using novel molecules to replace or reduce usage of more traditional nutrient loading materials, such as phosphates and phosphonates. Solugen's chemical process is protected by 10 pending enzyme and process patents and 14 pending application patents which cover applications across the water treatment, energy, flavors, and fragrances, and construction applications. Solugen currently has two different products for corrosion protection and scale control for water treatment, including AcquaCore™ and AcquaCoreX™. These products were previously identified as BioChelate™ and BioChelate™ Pro in the H2Ohio TAP proposal, respectively. Solugen claims that AcquaCore™ provides water treatment customers with an estimated 80% reduction in their phosphorus usage while AcquaCoreX™ formulations can provide phosphorus free water treatment products. Key aspects of the AcquaCore™ technology include the following:

1. Can reduce the corrosion rate in mild steel by 50% while reducing the phosphorus content by 50% in traditional scale control and corrosion inhibitor products.
2. Can reduce the corrosion rate in copper applications by 91% when compared to traditional tolytriazole formulations.

Solugen indicated that the technology was successfully demonstrated utilizing synthetic waters expected to be representative of the Lake Erie watershed through studies completed by Solugen under the direction of Dr. Donald Johnson (former Research and Development Tech Fellow at Ecolab, Inc.). Based on a comparison to the City of Cleveland water quality conditions reported in 2020 (Cleveland Water, 2020), the synthetic water evaluated for this study were reported to be equal to or more severe than conditions expected for the Lake Erie watershed project. These initial test results showed a (1) reduction in mild carbon steel corrosion when compared to phosphorus-based product, and (2) reduction in copper applications when compared to conventional azole formulas. Based on the initial results, Solugen's AcquaCore™ technology is expected to decrease the maintenance and operations requirements for industrial water treatment users due to increased corrosion protection and improved asset uptime. Additionally, Solugen reported that the technology is currently used by some Association of Water Technologies (AWT) companies in their scale and corrosion control product formulations reducing the overall usage of nutrient loading materials.

Solugen indicated that AcquaCoreX™ is an emerging technology and are planning on conducting validation studies for corrosion and scale inhibition in the near future. Solugen's had some initial discussions with faculty from Ohio State University, College of Engineering since they are a prime research and development candidate for completing the AcquaCoreX™ validation studies in their Fontana Corrosion Center research laboratory. This data, when it becomes available, should provide data that will further assist in evaluating performance of the Solugen technology in reducing nutrient loading in the Lake Erie watershed.

The anticipated benefits of AcquaCoreX™ are phosphorus and zinc free water treatment programs, galvanized zinc white rust corrosion protection and aluminum corrosion protection. All three of these water treatment challenges are currently considered to be unsolved problems that the industry faces today and AcquaCoreX™ research has the potential to provide a timely and environmentally friendly solution to meet these needs.

Since their proposal submission to H2Ohio TAP (Solugen, 2021), Solugen has completed a series of corrosion and scale inhibitor tests to evaluate the AcquaCore™' technology's effectiveness in reducing nutrient loading through replacement of phosphorus-based products or enhancement of existing formulations to reduce use of phosphorus-based products. The results of these studies are discussed in more detail in Section 4.3. Solugen is also currently building a commercial-scale enzyme-based chemical plant in Houston, Texas, to produce AcquaCore™ and AcquaCoreX™ bio-based molecules that is scheduled to start production soon.

4.2 FATAL FLAW ANALYSIS

A fatal flaw analysis was not submitted as part of the Solugen's proposal for AcquaCore™ so a limited fatal flaw screening was completed based on the technology limitations identified during the assessment process and summarized in this report. Only the criteria that require further evaluation or clarification for meeting the goals and objectives of the H2Ohio program were considered and are summarized in Table 1 along with a potential response to address the limitation/flaw identified.

Table 1 - Fatal Flaw Screening – AcquaCore™

Criteria	Limitation/Flaw	Potential Response to Address Limitation/Flaw
Evaluation of Cost	1. Provide a direct cost comparison of sustainable features of the technology vs traditional phosphorus-based systems, such as HEDP or PBTC. 2. Provide evaluation of technology longevity compared to traditional phosphorus-based treatment systems and cost implications.	1. Highlight other long-term cost benefits: • Optimization of chemical selection and feedstock control. • Reduction of operation and maintenance costs associated with equipment fouling at Publicly Owned Treatment Works (POTW). • Reduction of regulatory costs to end users and water quality trading cost differentials. • Return on investment for transition to Solugen technology. • Energy savings for processing compared to traditional systems. 2. Identify lessons learned from recent end users, such as AWT customers, to evaluate observations, challenges, recommendations, and ideas to be implemented or improved upon during future operations of the technology, that includes longevity and potential cost implications.
Large-Scale Evaluation	1) Lack of data quantifying nutrient loading on a large-scale within a watershed -studies limited to laboratory bench-scale.	1. Evaluate at large scale under various small and large user scenarios and monitoring nutrient loading within Ohio watershed conditions.

4.3 REVIEW OF PREVIOUS IMPLEMENTATION OF ACQUACORE™

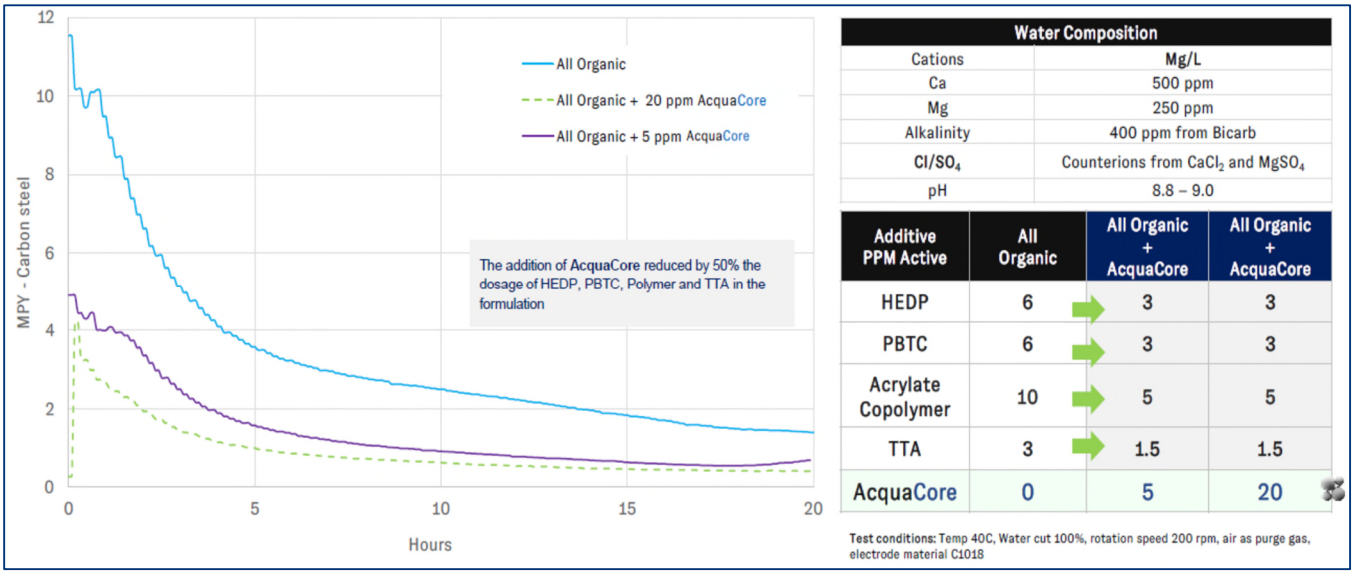
The following presents a summary of internal bench-scale laboratory studies on the AcquaCore™ technology completed by Solugen under the direction of Dr. Donald Johnson (former Research and Development Tech Fellow at Ecolab, Inc.). The test conditions and water composition presented in the studies below are expected to be representative or more stressed than the waters found in the Lake Erie watershed.

4.3.1 Water Treatment Formulation with AcquaCore™, Study 1 - 2021

A first study was completed by Solugen to evaluate the effectiveness of AcquaCore™ on impeding copper-induced corrosion on carbon steel and reducing phosphorus levels in "all organic" formulations. All organic formulations are normally used in light-duty cooling systems with low-to-moderate corrosive conditions and no pH control.

The results of the study showed a 50% reduction in HEDP and PBTC dosage when AcquaCore™ was applied at concentrations of 5 and 10 parts per million (ppm) as shown in Figure 2 (Ngantung et al., 2021).

Figure 2 - AcquaCore™ - 50% Reduction of HEDP and PBTC

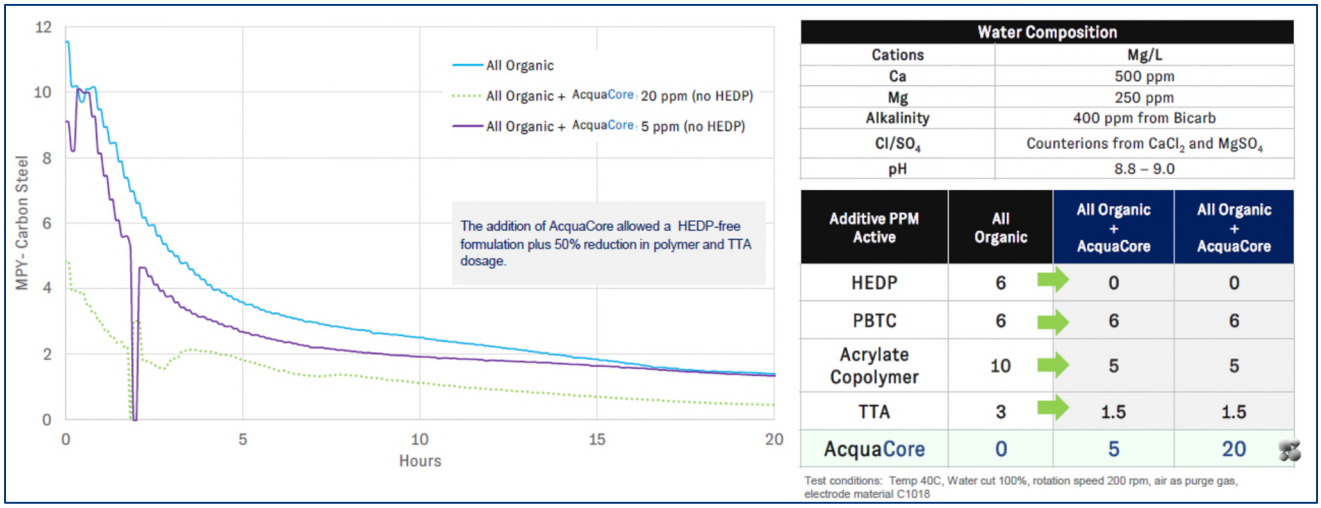


4.3.2 Water Treatment Formulation with AcquaCore™, Study 2 - 2021

A second study was completed by Solugen to evaluate the effectiveness of AcquaCore™ on impeding copper-induced corrosion on carbon steel when HEDP is replaced by this technology. HEDP is typically included in "all organic" formulations as it has a very high phosphorus content, is degraded by halogen biocides, and can precipitate as the calcium-HEDP compound under some conditions. However, it contributes to the mild steel corrosion inhibition of the formulation (Ngantung and Tan, 2021). The following test was performed in a HEDP-free formulation with the mild steel corrosion inhibition replaced by AcquaCore™. The test conditions and water composition remained the same as the previous study.

The test showed that replacing HEDP with 5 ppm of AcquaCore™ provides equivalent mild steel corrosion inhibition as the original dosage, whereas increasing the concentration of AcquaCore™ to 20 ppm improved mild steel corrosion inhibition. Results of the study are presented in Figure 3 (Ngantung et al., 2021).

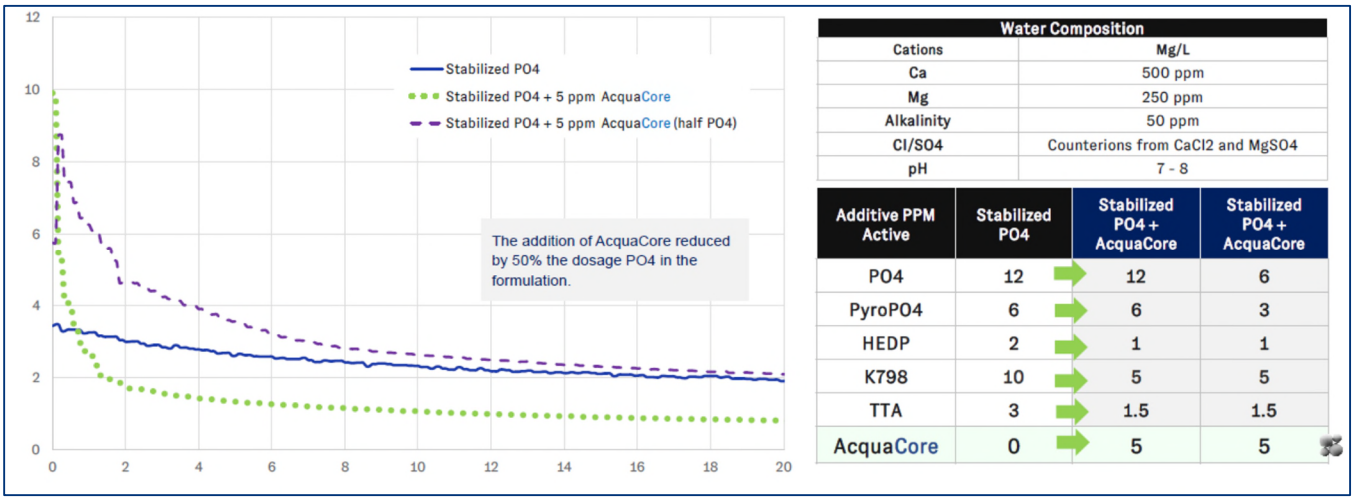
Figure 3 - AcquaCore™ - HEDP-Free Formulation



4.3.3 Water Treatment Formulation with AcquaCore™, Study 3 - 2021

A third study was conducted by Solugen with regard to stabilized phosphate formulations that were historically introduced as chromate replacements and are widely accepted in the heavy industrial market where pH control and severe corrosive conditions are observed (Ngantung and Tan, 2021). The study results show that the corrosion inhibition performance of stabilized phosphate can be improved through the addition of 5 ppm of AcquaCore™ as shown in Figure 4 (Ngantung et al., 2021). The data also suggests that the phosphate dosage can be reduced by half while maintaining corrosion inhibition.

Figure 4 - AcquaCore™ - Stabilized Phosphate Formulations



Additional studies were also completed on AcquaCore™ with the following conclusions:

- Improves halogen resistance in yellow metal formulations when compared to traditional azoles in the presence of copper (II) ion and biocides;
- Improves inhibition of aluminum control with existing formulations; and
- Stability and chemical compatibility with biocides.

4.4 COST EVALUATION

The biggest cost factors associated with meeting the demands of the Lake Erie watershed project include research and development that includes ongoing pilot and field testing, chemical and dosing formulations, and labor required to support pilot and field testing and meet production demands. Table 2 provides a breakdown of anticipated costs to support the Lake Erie watershed project and is based on past experience and recent customer feedback received during Solugen's technical presentation at the AWT convention in Sept 2021 (Ngantung and Tan, 2021):

Table 2- Lake Erie Watershed Projected Costs

Objective	Activity	Time Length	Cost
AcquaCore™ Pilot Studies and Field Trials (2)	Research and Development – RL 8 Validation	In Progress	$200,000
AcquaCore™ Field Trial Support (10 sites in Ohio)	Research and Development Operations – RL 8 Validation	6 months	$1M
AcquaCore™ 3rd party Lab Testing	Research and Development – RL 8 Validation	6 months	$250,000
AcquaCoreX™ Pilot Studies at Ohio State University Corrosion Lab	External Research and Development – RL 8 Validation	24 months	$2M
Scale and Manufacturing of AcquaCore™ and AcquaCoreX™ to support Ohio & Lake Erie Rollout	Operations / Capital – RL 9 Commercial	24 months	$10M

RL = Readiness Level

For the costs highlighted above, it is assumed that each field trial will be 6 months in length and will require on average $100,000 per site to accelerate customer field trials of the Solugen product.

Solugen reported that utilizing their AcquaCore™ technology will decrease the long-term maintenance and operational costs requirements for industrial water treatment users due to increased corrosion protection and improved asset uptime. Specifically, Solugen indicated that use of AcquaCore™ can reduce the corrosion maintenance costs for the average water treatment user by an estimated $500,000 per year. Based on the technical studies presented below, it is expected that use of Solugen's AcquaCore™ product will substitute phosphorus-based chemistries 1:1 and will have the added benefit of reducing the resultant nutrient loading in the Lake Erie watershed. It is expected that the funds from the H2Ohio program will be one time per customer and be used to accelerate the customer trial process and to accelerate adoption of the AcquaCore™ technology.

Once customers are switched to the AcquaCore™ product, it is expected that industrial end users will permanently switch to the AcquaCore™ technology due to its lower recurring operating costs and environmental benefits over the traditional phosphorus water treatment technologies.

Solugen's technology is designed to be a "drop-in" replacement to traditional phosphorus-based chemistries that water treatment customers commonly use today so no costs associated with infrastructure upgrades were identified.

The following figures present two cost scenarios provided by Solugen for comparison of their AcquaCore™ technology to conventional treatment for a large user (Table 3) and small user (Table 4). Cost assumptions used in preparing the two scenarios presented in Tables 3 and 4 include the following:

- Facility currently using an HEDP + PBTC product and switching to a PBTC AcquaCore™ formulation. Solugen estimates that this change will reduce the phosphorus content by at least 50%;
- Based on the Solugen HEDP-free formulation shown in Figure 3; and
- Calculated values are based off of initial representative benchtop studies and would be updated based on additional customer field data collected.

Detailed cost data associated with processing and distribution for Solugen's AcquaCore™ technology was not provided. Solugen's AcquaCore™ products are currently manufactured in Houston, Texas at small scale; however, they are currently constructing a 20,000 square feet commercial-scale enzyme-based chemical plant (BioForge™) also located in Houston, Texas. The BioForge™ facility is scheduled to be operating this year and can produce up to 10,000 metric tons of chemicals per year. If selected to support the H2Ohio program, Solugen plans to conduct pilot studies at Ohio State University to validate the AcquaCore™ and AcquaCoreX™ products.

Table 3 - Large User with Carbon Steel Hx

Item	Units	Untreated	Treated Conventional	Solugen AcquaCore Program - Treated With Copper Pitting And White Rust Control
Inputs				
Recirculating Rate	GPM	500,000	500,000	500,000
Delta T	Deg F	15	15	15
Average Exchanger Heat Flux	BTU/Sq Foot	10,000	10,000	10,000
Average Exchanger Life[1]	Years	5.00	7.00	10.00
Cost/Sq Foot Refurbish[2]	$/Sq Foot	$ 50.00	$ 50.00	$ 50.00
Cycles of Concentration	Cycles	8	8	8
Treatment Dosage	mg/l	0	100	100
Treatment Selling Price	USD/P	$0.00	$4.00	$5.00
Treatment P Content[3]	mg/l P	-	5.00	2.50
Cost of P removal from BD[4]	USD/P	$40.00	$40.00	$40.00
Calculated Values				
Evaporation Rate	GPM	6,375	6,375	6,375
Heat Dissipation	BTU/Hr	3,735,000,000	3,735,000,000	3,735,000,000
Estimated Exchanger Area	Sq Foot	373,500	373,500	373,500
Cost for Full Plant Hx Refurbish	USD	$ 18,675,000.00	$ 18,675,000	$ 18,675,000
Hx Refurbish Cost/Year	USD	$ 3,735,000.00	$ 2,667,857	$ 1,867,500
Blowdown	GPM	911	911	911
Blowdown	Million P/Year	478.67	478.67	478.67
Treatment Consumption	P/Year	-	47,867	47,867
Treatment Cost	USD/Year	$ -	$ 191,469	$ 239,336
Pounds of P In Blowdown	P/Year	$ -	$ 2,393	$ 1,197
Cost to remove P	USD/Year	$ -	$ 95,734	$ 47,867
Treatment + Refurbishment Cost	USD/Year	$ 3,735,000	$ 2,957,453	$ 2,155,900
Product Cost + P Removal	USD/Year	$ -	$ 287,203	$ 287,203

NOTES

[1] Bashar et al. 2017.
[2] Based on calculation of $20,000 to retube a carbon steel exchanger with 100 0.5 inch diameter 30 foot tubes
[3] Phosphorus content of a standard stabilized phosphate program and a reduced phosphorus version with HCA.
[4] Nakahara et al. 1994.

$/sq. foot - Dollars per square foot
BD - Blow Down
BTU - British Thermal Units
BTU/hr- BTU per hour
BTU/sq. foot- BTU per square foot
GPM - Gallons per minute
Hx- Heat Exchanger
mg/L - Milligrams per liter
mg/L P - Phosphorus in milligrams per liter
Million P / Year = Millions of pounds of water blowdown per year at the end-user
P - Phosphorus
P/Year for Treatment consumption = pounds of water treatment chemistry used per year
P/Year for pounds of P in blowdown = pounds of phosphorus per year that is discharged in the end user's blowdown stream to the outfall
USD - U.S. Dollars
USD/P for Treatment selling cost (Cost the water treatment company charges end-user) = US Dollars per pound of product
USD/P for the cost of P removal from BD = US Dollars to remove 1 pound of phosphorus at a wastewater treatment plant. It is estimated that the cost to remove phosphorus in Lake would be equal to or more expensive than this cost
USD/year - USD per year

Table 4 - Small User with Brass and Galvanized

Item	Units	Untreated	Treated Conventional	Solugen AcquaCore Program - Treated With Copper Pitting And White Rust Control
Inputs				
Recirculating Rate	GPM	10,000	10,000	10,000
Delta T	Deg F	10	10	10
Average Exchanger Heat Flux	BTU/Sq Foot	10,000	10,000	10,000
Average Exchanger Life[1]	Years	10.00	12.00	18.00
Cost/Sq Foot Refurbish[1]	$/Sq Foot	$ 200.00	$ 200.00	$ 200.00
Cycles of Concentration	Cycles	4	4	4
Treatment Dosage	mg/l	0	100	100
Treatment Selling Price	USD/P	$0.00	$4.00	$6.00
Treatment P Content[3]	mg/l P	-	3.00	1.00
Cost of P removal from BD[4]	USD/P	$40.00	$40.00	$40.00
Calculated Values				
Evaporation Rate	GPM	85	85	85
Heat Dissipation	BTU/Hr	49,800,000	49,800,000	49,800,000
Estimated Exchanger Area	Sq Foot	4,980	4,980	4,980
Cost for Full Plant Hx Refurbish	USD	$996,000.00	$ 996,000	$ 996,000
Hx Refurbish Cost/Year	USD	$ 99,600.00	$ 83,000	$ 55,333
Blowdown	GPM	28	28	28
Blowdown	Million P/Year	14.89	14.89	14.89
Treatment Consumption	P/Year	-	1,489	1,489
Treatment Cost	USD/Year	$ -	$ 5,957	$ 8,935
Pounds of P In Blowdown	P/Year	$ -	$ 45	$ 15
Cost to remove P	USD/Year	$ -	$ 1,787	$ 596
Treatment + Refurbishment Cost	USD/Year	$ 99,600	$ 90,789	$ 64,879
Product Cost + P Removal	USD/Year	$ -	$ 7,744	$ 9,531

NOTES

[1] Innovas Technologies. 2016.

[2] Phosphorus content of a standard alkaline phosphate program and a reduced phosphorus version with HCA.

[3] Nakahara et al. 1994.

$/sq. foot - Dollars per square foot

BD - Blow Down

BTU - British Thermal Units

BTU/hr- BTU per hour

BTU/sq. foot- BTU per square foot

GPM - Gallons per minute

Hx- Heat Exchanger

mg/L - Milligrams per liter

mg/L P - Phosphorus in milligrams per liter

Million P / Year = Millions of pounds of water blowdown per year at the end-user

P - Phosphorus

P/Year for Treatment consumption = pounds of water treatment chemistry used per year

P/Year for pounds of P in blowdown = pounds of phosphorus per year that is discharged in the end user's blowdown stream to the outfall

USD - U.S. Dollars

USD/P for Treatment selling cost (Cost the water treatment company charges end-user) = US Dollars per pound of product

USD/P for the cost of P removal from BD = US Dollars to remove 1 pound of phosphorus at a wastewater treatment plant. It is estimated that the cost to remove phosphorus in Lake would be equal to or more expensive than this cost

USD/year - USD per year

Following the pilot studies, Solugen will process the biobased feedstocks at the BioForge™ facility to meet the production demands required for the Lake Erie watershed project. Solugen's manufacturing process relies primarily on biobased feedstock sources that are grown in the U.S. with no reliance on purchase of imported raw materials. Specifically, Solugen utilizes midwestern liquid dextrose corn sugar as its process feedstock and intends to co-locate the BioForge™ process with cellulosic sugar providers in the near future.

Solugen's proposal indicated equivalent costs of $2.00/pound (dry) on average for AcquaCore™ products compared to traditional phosphorus-based products, such as HEDP.

The cost of transportation was identified as an additional minimal cost due to the location of the BioForge™ facility in relation to the Lake Erie watershed project in Ohio.

4.5 SCALABILITY EVALUATION

As indicated in Section 4.4, Solugen's BioForge™ green technology facility is currently operating with the capability to meet the demands for processing the AcquaCore™ technology formulations to support the Lake Erie watershed project. Solugen indicated that AcquaCore™ is designed for low phosphorus water treatment and AcquaCoreX™ for phosphorus free water treatment. AcquaCore™ is a more developed technology that has been in production and currently utilized by water treatment customers who are looking for green chemical products that are only improvements to the existing phosphorus based programs. AcquaCoreX™ is an emerging technology and Solugen is planning on conducting validation studies for corrosion and scale inhibition for further development at a local Ohio university, such as Ohio State University, as previously mentioned in Section 4.1.

Solugen's manufacturing process relies primarily on biobased feedstock sources that are grown in the U.S. with no reliance on imported materials. Solugen currently utilizes midwestern liquid dextrose corn sugar as its process feedstock and can process an estimated 15,000 tons annually. Solugen has estimated a minimum of 665 tons of biobased feedstock material annually would be required to deploy the technology at point source water treatment facilities located within the highest nutrient-impacted areas within the Lake Erie watershed. This estimate is based on AcquaCore™ being able to replace 50% of the phosphorus point source loading in the Lake Erie region.

Solugen can meet or exceed the expected feedstock demands presented above to support the H2Ohio program. For the Lake Erie watershed project, processing would be completed at Solugen's BioForge™ facility located in Houston, Texas that can process biobased material across multiple markets including water treatment, energy, flavors, fragrances, and construction applications. The BioForge™ facility would not require any scalability upgrades.

Distribution of Solugen's "drop-in" replacement technology would be shipped from Houston, Texas directly to the selected Ohio water treatment locations for the Lake Erie watershed project. Solugen also has plans to develop scaled up mini-processing plants in key customer regions in the future.

4.5 INFORMATION GAP EVALUATION

Based on Solugen's technology submission for AcquaCore™, it is necessary to obtain more information about performance of the technology compared to conventional phosphorus-based treatment systems, including (1) quantifying reduction of nutrient loading within the watershed when applied at large-scale and (2) its effectiveness when utilized at water treatment facilities under various small and large water treatment users and watershed conditions in Ohio. To Tetra Tech's knowledge, no large-scale paired studies on nutrient loading comparing AcquaCore™ or other similar technologies to conventional phosphorus-based treatment applications have been performed. There is also a lack of information regarding the long-term performance of AcquaCore™ application longevity compared to conventional treatment applications and should be further evaluated for cost implications.

Based on the experience of Solugen in assisting current AWT customers to plan, design, and implement their AcquaCore™ technology, it is believed that AcquaCore™ will outperform conventional treatment processes with regard to nutrient loading through reduction in phosphate-based formulations and maintaining or improving scale and corrosion inhibition. There is also the expectation that the technology will become more favorable due to its lower environmental footprint as shown in Attachment 1 (Solugen, n.d.) in comparison to conventional chemical processes that will create greater incentive for producers to adopt Solugen's technology when its benefits are fully understood. However, with the overall lack of case studies specific to nutrient loading on a large scale for this type of technology, it is difficult to fully evaluate.

A more detailed economic analysis is also recommended that provides a comparison of the more sustainable long-term cost factors. Cost factors for further evaluation could include (1) reduction of feedstock costs through optimization of chemical selection and control; (2) reduction of operation and maintenance costs associated with equipment fouling at Publicly Owned Treatment Works (POTW); (3) meeting regulatory discharge limits; and (4) overall energy cost savings compared to traditional phosphorus-based systems.

4.6 FEASIBILITY FOR LARGE-SCALE TECHNOLOGY DEMONSTRATION

A large-scale technology demonstration is feasible with Solugen's AcquaCore™ technology. They have existing bio-based feedstock providers and their own processing facility located in Texas with the ability to meet the production demands for the Lake Erie watershed project. Solugen has successfully demonstrated that its AcquaCore™ technology can meet or exceed corrosion and scale performance standards compared to phosphorus-based products at both Solugen (previously presented in Section 4.3). Solugen's technology was tested using multiple synthetic waters that were reported to be representative of the Midwest waters and performance results are expected to be representative of the typical conditions within the Lake Erie watershed. In addition to providing effective corrosion and scale inhibition performance, Solugen's technology is expected to reduce nutrient loading in rivers, streams, and lakes in Ohio by replacing phosphorus-based corrosion and scale inhibitors that are commonly used by industrial water treatment users.

No additional work is required to deploy Solugen's AcquaCore™ technology in support of the Lake Erie watershed project since it is designed to be a "drop-in" replacement similar to traditional phosphorus-based systems that water treatment customers commonly use today. Phosphorus-based chemistries are also

continuously applied in small doses for optimal corrosion and scale inhibition performance and Solugen's AcquaCore™ is applied in a similar manner so no modifications or system upgrades are required for the industrial water treatment users.

If Solugen were to receive funds for a large-scale AcquaCore™ technology demonstration project, their preference would be to introduce a multitude of AcquaCore™ systems across the Lake Erie watershed such as the following:

- Water Treatment Service Companies (Nalco Water, Suez Water Technologies and Solutions, ChemTreat, Inc., etc.);
- Large End Users with Cooling or Boiler Steam Systems (NRG in Avon Lake, Ohio, Davis-Besse Nuclear Power Station, Walleye Power LLC – Bays Shore Plant, etc.); and/or
- Municipal or State-owned Water Treatment Plants (Collins Park Water Treatment Plant, etc.) .

Solugen has primarily been engaging with water treatment service companies to validate and market its AcquaCore™ technologies as these companies provide the recommendations for new water treatment products to end users with cooling or boiler steam systems. Solugen has also found that its AcquaCore™ products are applicable to replace phosphorus-based scale inhibitors and cleaners in reverse osmosis (RO) water treatment applications. Many large RO membrane end users are local municipal or state-owned water treatment plants. The same biobased chemistries that AcquaCore™ is based on are also reported to work well in phosphorus-free cleaning formulations for industrial and consumer applications, such as ware washing, laundry detergents, and alkaline surface cleaners (HAPPI, 2022). It is expected that Solugen's "lessons learned" during development of its AcquaCore™ technology and other biobased industrial cleaners will serve as the technical basis for future research and development under the H2Ohio program.

Following implementation of Solugen's AcquaCore™ technology in the watershed at select locations, monitoring of nutrient loading and corrosion and scale inhibition effects would occur. Funding would be managed between Ohio and Solugen, and Solugen would work with the various end users to install and manage the AcquaCore™ systems. There would be no cost to end users for implementation in a properly designed multi-year cooperative funding agreement, which also could include other contributing partner agencies and organizations that share concerns for the Lake Erie watershed and producer adoption of innovative conservation technologies and approaches. The selected locations would need to have at least one on-site cooling tower, steam boilers, or Heating, ventilation, and air conditioning (HVAC) cooling.

4.7 FEASIBILITY FOR FULL-SCALE IMPLEMENTATION

Previous small-scale studies summarized in Section 4.3 and the cost scenario data presented in Section 4.4, demonstrate that this technology has the opportunity for success in addressing nutrient loading issues that are contributing to the Lake Erie algal blooms if it is applied on a large-scale. Solugen's AcquaCore™ technology has completed the National Oceanic and Atmospheric Administration (NOAA) Readiness Level of RL 7: prototype system, process, product, service, or tool demonstrated in an operational or other relevant environment. Additionally, Solugen is in the process of completing field trial validation of NOAA RL 8, where technology performance is demonstrated at customer water treatment sites. Solugen's proposal indicated that

implementation of the AcquaCore™ technology at a new water treatment location can be completed within 30 days due to its drop-in replacement nature in existing systems.

The processing and use of Solugen's bio-based feedstock, utilizing liquid dextrose corn sugar, has also been proven as a sustainable option compared to use of traditional phosphorus-based systems. Other sustainable features of Solugen's technology are summarized in a life cycle assessment provided in Attachment 1. Past studies also show that mixed formulations of AcquaCore™ with other high soluble phosphorus-based chemicals used for corrosion and scale inhibition, has the potential to reduce nutrient loading and provide wastewater treatment facilities with greener options that can reduce operations and maintenance and meet nutrient regulations.

Additional data and regulatory incentives may further demonstrate the economic and environmental benefits of nutrient reduction in the industrial water services market.

4.8 PROBABILITY OF SUCCESS

Previous studies of Solugen's AcquaCore™ technology demonstrate that this technology is capable of reducing nutrient loads that are contributing to the Lake Erie algal blooms if it is applied on a large-scale. Success in most of the information provided by Solugen has focused specifically on the effects of trace metal ions in the control of calcium phosphates scaling and copper-induced pitting and corrosion through reduction of phosphate dosage in treatment formulations with AcquaCore™ products. When the H2Ohio objectives are used as metrics of success the evaluation is more nuanced; however, this technology provides the use of low-phosphorus water treatment that can have a reduced environmental impact when compared to traditional methods. The probability of success is therefore high if it can be deployed at a sufficient scale, which will be dependent on the incentives offered to industrial water treatment users and their greater awareness of the long-term sustainability of this technology and positive environmental and corrosion and scale inhibition effects.

4.9 FINANICAL VIABILITY

A report published by Clean Tech on September 9, 2021, identified Solugen as a sustainable chemical startup company that was established in 2016 and headquartered in Houston, Texas (Clean Tech, 2021). It was reported that Solugen has raised $357 million through several venture capital firms operating in the U.S., Europe, and Asia with its valuation exceeding $1.8 billion and its total capital raised to over $400 million. Solugen designs and grows enzymes in its BioForge™ facility that can turn sugar into chemicals that are needed to make a variety of products and used in many industrial and water treatment applications.

Based upon this information Tetra Tech believes that Solugen is financially viable to support and maintain implementation of the AcquaCore™ technology in Ohio.

4.10 QAPP

Solugen did not provide any raw data to support the technology evaluation and therefore no Quality Assurance Project Plan (QAPP) was provided. Solugen provided information primarily on the performance of its mature

technology, identified as AcquaCore™, much of which was completed through stringent testing under the direction of Dr. Donald Johnson on behalf of Solugen as indicated in Section 4.3. Solugen also recently presented a technical article at the AWT water treatment conference that included a 3rd party peer review of their technology. The data presented in the literature provided by Solugen are therefore assumed to be of high quality.

Tetra Tech recommends that a QAPP be developed prior to implementation of a pilot study or as part of a demonstration project.

4.11 DATA VALIDATION

Data validation and quality assurance/quality control checks are not mentioned in the original technology submission for the Solugen AcquaCore™ technology. However, the data reported from the studies completed under the direction of Dr. Donald Johnson and used to prepare a portion of this evaluation are considered to be validated.

4.12 SUPPLY CHAIN

Tetra Tech did not identify any obvious supply chain risks associated with the Solugen AcquaCore™ technology. Solugen's biobased feedstock sources are grown in the midwestern U.S. and are readily available with no reliance on imported materials.

4.13 ENVIRONMENTAL RISKS

Solugen's AcquaCore™ technology is predominantly made up of a biobased organic acid. The U.S. Environmental Protection Agency (U.S. EPA), Toxic Substances Control Act (TSCA) recently designated this biobased organic acid and associated salts as "low priority" substances for further evaluation under the chemical substances inventory list due to the favorable toxicity profiles (U.S. EPA, 2020). This designation is based on available health and environmental effects, exposure potential, persistence, bioaccumulation, expected conditions of use, and production volume information. Details on U.S. EPA TSCA's designation for this biobased organic acid and salts are presented in more detail below.

4.13.1 Aquatic Effects

The U.S. EPA assessed environmental hazards from acute exposures to the biobased organic acid. The results for this biobased organic acid salt provide sufficient information to indicate that this biobased organic acid is expected to have low environmental hazard for aquatic vertebrates, aquatic invertebrates, and algae. Chronic aquatic toxicity values for the biobased organic acid were estimated by U.S. EPA's Ecological Structure Activity Relationships Program (ECOSAR) model using the neutral organics chemical class. The predicted toxicity values provided sufficient information to indicate that this organic acid is expected to have low chronic environmental hazard.

The U.S. EPA assessed environmental hazards from acute exposures to this biobased organic acid. No adverse effects were observed in aquatic invertebrates and aquatic vertebrates exposed to this biobased organic acid salt at the highest doses tested (100 milligrams per liter [mg/L] and 1,000 mg/L, respectively), resulting in no

effects expected at concentrations less than 100 mg/L for aquatic vertebrates (OECD, 2004; ECHA, 2002) and 1,000 mg/L for invertebrates (OECD, 2004; ECHA, 2001a). Two studies evaluated the effects of acute exposures of this biobased organic acid salt to algae. *S. subspicatus* exposed to this biobased organic acid salt resulted in 70% biomass inhibition at 100 mg/L (ECHA, 2001b), while *S. capricornutum* exposed to this biobased organic acid salt resulted in a no observed effect concentration of 560 mg/L based on growth rate (OECD, 2004). The toxicity values indicate that this biobased organic acid salt has low environmental hazard for aquatic vertebrates, aquatic invertebrates, and algae, based on the low-concern criteria acute aquatic toxicity threshold of 100 mg/L.

4.13.2 Persistence

U.S. EPA assessed environmental persistence for biobased organic acids using read-across from an analog, organic acid salt. An experimental Organization for Economic Co-operation and Development (OECD) Guideline 301D biodegradation study demonstrated that this biobased organic acid salt biodegraded by greater than 60% in 10 days, confirming it is aerobically readily biodegradable in a sludge inoculum (OECD, 2004). Further, using read-across from this biobased organic acid salt, this biobased organic acid is expected to anaerobically biodegrade completely after 35 days (OECD, 2004). No degradation products of concern were identified for this chemical substance. The available biodegradation results meet the low concern benchmark by readily biodegrading within 28 days under aerobic conditions and provide sufficient information to indicate this biobased organic acid has low potential for persistence.

U.S. EPA assessed environmental persistence for this biobased organic acid salt. An experimental OECD Guideline 301D biodegradation study demonstrated this substance biodegraded by greater than 60% in 10 days, confirming it is aerobically readily biodegradable in a sludge inoculum (OECD, 2004). Further, this chemical anaerobically biodegrades completely after 35 days (OECD, 2004). No degradation products of concern were identified for this chemical substance. The available biodegradation results meet the low-concern threshold by readily biodegrading within 28 days under aerobic conditions and indicate this chemical has low potential for persistence.

4.13.3 Bioaccumulation Potential

Based on the estimated bioaccumulation factor values of 0.9 using the Estimation Programs Interface Suite models, the U.S. EPA concluded that both the biobased organic acid and the biobased organic acid salt have a low potential for bioaccumulation in the environment.

Solugen has U.S. EPA TSCA clearance for the AcquaCore™ technology. Also, Solugen has already submitted its AcquaCoreX™ technology for the U.S. EPA TSCA approval through the pre-manufacture notice (PMN). The PMN for AcquaCoreX™ is approved and the notice of commencement is in the process of being filed. Furthermore, Solugen's bio-based chemistry is considered non-toxic and readily biodegradable based on studies from literature, using standardized OECD testing.

4.13.4 Health & Safety

It is unlikely that implementation of the AcquaCore™ technology poses a significant risk to the health and safety for industrial water treatment users due to its favorable toxicity profile as previously indicated in Section 4.14. The "drop in" application technique is also compatible with current industrial water treatment practices. As with most industrial settings, following a health and safety plan and use of proper personal protective (PPE) equipment is necessary to reduce worker's exposure risk by inhalation and skin contact.

4.14 COMMUNITY PERCEPTION & DISPROPORTIONATE IMPACT

Limited information is available to assess the community acceptance of this technology due to its limited use; however, it is expected to be positive with no disproportionate impacts. Providing a more sustainable corrosion and scale inhibition product and reducing nutrient loading is seen as a necessary step towards reestablishing a quality watershed within the Lake Erie region. Continued community involvement and regulatory agency support will be necessary for long term success. Solugen's AcquaCore™ technology has been well received by the community to date as demonstrated below (Solugen, 2021):

- Forbes Next Billion-Dollar Startups, 2020;
- Oil and Gas Awards – Water Management Company of the Year, 2019;
- Houston Business Journal's Innovation Award, 2019;
- Akzo Nobel's Imagine Chemistry Award Winner, 2018;
- U.S. EPA Safer Choice Partner of the Year - Innovation, 2018; and
- MIT 100K Competition – 2nd Prize, 2016 .

Solugen's AcquaCore™ water technology was also presented and published in the following industry journals, conferences, and magazines:

- The Analyst Technical Supplement – published by Association of Water Technologies (AWT) in Fall 2021 issue (AWT, 2021a).
    - Can a Biobased Additive Improve Performance and the Environmental Profile for Cooling Tower Formulations?
- Water Technology Magazine – published in December 2021 issue (Water Technology Magazine, 2022).
    - Bio-based additives are solving performance challenges in heavy-duty water treatment formulations
- AWT Convention 2021 – presented technical presentation on Sept 25, 2021 (AWT Conference, 2021b).
    - Novel biobased additive to improve performance and environmental profile in cooling tower formulations

4.15 WASTE/BY-PRODUCT MANAGEMENT REQUIREMENTS

There are no waste and/or by-product management requirements that will impact implementation of the AcquaCore™ technology.

5.0 FINDINGS AND OPINIONS

Based on a review of the available information and correspondence with Solugen, Tetra Tech has the following conclusions regarding the AcquaCore™ technology:

- Agreement that the AcquaCore™ technology is effective at controlling scale and corrosion and can reduce phosphorus content in dosage formulations as demonstrated in the studies provided in Section 4.3.

- Additional research is needed on how AcquaCore™ performs at reducing nutrient loads (i.e., instead of relying on lab studies) at large scale within the watershed. This could be a goal of a pilot project funded by H2Ohio along with Solugen's emerging product identified as AcquaCoreX™ (phosphorus-free technology).

- AcquaCore™ is a cost effective technology when compared to other phosphorus-based treatment practices as shown in Section 4.4, especially when financial assistance becomes available to support its planning, design, and implementation and its reduction of phosphorus content and effectiveness at controlling scaling and corrosion are considered. Estimated total cost savings per year for the average water treatment user is $500,000 in maintenance. A more comprehensive analysis is recommended to evaluate sustainable long-term cost factors, such as (1) optimization of chemical selection and control; (2) reduction of operation and maintenance costs associated with equipment fouling at POTWs; (3) reduction in greenhouse gases and meeting regulatory discharge limits; and (4) overall energy cost savings compared to traditional phosphorus-based treatment systems.

- Additional research is needed on longevity and any life cycle cost implications (if applicable) of the AcquaCore™ technology compared to traditional phosphorus-based treatment.

- No scalability or supply chain issues were identified for the technology, and feedstocks materials are grown in the midwestern U.S.

- Biggest barrier to widespread adoption of AcquaCore™ is industrial end user willingness, which could be further evaluated through a pilot project funded by H2Ohio.

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ATTACHMENT 1

Solugen

Sustainable Water Treatment Chemistry:

Life Cycle Assessment (LCA) of Solugen's AcquaCore™ Line in Industrial Water Treatment (IWT) Applications

Solugen Facts

Solugen's life cycle of greenhouse gas (GHG) emissions associated with AcquaCore™ have far lighter environmental footprint than other commonly used corrosion and scale control traditional chemistries.

Solugen's domestic chemoenzymatic process delivers innovative biobased solutions to the industry, enabling efficacious, sustainable and decarbonized technology for a changing world.

Solugen's biobased solutions are the lowest carbon intensity molecules when compared to traditional alternatives. Ultimately, AcquaCore™ is sustainable without compromised performance.

Solugen's Environmental Benefits at a Glance

These facts highlight the environmental benefits when IWT service companies replace 1,000 metric tons of Hydroxyethylidene diphosphonic acid (HEDP) per year with AcquaCore™:

- 2.5 million miles driven by an average passenger vehicle
- Saving enough energy to power over 200 households for one year
- Absorbing CO2 equal to over 15,000 tree seedings grown for ten years For every ton of AcquaCore™ used to replace HEDP, more than 3 tons of GHG equivalents are reduced.

Mini-mill FAQs

Which raw materials are used besides sugar/corn/beets?
Any glucose feedstock is sufficient. Corn in the US, sugar beets in the EU, tapioca/rice in Asia. In the near future, we intend to co-locate with cellulosic sugar providers.

Is it energy-intense, are there by-products?
There are no by-products and the process can be operated without natural-gas-fired boilers by using mechanical vapor recompression to drive evaporation. 1200 kW are required to produce one ton of product.

What capacity could a plant make and how does it work?
Plants can be sized anywhere from 5,000 tpy on the low side beyond 100,000 tpy on the large side. Solugen's first commercial plant is 10,000 tpy.

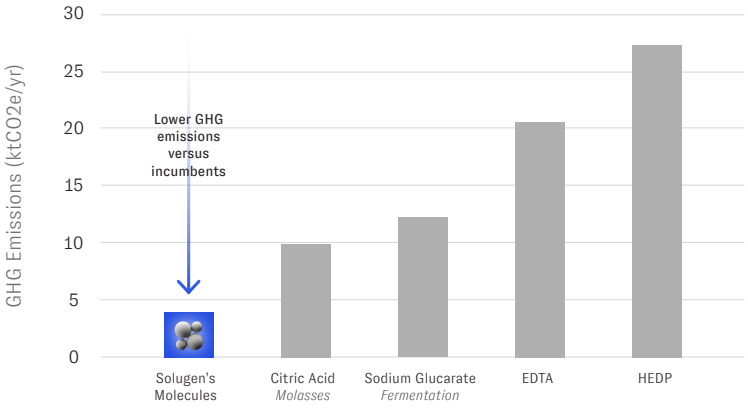
How would a modular plant work?
Modular manufacturing enables the same plant to be constructed by the same vendors, ensuring quality and continuity. Once a site is selected, construction can begin immediately even without site permits. The modular fabricators begin procuring and building 3mx3mx12m frames, and all equipment is mounted on these frames. Once site permits are achieved and the concrete is poured, then the plant arrives by sea and by truck in these modules. They get placed on the concrete and connected together.

Do they have to source beets or could by-products from their process be used?
Solugen would have to evaluate their by-product streams for sugar content. It is easiest to source the sugar syrup feedstock.

Would Solugen run a plant at their site or is the process licensed for the customer to run it?
Either model can be considered. Solugen is investing heavily into automation so the plants run as simply as possible with high uptime and reliability. On the peroxide/chelant combo, we have already developed this product and actively sell it in truckload quantities to our water treatment customers in the energy space.

Solugen's Biobased Molecules GHG Profile

Life Cycle GHG Emissions for end use of Wastewater Treatment (mass allocated).
Study performed by Life Cycle Associates 2021



These values are based on a usage of 9kTa/yr of each molecule