Nutrient Recovery

Process Overview For Operators

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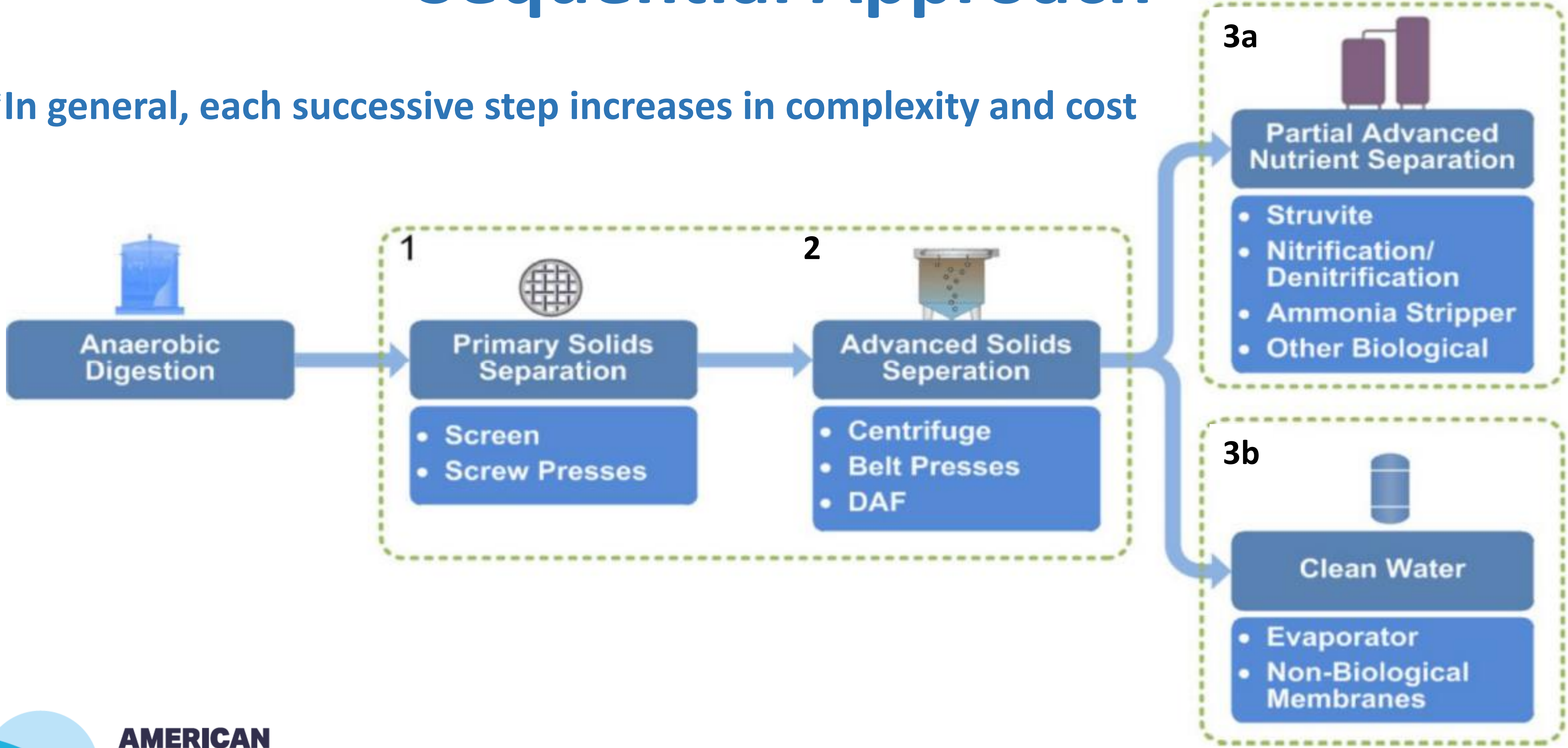
Sequential Approach

*In general, each successive step increases in complexity and cost



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Drivers

Inclusion of each potential step, technology choice, vendor choice is a result of analysis of key drivers:

- **Industry classification**—i.e. industrial, municipal, or agricultural
- **Specific feedstock**—i.e. swine, dairy, or poultry feedstock
- **Scale**—i.e. flows, mass/nutrient loadings
- **Location**—i.e. weather, urban/rural, utilities, work environment
- **Constituent(s) of concern**—i.e. pathogens, nitrates, P-eutrophication, PM 2.5, etc.
- **Capital and operating cost constraints—**i.e. tipping fees, tax-payers, private business
- **End use/disposal**—i.e. value-add, field application, sewer, receiving water, etc.

STEP 1: Coarse or Primary Solids

Each digestate is different—some with obvious settleable solids, with or without a fibrous nature, while others devoid of such solids and instead composed of just suspended and/or dissolved solids. If present, removal of these settleable solids is for:

- **Reduction of Bulk TS, BOD/COD Loading—**As these constituents can interfere with downstream processing—best to remove them up-front.
- **Reduction of Storage/Hauling/Disposal Costs**—Reduced mass, density, viscosity, settling in storage tanks
- **Value-Add**—Via removal, these solids could be separately, further processed

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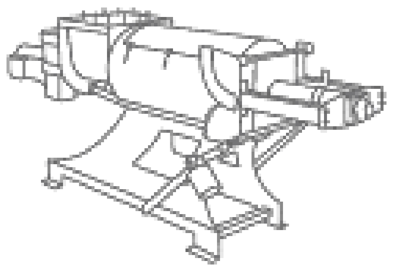
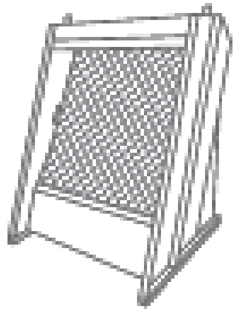
Coarse Solids Separation

Although pre-digester treatment can include rags, grit, and sand separation using lanes, clarifiers, and screens, the focus of this review is on separation post-digestion.

Screw Press



Slope Screen



Rotary Screen

Essentially, three general classes of screens are utilized for post-digestion, coarse solids separation: Screw presses, slope/inclined screens, and rotary screens. Each has their own set of ideal application conditions, plusses/minuses, and unique operational concerns.

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Operator Overview

Whatever the choice of equipment for coarse solids separation, operation involves not just maintenance of separation equipment but often pre-post auxiliary systems, conveyance, and handling of produced solids.

- **Piping/Flow**—flow control, pumps, weather, struvite, clean-outs, pipe sizing
- **EQ Tanks/Pits**—agitators, mixers, odor control systems, periodic clean-out
- **Separation Equipment**—screens, grease/oil, augers, pressure/acid wash, etc.
- **Conveyance**—grease, belt replacement, motors, bearings/rollers/splicing, washings
- **Electrical**—drives, timers, sensors, flow meters, interconnected system
- **Handling**—front-end loader certification/skill
- **Post**—drying, compost, bagging, etc.

STEP 2: Fine or Suspended Solids

Digestate, regardless of settleable solids, contain suspended solids—these solids are often associated with nutrients—organic N and P:

- **Reduction of Bulk TS, BOD/COD Loading—**These solids can also interfere with downstream processing—best to remove up-front.
- **Reduction of Storage/Hauling/Disposal Costs**—Reduced mass, density, viscosity, settling in storage tanks
- **Nutrient Partitioning**—Excellent way to cost-effectively separate bulk of nutrients
- **Value-Add**—Via removal, these solids could be separately, further processed

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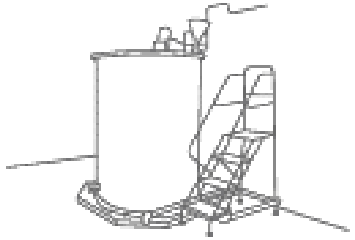
Fine Solids Separation

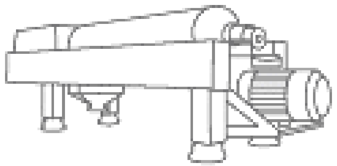
After coarse solids separation, is the potential for further solids treatment, specifically the separation of suspended, fine solids—solids which are often associated with significant levels of nutrients.

Suspended, fine solids can be removed through settling/clarification, but typical technologies for post-digestion involve various methods for chemical flocculation—or if chemicals are to be avoided, decanting centrifuge or membrane separation.

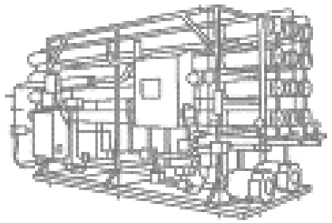
Chemical Flocculation



Decanting Centrifuge



UF Membrane



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Operator Overview

As still a solids separation process, fine solids separation involves the same pre-post auxiliary systems, as well as additional components due to the added complexity.

- **Piping/Flow**—flow control, pumps, weather, struvite, clean-outs, pipe sizing
- **EQ Tanks/Pits**—agitators, mixers, odor control systems, periodic clean-out
- **Separation Equipment**—screens, grease/oil, augers, pressure/acid wash, etc.
- **Additional Components**—chemical storage/safety/reaction, chemical spills, mathematical dosing calculations, high pressure/G-forces, greater critical thinking
- **Conveyance**—grease, belt replacement, motors, bearings/rollers/splicing, washings
- **Electrical**—drives, timers, sensors, flow meters, interconnected system
- **Handling**—front-end loader certification/skill
- **Post**—drying, compost, bagging, etc.

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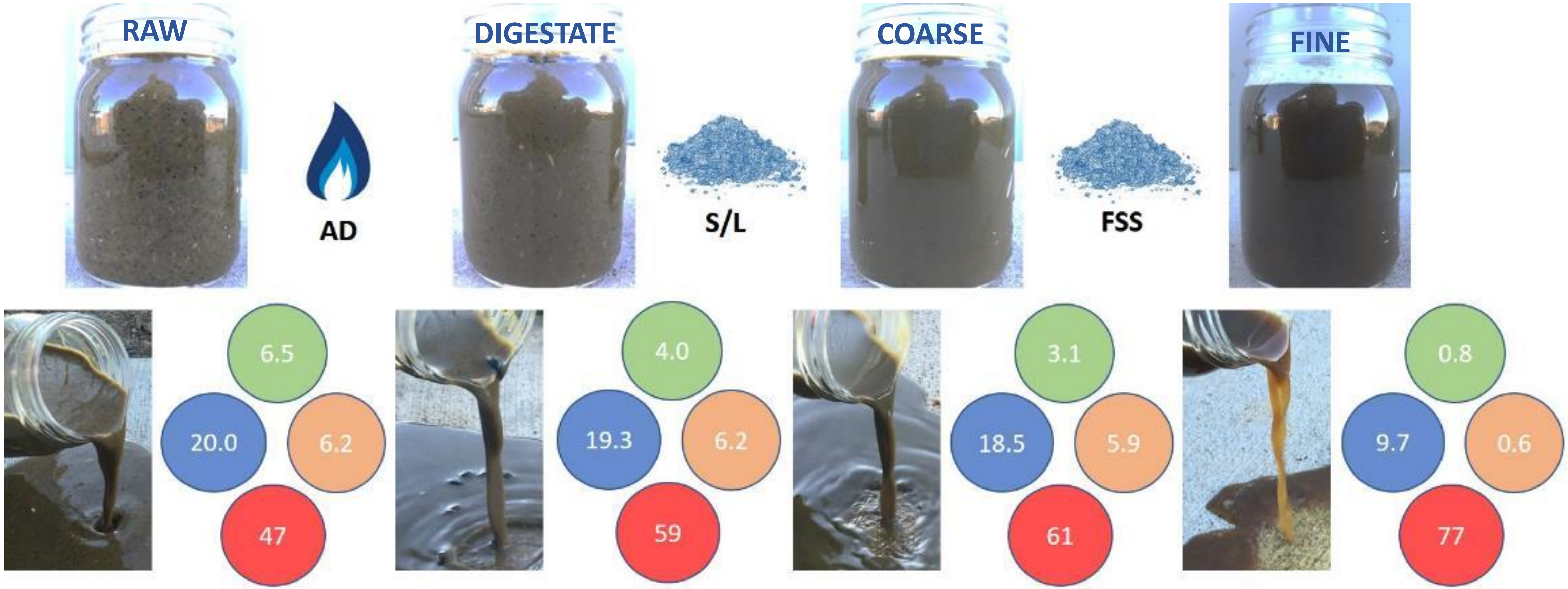
Combined Solids Separation—Impact



% Total Solids | lbs. N/1,000 gallons | lbs. P_2O_5/1,000 gallons | % N as Ammonia

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Dairy Manure Example: Raw—Digestate—Coarse—Fines

STEP 3a: Partial Advanced Nutrient

After solids are removed, the resulting digestate with mostly dissolved solids can be further treated to remove soluble forms of nutrients particularly ammonia and phosphates.

- **Meeting Total N and Ammonia-N Requirements—**Remove ammonia-N to the point of meeting discharge requirements
- **Meeting Total P and Phosphate Requirements**—Remove phosphorous to low levels required by regulations
- **Nutrient Partitioning/Value Add**—More costly techniques for partitioning of soluble N/P, and production of valued fertilizer products as well as further treated liquid

STEP 3a: Struvite Crystallization

Instead of uncontrolled build-up of struvite at facility, controlled crystallization of struvite has been commercialized for treatment of various digestates, particularly municipal digestate.

- **Chemical addition for control of pH and magnesium/ammonium/phosphate ratios**
- **Up-flow crystallizer using seed crystal nucleation—concentrated slow-release fertilizer 6:29:0:10(Mg)**
- **Operations—Chemical handling/storage/safety, pumps, flow and pressure controls, solids handling, electronics, clean-outs/pressure wash, system optimization/critical thinking**

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STEP 3a: Nitrification/Denitrification

Sequencing of aerobic bacteria to convert N to nitrate and subsequent anaerobic conversion to non-reactive N_2 gas. Traditional and partial pathways.

- **Control of flows/recycles, aeration, oxidation/reduction potentials, biological growth/seeding to accomplish conversion**
- **No by-product so no storage, up-grades, marketing, but also energy to lose reactive N**
- **Operations—Sensitive biological process, requiring careful monitoring, testing, and control of systems. Aeration, various complexities of reseeding of bacteria—can be non-slurry, such as worm trickling-filter**

STEP 3a: Ammonia Stripping

Use of pH/temperature to convert aqueous ammonia in digestate to gaseous ammonia for release and subsequent conversion to fertilizer.

- **Air stripping, steam stripping, CO_2 stripping, membrane diffusion or combinations with/without chemical to accomplish conversion and capture.**
- **Particularly useful with high-N digestates—poultry, co-digestion.**
- **Operations—Chemical storage/use/safety, micro-aeration systems, steam systems, membrane systems, contact media towers, pH/temperature control systems, foaming, blowers, pumps, crystallizers.**

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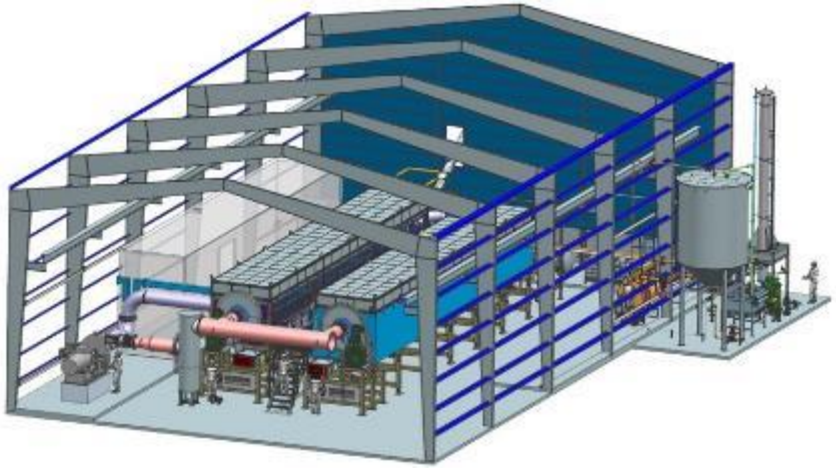
STEP 3b: Clean Water

Prior treatment yielded a reduced solids/nutrient liquid digestate, but one which is still high in salts, pigments/color, and other constituents suitable for discharge or reclaim water. To take the next step requires more complete removal of these impurities—generally at even higher complexity and cost. In general, beyond biological aeration, 2 main approaches.

- **Pressure-driven membranes**
- **Evaporative technologies**



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STEP 3b: Membranes

Sequencing of membranes whereby pressure is used to force liquid through various pore-sized openings, so that large particles are rejected out (concentrate) while small particles are allowed to proceed through (permeate). Eventually, even bacteria/virus and salts can be rejected, leaving 'clean water' suitable for discharge or other reclaim uses.

- **Operations—high pressure pumps, high pressure membrane vessels, recycles, flow controls, pumps, sensor/electronic controls, chemical storage/use/safety, clean-in-place systems, filters**

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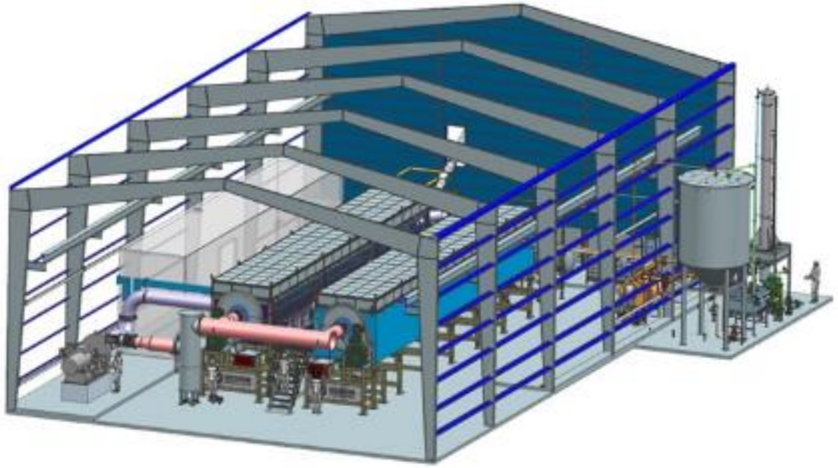
STEP 3b: Evaporation

Sequencing of vacuum evaporators to evaporate water from the digestate, leaving behind a concentrate/solid as well as re-condensed 'clean water', although controls are needed to remove volatiles that left with the water.



- **Use of vacuum systems and mechanical vapor compressors to reduce energy inputs—addition of MVC driers can reduce concentrate to a solid**
- **Operations—vacuum systems, complex MVC systems, distillation/compression systems, volatile conditioning systems, driers, pumps, electrical/thermal/vapor controls, chemical storage/use/safety.**

Auxiliary Systems

Value-add markets are essential to capital/operating expense cash-flow. In particular, solids are usually separated as a wet solid, with little market viability (low nutrient density, hauling/storing water, still putrescent with short shelf-life and not meeting pathogen targets). As such, auxiliary systems to dry, pyrolyze, pellet, compost, etc. the solids can be essential to sales/market penetration.

Dried/Pelleted

Pyrolysis/Char

Co-Composted

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Final Thoughts

- Addition of solid/nutrient/clean water systems create a sequential and integrated pseudo-biorefinery, with potential for significantly increased complexity of operations.

- General principles of walk through, SOP, planned maintenance, reactive maintenance, and administrative reporting/testing/ordering, etc. are required but at additional levels.

- Mechanical, chemical, biological, physical, electrical, thermal, IT principles are all involved and required.

- In order to respond effectively to reactive maintenance needs, working knowledge of each unit operation as well as integrated system required—this working knowledge united with critical thinking and operations skills will 'save the day' and allow for an excellent uptime and performance.