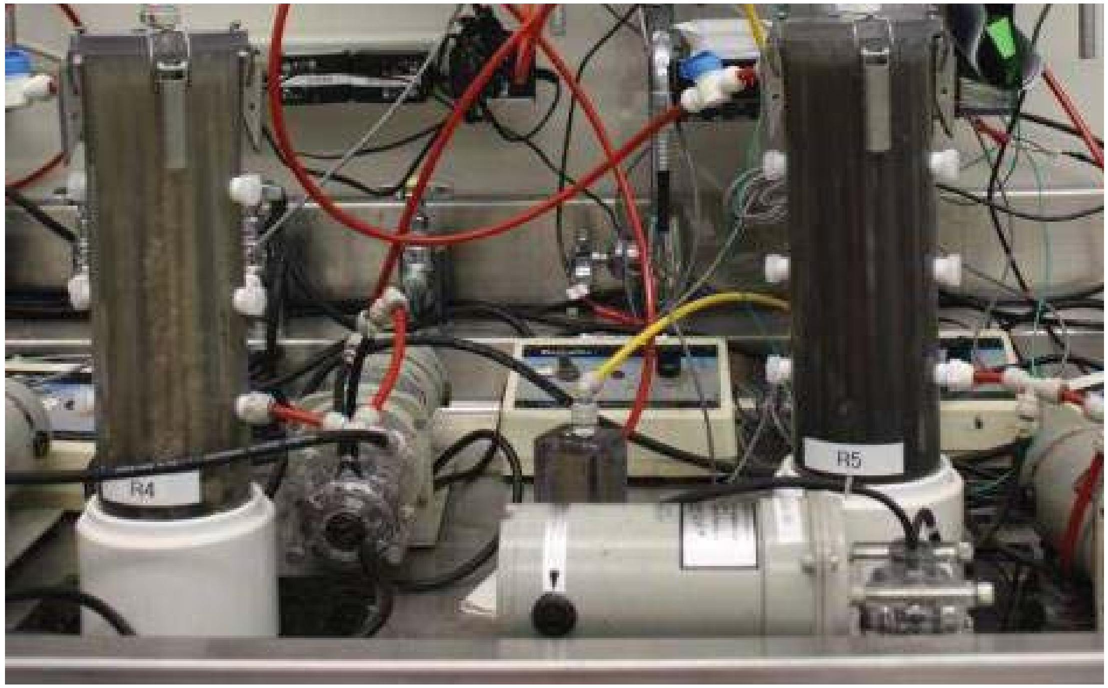
Water Recovery from Brine in the Short and Long Term: A KSC Approach

Griffin Lunn (ESC)
Dr. Orlando Melendez (NE-S)
Steve Anthony (NE-F)

How did we come to these designs?

- KSC has spent many years researching Hollow Fiber Membrane Bioreactors as well as research encompassing:
  - Alternate ammonia removal
  - Advanced oxidation
  - Brine purification technologies
- KSC-ISRU has built an electrolysis cell for the removal of acids in ISRU mining brines
- Our goal is to combine all such technologies

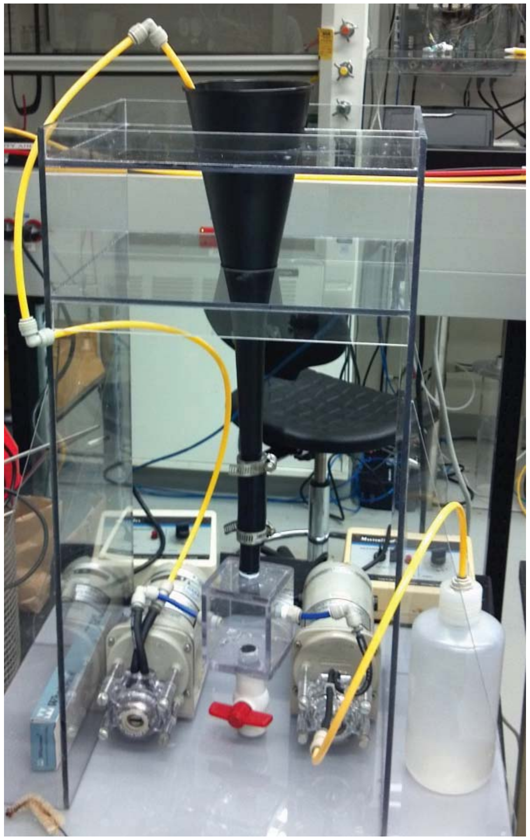
Hollow Fiber Membrane Bioreactors

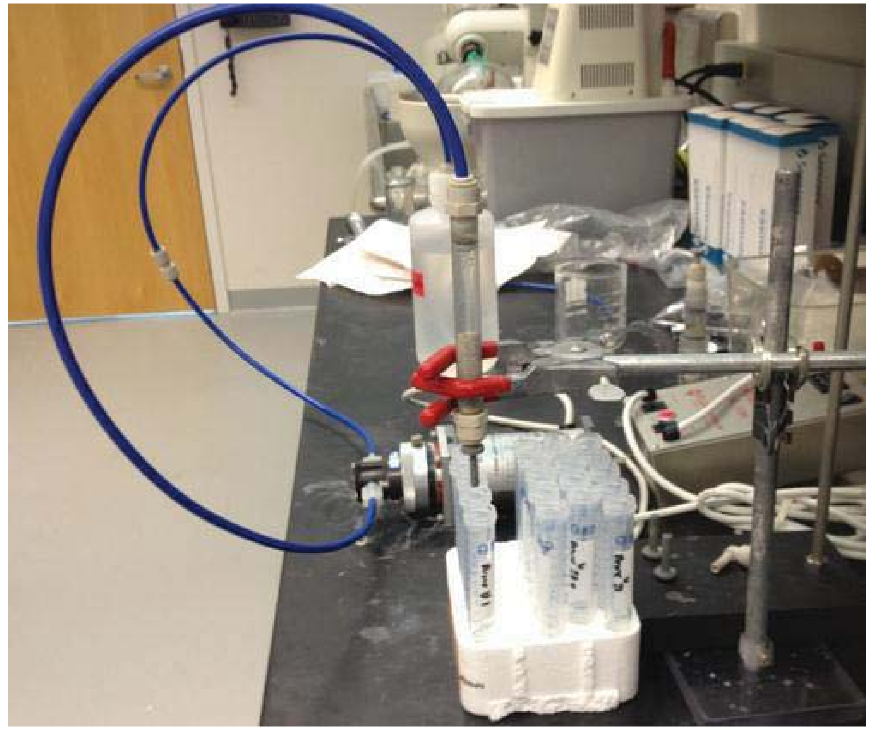


Two-Stage HFMB system for Carbon Oxidation and Nitrification

- KSC has mainly ~1-L and sub-liter bioreactors using silastic tubing with, in most cases, a U-channel design to allow easy construction and operation
- Reactor set-ups have included:
  - Combined-stage bioreactors that perform carbon oxidation, ammonia oxidation, and denitrification
  - Multi-staged reactors perform carbon oxidation and nitrification reactions separately
- We have also worked on bioreactor automation, flow improvements, biofilm attachment, reactor rapid start-up, and reactor dormancy studies

Advanced Ammonia Removal





Left: Fluidized Bed Test Stand
Above: Plug Flow Test Stand (Mock Up)

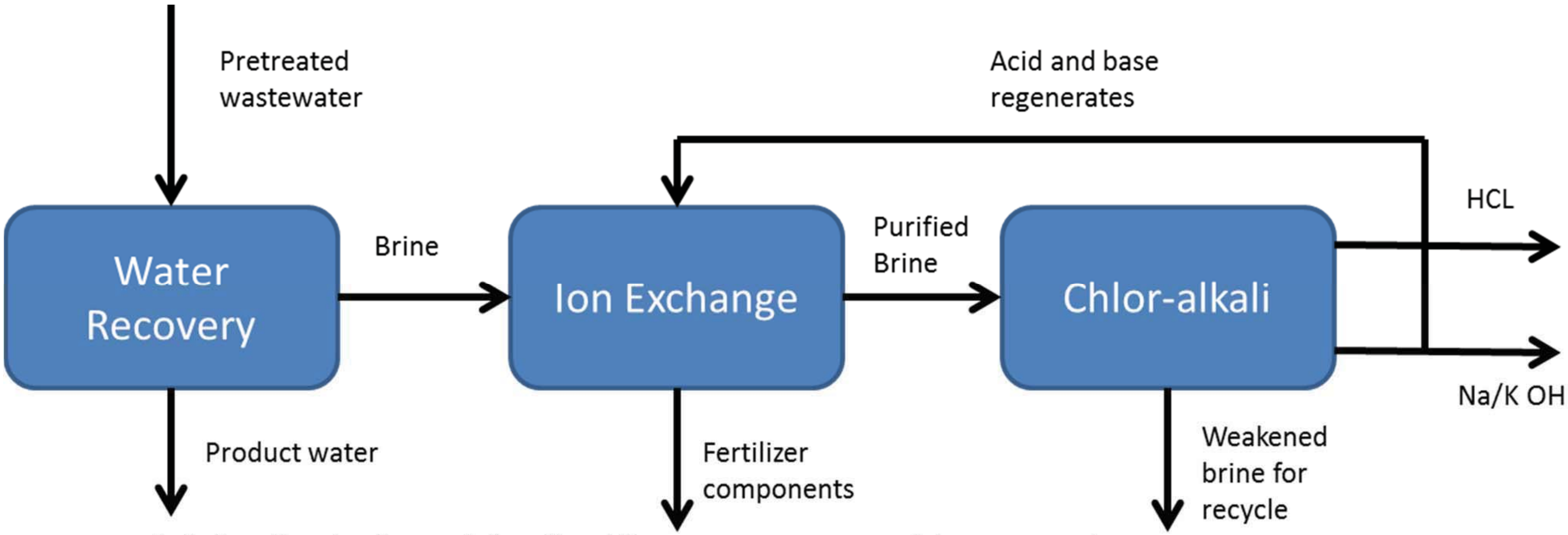
- Magnesium phosphate dibasic trihydrate ($MgHPO_4*3H_2O$) or MP reacts with ammonia, exclusively, to produce struvite
- The resulting struvite ($MgNH_4PO4*6H_2O$) or MAP is treated using heat and/or vacuum to regenerate the MP
- Cycle can be repeated indefinitely and only requires base and vacuum (heat makes it faster)
- Has many-fold higher selectivity than cation exchange resins and 2-4x ion capacity with higher expected lifecycles

Advanced Catalytic Oxidation

Vortex Voyager System

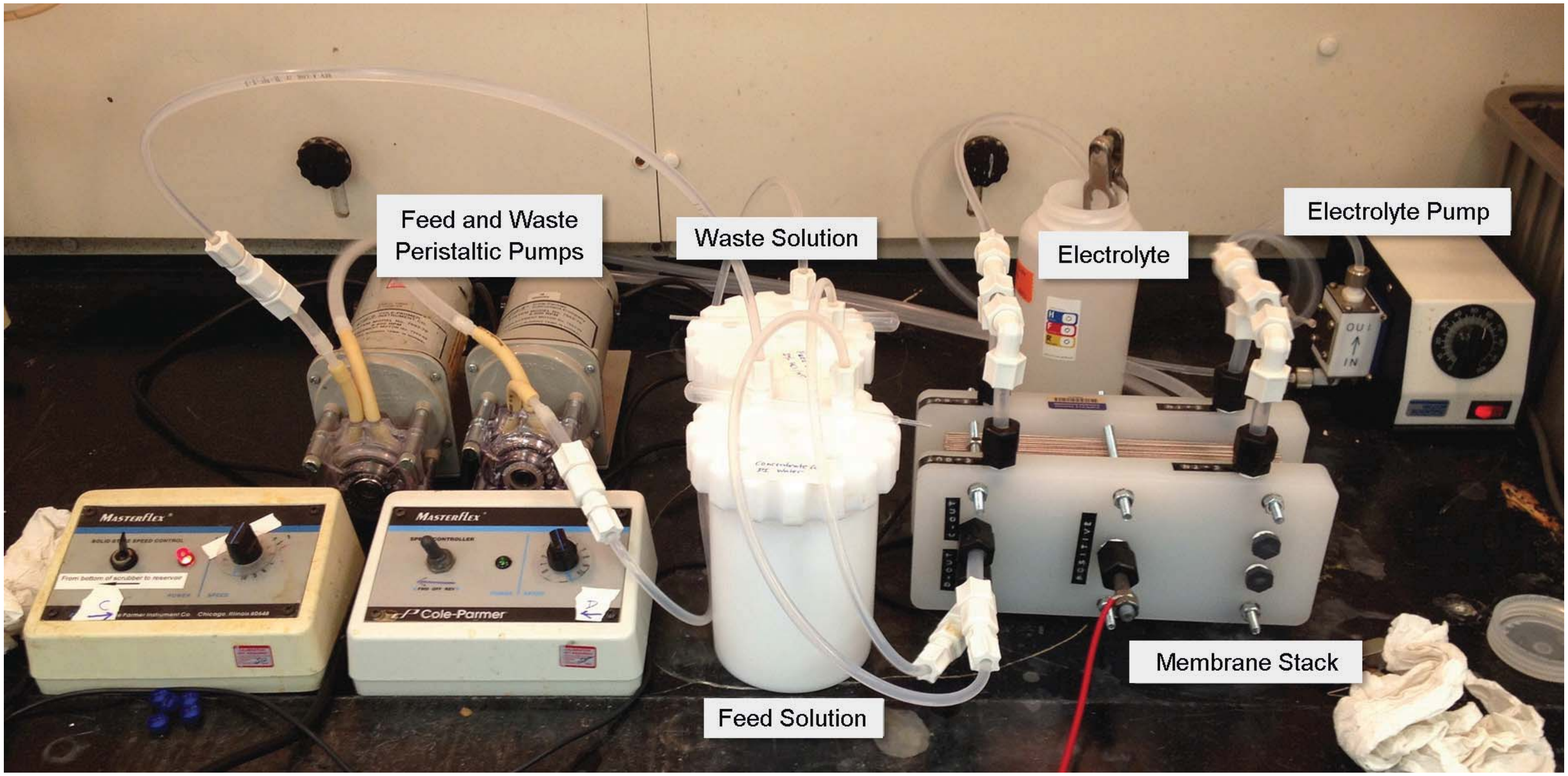
- Uses ozone or hydroxyl molecules to rapidly oxidize contaminates (e.g., urea, ammonia, nitrate)
- Other Benefits:
  - Reduces Total Organic Carbon (TOC)
  - Reduces microbial loads by many logs (orders of magnitude)
- Benefits of Ozone:
  - Can be generated via UV light, cavitation, or by corona discharge
  - Does not persist in the system beyond the unit operation (low half life)
  - Takes low amounts of energy to form
- The reaction of ozone with relevant contaminants is not well documented
  - Limited testing at KSC several years ago showed promising, successful destruction of contaminants
- Ozone-based systems can be challenge due to two-phase flow, but there are ways around it

Brine Purification



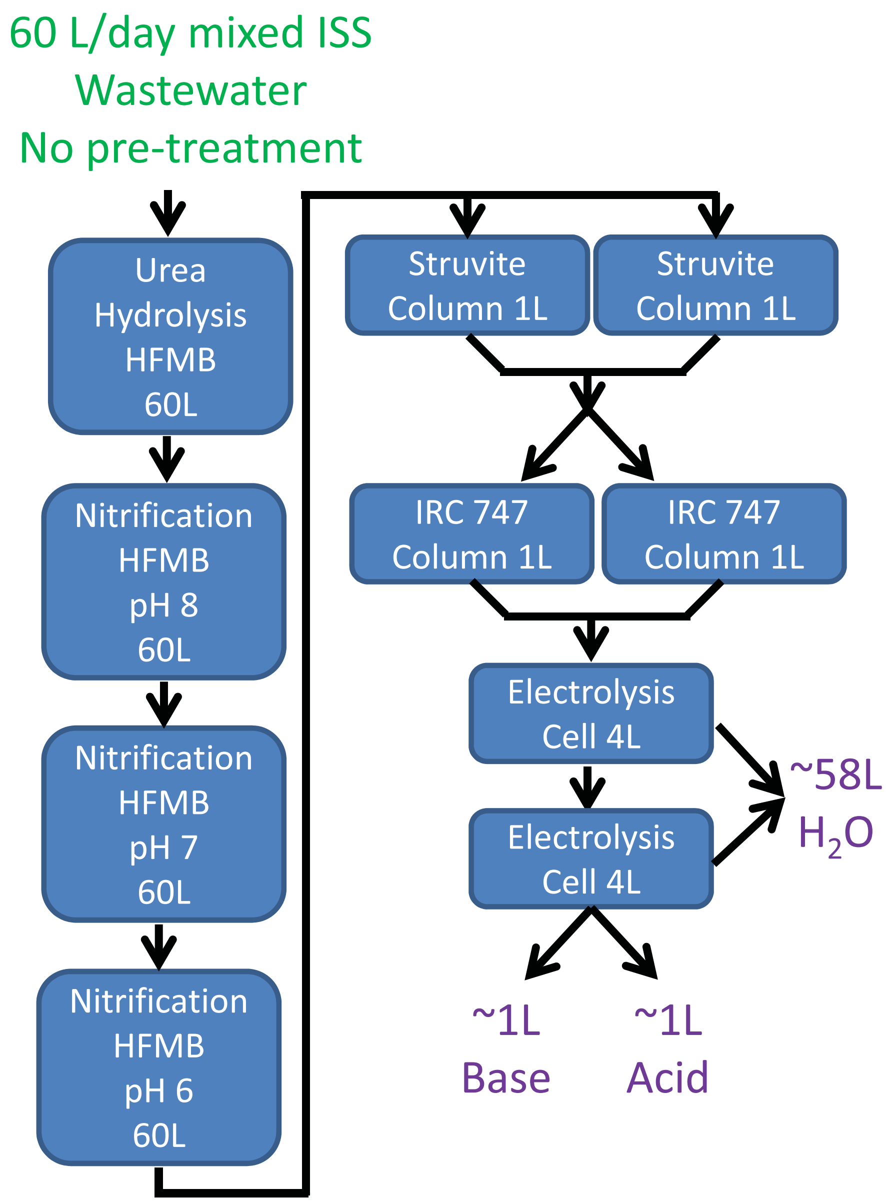
- Originally designed for fertilizer recovery and increased water recovery
- Pre-treated ECLSS brine (removed urea/carbon) is sequentially treated to remove hardness, polyvalent ions, and, optionally, nitrate
  - Resulting sodium/potassium chloride stream is then deionized, producing pure water and either a concentrated brine stream or separate acid and base streams
  - Acid and base streams can be used to continuously regenerate the ion exchange resins
    - Spent regenerate contains fertilizer components (i.e., K_3PO_4, KNO_3, K_2SO_4)
- KSC built and tested an electrostatic separator to enrich dry sodium/potassium salt streams
- Without fertilizer recovery, only the first ion exchange resin needs to be used to prevent membrane fouling, but the other ions will persist in the brines

ISRU Acid Removal



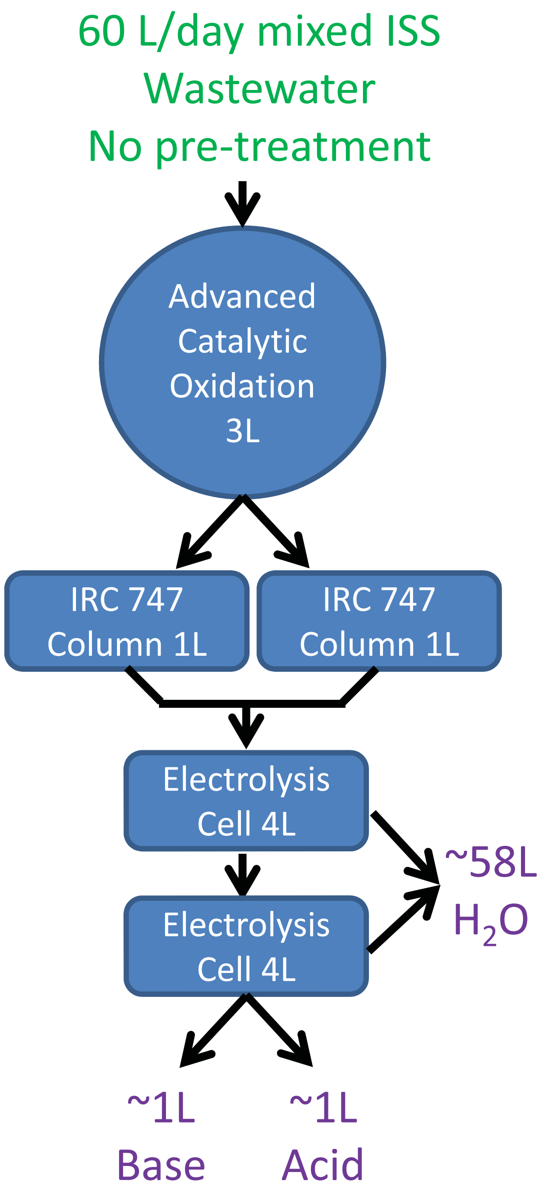
- The above test stand was used to deionize 2% HF from acid streams generated by ISRU
- Water quality was extremely high, but only 50% recovery was noted at lower amperage
- We expect 80-90% recovery (per stage) once we use a higher amperage (60 instead of 6) power supply running at 3-5 volts
- Treatment time for 1L of fluid for a test stand this size was well under an hour

Long-Term Multi-Redundant System



- Uses 4 modular HFMBs, 2 carousel absorbers, and 2 membrane electrolyzers
- Designed to survive up to 3 HFMB failures or 2 HFMB and struvite failure by increasing consumable use until repairs or replacements are made
- Cascading electrolyzers first concentrate brine and produce water, then produce concentrated acid and base from brine concentrate
  - If 1 electrolyzer fails, the other can become the first stage while still yielding 80-90% water recovery
- Base consumed the nitrifying HFMBs and/or struvite columns
- Acid consumed (along with some base) by IRC 747 columns
- Energy required for electrolyzers
- Vacuum and/or heat required for struvite columns

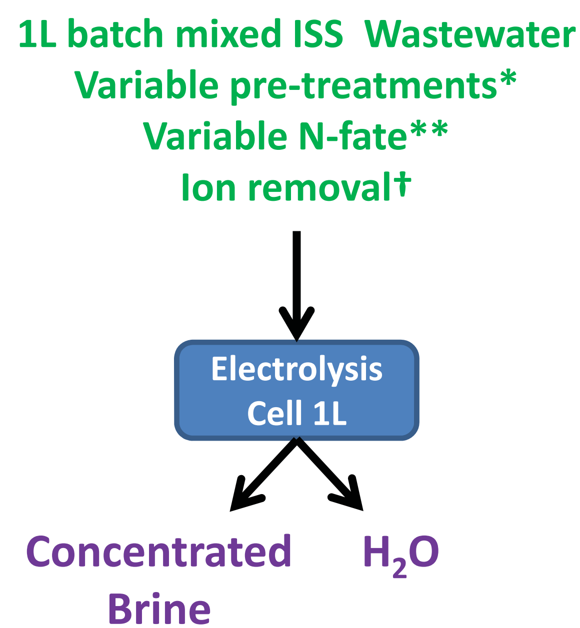
Long-term Multi-Redundant System Excluding Biological Reactors



- Replaces the carbon/ammonia removal train with a single (or dual, redundant) Advanced Catalytic Oxidation (ACO) unit.
- Similar to the previous design
  - Much smaller and more “mechanical”
  - Should have a similar consumable loop
- ACO unit:
  - Should be able to break down urea to ammonia/nitrate/N_2
  - Depending on the ratio, it will potentially require more unit ops
- We have two competing ACO technologies:
  - Both require some modification for µ-gravity use
  - Also have a third design that is a hybrid of the two

Proposed Testing

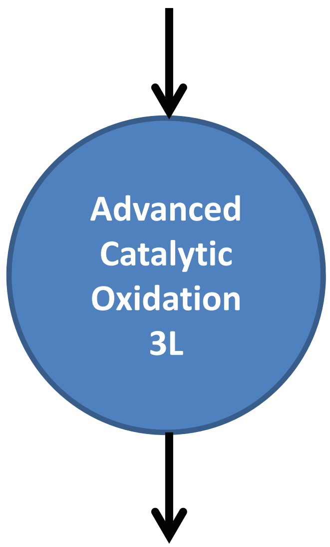
- Test multiple influent streams for KSC's current electrolysis cell to determine processing capabilities
- Calculate mass and energy balances (wh/L treated, residence, removal rates, etc.)
- Examine performance over time and assess possible membrane fouling agents
- Figure out any "blockers" and remove them using ersatz mixtures formulated without them
    - Also includes testing of alternate unit operations capable of removing species in question
- <u>This cell currently exists at KSC</u> and, if funded, we would build another one at low costs (cost of headers and machining)



*: chromic acids, organic acids, none
**: urea, ammonia, nitrate, mixture
†: hardness, poly-valents, C, N

Further Testing Capabilities

1L batch mixed ISS Wastewater
Variable pre-treatments*
Variable N-fate**
Ion removal†



Unknown Effluent Stream
(to be assessed)

Test Variables:
Residence Time
Recycle Ratio
"Enhanced Oxidation" methods

***: chromic acids, organic acids, none**
****: urea, ammonia, nitrate, mixture**
†: hardness, poly-valents, C, N

- Effluent Stream from ACO unit should be assessed to determine compatibility with electrolysis cells
  - May be the only viable physical chemical method capable of removing urea and other organics
  - Such compounds will likely foul/prevent water recovery from the electrolyzer or any other brine dewatering system
- As with the electrolyzer, pretreatment regimes, N-fate, and ion concentrations can be tested to determine full capabilities
- KSC currently owns an ozone test stand can also procure/build the other 2 designs
- Based on testing results, it may be possible to combine units to make a high-fidelity test stand and add other required unit ops (hardness removal, maybe some sort of N-removal, etc.)

Questions?