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Electrochemical Destruction of Cyanide in Water

Jose Alvarez, Ph.D., P.E.
Director of Technology and Operations
jose.alvarez@aclaritywater.com

Orren Schneider, Ph.D., P.E.
Chief Science Officer
orren.schneider@aclaritywater.com

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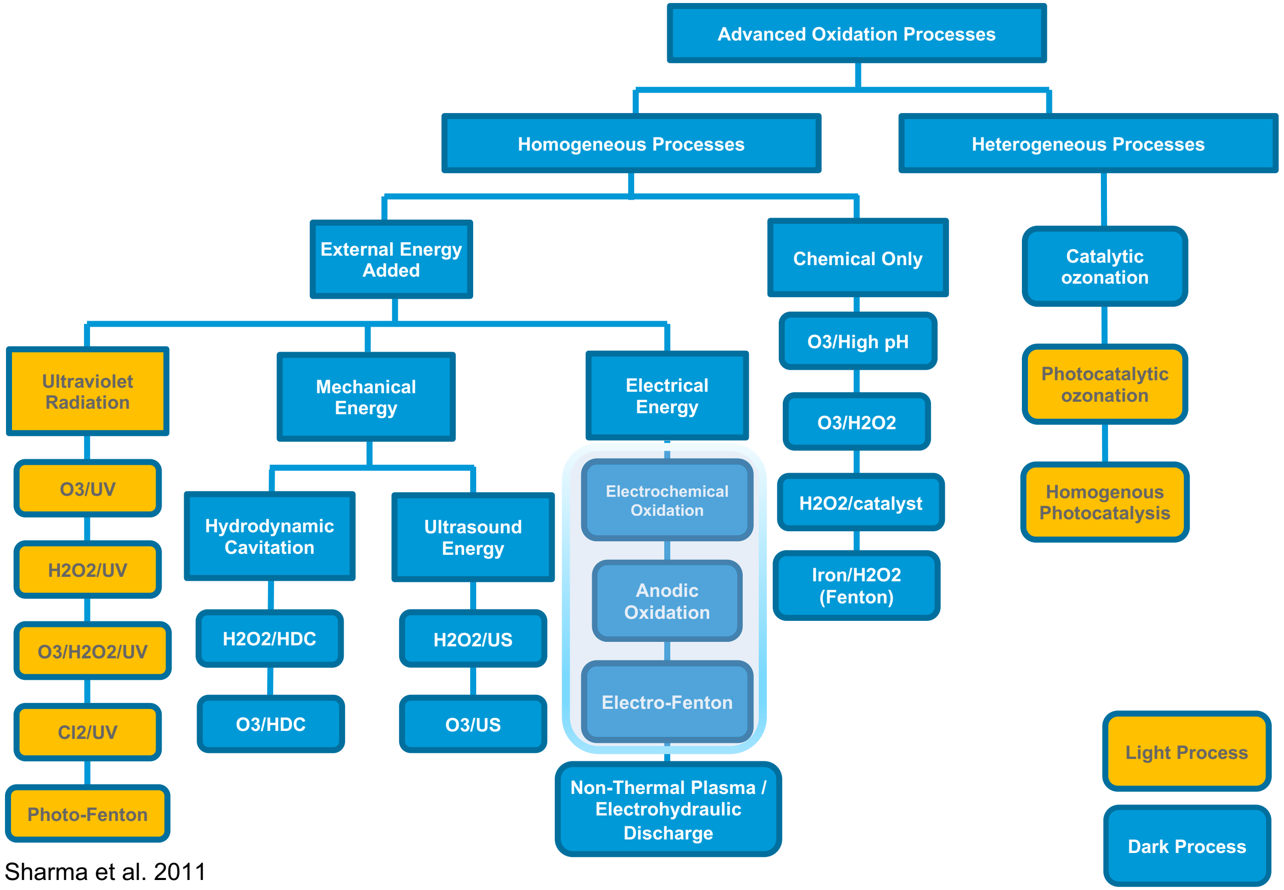
Electrochemical Oxidation Background

- Studied mostly at bench scale and currently emerging into commercial applications
- Significant amount of publications
- Fits into a continuum of advanced oxidation processes



Source: Adapted from Sharma et al. 2011

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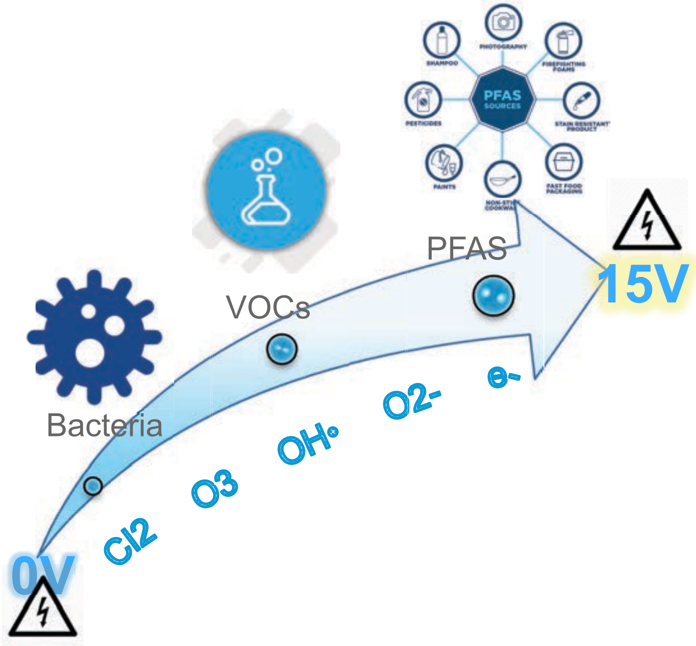
EAOPs 101 Fundamentals

Electrodes placed in water

- Anode(+)/Cathode(–)



Electric potential above 1.23 V applied

- Surficial voltage at which water splits to O_2 and H_2

Mixed oxidant production with increasing voltage

- Anodes with high overpotential are

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Modes of Operation

Indirect oxidation

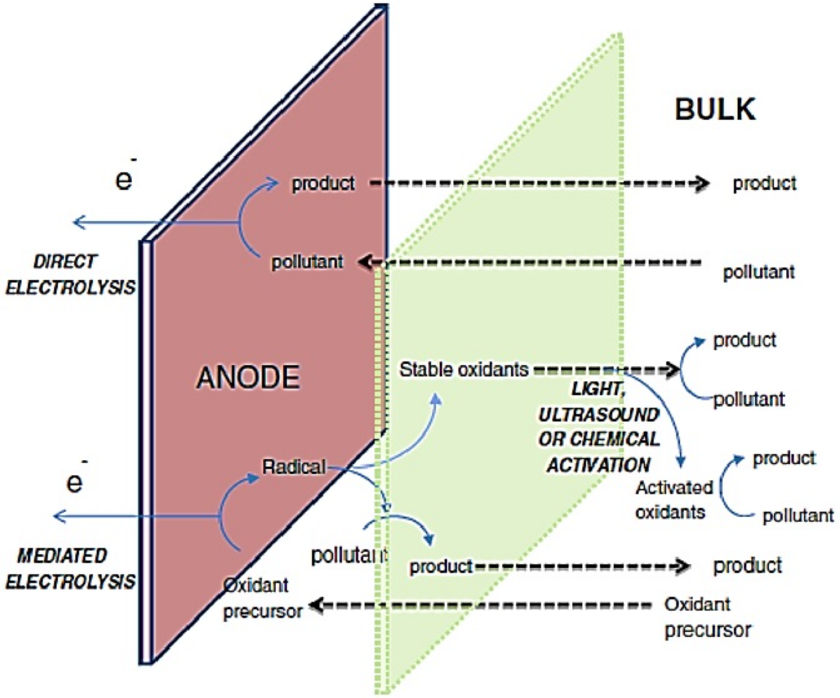
- Oxidants formed in-situ react in bulk solution (OCl^-, HOOH, ClO_2, O_3, $HO^\cdot$, O_2^-, $S_2O_8^{2-}$)

Direct oxidation

- Adsorbed molecules react with electrons generated on surface of electrode
- Direct electron transfer reactions slower than indirect reactions and require adsorption of molecules to electrode surface

High degree of oxidation achieved

- Mineralization of organics to CO_2 and other trace gases
- Disinfection of microbes
- AOC produced by incomplete mineralization



Electrode Types

Noble metals

- Pt, Ti/Pt

Metal Oxides and Mixed Metal Oxides (MMO)

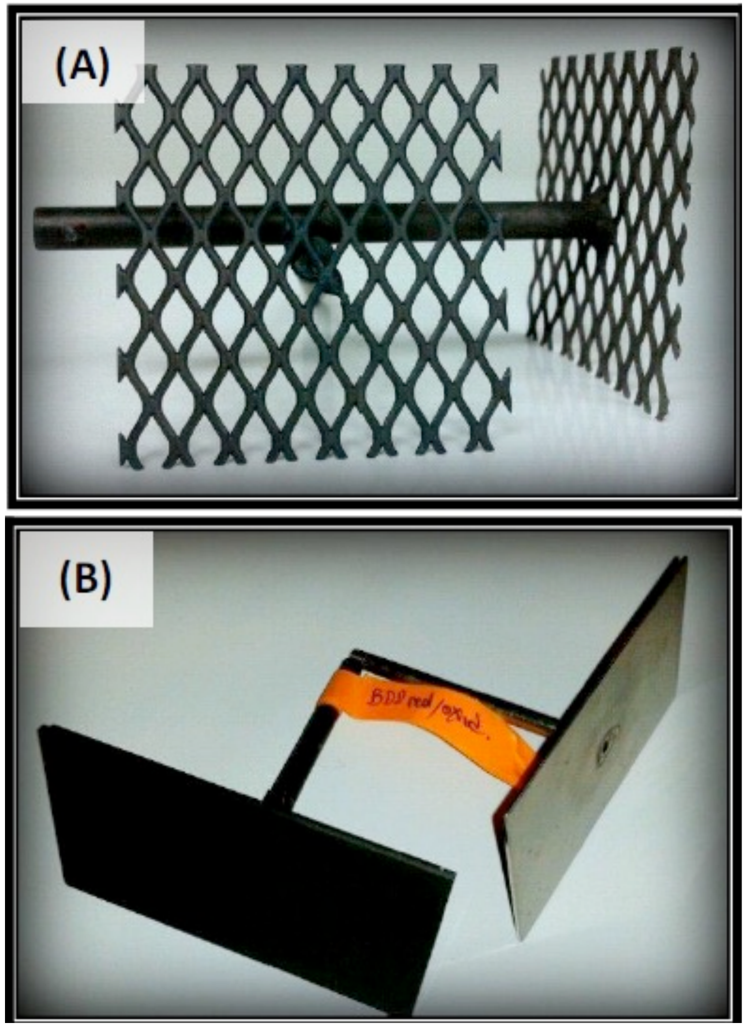
- PtO_2, PbO_2, IrO_2, TiO_2, SnO_2, RuO_2,
- Substoichiometric titanium oxides

Boron Doped Diamond (BDD)

- BDD is claimed to have the largest electrochemical potential window in aqueous solutions compared to traditional electrode materials

Carbonaceous and Graphitic Materials

- Carbon black, carbon fibers, carbon nanotubes, graphite



Ideal Electrode

- High oxidation potential
- Low cost
- Low energy (<0.5 kWh/gal)
- Long-lasting (years)
- Low maintenance
- Available in a variety of form factors

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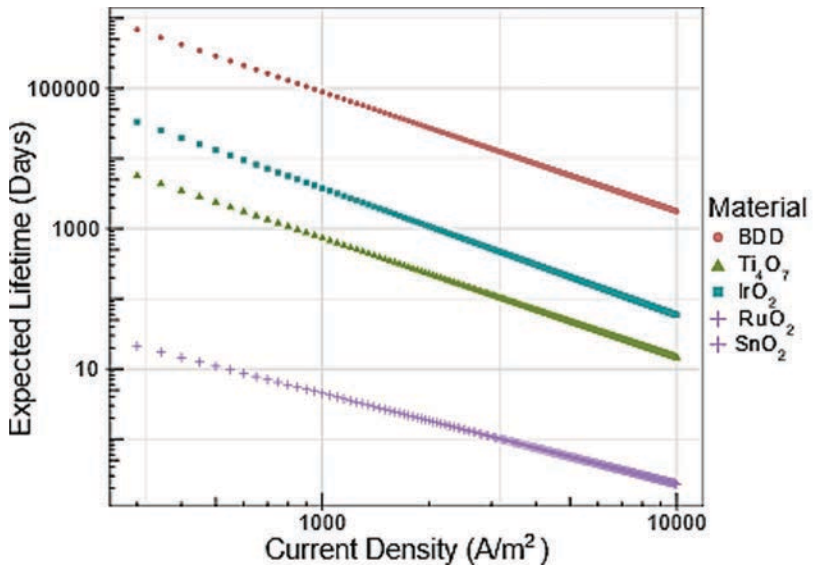
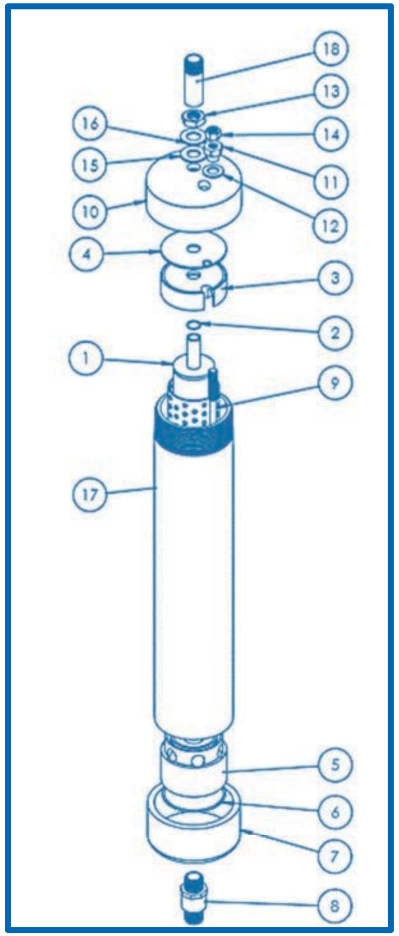
Electrode Material	Overpotential (V)
Aclarity	2.5+
BDD	2.2-2.6+
Ti/SnO_2-Sb_2O_5	1.9-2.2
Ti/Pt	1.7-1.9
IrO_2/Ta_2O_5	1.5-1.8
RuO_2/TiO_2	1.4-1.7



PATENT PENDING
FILED FOR U.S. AND INTERNATIONAL PATENTS

Novel reactor design and electrodes



Electrode materials Unique profile of inherent power, low-cost anodes; pairing right cathodes increase this further

+

Geometry Radial, porous shape with small band gap optimizes efficiency and speciation

+

Reactor flow Flow-through path, mixing, and detention time ensure oxidants are used

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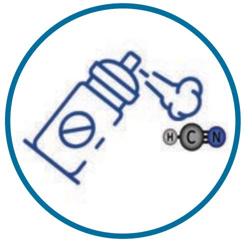
Cyanide Uses and Occurrence

Widely used in industry

- Market for NaCN alone expected to be $3B in us by 2027



Recovery of metals from mining

- Metal processing and plating from 2500 metal plating shops in US

Salt manufacturing and processing

- Sodium ferrocyanide decahydrate (YPS) used as anti-caking agent

Cyanide Chemistry

- **Hypochlorite**

  $CN^- + OCl^- \rightarrow CNCl + Cl^-$

  $CNCl + H_2O \rightarrow OCN^- + 2H^+ + Cl^-$

  $OCN^- + H_2O + OH^- \rightarrow NH_3 + CO_3^{-2}$

- **Ozone**

  $CN^- + O_3 \rightarrow OCN^- + O_2$

  $2OCN^- + 3O_3 + H_2O \rightarrow 2HCO_3^- + N_2 + 3O_2$

- **Chlorine Dioxide**

  $CN^- + 2ClO_2 + 2OH^- \rightarrow OCN^- + 2ClO_2^- + H_2O$

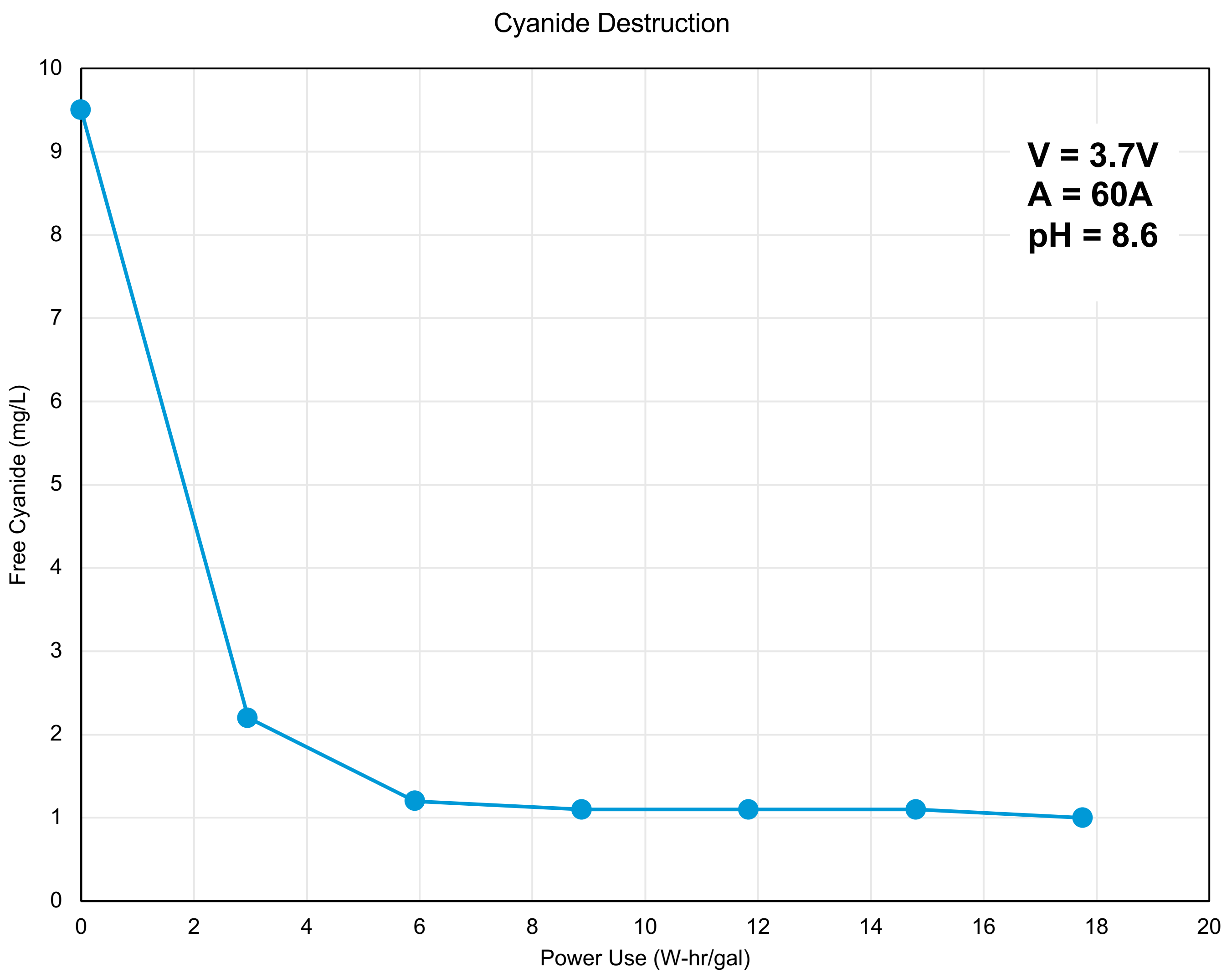
  $OCN^- + H_2O + OH^- \rightarrow NH_3 + CO_3^{-2}$

- **Hydrogen Peroxide**

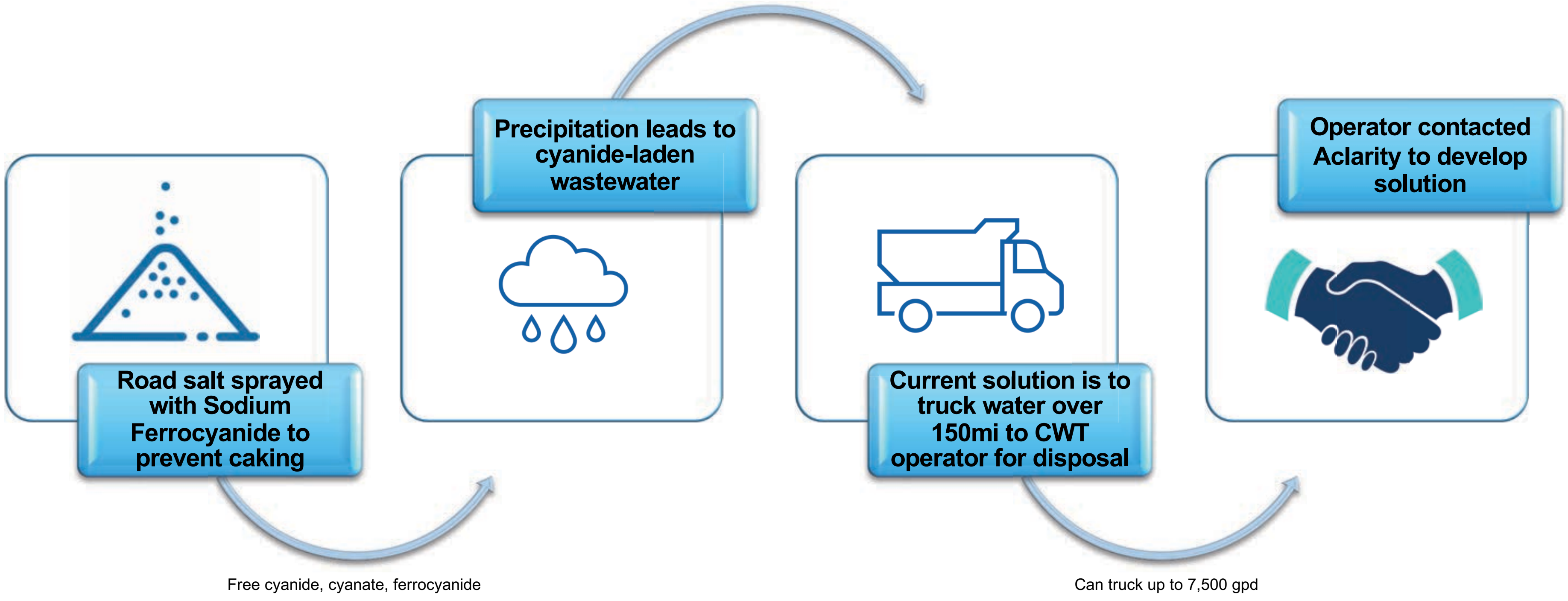
  $CN^- + H_2O_2 \rightarrow OCN^- + H_2O$

  $OCN^- + H_2O + OH^- \rightarrow NH_3 + CO_3^{-2}$

Cyanide Bench Results



Case Study – Cyanide Destruction Road Salt Depot



- Conducted bench and on-site pilot testing
- Designed, constructed and installed system in less than 6 months (Capacity 16,000 gpd)
- Working with local POTW to accept treated water

Aclarity Skid-mounted reactors

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Cyanide Destruction Economics

Existing Costs

Trucking wastewater
- Time/labor
- Mileage/tolls
- Disposal Fees
- $286,000/yr

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CAPEX
- Construction of shed
- Reactor(s)/Skid(s)
- Engineering
- Installation
- $130,000.00

OPEX
- Power $1,600/yr
- Disposal $91,000/yr

ROI
- ~ 7 months

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Conclusions

Free cyanide readily destroyed by electrochemical generation of hypochlorite at power

Achieving <1 mg/L cyanide limit

Complexed cyanide requires higher power to create hydroxyl radicals

Reactions are pH dependent

Economics are favorable

ROI < 1 year

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Questions

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Thank you!

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