ASSESSMENT OF EMERGING AND INNOVATIVE TECHNOLOGIES AND MONITORING STRATEGIES

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Recycled Water Research Workshop

CA SWRCB

October 27-28, 2015

Costa Mesa, CA

Overview

Goal:

Summarize the status and potential for emerging treatment technologies and monitoring strategies for the control of CECs and for assessing treatment performance.

Overview

- Review of a few recycled water emerging technologies
  - Osmotic MBR, Membrane distillation, METs, UV/Cl AOP
- Validation and Monitoring New Technologies
  - The case of UV disinfection as an example technology
- Questions to consider:
  - What would the advantages be of these new technologies?
  - How are these new technologies validated or proven?
  - How can the adoption of new technologies be supported?
  - What is the importance of pilot or demonstration projects for these new technologies?
  - What role can the State provide?

Water Reclamation: Protecting Public Health

Given our modern water quality concerns…

- **Challenge 1**: Inactivation of pathogens
  - Protect the public from waterborne diseases
- **Challenge 2**: Removal of chemical pollutants
  - Organic and inorganic contaminants
  - No new harmful chemicals formed
- **Challenge 3**: Maintain favorable aesthetics
  - No adverse taste and odor issues

- **Result**: *Appropriate water recycling solutions*

What is an Ideal Water Reclamation Process?

- No synthetic/harmful chemicals
- Free of unwanted byproducts
- Free of unwanted residuals
- No unintended consequences
- Sustainable materials
- Low or no energy
- Fast acting
- Easy to operate

What It Takes to Get an Advanced Treatment Technology Accepted in the 21st Century

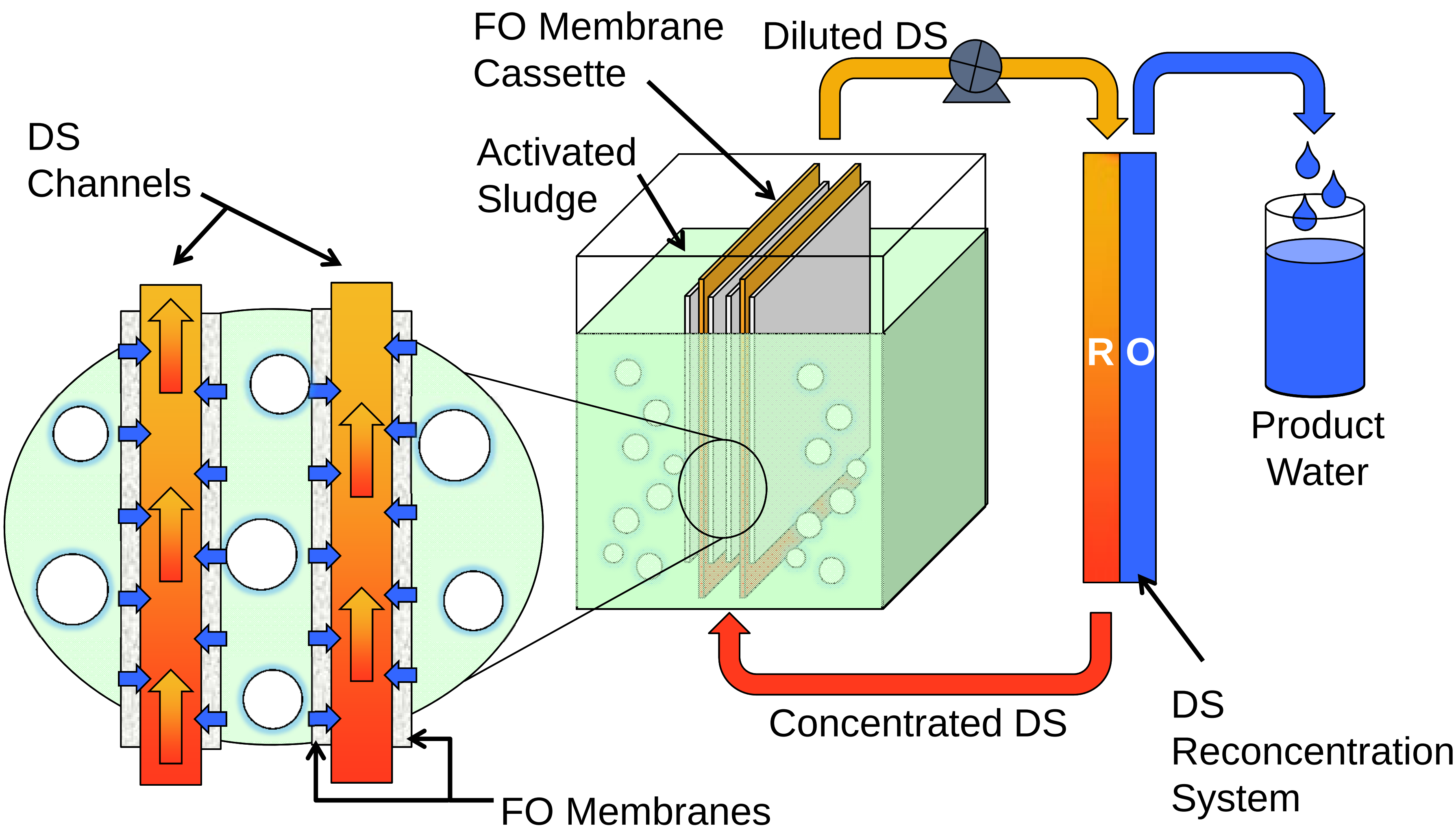
- Good stuff
  - Validation procedures
  - Safety factors
  - Basic Research
  - Sensors
  - Certificates
  - Mathematical models

- Bad stuff
  - Residuals
  - Byproducts
  - Harmful side effects
  - Toxic materials
  - Dangerous handling

Require the GOOD

Minimize the BAD

Emerging Technology I: Osmotic MBR (OMBR)



Courtesy of Professor Tzahi Cath, Colorado School of Mines

Osmotic MBR: promises and challenges

Promises

- Removal of CECs
  - Biological and FO/RO
- Run LCA to evaluate and compare (GHG, Energy)
- Phosphorous recovery

Challenges

- Salt accumulation
  - Reduce driving force, inhibit biological activity, fouling
- Draw solution needs development
- Verification under different oxic conditions
- Monitoring parameters to be developed

Courtesy of Professor Tzahi Cath, Colorado School of Mines

Treatment Technology Assessment

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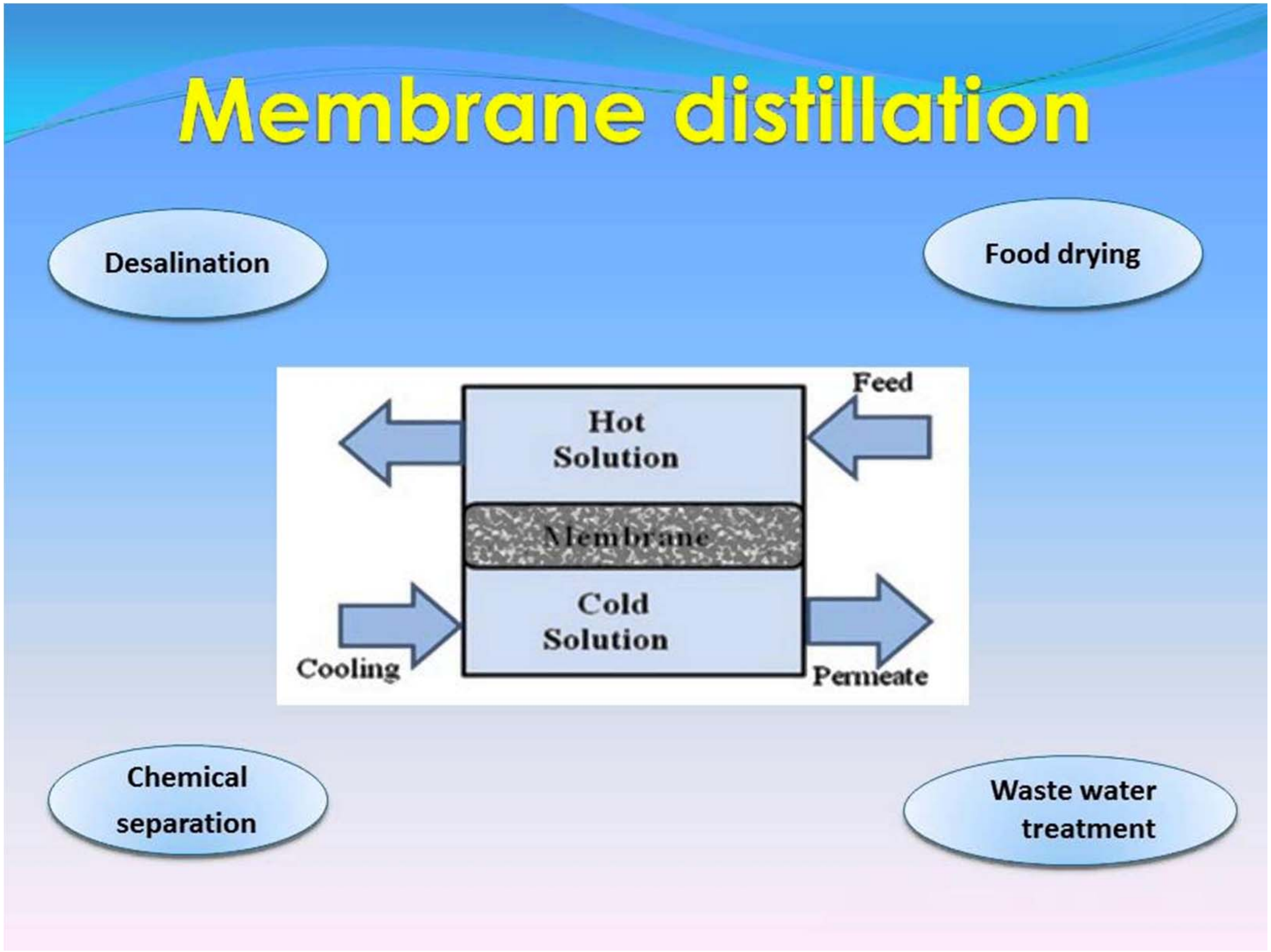
Blue: still needs understanding

Emerging Technology II: Membrane Distillation



Membrane Distillation–Thermophilic Bioreactor System: promises and challenges

Promises

- MDBR achieved high performance regarding all water quality parameters.
- Biodegradation governed the removal of most CECs by the bioreactor.
- Physical separation by MD governed the removal of recalcitrant CECs.

Challenges

- Salinity build-up occurred during MDBR operation.
- Salinity build-up could affect TN and CEC removal by the bioreactor.
- Membrane fouling and long term hydrophobicity of membranes

Courtesy of Professor Tzahi Cath, Colorado School of Mines

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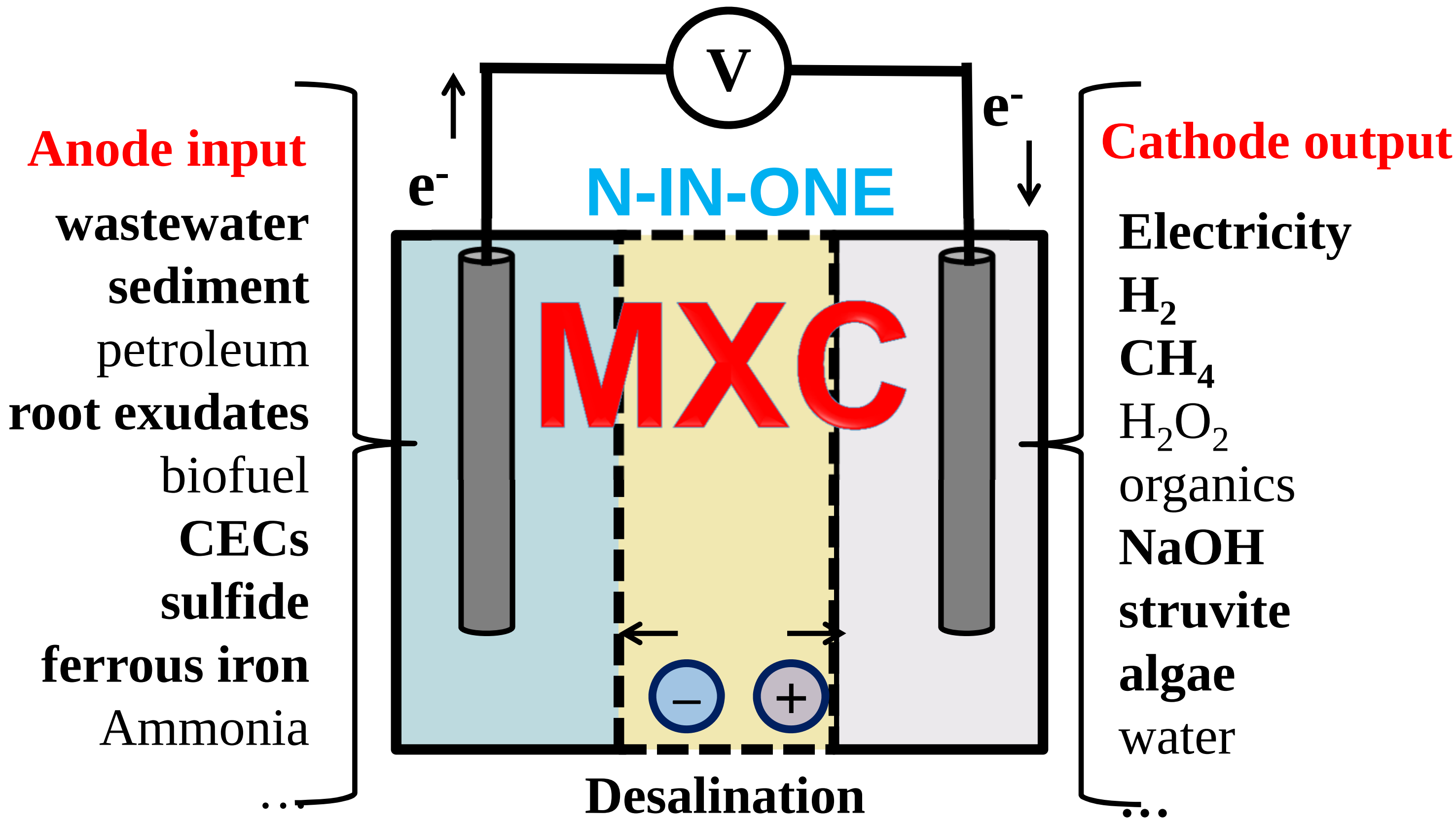
Emerging Technology III: Microbial Electrochemical Technology



Courtesy of Professor Jason Ren, University of Colorado *(Wang and Ren, Biotechnol. Adv. 2013)*

Types of Microbial Electrochemical Technologies

Main type of METs	Products
Microbial Fuel Cell (MFC)	Electricity
Microbial Electrolysis Cell (MEC)	H_2, H_2O_2, NaOH, Struvite, etc. – mainly inorganic chemicals
Microbial Electrosynthesis (MES)	CH_4, CH_3COOH, C_2H_5OH, lipid, etc. - mainly organic chemicals
Microbial Desalination Cell (MDC)	Desalinated water, in combination with other functions

Courtesy of Professor Jason Ren, University of Colorado

Microbial Electrochemical Technology: promises and challenges

Promises

- Energy neutral potential
- LCA: Reduce GHG
- COD removal
- Reduced Sludge production
- Power generation
- Promising for many CECs
  - Sorption, biodegradation and electrochemical oxidation
- Carbon capture

Challenges

- Electrode material development
- CEC removal depends on properties of contaminants
- Fouling
- Scale up

Courtesy of Professor Jason Ren, University of Colorado

Treatment Technology Assessment

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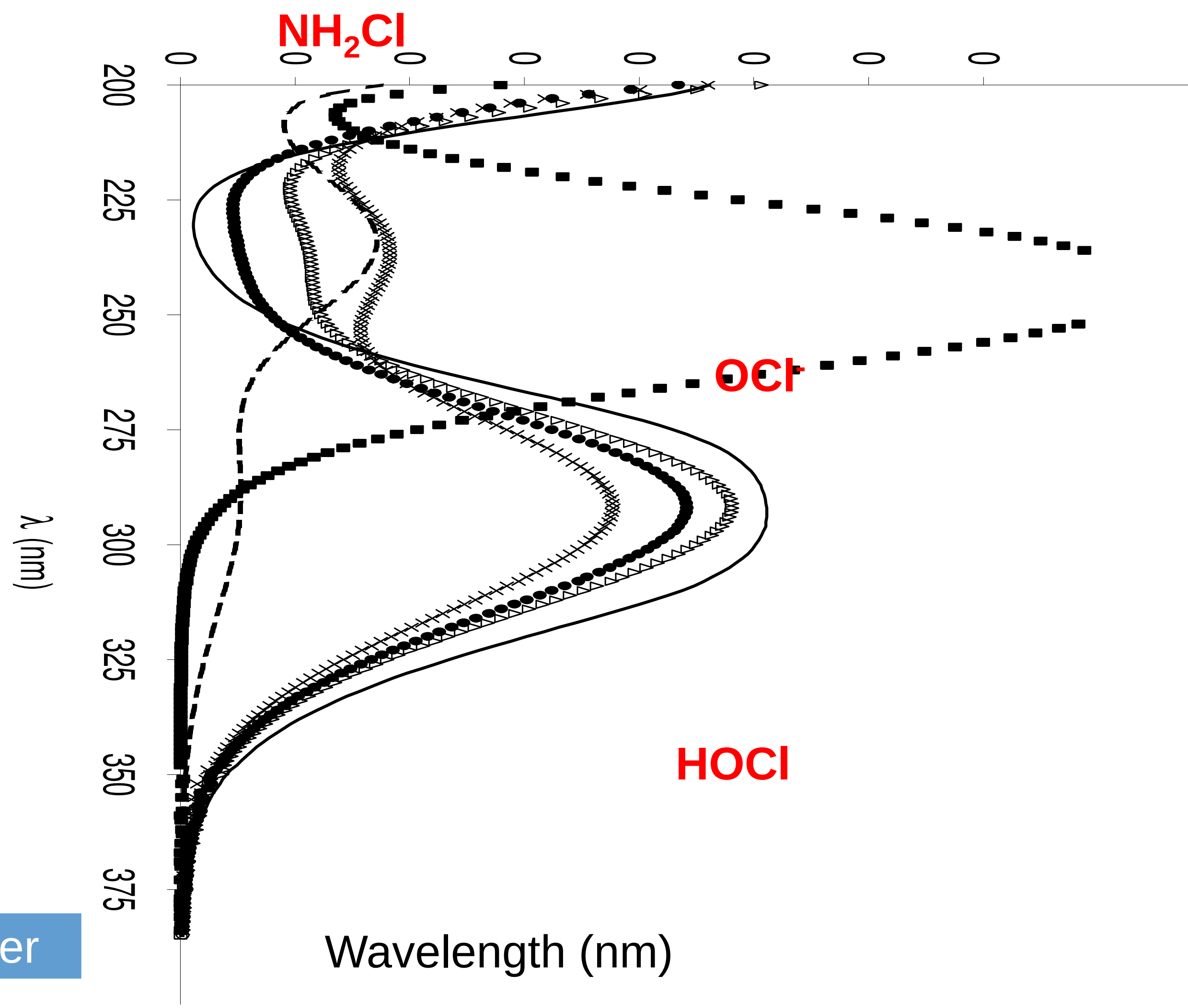
Emerging Technology IV: UV-Chlorine AOP

$$HOCl \xrightarrow{h\nu} \cdot OH + Cl\cdot$$

$$OCl^- \xrightarrow{h\nu} O^- + Cl\cdot$$

$$O^- + H_2O \rightarrow \cdot OH + OH^-$$

OCl- is major OH radical scavenger



Watts and Linden, 2007

Applications and Issues with UV/Cl

Ideal at Lower pH

- After RO in reuse treatment, typically low pH

What about Chlorinated Byproducts?

- If after RO, organic precursors not an issue

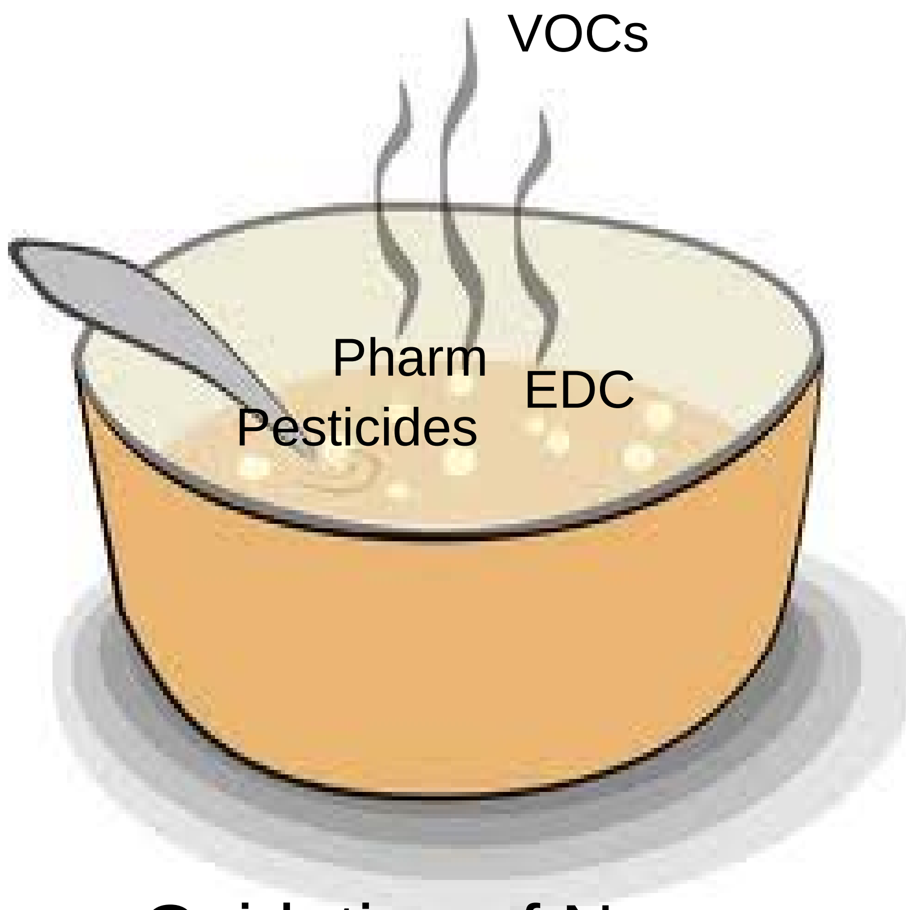
What about Quenching?

- No need to quench – often want Chlorine residual

Avoid cost of H_2O_2

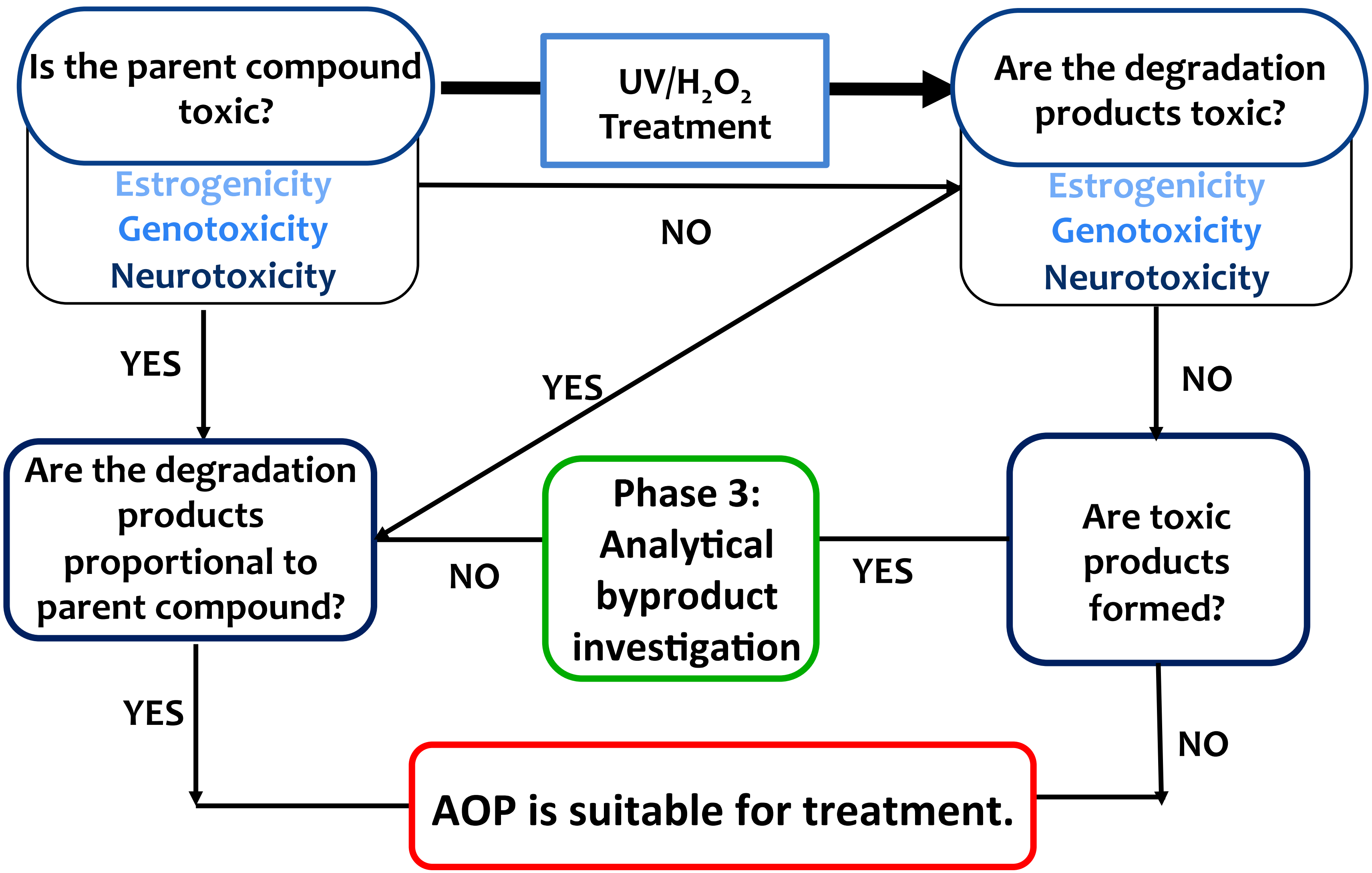
Unknown Byproducts May Be Created

Incomplete Oxidation
of Target Contaminant



Oxidation of Non-
Target Contaminant

Toxicity Screening Approach: AOP Example



From Water Research Foundation 4241: AOP for CCL3 Chemicals

Treatment Technology Assessment

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Validating New Technologies:

The Case of UV Disinfection in Water Treatment

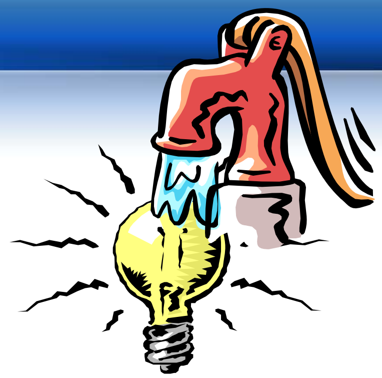
- Disinfection
  - Sensibility: i.e., Wastewater disinfection
  - Non-chemical (chlorine), No byproducts
  - *Cryptosporidium*** (and *Giardia*)
  - “Green” Technology

UV Disinfection: Status in North America

- Increasing use in wastewater disinfection
  - Mid 1980's to present
  - > ½ of all new WW disinfection systems are UV
- Not much municipal water disinfection use before Y2000
- Thousands of small systems in use (households and non-community systems) before Y2000
- 1998: Discovery that UV is VERY effective against *Cryptosporidium* and cost effective
- Today: UV is a best available and cost effective technology for pathogen inactivation

How did we get here?

UV Disinfection Research



- Fundamentals of pathogen inactivation
  - Relative to surrogates used to test UV Systems
- Modeling hydraulics
  - CFD, Light intensity models
- New methods for validation
- Examination of byproducts
- New UV technology evaluation and verification
  - E.g., UV LEDs
  - Statistical analyses of validation
- Applied knowledge of UV in Water Treatment

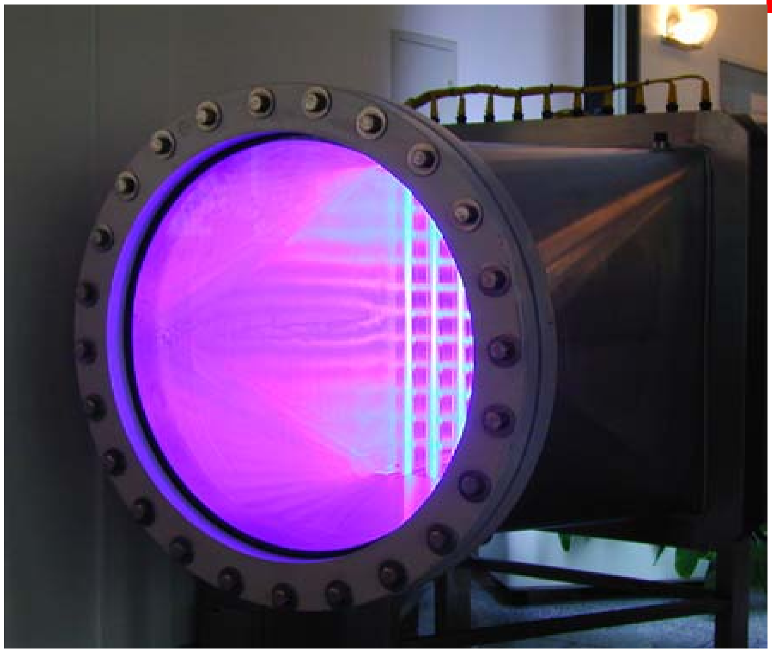
Research is on-going but technology is accepted

Research Partners

- Water Research Foundation
- WateReuse Research Foundation
- Water Environment Research Foundation
- National Science Foundation
- National Laboratories (NIST, USGS)
- Water and Wastewater Utility partners
- Industry cooperators

Availability of UV Disinfection Is a Fundamental Premise of US Regulations

EPA recognized that UV disinfection is a new technology to the water industry and that documents needed to be developed to bridge the knowledge gap



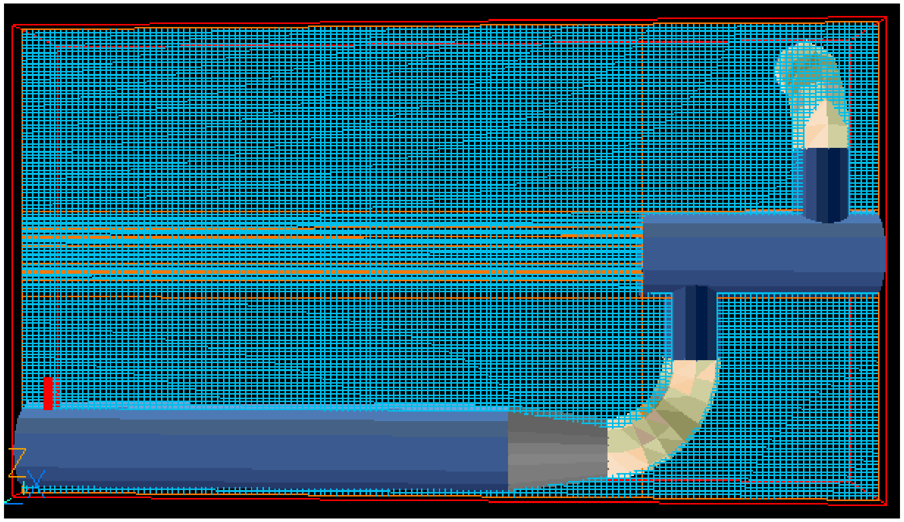
- Performance: UV dose tables
- Validation: develop protocol
- Monitoring: set requirements
- Guidance: develop manual

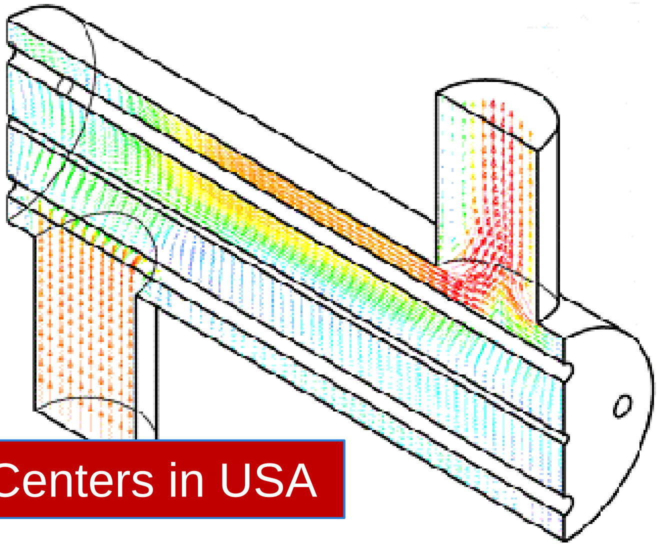
Components of USEPA Validation Protocol

- Microbial Methods
- UV Sensor Tests
- Biodosimetry Procedures
- Data Analysis
- Calculation of Safety Factors
- Determining Operating Setpoints
- Determination of Log Credit
- Inlet/Outlet Hydraulics

Validation of UV Disinfection

- Hydraulic Validation
  - Mathematical models
  - CFD analysis
- Lamp validation
- Sensor validation
- UV Transmittance
- Biological assay validation
  - Challenge testing
- On-line dose monitoring protocol
- Uncertainty and Bias evaluations





Two UV Validation Centers in USA

Which way? Regulations or Guidance

LT2ESWTR defines requirements for UV disinfection

↓

Enforceable by State Primacy Agency

UV Disinfection Guidance Manual provides guidance to meet the requirements

↓

Not enforceable unless State adopts as requirements

Proposed EPA UV Disinfection Specific Requirements and Recommendations

UV Doses

UV Reactor Validation

Off-specification Operation

O & M

What is Validation?

- Reactor is designed to achieve a given level of disinfection performance
  - under specific conditions
- Must verify claims made on performance
  - evaluate the reactor performance
- Specifically need to evaluate dose delivery and dose monitoring
  - monitoring provides the basis for assigning disinfection credit during operation

Who Will Validate?

- Once a reactor is validated under a set of water quality parameters - it is good to go anywhere, within those parameters
  - Unless changes made to reactor design
- Manufacturers typically validate their reactors over a range of water quality conditions
- Site specific conditions may need revalidation
  - Depends on State regulators
- Verification/demonstration testing may be desirable
  - Verify manufacturer claims, learn about operations

Existing Validation Protocols

- German DVGW
- Austrian ONORM
- NSF Standard 55 (POE/POU)
- NWRI/AWWARF UV Guidelines
- US EPA Guidance Manual

ONORM
M 5873-2

Austrian Standards Institute

Plants for the disinfection of water using ultraviolet radiation

Requirements and testing

Part 2: Medium pressure mercury lamps

1. UV Fluence (rel. to 253.7 nm): 400 J/m² (REF)
2. Fullscale Typtest (Biodosimetry)
3. Surveillance (Sensor calibrated in W/m²)
4. Independent check during operation (standardized measuring window, reference sensor)

LT2: "Log credit based on validated UV dose in relation to UV dose table; reactor validation testing required to establish UV dose and associated operating conditions"

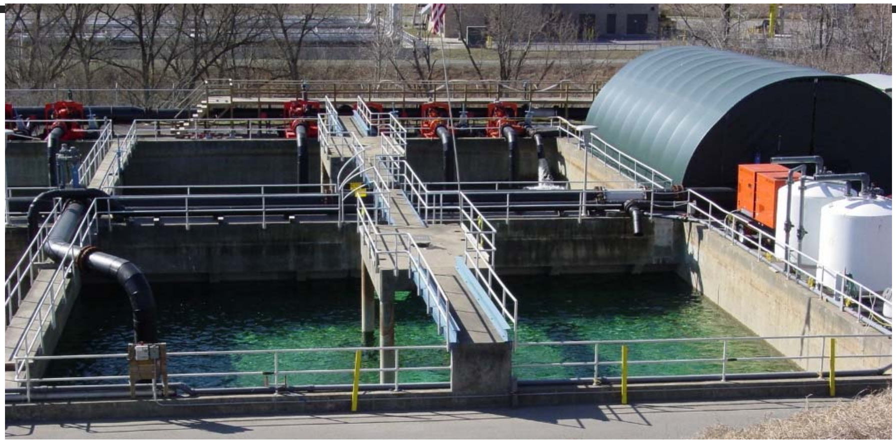
Principal Elements of a Validation Protocol

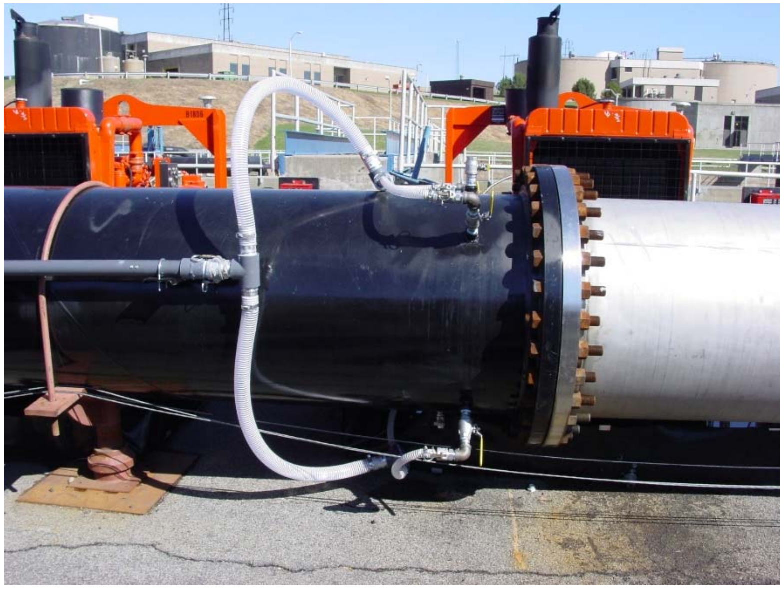
- Documentation of the reactor and its components to ensure it matches the system that was spec'ed out
- Measurement of performance
  - Disinfection or CEC removal
- Correlation of the performance with on-line monitoring: Critical monitoring equipment
  - Protocol for interpreting monitoring information
- Assessment of uncertainty and bias in the interpretation of results

On-site vs. Off-site Validation
The importance of a Validation Facility

- Off-site
  - Positives
    - At test facility (e.g. German, Austrian, NY, OR)
    - At available test site (WTP)
    - May have more flexibility for spiking chemicals/bugs
    - Experience and established protocols
  - Negatives
    - Flow rate limitations at some sites
    - Limited conditions available for piping/reactor size
    - Long wait for testing time

NY UV Validation Facility (1)





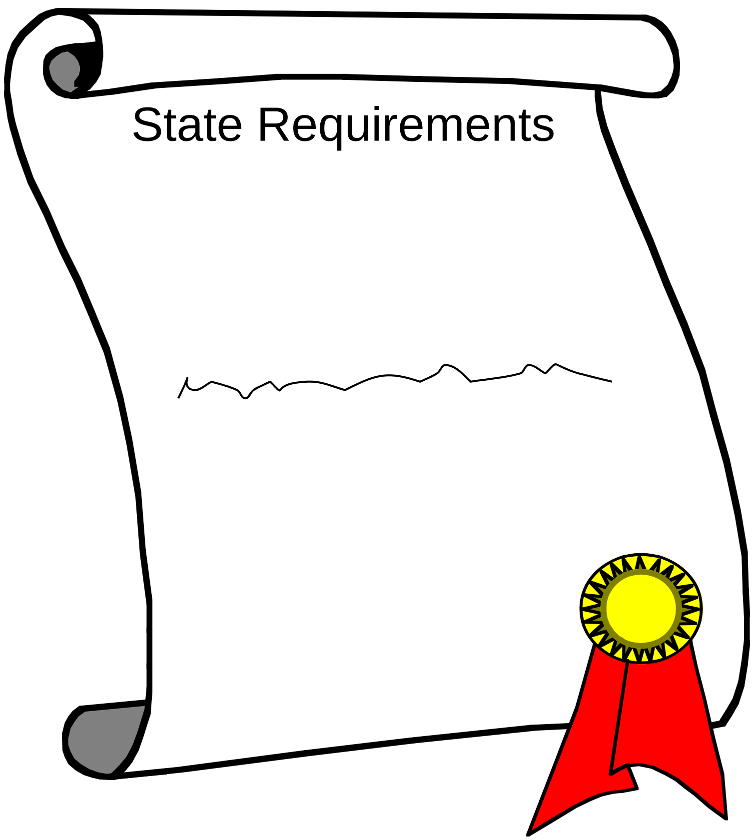
NY UV Validation Facility (2)

On-site vs. Off-site Validation

- On-site
  - Positives
    - Flow rates similar to operation
    - Evaluate fouling of specific water
    - Identical inlet/outlet conditions
  - Negatives
    - Capital costs could be high for testing train
    - May have problems wasting flow with microbes/CECs
    - May not have wide range of water quality needed
    - What if the reactor does not validate?

Real World Implications of O&M Requirements and Recommendations

- End Goals: State approvals
- Actual recording and reporting requirements depend on **State regulatory requirements**
  - Off-specification parameters and volumes defined
  - Operational parameters
  - Calibration of key components



Key Questions/Research Needs

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