Application of Bioreactors in 1,4-Dioxane Treatment

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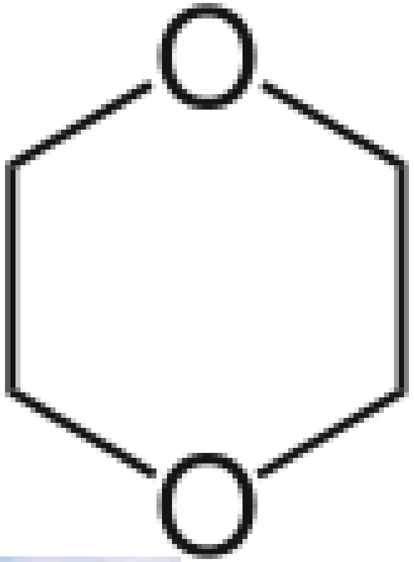
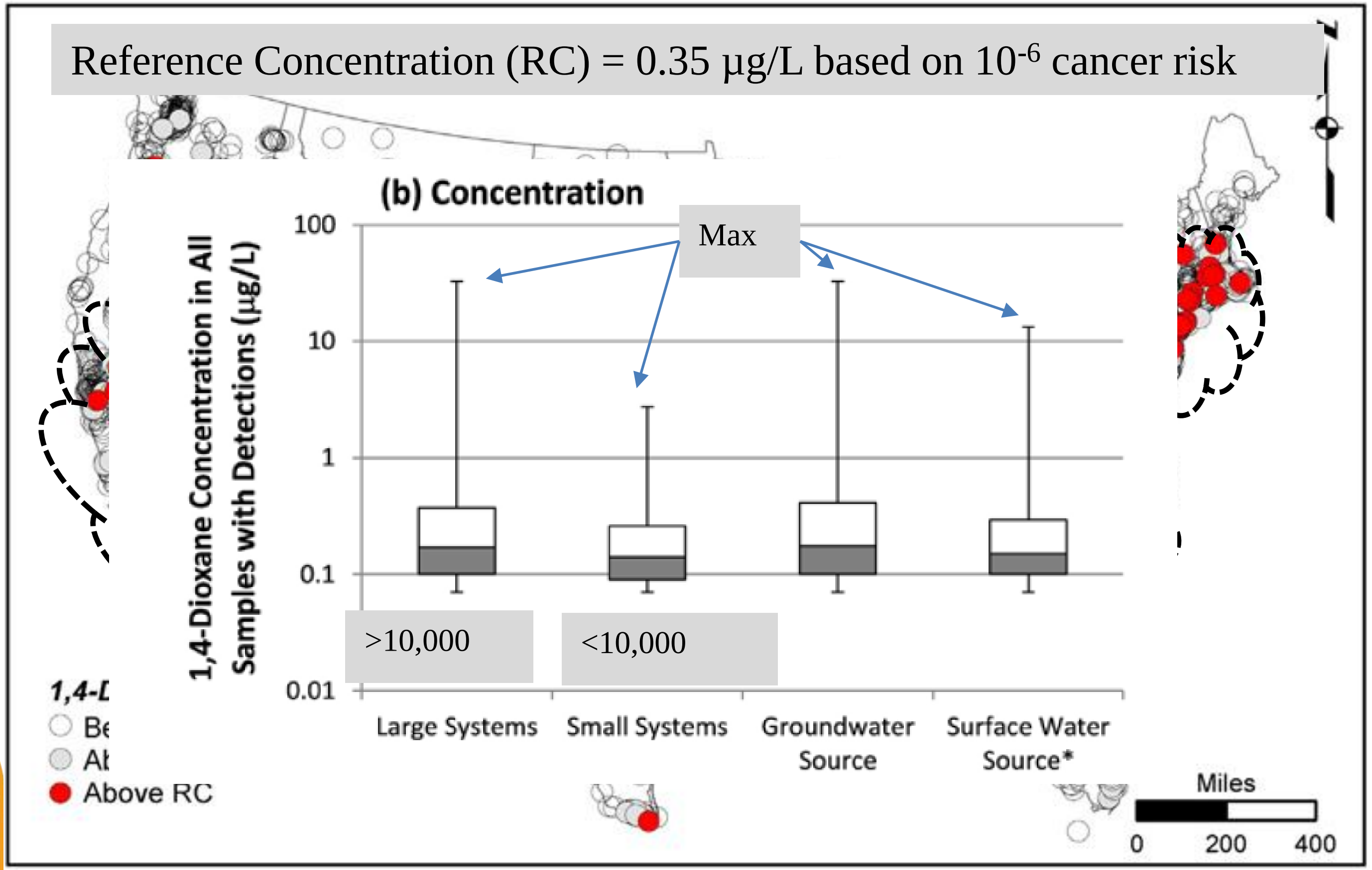
1,4-Dioxane in the Environment



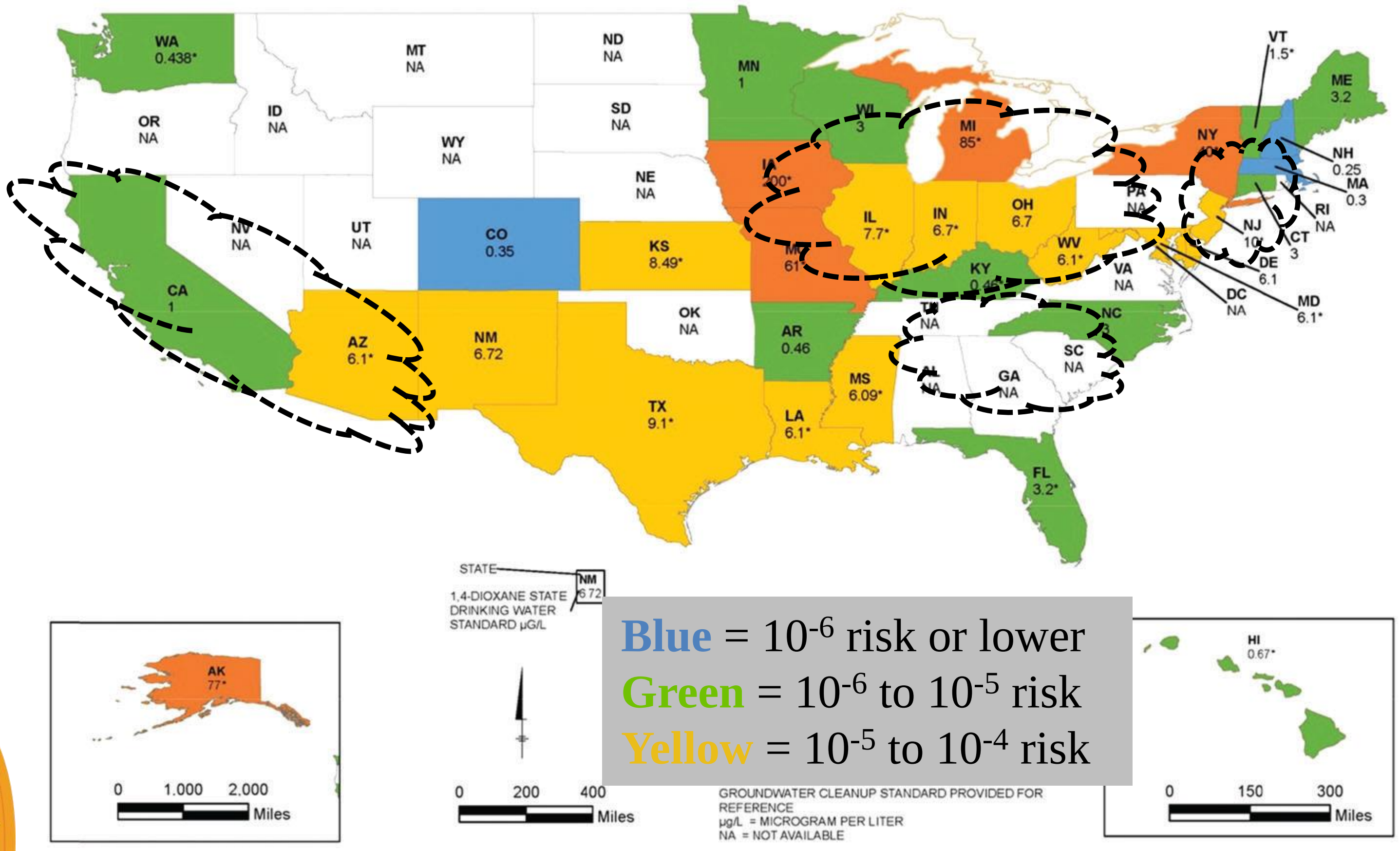
EPA's Third Unregulated Contaminant Monitoring Rule Results (UCMR 3)



Anderson et al. (2017)

- >4800 PWSs sampled, including all large/very large PWSs and 800 representative smaller PWSs
- 21% detection rate (MRL =0.07 µg/L)
- 7% above 10^{-6} cancer risk
- Not just a groundwater issue
- 4 Regional clusters
- CA, NY, NJ, NC and IL leading RC exceedances
- Some detections between 1 and 10 µg/L or >10 µg/L

Regulatory Landscape



Suthersan et al. 2016

- No federal MCL
- 30+ states with drinking water or groundwater standards
- State levels vary by orders of magnitude
- NJ and MI have lowered their regulatory levels since
- Regional clusters do not necessarily align with state standards

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Treatment Technologies

In Situ	Phytoremediation	✓
	Chemical Oxidation	✓
	Natural Attenuation/Enhanced Bio	✓
	Thermal	✓
	Extreme Soil Vapor Extraction	✓
Ex Situ	Advanced Oxidation Processes (AOPs)	✓
	Synthetic Media	✓
	Granular Activated Carbon (GAC)	✗ (most cases)
	Air Stripping	✗
	Bioreactor	More data needed

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Comparison of 1,4-dioxane Ex Situ Treatment Options

	AOP	Synthetic Media	Bioreactor
Technology Maturity	Industry gold standard Only technology used for drinking water	Emerging technology	Limited full-scale systems
Ability to Meeting Low Regulatory Concentrations	High	High	Currently low
Capital Cost	$$$$	$$$	$$
O&M Cost	$$$$	$$	$$
Process Complexity	+++	++	+
Other Limitations	Pre-treatment (wastewater and landfill leachate); Interference (Nitrate, NOM, alkalinity); Regulated byproducts (e.g., bromate)	Pre-treatment (wastewater and landfill leachate); Removal efficiency affected by higher temperature.	No data

Past 1,4-dioxane Bioreactor Studies

- Very few full-scale systems
- Focused on industrial wastewater and landfill leachate
  - Polyester manufacturing wastewater (Sandy et al., 2001; DiGuiseppi et al., 2016)
  - Lowry Landfill (Shangraw et al., 2006; Cordone et al., 2016)
  - Probably a handful of others based on our own experience (e.g., Zhou et al., 2016)
- Effluent concentrations
  - Sandy et al. (2001), DiGuiseppi et al. (2016): meeting 40 µg/L discharge limit (with AOP?)
  - Lowry Landfill: average ~90 µg/L
  - Our experience (landfill leachate) : 5~50 µg/L, average <15 µg/L
- Metabolic and co-metabolic degradation
- Other lab- or pilot-scale studies

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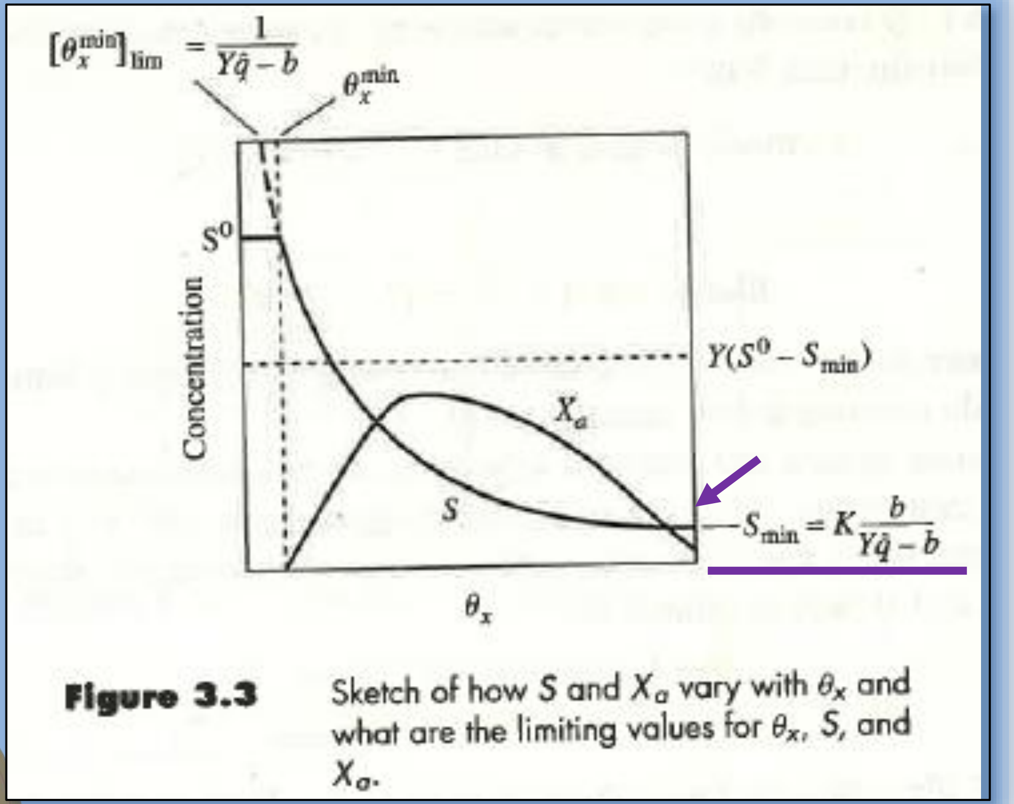
Full-Scale 1,4-dioxane Biological Treatment Systems for Landfill Liquids

Lowry Landfill, Denver, CO

Shangraw
et al., 2003

SoCal Landfill

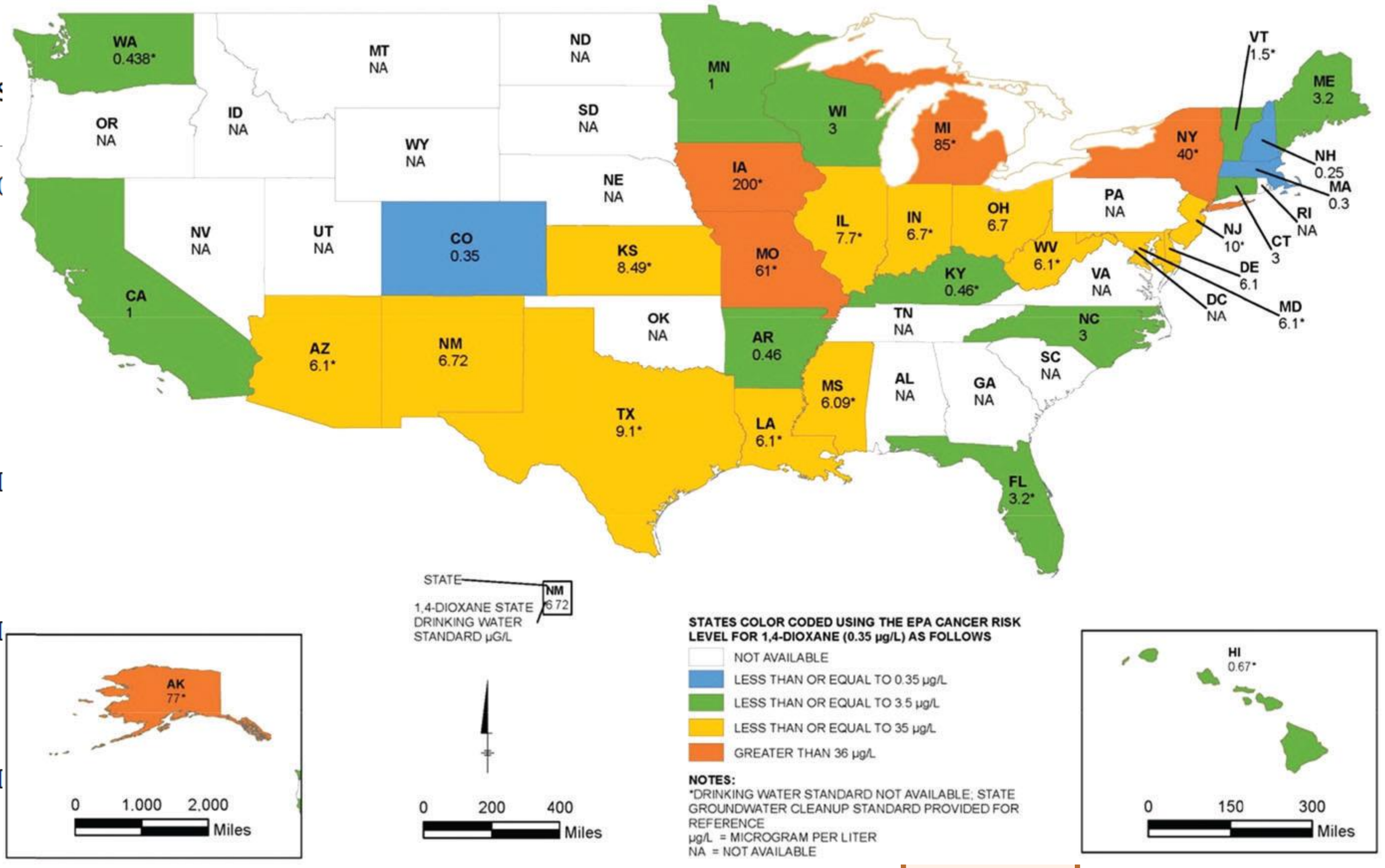
Importance of S_{min} in Meeting Low Effluent Standards



Rittmann and McCarty, 2001

- Defines the lowest effluent concentration capable of supporting steady-state metabolic degradation in a continuous stirred-tank bioreactor
- Occurs when the solids retention time (SRT) is sufficiently long
- Depends only on culture's intrinsic kinetic properties – not on reactor configuration or influent conditions
  - K defines affinity to substrate, smaller is better
  - The other part defines the invert of "growth potential", smaller is better

S_{min} of Existing 1,4-Dioxane Metabolizing Cultures



		factory					
D17	Gram-positive *Actinomycetes*	Soil in the drainage area of a chemical	0.223	0.096	59.7	Sei et al.	2013

- Much smaller K for CB1190 (6.3 mg/L) recently reported by Barajas (2016)
- S_{min} = 460 µg/L
- S_{min} > 1 mg/L for the other cultures

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Reactor Configurations

- Key is long SRT, biomass retention
- Both suspended and attached growth systems work
  - Lowry: moving bed biofilm reactor (MBBR)
  - SoCal Landfill: activated sludge, membrane bioreactor (MBR)
  - Polyester WW: presumably activated sludge (followed by AOP?)
  - Probably other configurations, too
- Cannot change S_{min}
- Other considerations (co-metabolism, temperature, DO, etc.)

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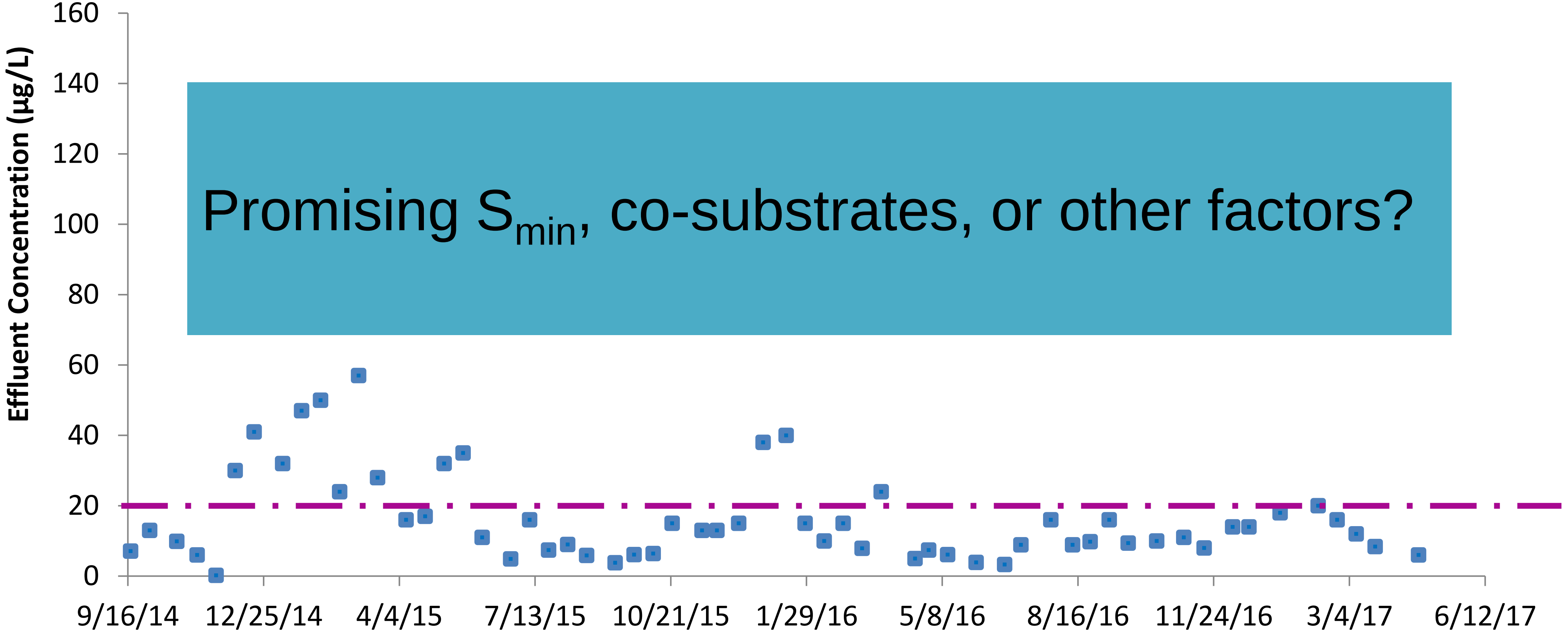
Make 1,4-dioxane Bioreactor Treatment More Viable

- For metabolic and steady-state systems, S_{min} needs to be 2 orders of magnitude lower
- Supplemental/co-metabolic substrate(s)
- Bioaugmented bioreactor (i.e., providing higher-than-steady-state biomass concentration)

Effluent 1,4-Dioxane Concentrations at a SoCal Landfill Leachate Treatment Plant



Promising S_{min}, co-substrates, or other factors?

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Results of Our Testing Programs To Date

<table>
<tr><th>Reactor</th><th>Scale</th><th>Influent (μg/L)</th><th>Medium</th><th>HRT (hrs)</th><th>Average Removal</th></tr>
<tr><td>Activated Sludge</td><td>Full</td><td rowspan="3">2500</td><td rowspan="3">Leachate</td><td>60</td><td>99.7%</td></tr>
<tr><td>MBR</td><td rowspan="4">Pilot</td><td>25</td><td>99.2%</td></tr>
<tr><td>MBBR</td><td>128</td><td>96%*</td></tr>
<tr><td>MBR</td><td rowspan="2">12000</td><td rowspan="2">Leachate</td><td>25</td><td>99.4%</td></tr>
<tr><td>MBBR</td><td>60</td><td>98.8%</td></tr>
<tr><td>Various</td><td>Bench</td><td>500</td><td>Synthetic</td><td>6</td><td>40~60%</td></tr>
</table>

***: Optimal (not average) removal**

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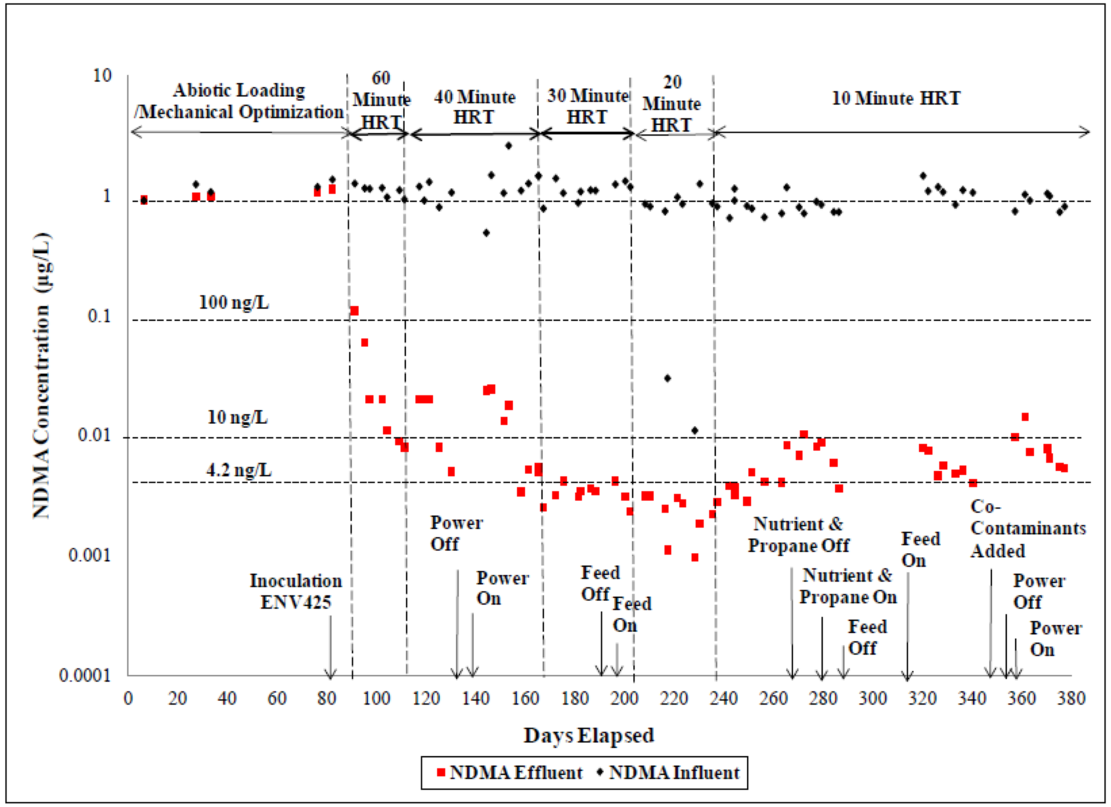
Testing run > 8 weeks

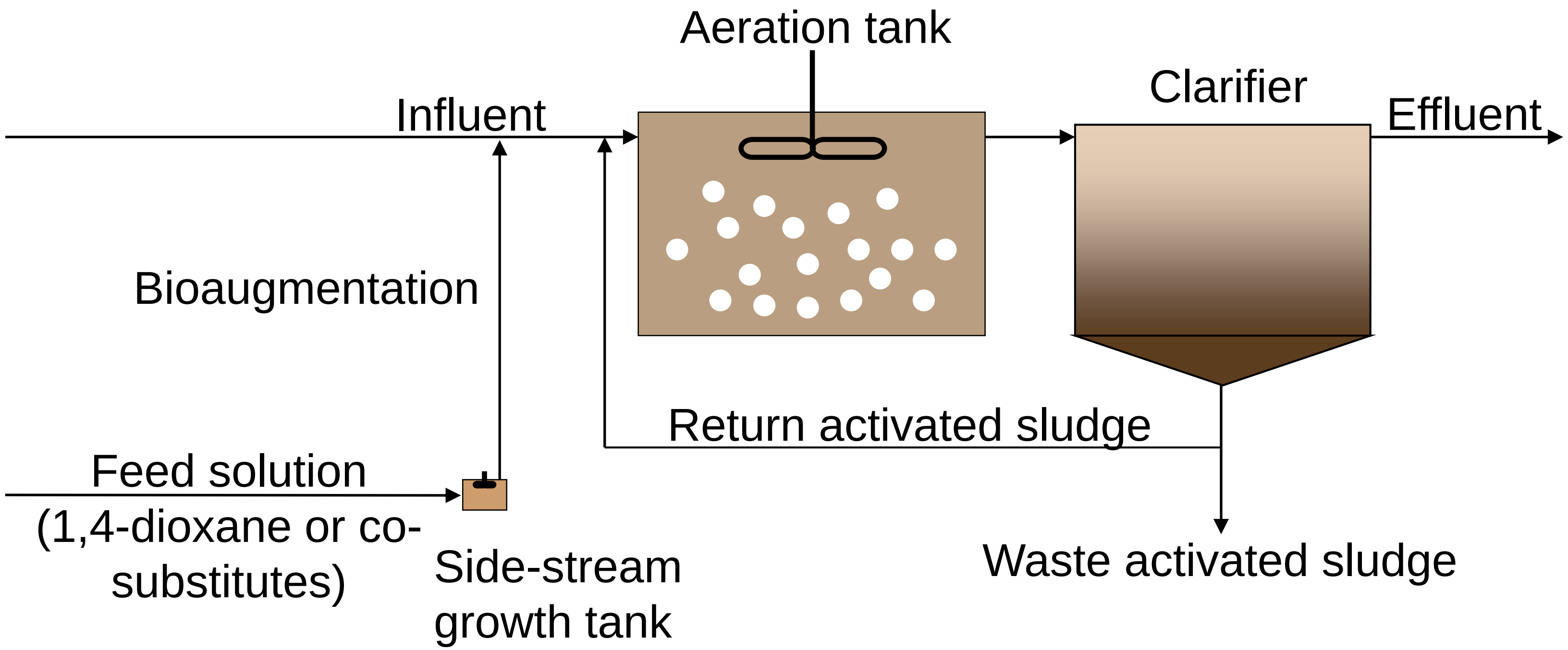
Co-metabolic Bioreactor Example:
Propane-Fed Fluidized Bed Reactor (FBR) Treating NDMA

Figure 5.12 NDMA in the FBR influent and effluent over the duration of the study.



Hatzinger and Webster, 2014

Bioaugmented Bioreactor Schematics



Modified from Dr. Heidi Gough

Conclusions

- 1,4-Dioxane is an emerging contaminant facing increasingly more stringent regulations by many states.
- Effective ex situ 1,4-dioxane treatment technologies are limited to advanced oxidation processes and synthetic media adsorption.
- Bioreactor treatment may offer potential cost-saving opportunities.
- Past full-scale studies were focused on industrial wastewater and landfill leachate, not groundwater, and have not demonstrated that regulatory standards can be met.
- Improving metabolizing culture's intrinsic kinetic properties is needed to meet regulatory standards.
- Alternative strategies include utilizing co-metabolism and bioaugmented bioreactors.

Questions?