

**New Advances in Phytoremediation and Successful
Treatment on Chlorinated Solvents Sites**

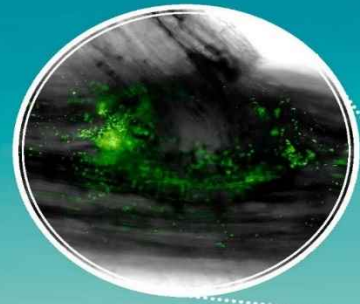
Dr. Chris Cohu



Intrinsyx Environmental

Combining nature with engineered solutions for sustainable environmental remediation

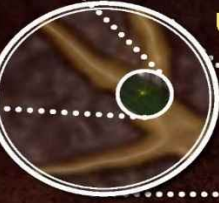
Phytoremediation



Endophytes



Endophytes



Sequestration + Mineralization
Organic Chemicals + Metals

Uptake + Phytoextraction
Water + Contaminants

Sun Light

Photosynthesis

Transpiration

Xylem
 H_2O + Nutrients

Phloem

CO_2

Carbon Sequestration

Exudation

Rhizosphere Degradation

CO_2

Contaminants

Water Table

Photosynthesis

Sun Light
+ CO_2

O_2

Sugars

Transpiration
 H_2O

Cl^-
(to roots)

Cl^-

$CO_2 + H_2O$

Respiration

O_2

$CO_2 + H_2O$

Plant + Endophyte
Cometabolism

eg. $C_2HCl_3 + O_2 \rightarrow Cl^- + CO_2 + H_2O$

Root Respiration

$CO_2 + H_2O$

O_2

Exudation

$O_2 + Cl^- +$ Sugars +
Organic Acids

$CO_2 + H_2O + Cl^-$

Rhizosphere Degradation
+ Mineralization

Cometabolism

Organic Chemicals

$C_x + H_y + O_z$

$C_x + Cl_w + H_y + O_z$



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Depending on the Concentrations a Limiting factor in PAH Soil and Groundwater Phytoremediation.

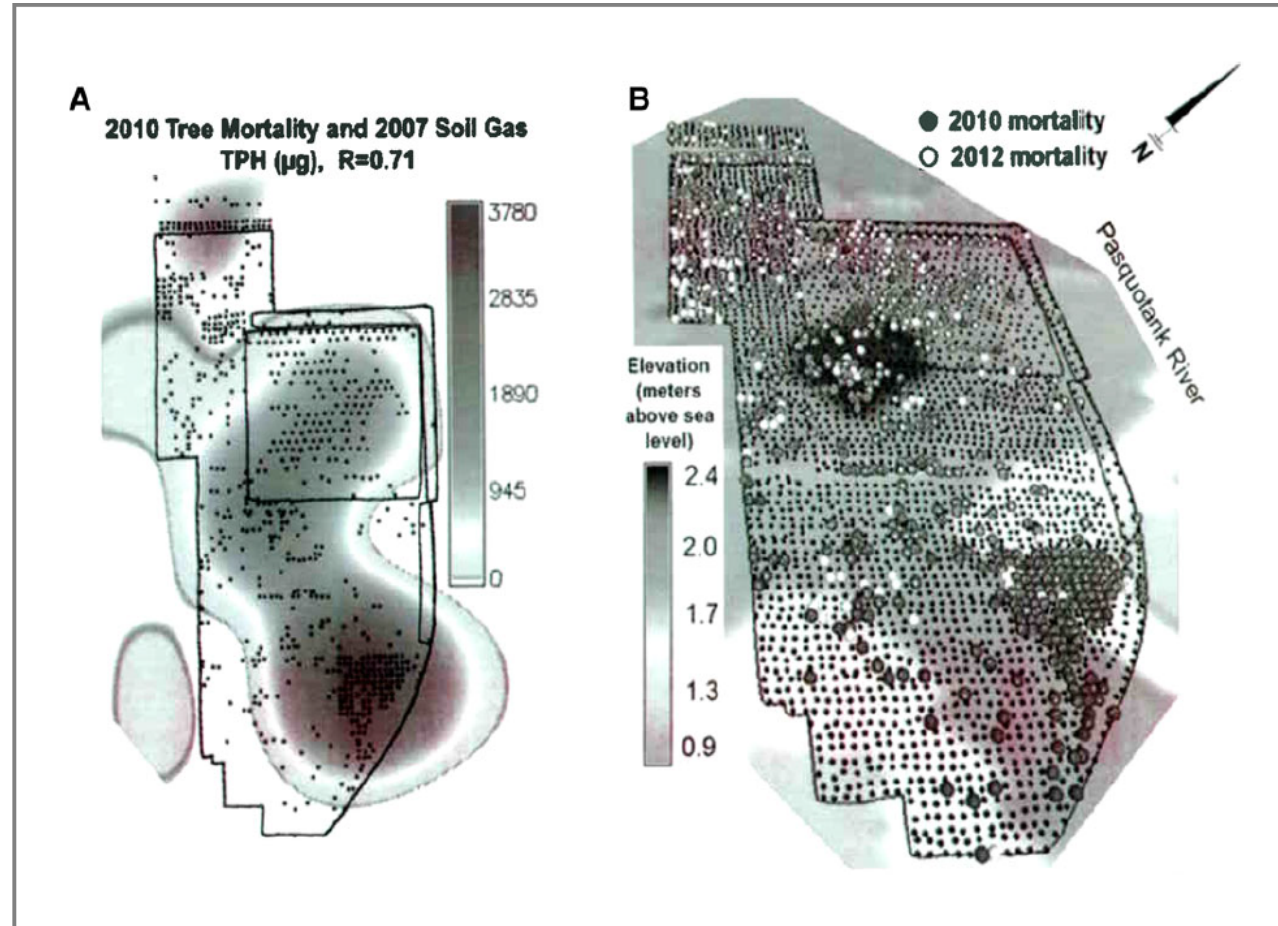
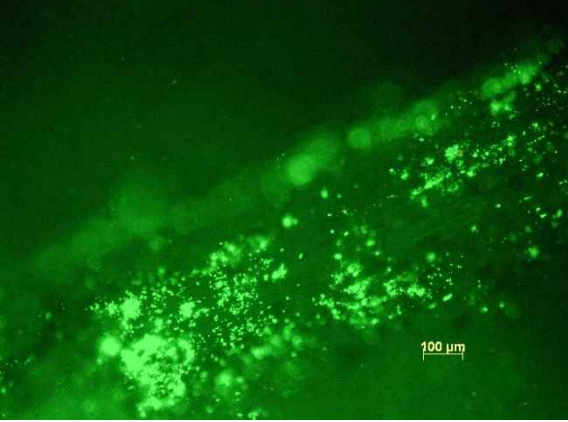


Exhibit 2. Locations of tree mortalities relative to 2007 soil-gas contours (A) and surface elevation (left) for 2010 and 2012 (B)

Nichols, E.G., Cook, R.L., **Landmeyer, J.E.**, Atkinson, B., Malone, D.R., Shaw, G., and Woods, L., 2014, Phytoremediation of a petroleum-hydrocarbon contaminated shallow aquifer in Elizabeth City, North Carolina, USA: Remediation Journal, vol. 24, pp. 29-46. [\[Link\]](#)

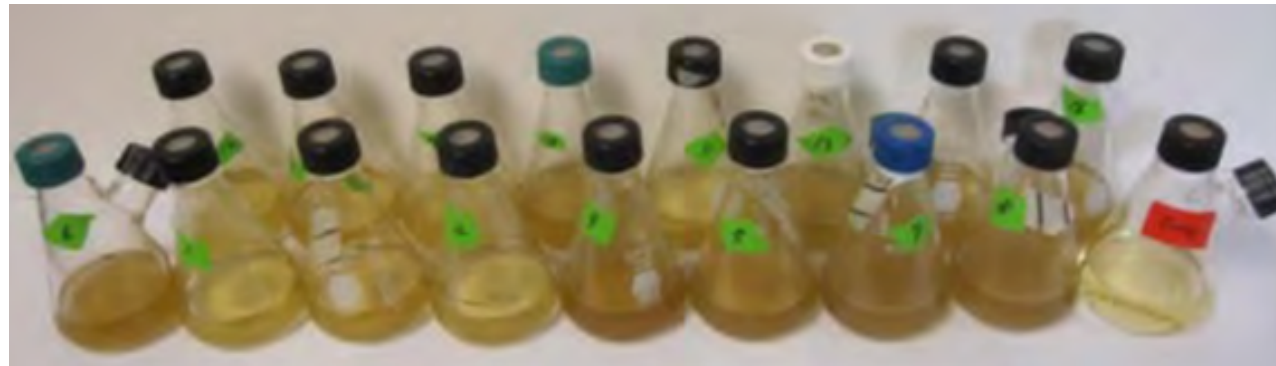


Discoveries in Tree Microbiome Research

Endophyte Bacteria symbiosis for improved metabolism of a broad range of carcinogenic pollutants



Sharon L. Doty, Professor
University of Washington



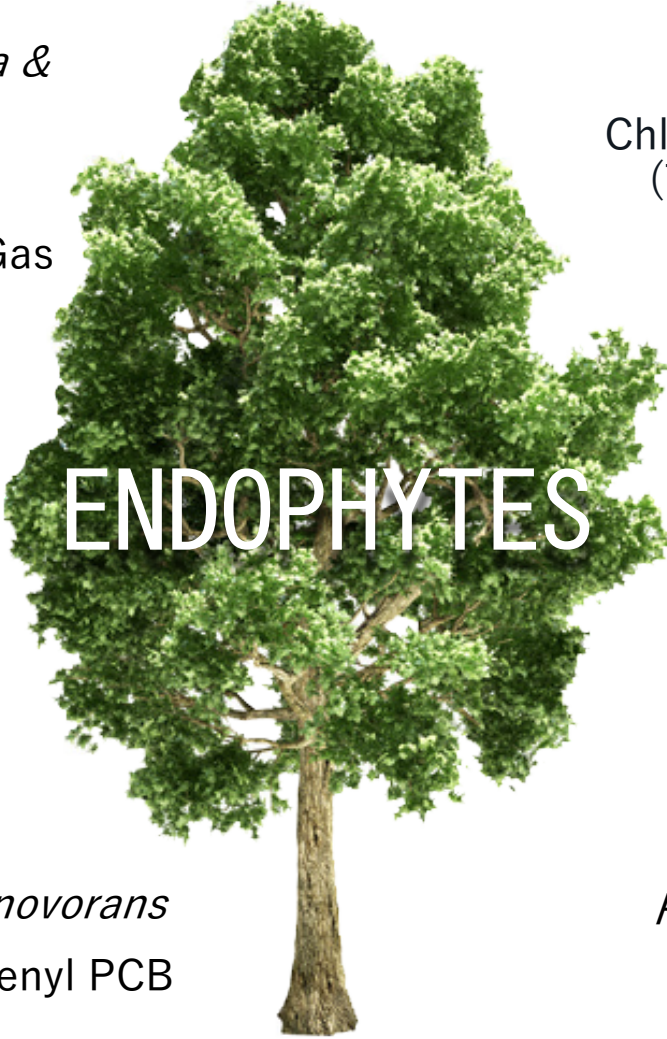
PD1 & WW5

Pseudomonas putida &
Sphingomonas yanoikuyae

PAH / BTEX / Oil / Gas
1,4-D

PDN3

Enterobacter sp.
Chlorinated Solvents
(TCE, Carbon Tet)



ENDOPHYTES

TPSN7

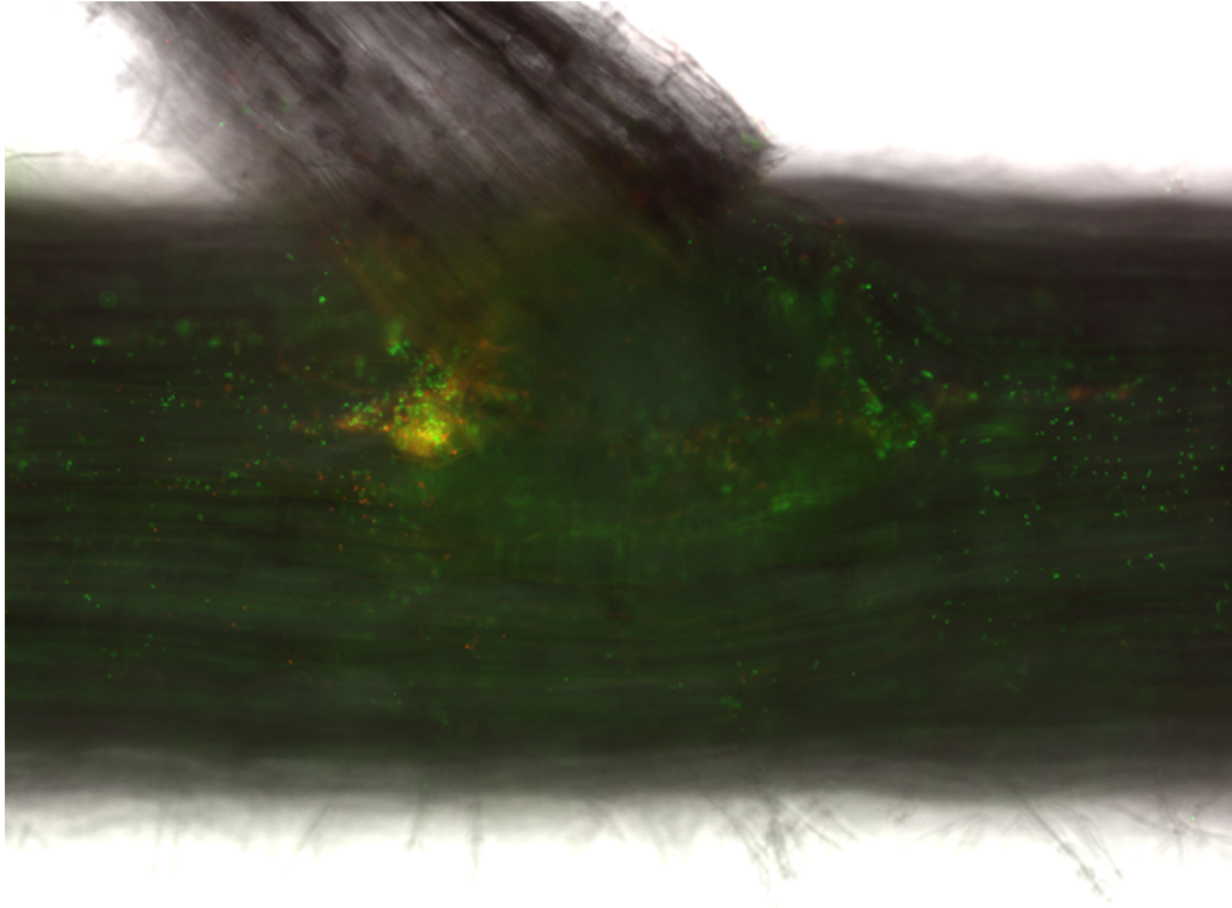
Paraburkholderia xenovorans
Polychlorinated biphenyl PCB

PTA1...4

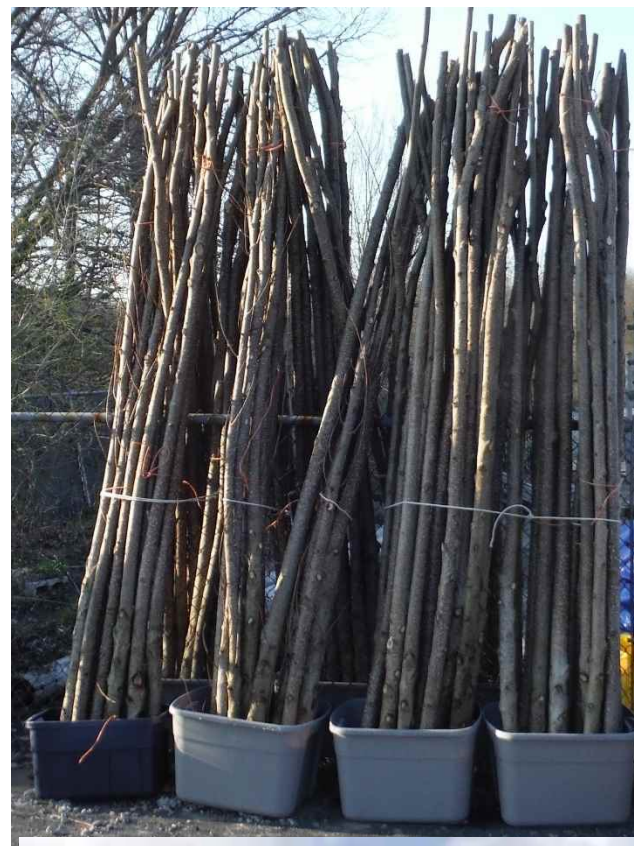
Pseudomonas sp
TNT & RDX

Co-inoculation for Phytoremediation of Mixed Carcinogenic Pollutants

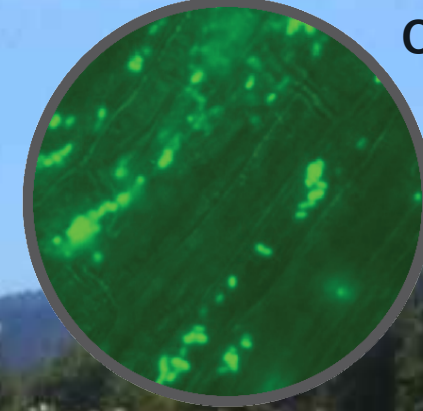
Endophytes enter through cracks at lateral root junctions



PD1 (red) and PDN3 (green) on a poplar seedling root.

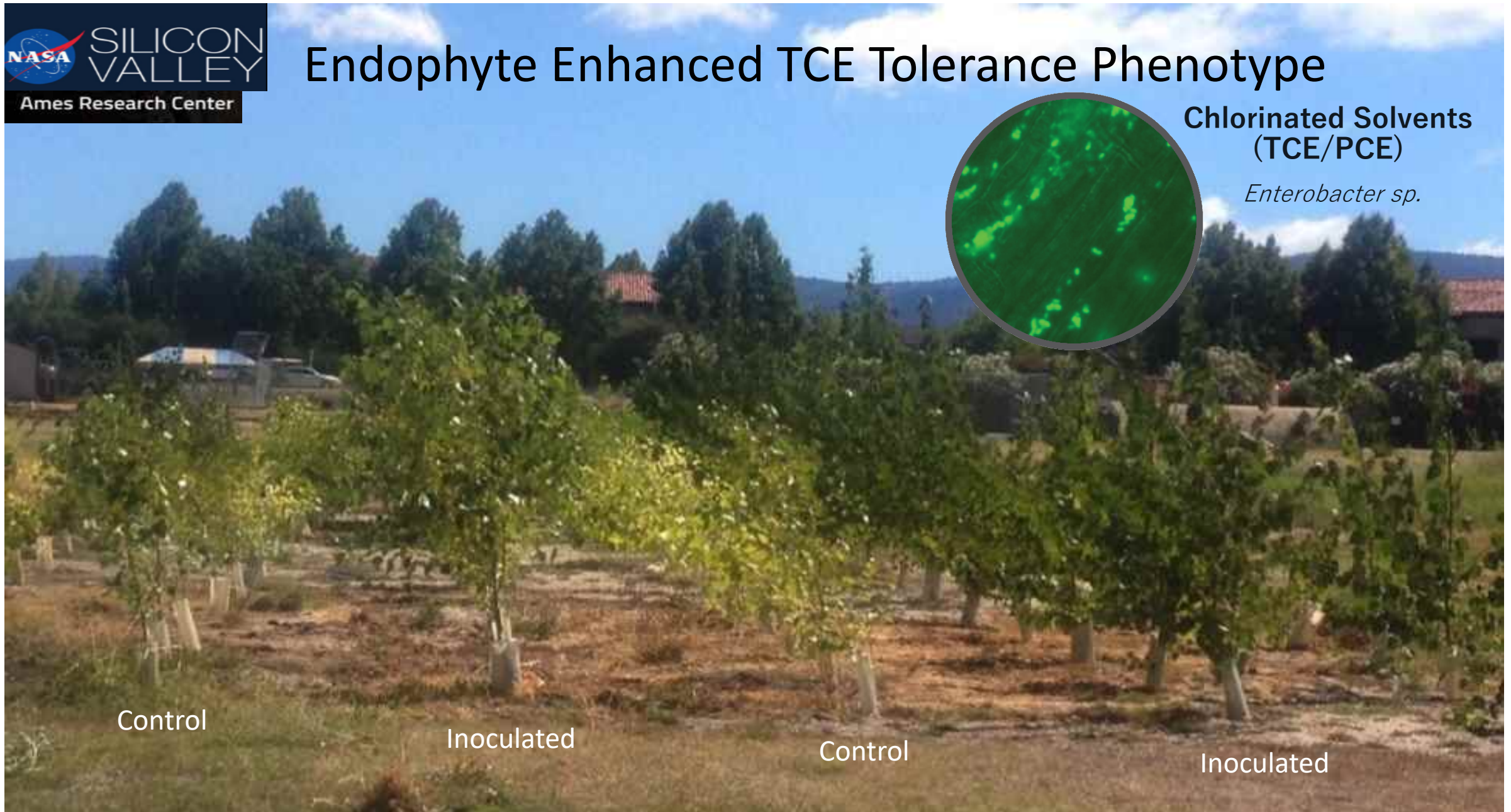


Endophyte Enhanced TCE Tolerance Phenotype



Chlorinated Solvents
(TCE/PCE)

Enterobacter sp.



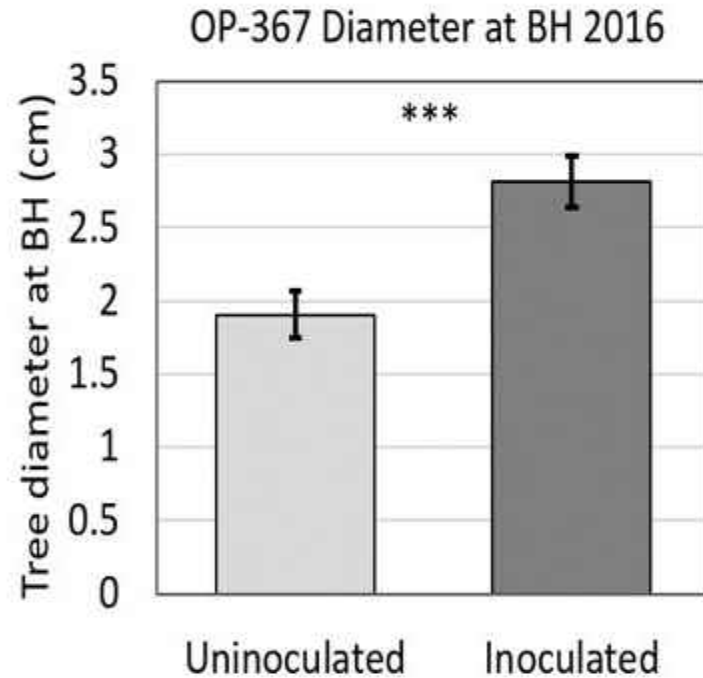
Control

Inoculated

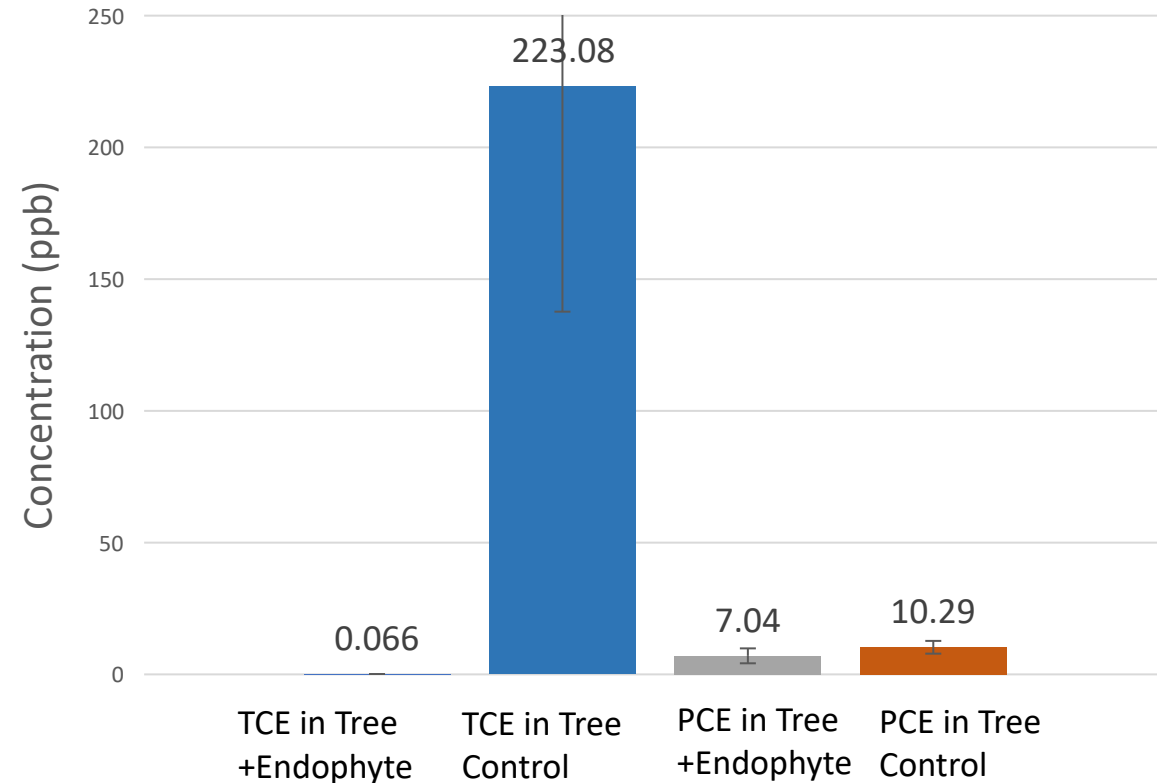
Control

Inoculated

Growth and Degradation Benefits from Endophyte Inoculation



Tree trunk diameter at
breast height (cm)



Enhanced degradation

Monitoring Well Results

Test Well 1 Upgradient from Trees vs. **Test Well 2 Down Gradient** from Trees

	August 28, 2016 Test Well		November 21, 2016 Test Well		July 28, 2017 Test Well		July 19, 2018 Test Well		MDL	Reporting Limit
	1	2	1	2	1	2	1	2		
	µg/L									
Trichloroethene	280	ND	300	ND	260	ND	130	ND	1.1	5
trans-1,2-Dichloroethene	1.7	ND	3.1	ND	2.2	ND	2	ND	0.13	0.5
cis-1,2-Dichloroethene	140	ND	160	ND	120	ND	90	ND	1.5	5
1,1-Dichloroethene	7.6	ND	6.8	ND	5.8	ND	4.6	ND	0.092	0.5
1,1-Dichloroethane	7.9	0.64	9	0.58	8.1	ND	6	0.48	0.12	0.5
Vinyl chloride	0.54	ND	0.77	ND	ND	ND	0.50	ND	0.17	0.5
Tetrachloroethene	0.85	ND	0.88	ND	0.86	ND	ND	ND	0.12	0.5
Chloroform	0.38	ND	ND	ND	ND	ND	ND	ND	0.13	0.5
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	1.5	ND	1.5	ND	2.2	ND	2.4	ND	0.15	0.5

- Effectively cut off TCE plume migrating onto base
- EPA Approval to expand remediation efforts over the next phase – incorporating phytoremediation into the redevelopment plan for a housing project

Phytoremediation Pre- and Post-Endophytes

Endophyte Root Drench Tree Rescue using PD1 on **blue rows**

RESULT: Increase in tree health and survival rate



Trees Dead: ●
Trees Dying: ●
Trees Severely Stressed: ●

3-4 Years After Planting CA State Water Board Authorized Shut-Off and Dismantling of Pump & Treat and Soil Vapor
Extraction Systems

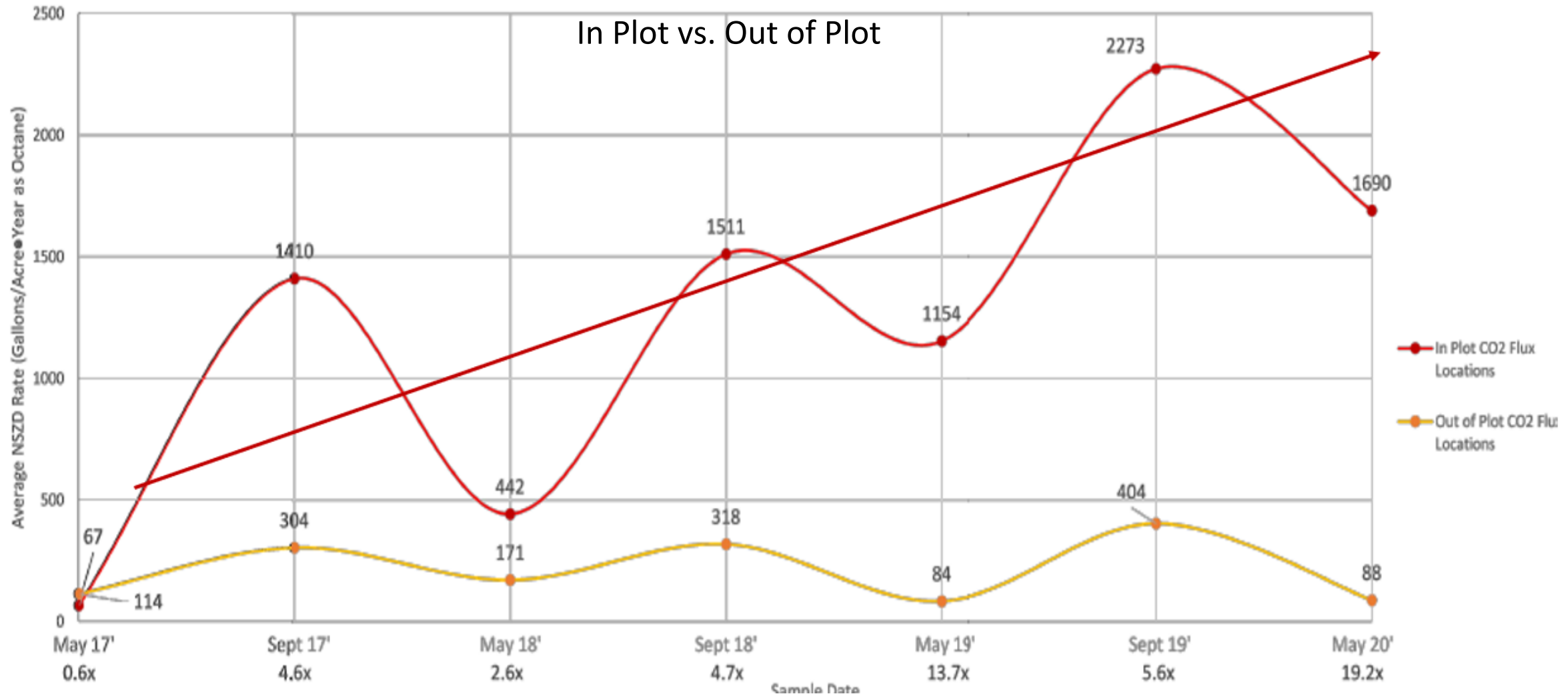
Positive Impact on Neighborhood Community Forest

Client saving ~\$1M/year



CO2 Flux- Gallons of Octane / Acre / Year

Trees Enhance Natural Source Zone Depletion Rates over Time

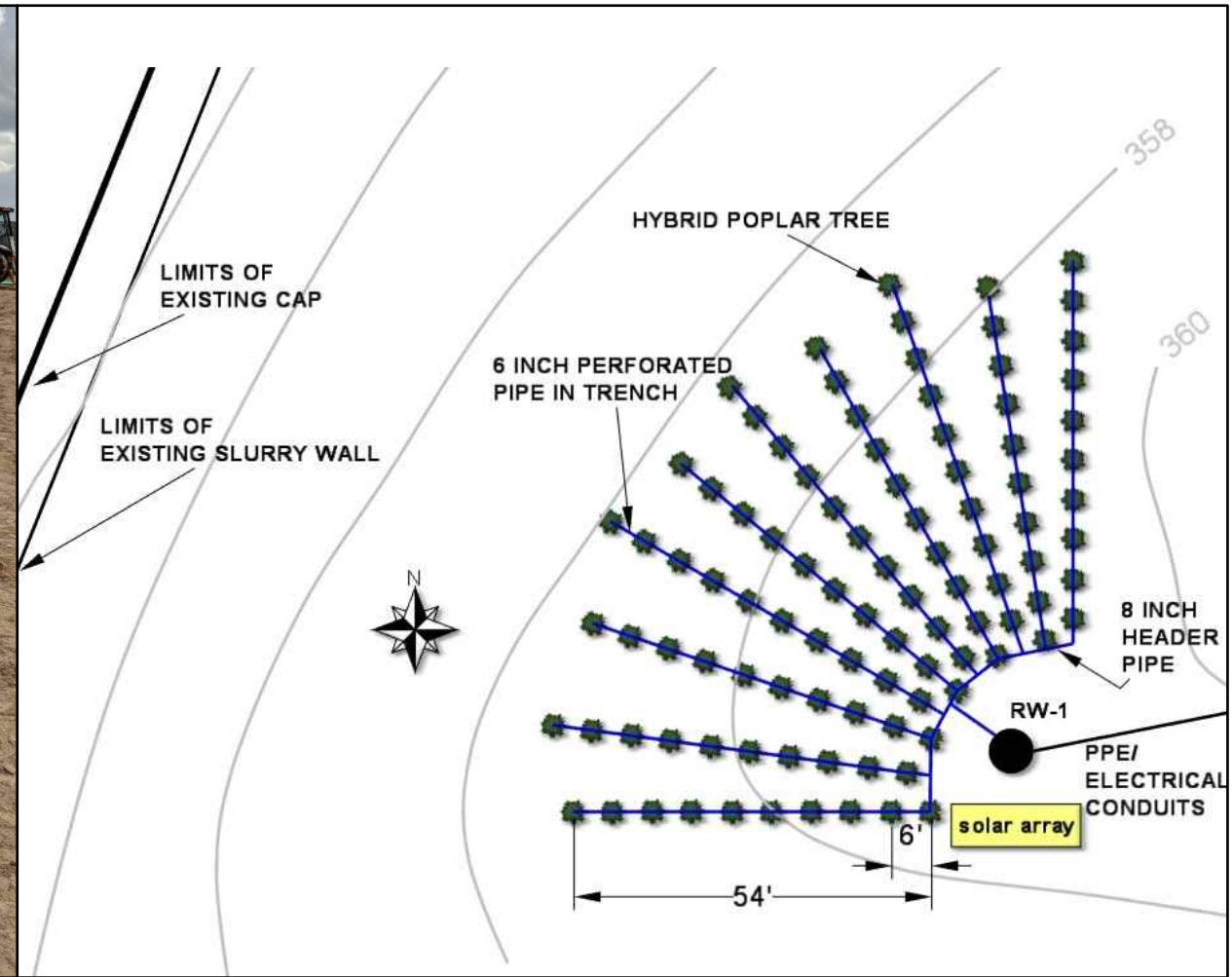
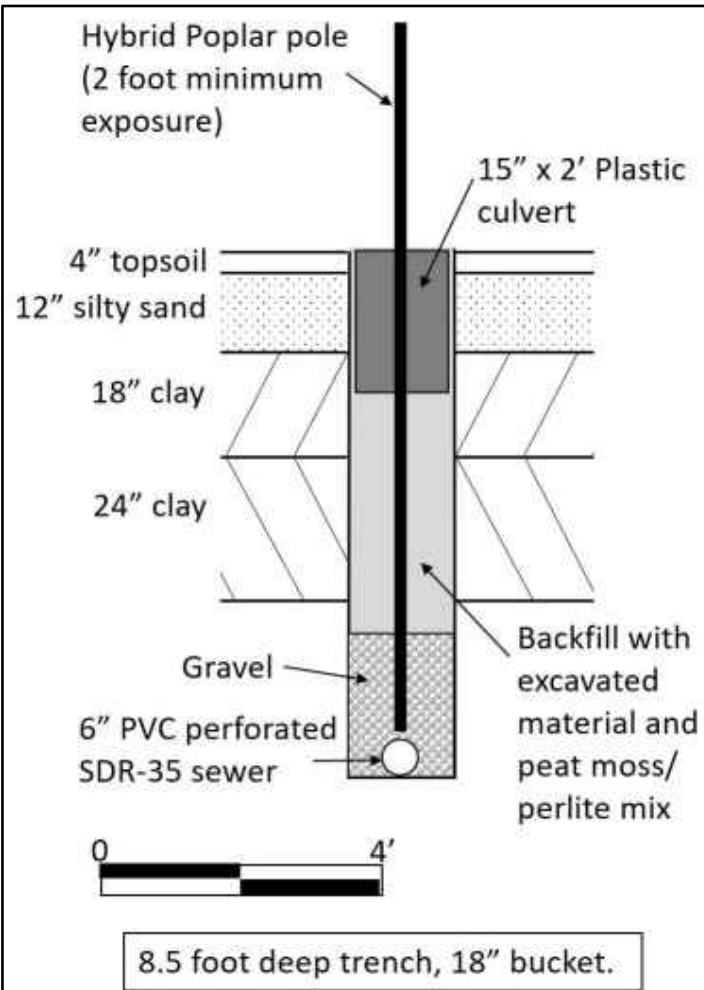


Fairbanks Bulk Fuel Transfer Station 300 Trees augured 8ft deep through asphalt
Petroleum hydrocarbons and chlorinated solvent site using three endophytes

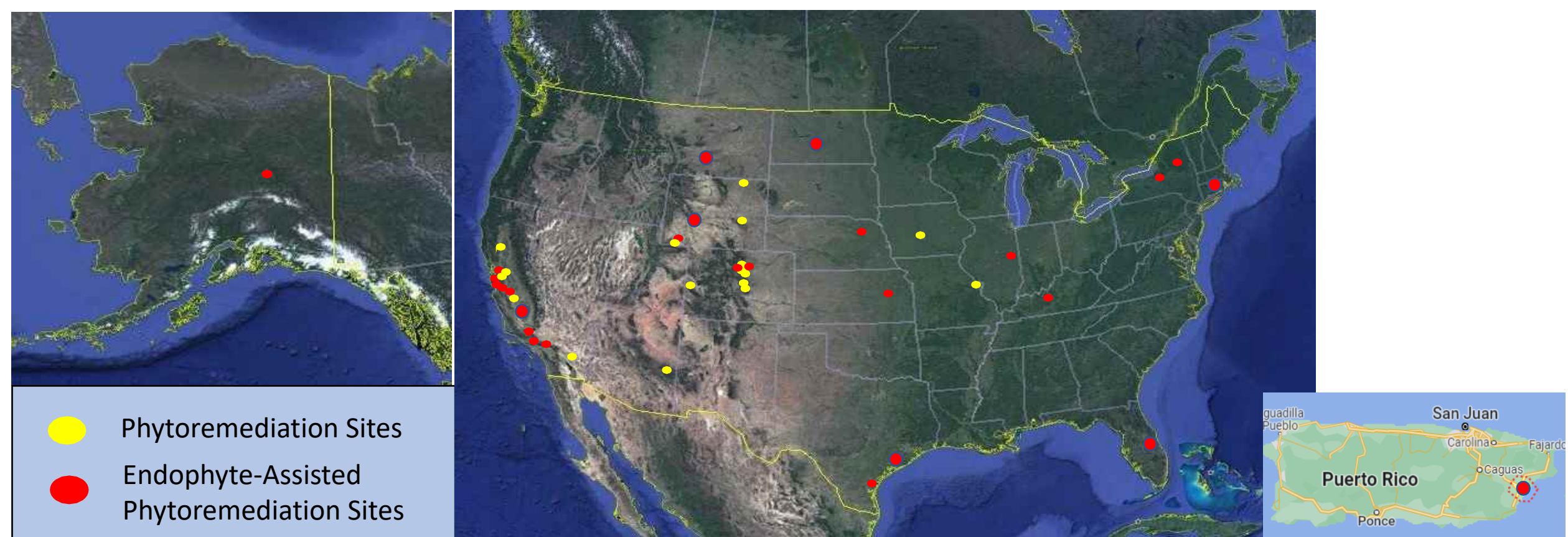


Pump & Tree Phytoremediation and Bioreactors

- Tree—Grass—Microbe Contained Systems
- Sub-surface irrigation, unlined
- Lined trenches
- Rhizofiltration Treatment
- Dewatering & treatment
- Containerized systems



Full-Scale Commercial Tree Phytoremediation Across United States



2021 Established a Nationwide Partnership with Arbor Day Foundation:

arborday.org/phyto



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Summary of Endophyte Benefits in Phytoremediation

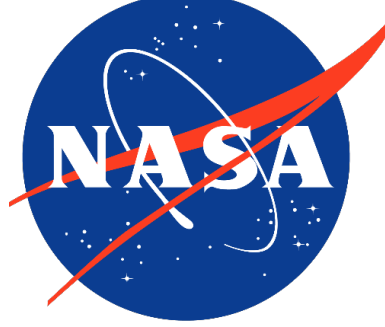
- Allows plant selection specific to site environment and needs
 - Allows for phytoremediation on pollutant concentrations previous thought impossible
 - Able to remediate mixed contaminate sites
 - Increased tolerance, survival and growth rates
 - Enhanced contaminant degradation
 - One of the most sustainable methods and carbon negative
- **endophytes are ubiquitous in nature



Partners and Collaborators



Intrinsyx Environmental



Arbor Day
Foundation®



Jacobs



"Finding a Better Way"

