Phytotechnologies as a Sustainable Approach for Exposure Prevention: A Public Health Perspective

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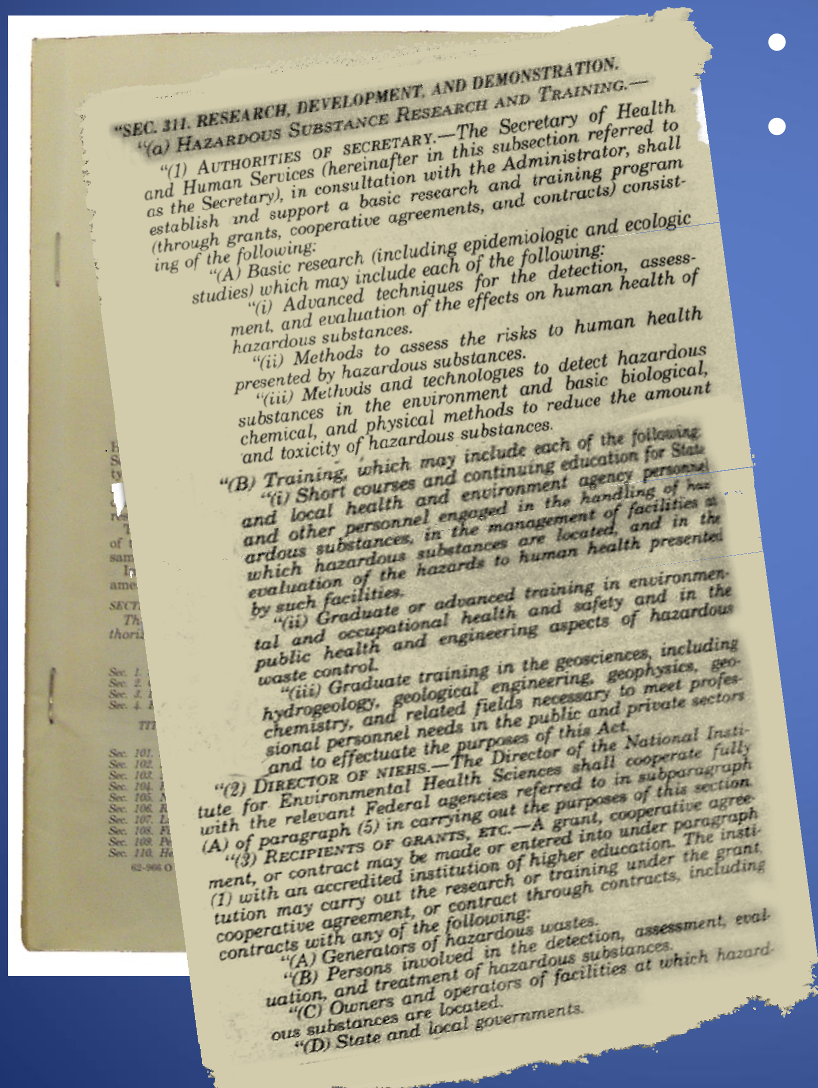
Director, Superfund Research Program

National Institute of Environmental Health Sciences

Outline of Talk

- Superfund Research Program
- SRP and Phytotechnologies
- Public Health Perspective
  - Primary prevention
  - Reducing exposures
- Integrating Phytotechnologies and Public Health

Superfund Research Program Formed under SARA



"SEC. 311. RESEARCH, DEVELOPMENT, AND DEMONSTRATION.

"(a) HAZARDOUS SUBSTANCE RESEARCH AND TRAINING.—

"(1) AUTHORITIES OF SECRETARY.—The Secretary of Health and Human Services (hereinafter in this subsection referred to as the Secretary), in consultation with the Administrator, shall establish and support a basic research and training program (through grants, cooperative agreements, and contracts) consisting of the following:

"(A) Basic research (including epidemiologic and ecologic studies) which may include each of the following:

"(i) Advanced techniques for the detection, assessment, and evaluation of the effects on human health of hazardous substances.

"(ii) Methods to assess the risks to human health presented by hazardous substances.

"(iii) Methods and technologies to detect hazardous substances in the environment and basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances.

"(B) Training, which may include each of the following:

"(i) Short courses and continuing education for State and local health and environment agency personnel and other personnel engaged in the handling of hazardous substances, in the management of facilities at which hazardous substances are located, and in the evaluation of the hazards to human health presented by such facilities.

"(ii) Graduate or advanced training in environmental and occupational health and safety and in the public health and engineering aspects of hazardous waste control.

"(iii) Graduate training in the geosciences, including hydrogeology, geological engineering, geophysics, geochemistry, and related fields necessary to meet professional personnel needs in the public and private sectors and to effectuate the purposes of this Act.

"(2) DIRECTOR OF NIEHS.—The Director of the National Institute for Environmental Health Sciences shall cooperate fully with the relevant Federal agencies referred to in subparagraph (A) of paragraph (5) in carrying out the purposes of this section.

"(3) RECIPIENTS OF GRANTS, ETC.—A grant, cooperative agreement, or contract may be made or entered into under paragraph (1) with an accredited institution of higher education. The institution may carry out the research or training under the grant, cooperative agreement, or contract through contracts, including contracts with any of the following:

"(A) Generators of hazardous wastes.

"(B) Persons involved in the detection, assessment, evaluation, and treatment of hazardous substances.

"(C) Owners and operators of facilities at which hazardous substances are located.

"(D) State and local governments.

- Basic Research Program
- Advances Methods and Techniques to:
  - detect, assess, and evaluate effects and risks on human health by hazardous substances
  - detect hazardous substances in the environment
  - methods to reduce amount & toxicity of hazardous substances

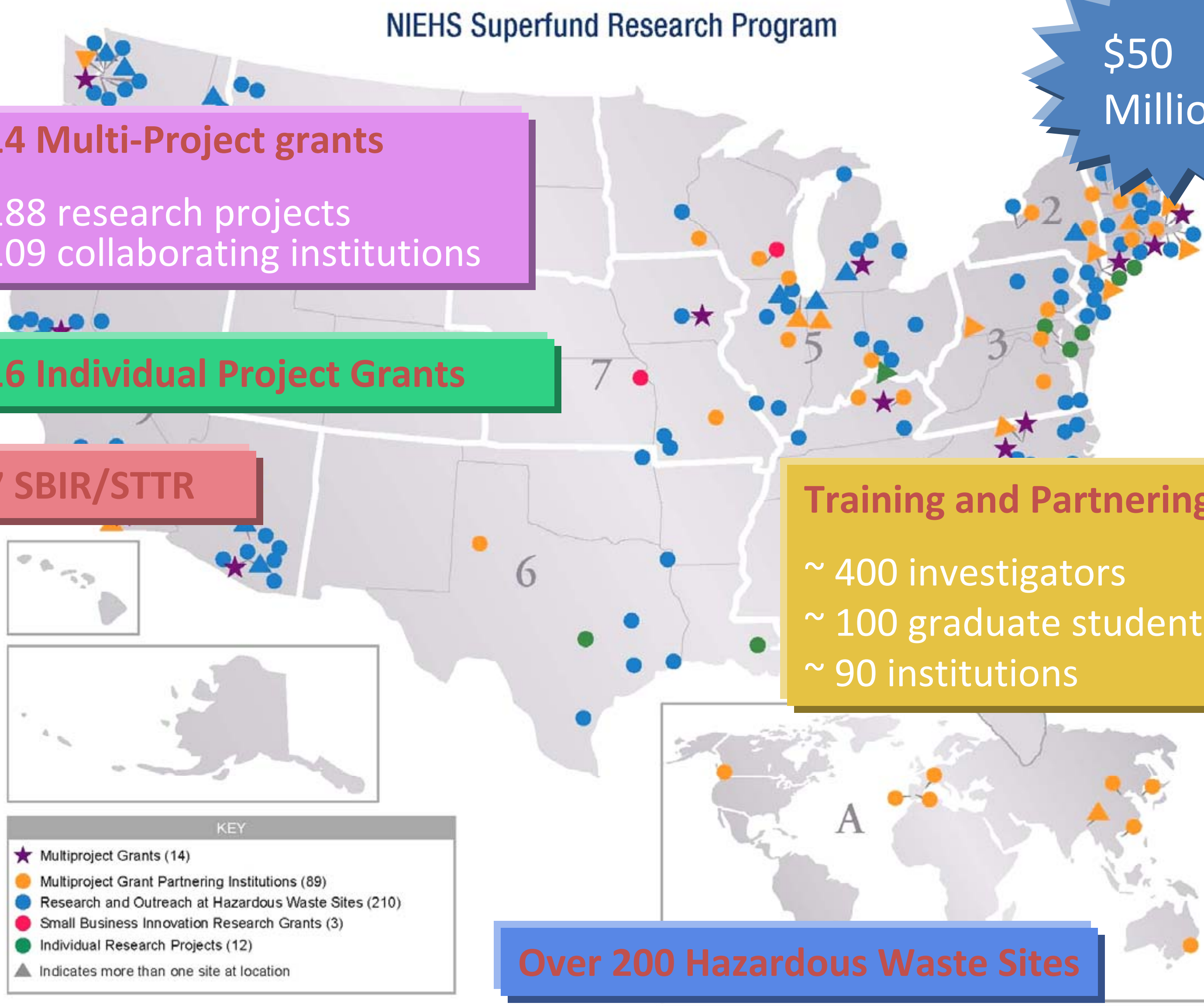
$50 Million

14 Multi-Project grants

188 research projects
109 collaborating institutions

16 Individual Project Grants

7 SBIR/STTR

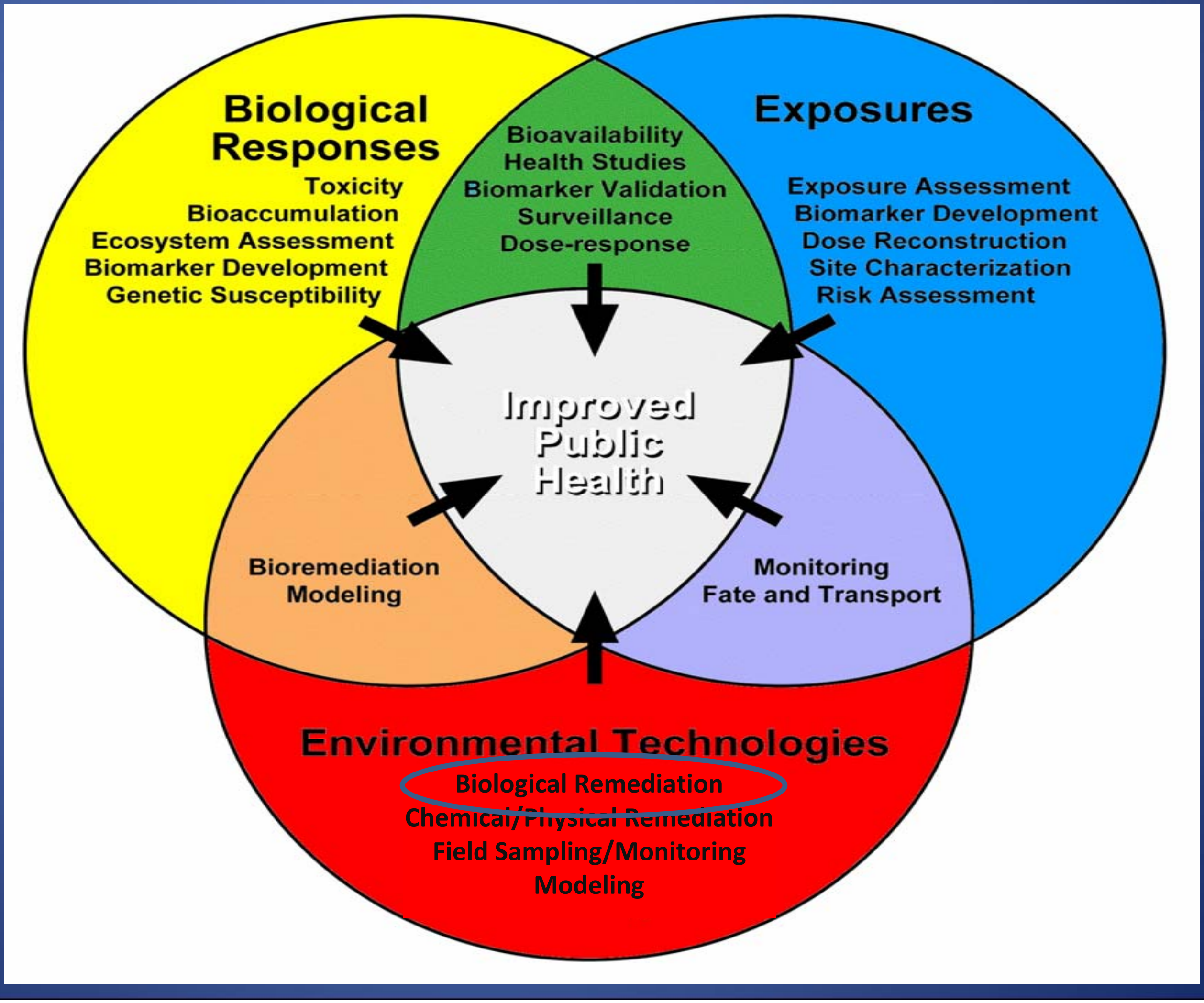


Training and Partnering

~ 400 investigators
~ 100 graduate students
~ 90 institutions

Over 200 Hazardous Waste Sites

Superfund Research Program:
Interdisciplinary Research for Improving Public Health



SRP Phytotechnology

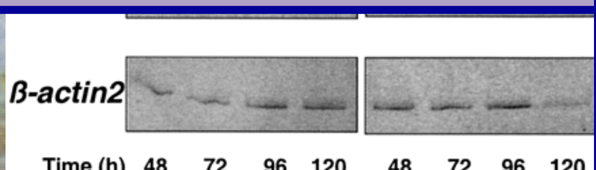
University of California-San Diego
Molecular Mechanisms of Heavy Metal Detoxification and Accumulation in Plants
Project Leader: Julian I. Schroeder

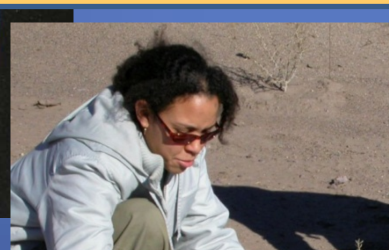
University of Iowa
Phytoremediation to Degrade Airborne PCB Congeners from Soil and Groundwater Sources
Project Leaders: Jerald L. Schnoor, Benoit Van Aken

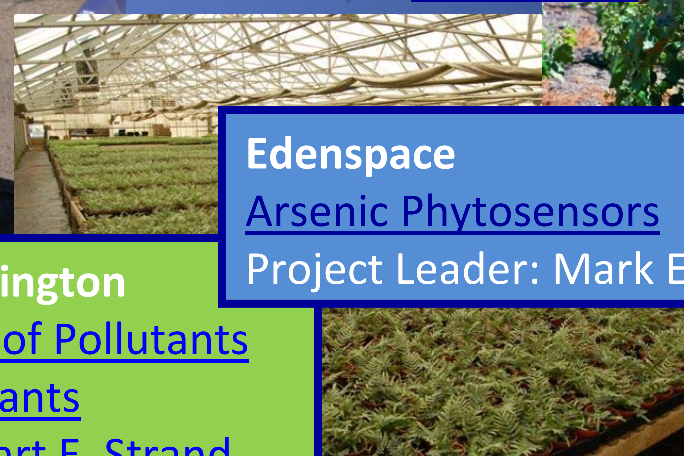
University of Arizona
Phytostablization of Mine Tailings in the Southwestern United States: Plant-Soil-Microbe Interactions and Metal Speciation Dynamics
Project Leader: Raina M. Maier

BASIC → **APPLIED**

University of Arizona
Nano-scale Mechanisms of Metal(loid) Rhizostabilization in Desert Mine Tailings
Project Leader: Jon Chorover

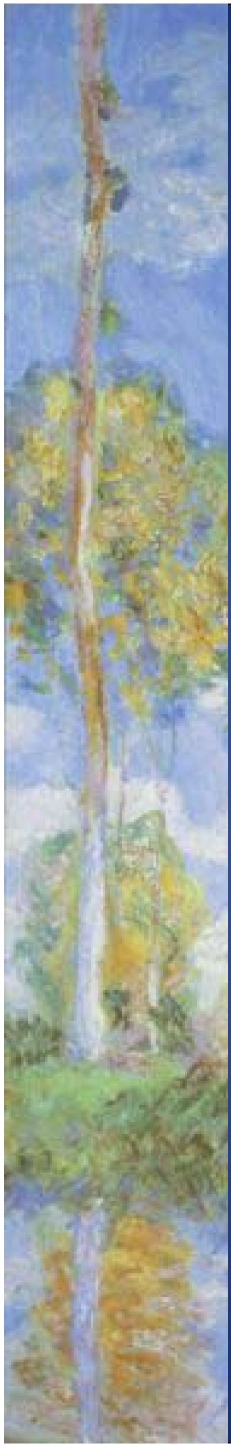






University of Washington
Phytorermediation of Pollutants Using Transgenic Plants
Project Leader: Stuart E. Strand

Edenspace
Arsenic Phytosensors
Project Leader: Mark Elless



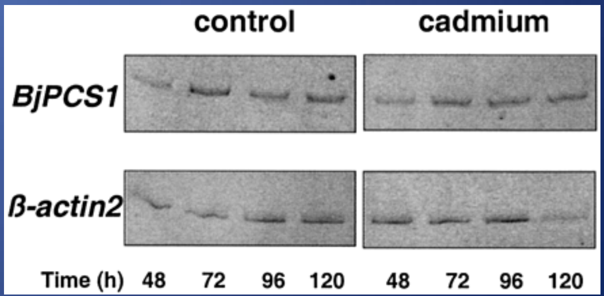
Genomics Strategy for Developing Transgenic Plants for Remediation

Observation - Phytochelation synthase complexes with heavy metals. *Brassica juncea* is an effective metal bioaccumulator.

Strategy - Microarray analysis used to identify new genes and stress-signaling pathways involved in heavy metal accumulation in plants.

Outcome - Transgenic overexpression of phytochelation synthase in *Brassica juncea* was associated with metal detoxification mechanisms to enhance heavy metal tolerance and accumulation.

University of California-San Diego
Molecular Mechanisms of Heavy Metal Detoxification and Accumulation in Plants
Project Leader: Julian I. Schroeder

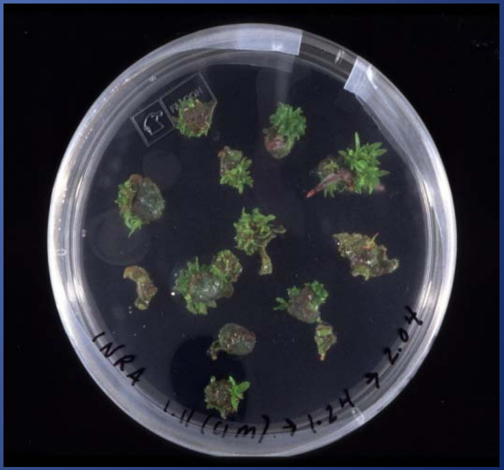


Phytoremediation of TCE Using Transgenic Plants

Observation - Mammalian hepatic cytochrome P450 2E1 oxidizes trichloroethylene (TCE) and other single-ring aromatics. Axenic poplar cell cultures use a TCE degradation pathway similar to that in mammals.

Strategy - Developed transgenic poplars expressing the mammalian cytochrome P450 2E1 (CYP2E1).

Outcome - Achieved orders of magnitude greater oxidation of TCE in transgenic poplar.



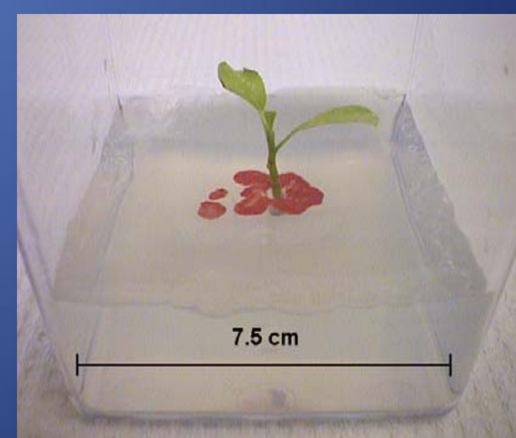
University of Washington
Phytorermediation of Pollutants Using Transgenic Plants
Project Leader: Stuart E. Strand

Hydroxylated PCBs - Mechanisms of Phytodegradation

Observation - Hybrid poplar uptakes PCB congeners from soil and groundwater, as well as from air.

Strategy - Identified metabolic pathways of PCBs and genes that encode for catabolic enzymes.

Outcome - Found cytochrome P450 and glutathione-S-transferase genes involved in detoxification of PCB congeners . These may catalyze the conjugation of hydroxy- and di-hydroxy PCBs in the metabolism and detoxification of these congeners.



University of Iowa
Phytoremediation to Degrade Airborne PCB Congeners from Soil and Groundwater Sources
Project Leaders: Jerald L. Schnoor, Benoit Van Aken

Native Desert Plants for Phytostabilization of Mine Tailings

Observation – Phytostabilization of arid region mine tailings is limited by remote location and challenging growing conditions.

Strategy – Optimize metal/drought-tolerant native plant species with plant growth promoting bacteria seed inoculum to minimize organic matter amendment and irrigation requirements.

Outcome – Completed greenhouse studies for Iron King Mine, finding four native species tolerant of growth conditions.

0% compost 10 % compost 15% compost 20% compost

University of Arizona

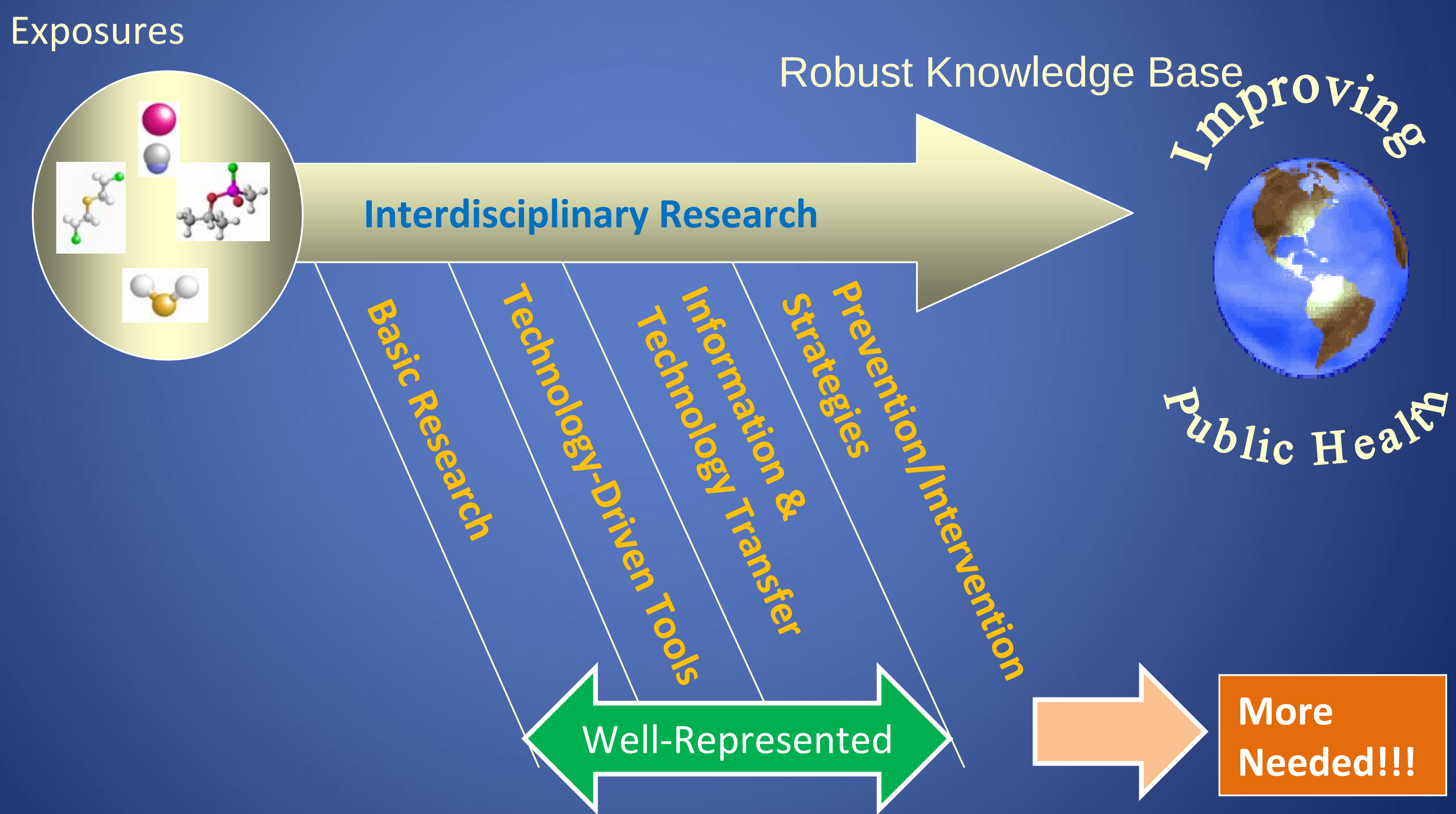
Phytostablization of Mine Tailings in the Southwestern United States: Plant-Soil-Microbe Interactions and Metal Speciation Dynamics

Project Leader: Raina M. Maier

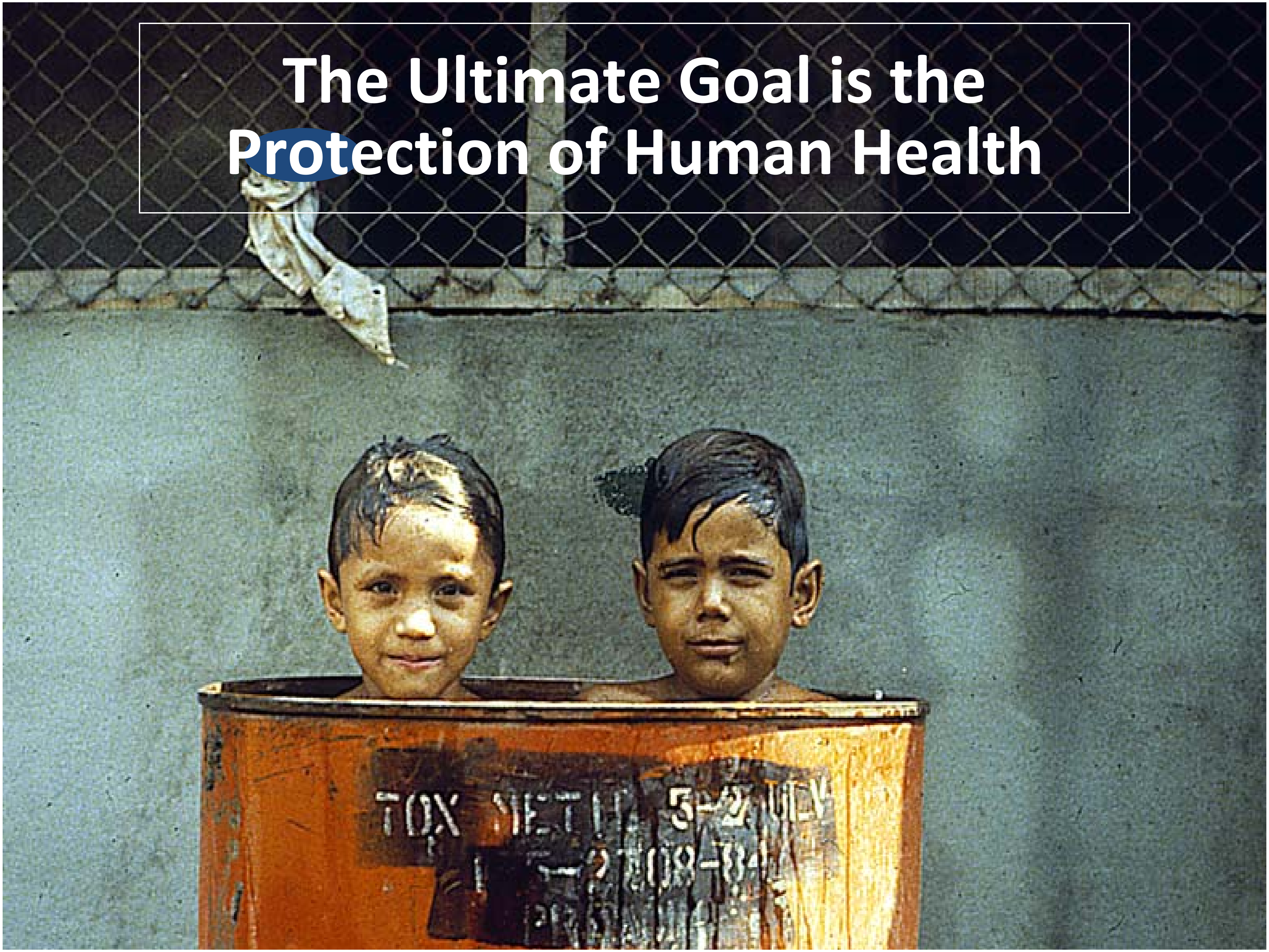
SRP Research Demonstrates Advantages of Phytotechnologies

- Technology-driven
  - Transgenics
  - Growth-promoting bacteria
- Sustainable
  - Native plants adapted to local conditions
  - Low energy input
- Cost effective
- Achieves clean-up goals
  - Demonstrated in pilot/field studies
  - Supported by mechanistic research

Another Benefit of Phytotechnologies – Reduce Exposures, Reduce Disease



The Ultimate Goal is the Protection of Human Health



Public Health

- Focuses on populations
- Mission … to fulfill society's interest in assuring conditions in which people can be healthy
- System includes the community, the health care delivery system, employers and business, the media, and academia

IOM Reports, "The Future of Public Health," 1988, and "The Future of Public Health for the 21st Century," 2002.

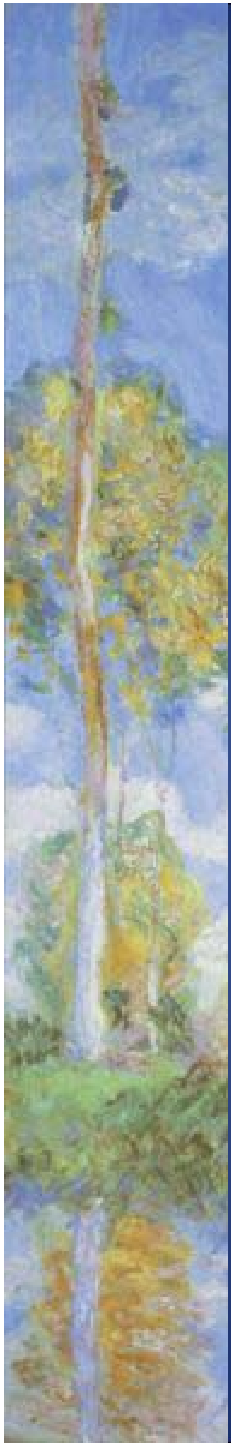
Definition of Human Health

“A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity”

-WHO, 1948

Environmental Public Health

Aspects of human health, including quality of life, that are determined by interactions with physical, chemical, biological and social factors in the environment.

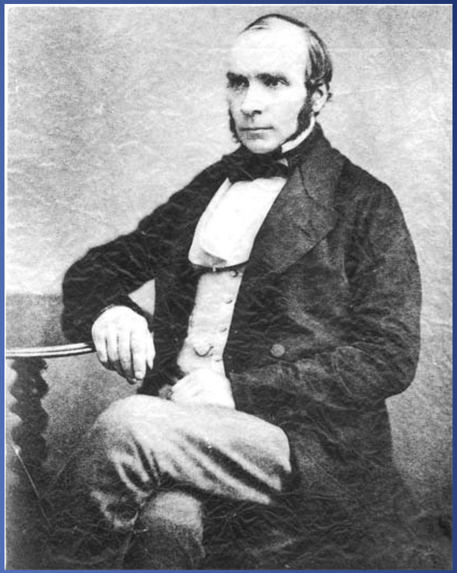


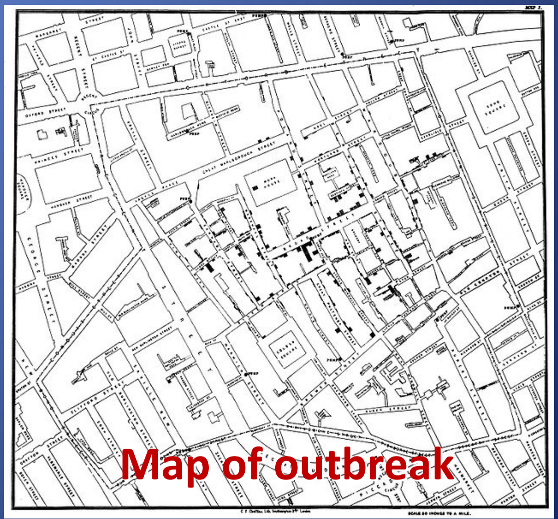
Public Health - Prevention

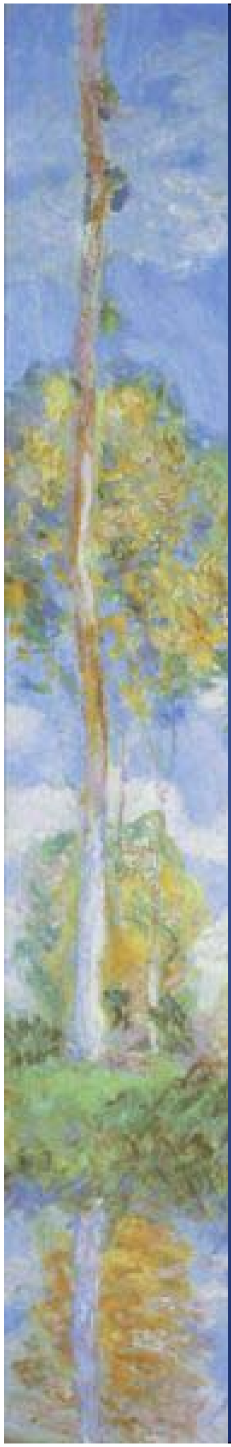
- Primary Prevention
  – prevention of diseases and conditions before their biological onset
  – includes preventing environmental exposures

Public Health - Prevention

- John Snow
  - England, 1854 cholera outbreak
  - Traced epidemic to well pump
- Primary Prevention
  - Removed well handle
  - Prevented exposure to cholera

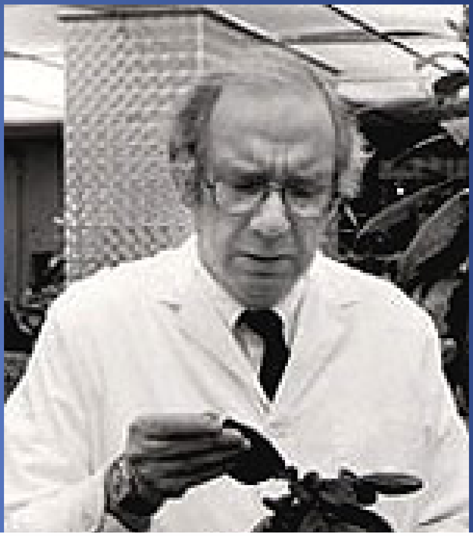




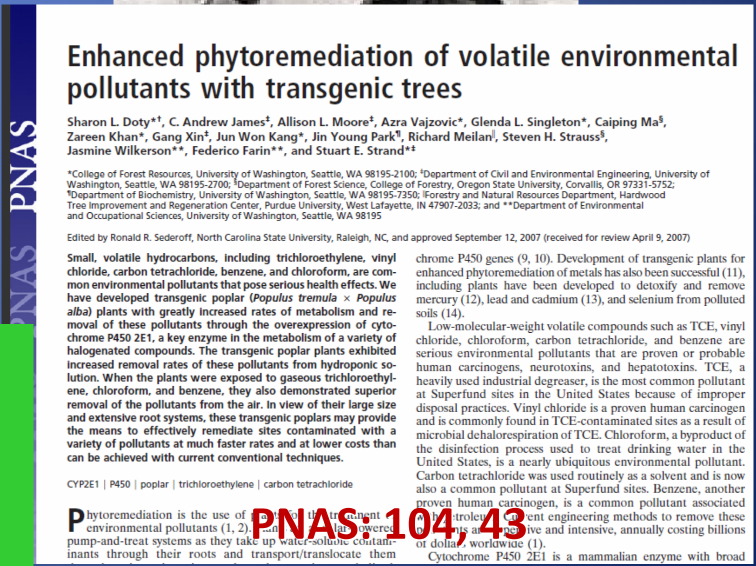


Phytotechnologies - Prevention

- Milton P. Gordon
  - University of Washington
  - TCE phytodegradation by hybrid poplars
- Interdisciplinary Science
  - Biochemists, soil scientists, botanists, engineers, toxicologists
  - Primary Prevention



Milt Pioneer:
Linking Phytotechnologies and Primary Prevention



PNAS

Enhanced phytoremediation of volatile environmental pollutants with transgenic trees

Sharon L. Doty*†, C. Andrew James‡, Allison L. Moore‡, Azra Vajzovic*, Glenda L. Singleton*, Caiping Ma§, Zareen Khan*, Gang Xin‡, Jun Won Kang*, Jin Young Park¶, Richard Meilan‖, Steven H. Strauss§, Jasmine Wilkerson**, Federico Farin**, and Stuart E. Strand*‡

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Edited by Ronald R. Sederoff, North Carolina State University, Raleigh, NC, and approved September 12, 2007 (received for review April 9, 2007)

Small, volatile hydrocarbons, including trichloroethylene, vinyl chloride, carbon tetrachloride, benzene, and chloroform, are common environmental pollutants that pose serious health effects. We have developed transgenic poplar (*Populus tremula* × *Populus alba*) plants with greatly increased rates of metabolism and removal of these pollutants through the overexpression of cytochrome P450 2E1, a key enzyme in the metabolism of a variety of halogenated compounds. The transgenic poplar plants exhibited increased removal rates of these pollutants from hydroponic solution. When the plants were exposed to gaseous trichloroethylene, chloroform, and benzene, they also demonstrated superior removal of the pollutants from the air. In view of their large size and extensive root systems, these transgenic poplars may provide the means to effectively remediate sites contaminated with a variety of pollutants at much faster rates and at lower costs than can be achieved with current conventional techniques.

CYP2E1 | P450 | poplar | trichloroethylene | carbon tetrachloride

Phytoremediation is the use of p... for the treatment ... environmental pollutants (1, 2). ... powered pump-and-treat systems as they take up water-soluble contaminants through their roots and transport/translocate them

chrome P450 genes (9, 10). Development of transgenic plants for enhanced phytoremediation of metals has also been successful (11), including plants have been developed to detoxify and remove mercury (12), lead and cadmium (13), and selenium from polluted soils (14).

Low-molecular-weight volatile compounds such as TCE, vinyl chloride, chloroform, carbon tetrachloride, and benzene are serious environmental pollutants that are proven or probable human carcinogens, neurotoxins, and hepatotoxins. TCE, a heavily used industrial degreaser, is the most common pollutant at Superfund sites in the United States because of improper disposal practices. Vinyl chloride is a proven human carcinogen and is commonly found in TCE-contaminated sites as a result of microbial dehalorespiration of TCE. Chloroform, a byproduct of the disinfection process used to treat drinking water in the United States, is a nearly ubiquitous environmental pollutant. Carbon tetrachloride was used routinely as a solvent and is now also a common pollutant at Superfund sites. Benzene, another proven human carcinogen, is a common pollutant associated with petroleum. Current engineering methods to remove these pollutants are expensive and intensive, annually costing billions of dollars worldwide (1).

Cytochrome P450 2E1 is a mammalian enzyme with broad

PNAS: 104, 43

Phytotechnologies and Public Health

- The critical role of phytotechnologies to reduce exposure and improve health is often overlooked
  - Innovation in phytotechnologies driven by site-specific needs
  - What about applications of the technology for public health?

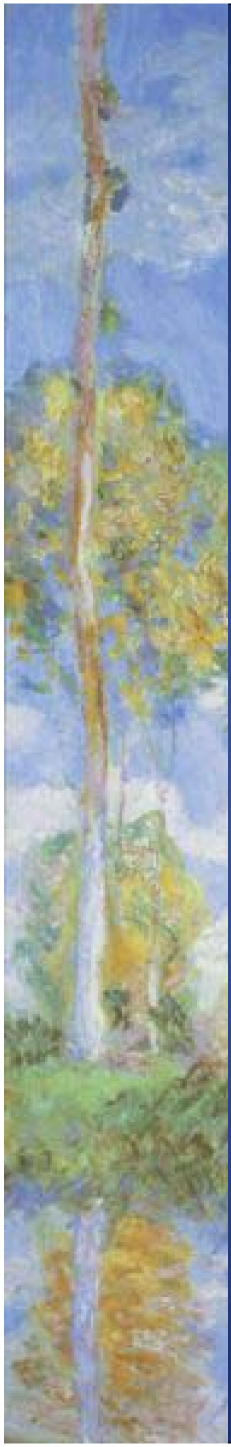
Phytotechnologies and Public Health

- Two-step Process
  - Translation of Successes
  - Finding New Applications for Phytotechnologies

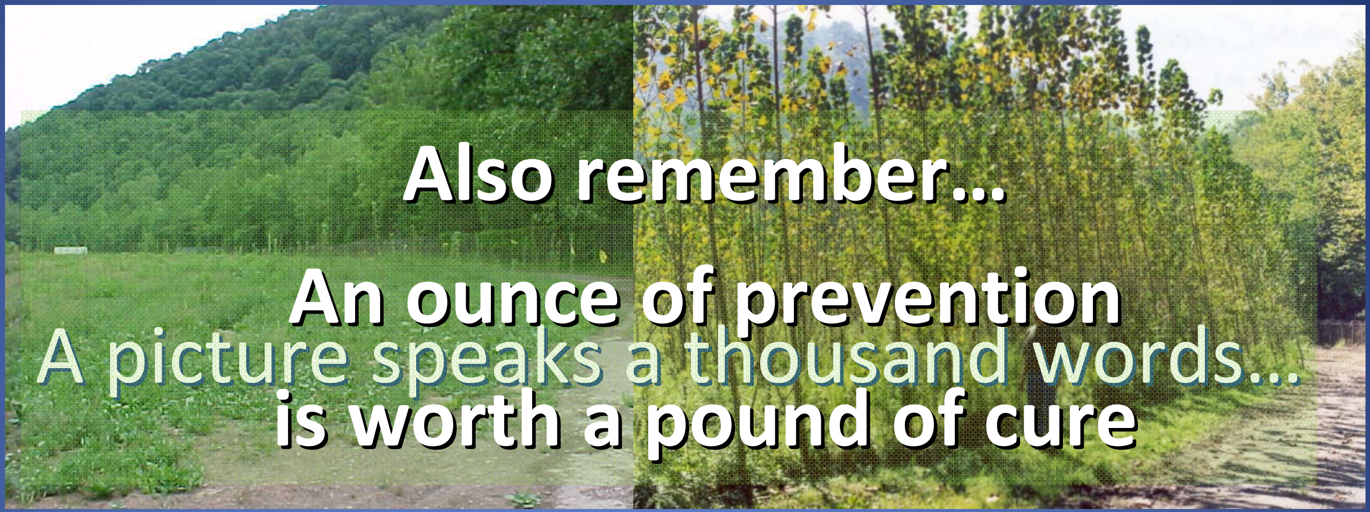
Step 1: Translation to Public Health

- Current Phytotechnology Success Stories
  – Relate to achieving clean-up goals
  – The "Before – After" photos

Cabin Creek, West Virginia (photo courtesy of Jerry Schnoor)



Step 1: Translation to Public Health



Reduction in Contaminants ⟷ Reduced Incidence of Exposures ⟷ Reduced Disease Incidence

What does this means in the context of public health?

?

Please…
Quantify!!!
Articulate!!!

Step 1: Translation to Public Health

- Market your successes
  - Beyond clean-up goals
  - Reducing exposure
  - Reducing disease
  - And, by the way…
    - Sustainable (economic, natural resources)
    - Greener

Partnerships with Public Health Professionals

Step 2: Identify New Applications for Phytotechnologies

Step 2: Applications in Public Health

- Beyond site-driven applications
  - Point of exposure
  - Incidence of disease
  - Protecting people
    - Vulnerable populations
    - Remote locations
    - Limited infrastructure (economic or utilities)
- Public Health Professionals
  - Well-versed exposures to toxicants
  - Need primary prevention solutions
    - Sustainable
    - Economical

Final Thought – Make Impact through Partnerships

- Phytotechnologists are well-positioned to meet the pressing exposure prevention needs faced by the world today
- Collaborations with public health researchers
  - Translate successes into exposure prevention
  - Identify new opportunities for application of phytotechnologies

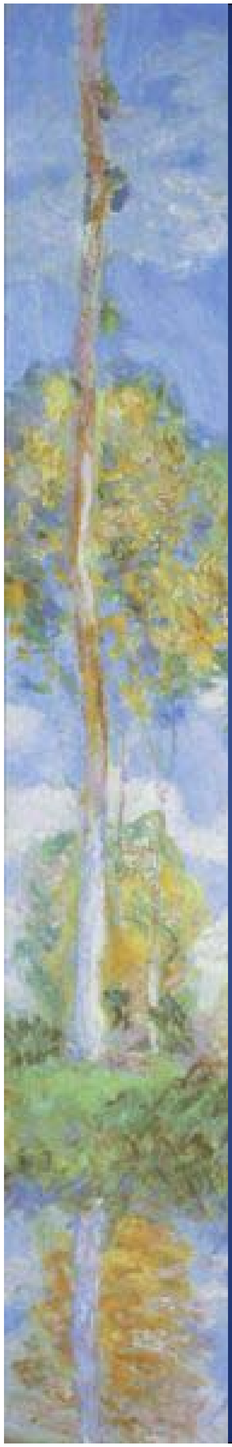
Conclusions

- SRP has been a long-time supporter of advancing phytotechnologies
- Value of phytotechnologies
  - Technology-driven
  - Effective
  - Sustainable
- Partnering with public health professionals
  - Recognize importance of phyto to reduce exposure and thereby reduce risk of disease
  - Identify more applications for phyto as a tool to reduce exposure

Looking Forward

- Applaud those making the public health connection already
- Encourage those who are not to think about
  - How your research fits in the context of public health
  - What exposure scenarios might your technology address?

- Join Me: Convince public health professionals that phytotechnology is a technology-driven form of primary prevention



Acknowledgements

- Conference Organizers
  - Joel Burken*
  - Lee Newman**
  - Jason White***
  - Heather Henry***
- Credits
  - Raina Maier (U Arizona)*
  - Julian Schroeder (UC – SD)*
  - Jerry Schnoor (U Iowa)*
  - Stuart Strand (U Washington)*
  - Edenspace*

* Current SRP Grantee

** Past Grantee

*** Former Trainee

Monet, *Poplars in the Sun,* 1891