Can Nanotechnology Thrive in the Environmental Technology "Bazaar"?

Workshop on
Nanotechnology for Site Remediation
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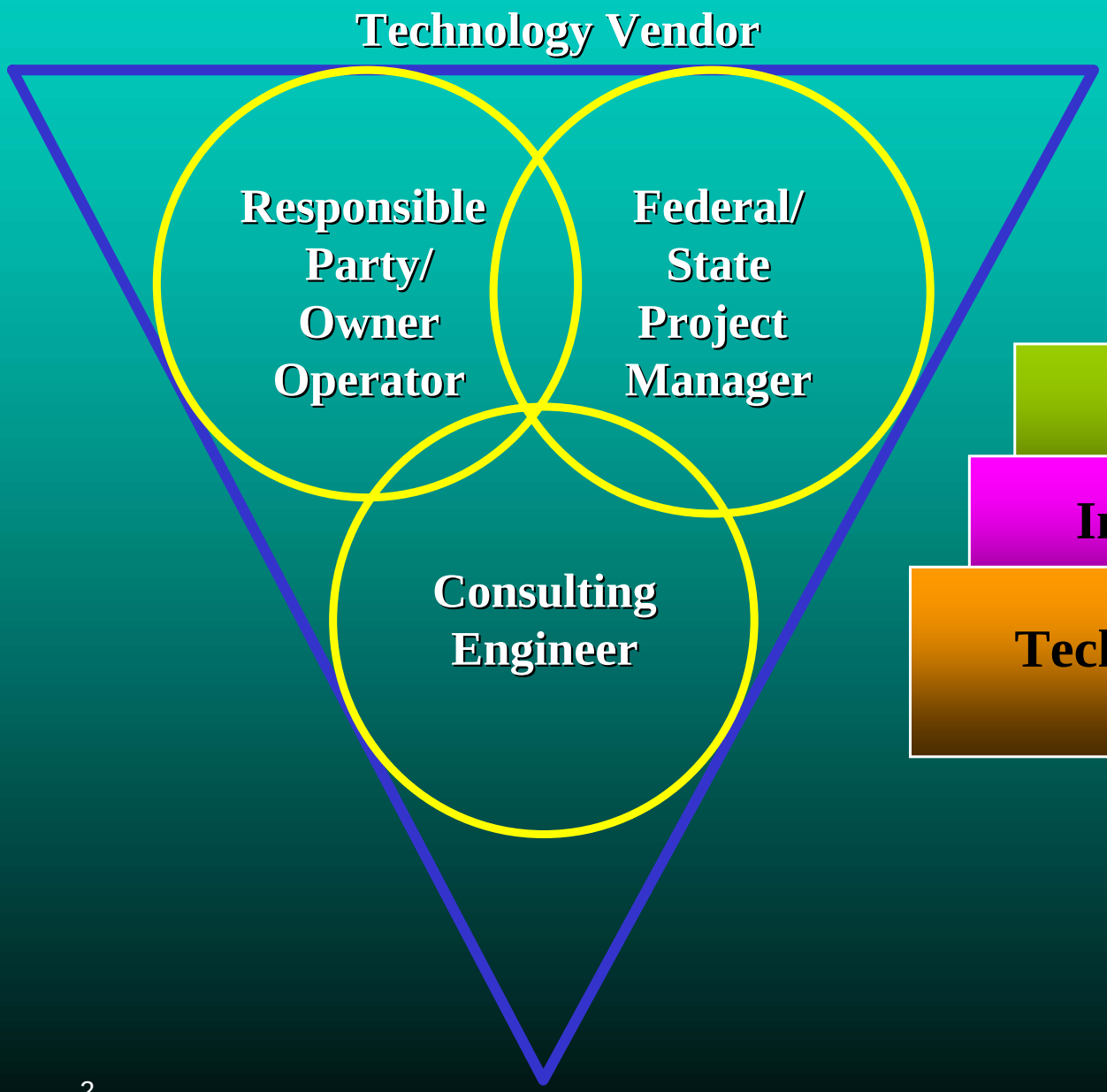
Technology Innovation Program Clients



- International Markets
- Investor Community
- Technology Vendors

Technology Innovation Mission

- Advocate “smarter” technologies for the characterization and cleanup of contaminated sites
- Work with clients to identify and understand better, faster, and cheaper options
- Seek to identify and reduce barriers to the use of innovative technologies

http://clu-in.org

Cleaning Up the Nation's Waste Sites: Markets and Technology Trends (2004 Ed.)

- Provides national overview of market for cleanup of sites with hazardous waste & petroleum products
- Includes:
  - Estimated number of contaminated sites needing cleanup
  - Estimated cost of cleanup
  - Site characteristics, technology trends, other factors affecting demand for remediation services
- Can help industry & government officials develop research, development, business strategies
- Can guide organizations developing, commercializing, & marketing new cleanup technologies to meet future demand

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Outline

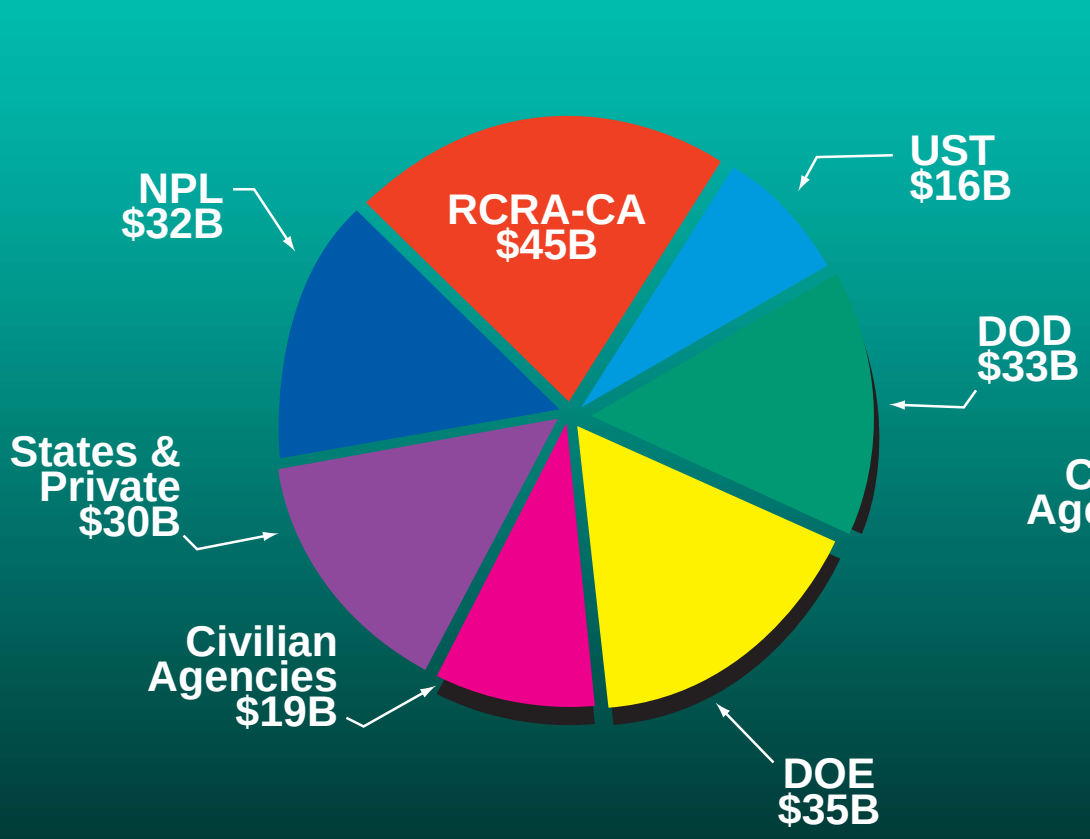
- U.S. cleanup market for site remediation technologies
- Update on field scale deployment of nanotechnology for site remediation
- Observations on entering the environmental technology “bazaar”
- Need to get the information out—who’s job?
- Charge to the conference

Estimated Number of Sites and Remediation Cost 2004-2033

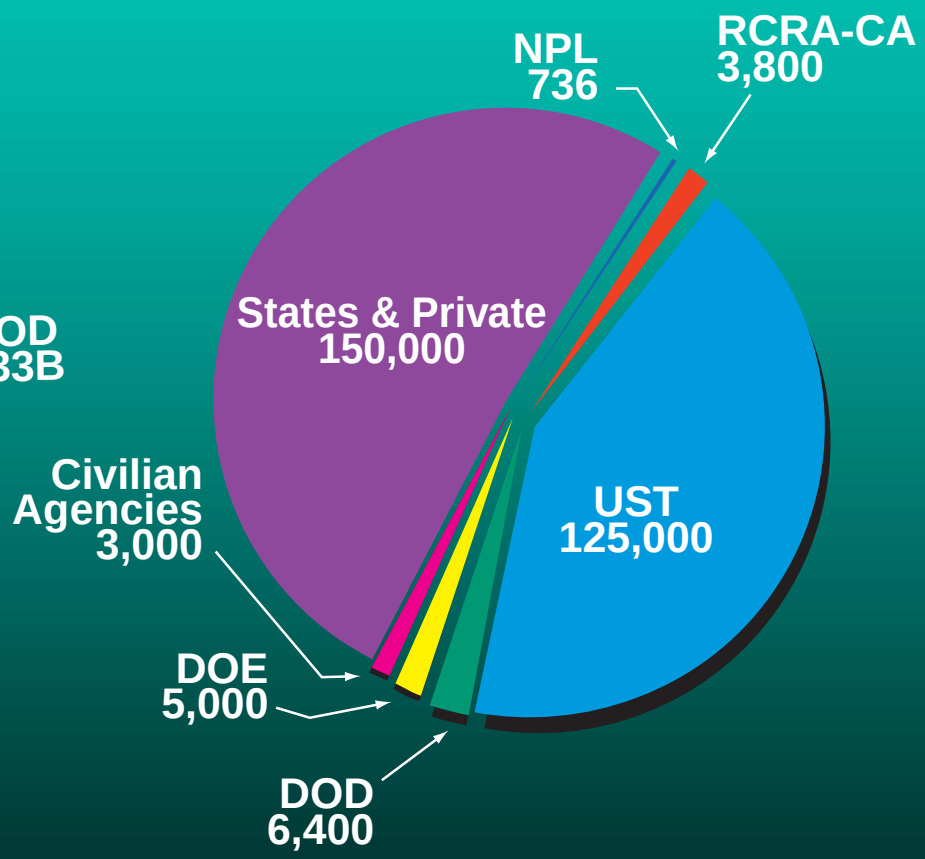
Program	Sites	Cleanup Cost
NPL	686 – 946	$24 – 50 B
RCRA, CA	3,800	$31 – 58 B
RCRA, UST	95,000 – 155,000	$12 – 19 B
DOD	6,400	$33 B
DOE	5,000	$35 B
Civilian Agencies	3,000	$15 – 22 B
States & Private	150,000	$30 B
Total Range Middle Value	235,000 – 355,000 294,000	$174 – 253 B $209 B

Estimated Number of Sites and Cleanup Cost 2004-2033

Total = $209 Billion

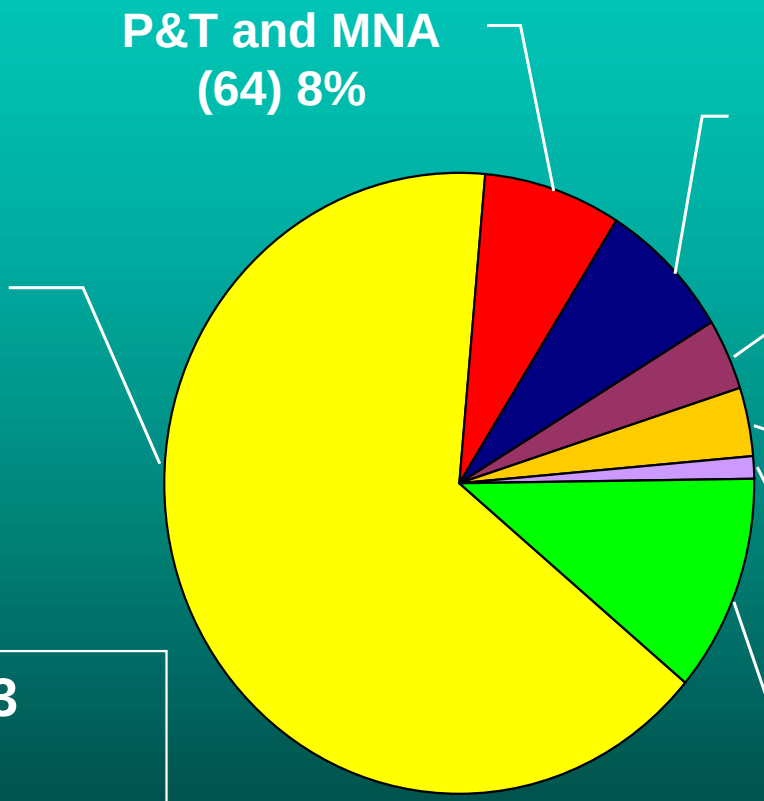


Total Sites = 294,000



GW Treatment Remedies in Superfund

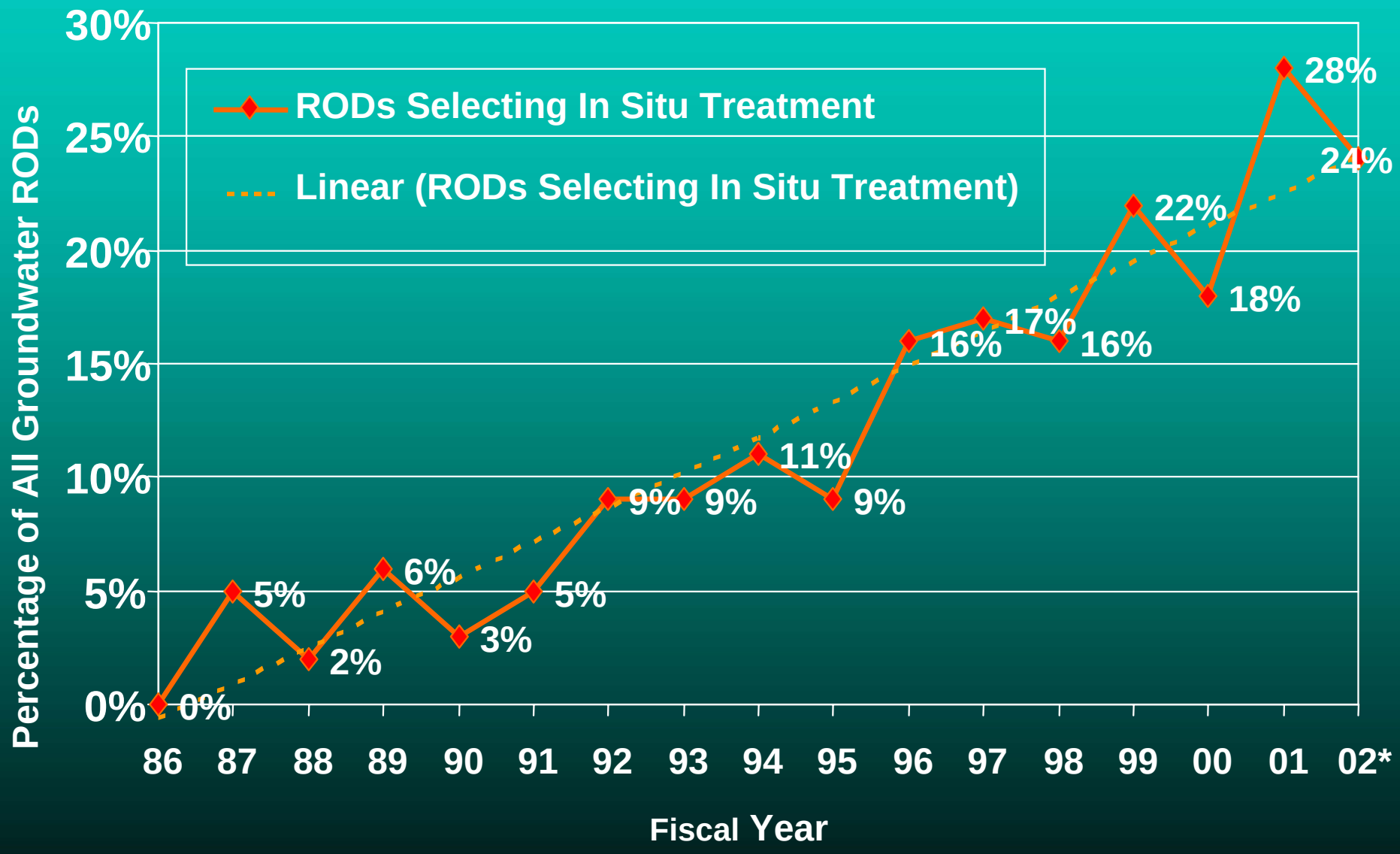
Sites with P&T, In Situ Treatment, or MNA Selected as Part of a Groundwater Remedy (Total Sites = 851)



Sites with P&T - 713
Sites with In Situ Treatment - 135
Sites with MNA - 201

* Includes information from an estimated 70% of FY 2002 RODs.

Superfund: Trends in Percentage of Groundwater RODs Selecting In Situ Treatment (FY 1986 - 2002)*



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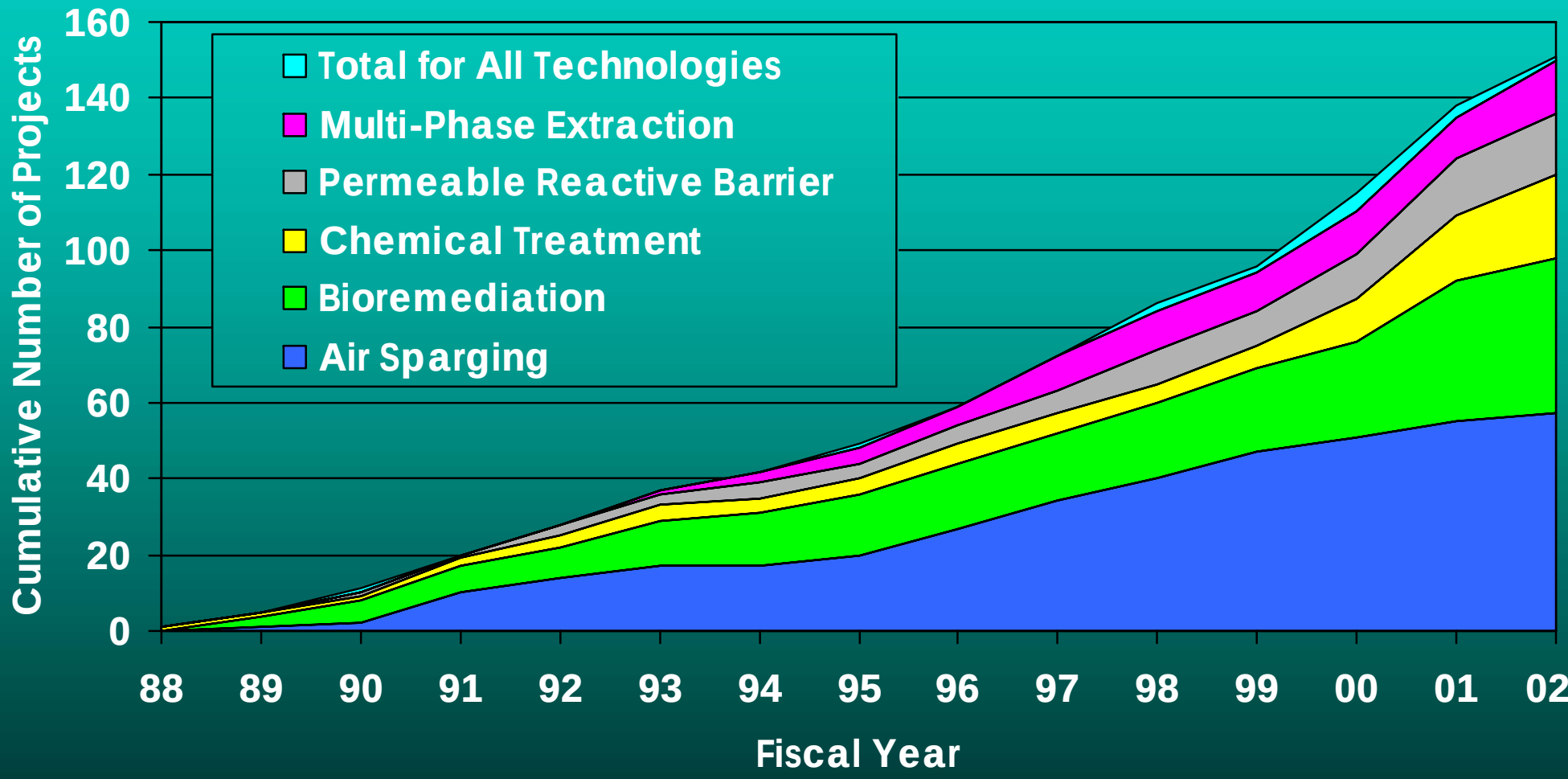
More Experience with More Technologies: In Situ Groundwater Technologies '88-02*



Includes information from an estimated 70% of FY 2002 RODs

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Ranking Criteria for Difficulty in Remediating Ground Water

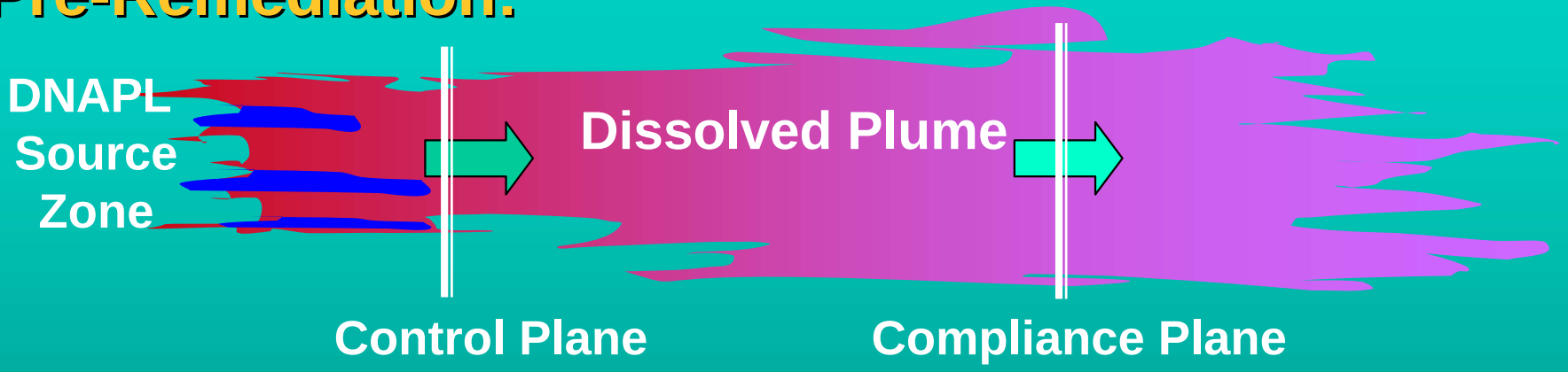
TIO Update to NRC Table, October 2002

Hydrogeology	Mobile Dissolved (Degrades/ Volatilizes)	Mobile Dissolved	Strongly Sorbed, Dissolved	Strongly Sorbed, Dissolved (Degrades/ Volatilizes)	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous, Single Layer	1	1-2	2	2-3	2-3	1-2
Homogeneous, Multiple Layers	1	1-2	2	2-3	2-3	2 ?
Heterogenous, Single Layer	2	2	3	3	3	3 ?
Heterogenous, Multiple Layers	2	2	3	3	3	4
Fractured Bedrock	3	3	3	3	4	4

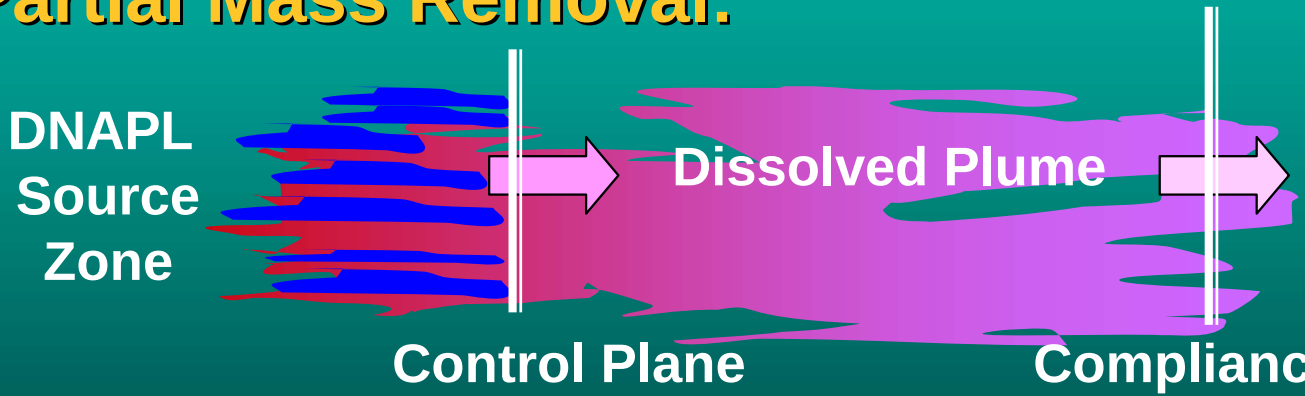
least difficult = 1 / most difficult = 4

Groundwater Plume Response

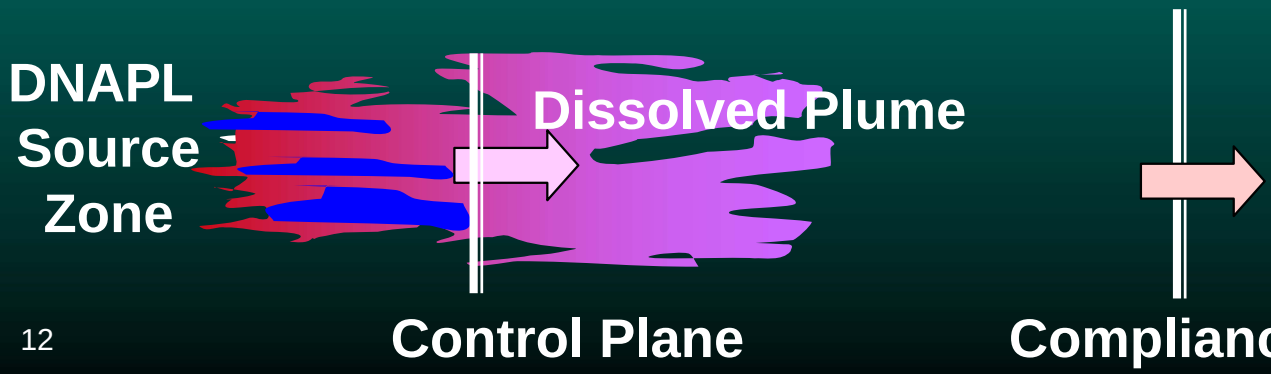
Pre-Remediation:



Partial Mass Removal:



Partial Mass Removal + Enhanced Natural Attenuation:



Technological Approaches For Non-Aqueous Phase Liquid (NAPL) Contamination

- In Situ Thermal
  - Steam Enhanced Extraction
  - Electrical Resistive Heating
  - Thermal Conductive Heating
- In Situ Chemical Oxidation
- Surfactant Co-Solvent Flushing
- Bioremediation
- Nanotechnology

Field Scale Studies*

- Over 15 reported field-scale applications of nanoscale iron and/or bimetallic nanoscale iron particles at waste sites
- 1 field study with oil emulsion of iron nanoparticles
- 2 EPA sites considering nZVI injections
  - BP, Alaska
  - Nease Chemical, Ohio
- Majority of field studies-
  - TCE, TCA, daughter products, some Cr(VI)
  - Gravity-feed or low pressure injection
  - Source zone remediation

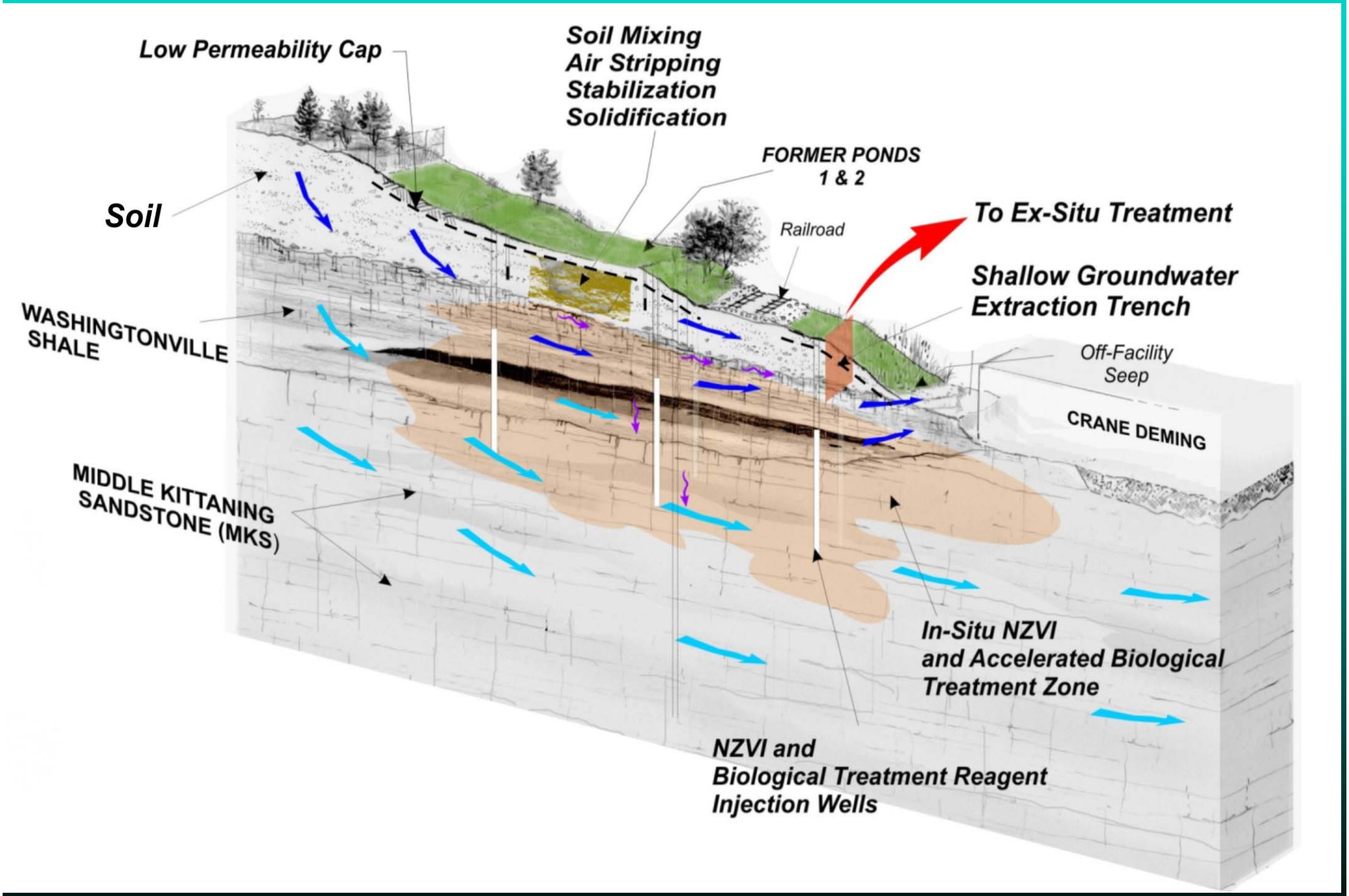
*From draft paper, “Emerging Nanotechnologies for Site Remediation and Wastewater Treatment” by Katherine Watlington, National Network for Environmental Management Studies; paper will be posted in the publications section of www.clu-in.org

Nease Chemical NPL Site

Columbiana County, Ohio

- Produced cleaning compounds, fire retardants, and pesticides from 1961 to 1973
- Contaminants:
  - Mirex (a pesticide) and volatile organic compounds (VOCs) in soil
  - VOCs in groundwater
- Fractured bedrock under the site
- Proposed remedy for deep groundwater is to inject nZVI into aquifer to reduce VOCs

Conceptual Diagram of Proposed Remedy



BP Exploration (Alaska), Inc., RCRA Site

North Slope, Alaska

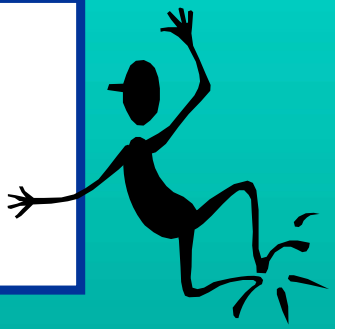
- Cleaned pipes used in oil well construction from 1978 to 1982
- Proposed remedy is injection of nZVI
- Proposed remedy is expected to
  - Reduce mobility of lead contamination
  - Reduce concentrations of TCA and diesel fuel contaminants

Potential Issues with the Technology

- Potential rebound of contaminants after in situ injection of nZVI
- Iron passivation
- Agglomeration reducing effective distribution
- Expense
- Incomplete knowledge of mechanism - abiotic v. biotic degradation
- Difficulty projecting particle movement

Environmental Technology Development Process

Acceptance: Commercial Application



Evaluation: Commercial Application

Outreach

Continuing Research: Scaling-Up

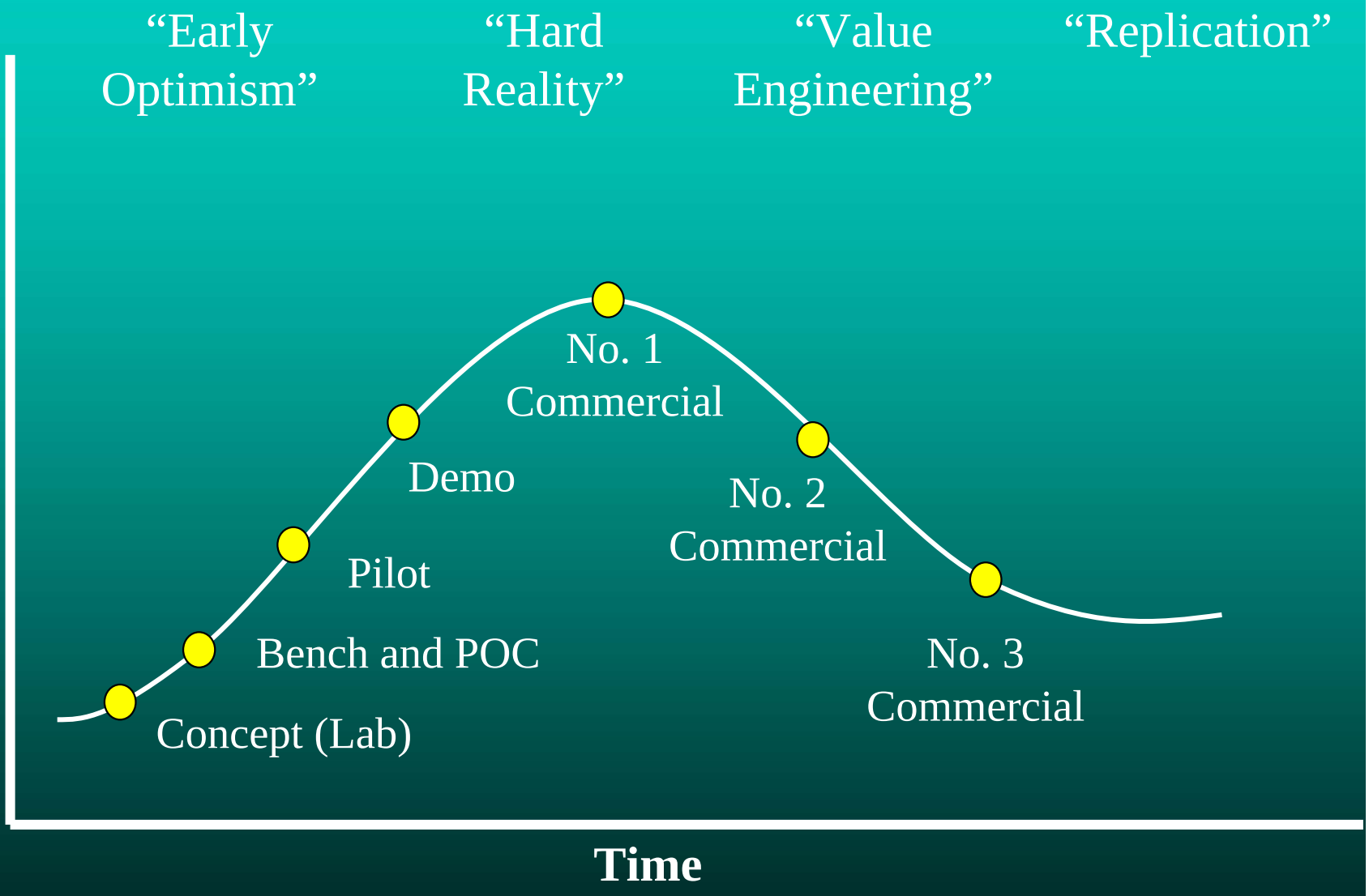
Existing programs: SBIR, ETV, SITE

Early Research

Environmental Technology Marketplace

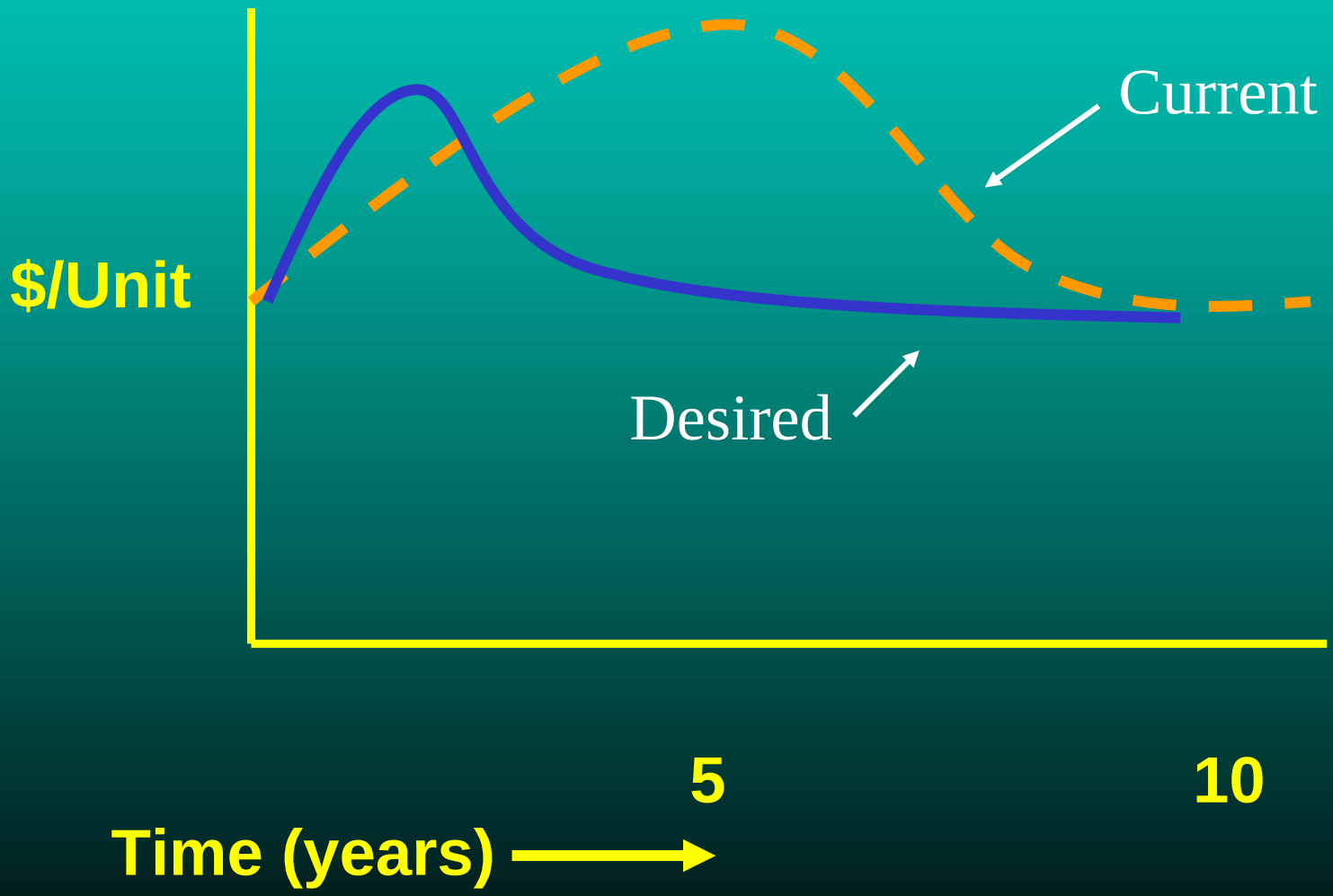
- Market is driven and constrained by regulations
- Enforcement is critical
- Stakeholder receptivity/fragmented state markets
- Transactions mediated by consulting engineers
- Risk-laden milieu
- Verification and testing needed
- Traditional commercialization issues
- Procurement/financial considerations

Stages of Technology Commercialization



Partnerships: Combining supply push with demand pull

Accelerating the Technology Maturation Process



Government Roles in Environmental Technology Marketplace

- Regulator/enforcer
- Funding agent/technology developer
- Information broker
  - Neutral
  - Verification agent
- Partner in deployment
- User of “first resort”

Getting the Word Out: Traditional U.S. Research Info Transfer Model—late 1990's

- Research results
- Journal article
- Fact sheet
- Searchable web database

- What about context & other communication channels?

(Define the) Context

- Frame the new result (in relation to the users' field of interest)
  - Scale dimension
  - Time dimension
  - Breadth of applicability
  - Relation to the "problem" boundaries
- Who has the responsibility to offer the new result in the appropriate context?
  - NOT the "customer"
  - Possibly NOT the PI

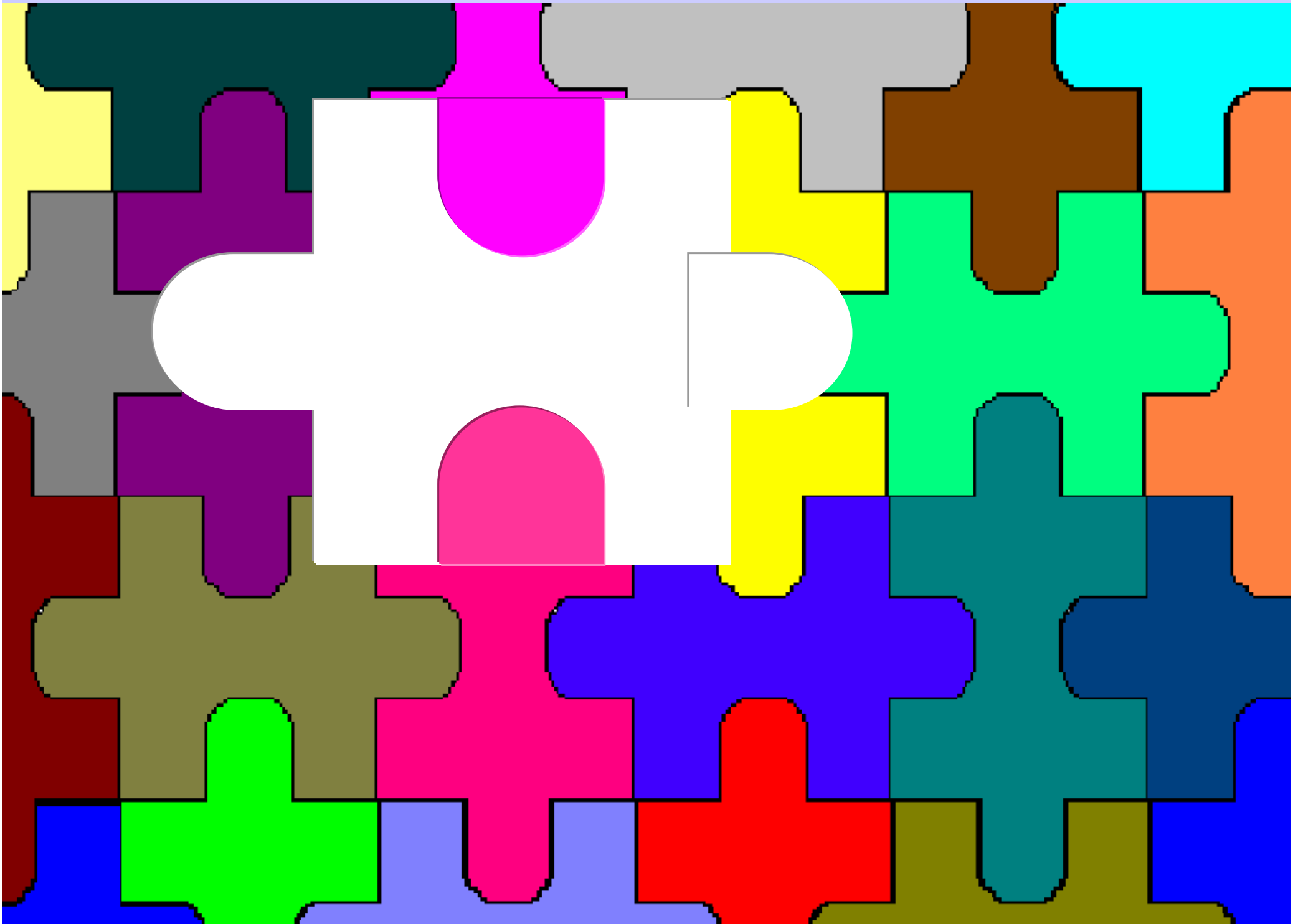
(Define the) Context (cont.)

Explain the result in relation to other research

(the OVERALL context)

- Confirming other work
- Broadening previous work under other operating or boundary conditions
- "Breakthrough" approach?

Defining the Context



Biodegradation Mechanisms

Typically Occurring with Enhanced *In Situ* Bioremediation of CAHs

CAH*	Aerobic Oxidation		Anaerobic Reductive Dechlorination	
	Direct	Cometabolic	Direct	Cometabolic
PCE			Yes	Yes
TCE		Yes	Yes	Yes
DCE		Yes	Yes	Yes
VC	Yes	Yes	Yes	Yes
Trichloroethane		Yes		Yes
Dichloroethane	Yes			Yes
C. tetrachloride				Yes
Chloroform		Yes		Yes
Methylene chloride	Yes	Yes	Yes	Yes

*Chlorinated aliphatic hydrocarbons

Technology Information Program "Channels"

- 6-8,000 person mailing keys
- Exhibit booth -- 12-14 remediation conferences per year
- Hard copy publications and one-page fact sheets
- *Technology News and Trends*--6 page/bimonthly newsletter; hard copy and electronic
- Biannual CD ROM collection of all pubs to date

Technology Innovation Program "Channels" (cont.)

- Clean Up Information web site (clu-in.org) with >300 EPA and non-EPA pubs
- *Tech Direct*--22,000 person list serv of remediation professionals with 1-3 page summary of new documents/ training/ etc.
- Classroom training
- Internet seminars

Internet Seminars: A Cost-Effective Communication Tool

- Live, 2 hour seminar on technical topics related to contaminated site management
- Typical seminar is presented to 150-250 people from 25-30 states, and 5-10 int'l locations
- Generally 2-3 speakers/instructors, national technical and regulatory experts
- Presentation and supporting information mounted on web site
- Audio transmitted over the phone or the internet with live Q&A

Keys to Technical Information Dissemination

- "Getting the word out" is NOT the audience's problem
- Not all results are created equal
- Interpreting CONTEXT is a critical function
- Audience, audience, audience
- Successful info transfer requires thoughtful planning and execution
- Consider multiple channels

Workshop Contents

- State of the science of use of nanoparticles to remove contaminants from environmental media
  - Focus is on nanoscale zero-valent iron
  - Additional work with other nanoparticles such as dendrimers, nanoporous materials
- Several field studies
- Fate and transport of nanoparticles
- Legal/Regulatory/Policy issues
- Risk assessment and public communication

Charge to Participants "Homework"

- Exchange information
- Form partnerships to facilitate technology transfer and to collaborate on research
- Produce recommendations for future research