Nanotechnology for Water Purification and Waste Treatment

Frontiers in Nanotechnology
US EPA Millennium Lecture Series
July 18, 2005
Washington D.C.

Wei-xian Zhang

LEHIGH University

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Acknowledgments

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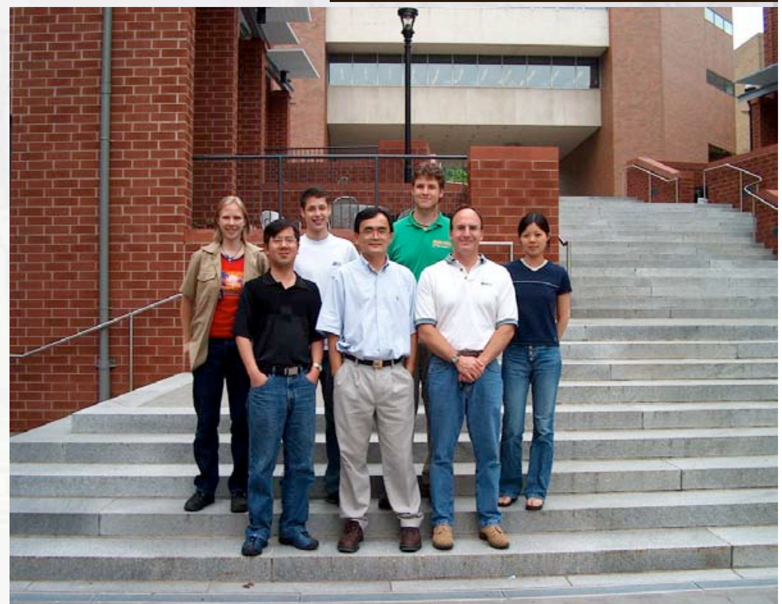

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Nanotechnology is...

the art and science of manipulating matter at the atomic or molecular scale

Size

A billionth (10^{-9}) meter

Structure

How things are put together -- arranged or assembled.

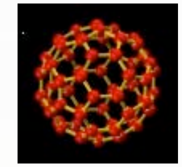
Novel properties

<u>Novel and significantly changed</u> physical, chemical, and biological properties

The ultimate goal of nanotechnology is to build essentially anything from scratch, atom by atom

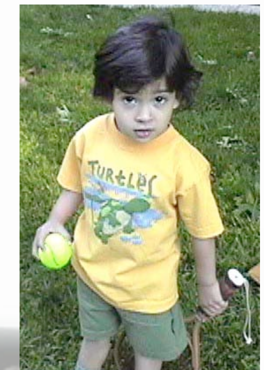
C_{60}

(~ 1 nm)



Human

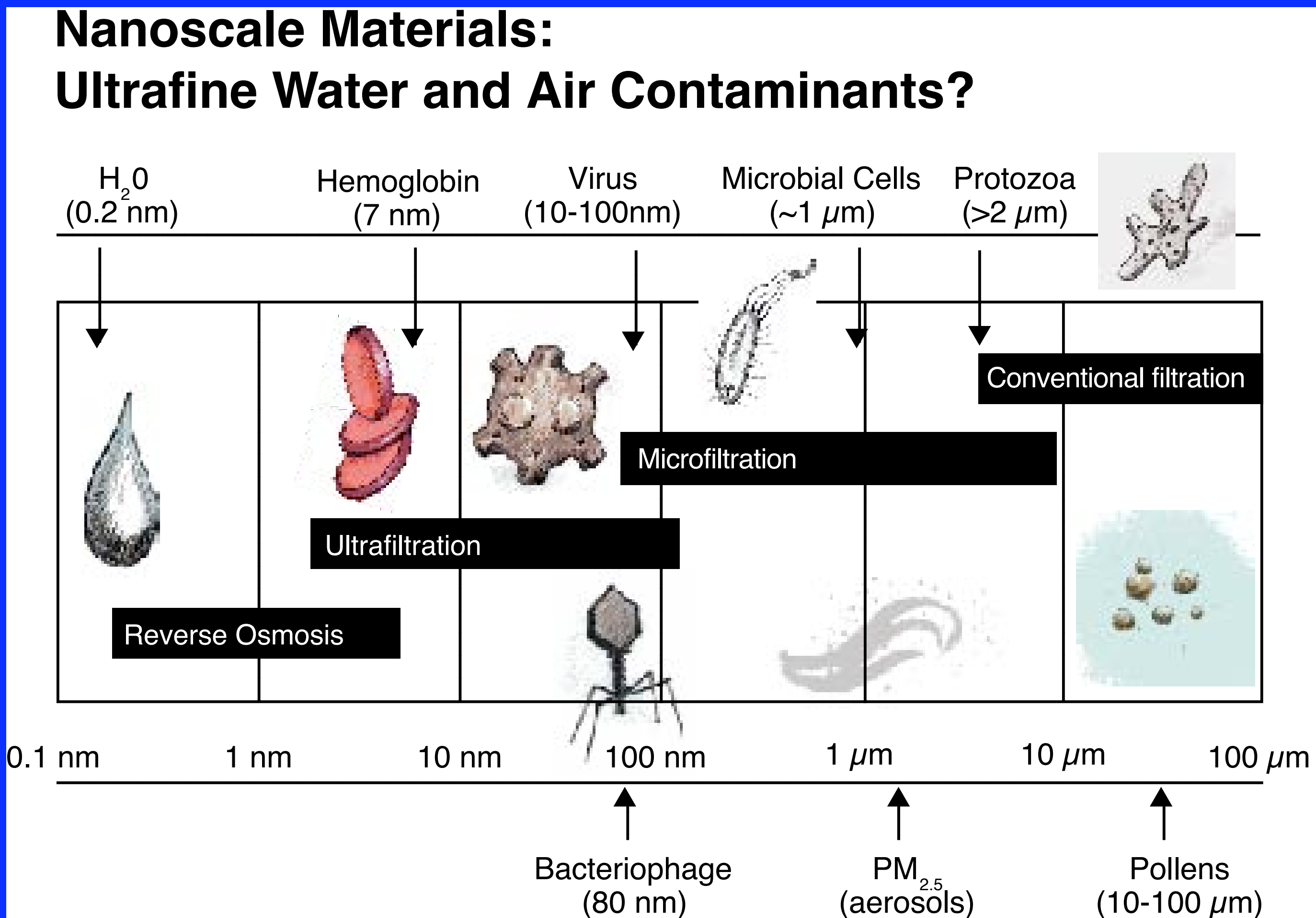
(~1 m)



Moon orbit

(10^9 m)

Nanoscale has already been with our profession …



Micropollutants

Nanopollutants

A Research Framework for NanoEnvironTech

Promote Applications
reactive to existing problems
or
proactive in preventing future problems.

Forecast Implications of
interactions of nanomaterials with the environment and possible risks that may be posed by the use of nanotechnology.

B.Karn, 2005, ACS

applications

Sensors
Treatment
Remediation
Green manufacturing
Green energy

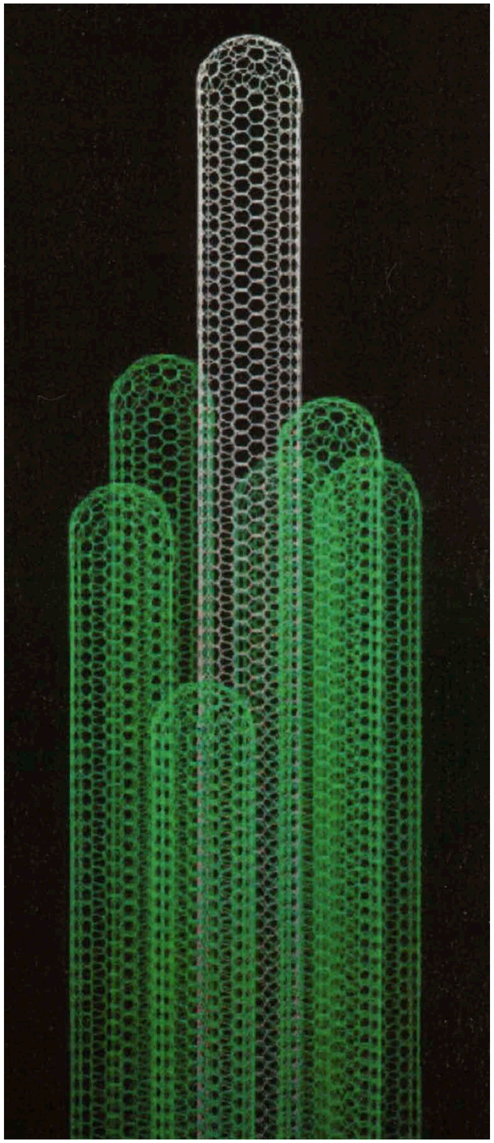
implications

Natural nano processes
Fate, transport, and transformation
Lifecycle aspects
Toxicology
Exposure, bioavailability, and bioaccumulation

Nanotubes as SuperSorbent

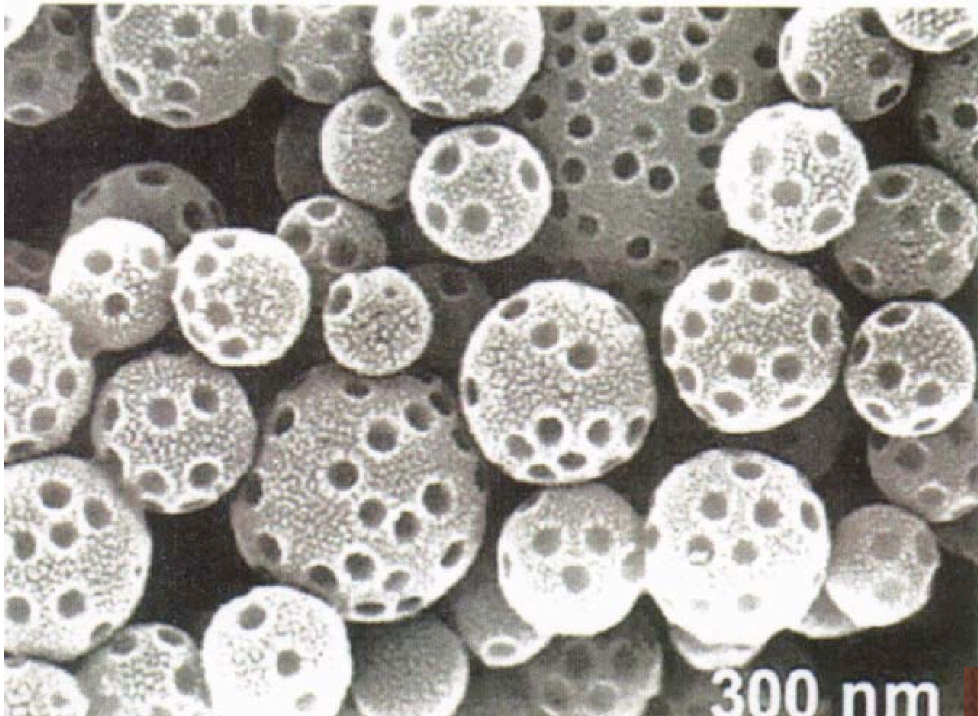
SWNT for Dioxin Sorption (Long & Yang, 2001, JACS)

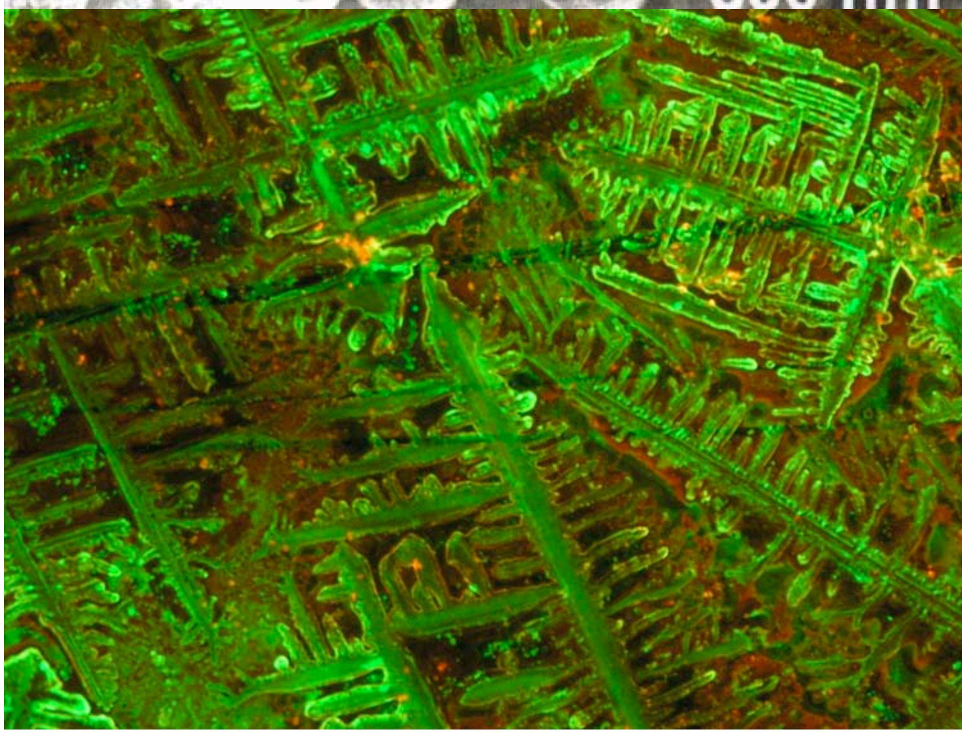
Sorbent	E (kJ/mol)	B (atm^{-1})
SWNT	315	$2.7x10^{52}$
Activated Carbon	119	$1.3x10^{18}$
γ-Al_2O_3	47.9	$4.5x10^{5}$



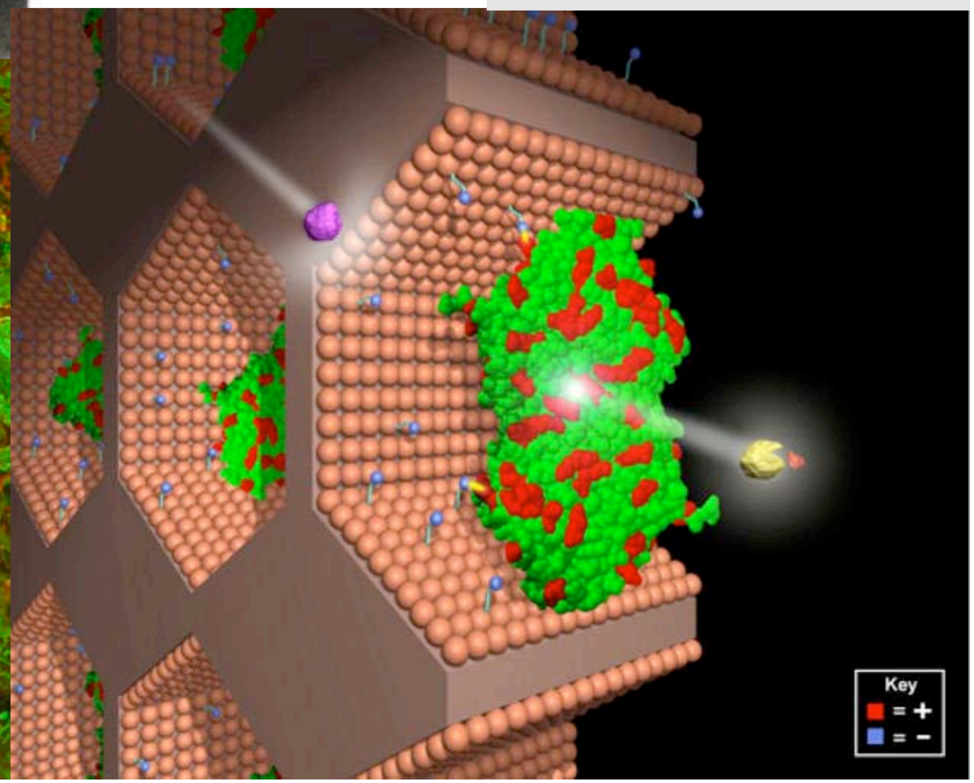
Nanocomposites

- Nanosorbents
- Nanoreactors



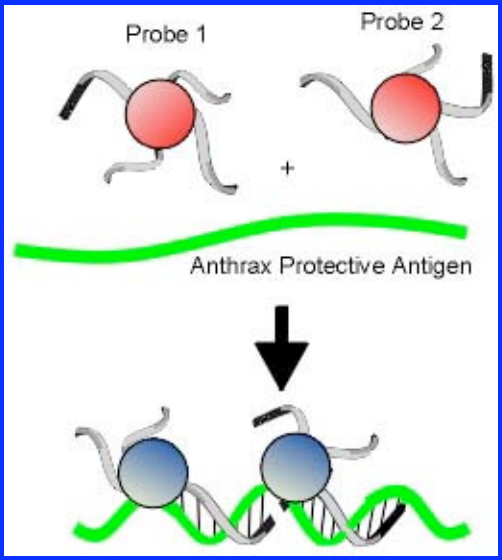


Pacific Northwest National Laboratory

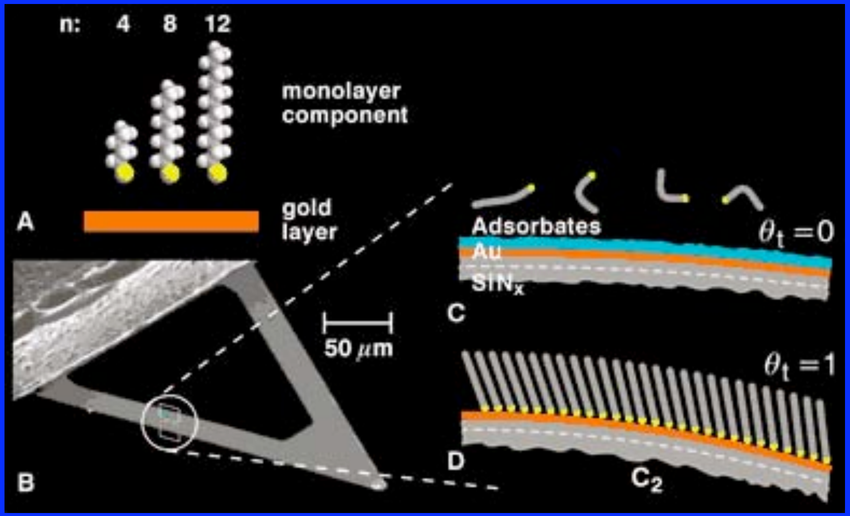


Sensing and Detection

Biological pathogens, heavy metals, organics, etc.



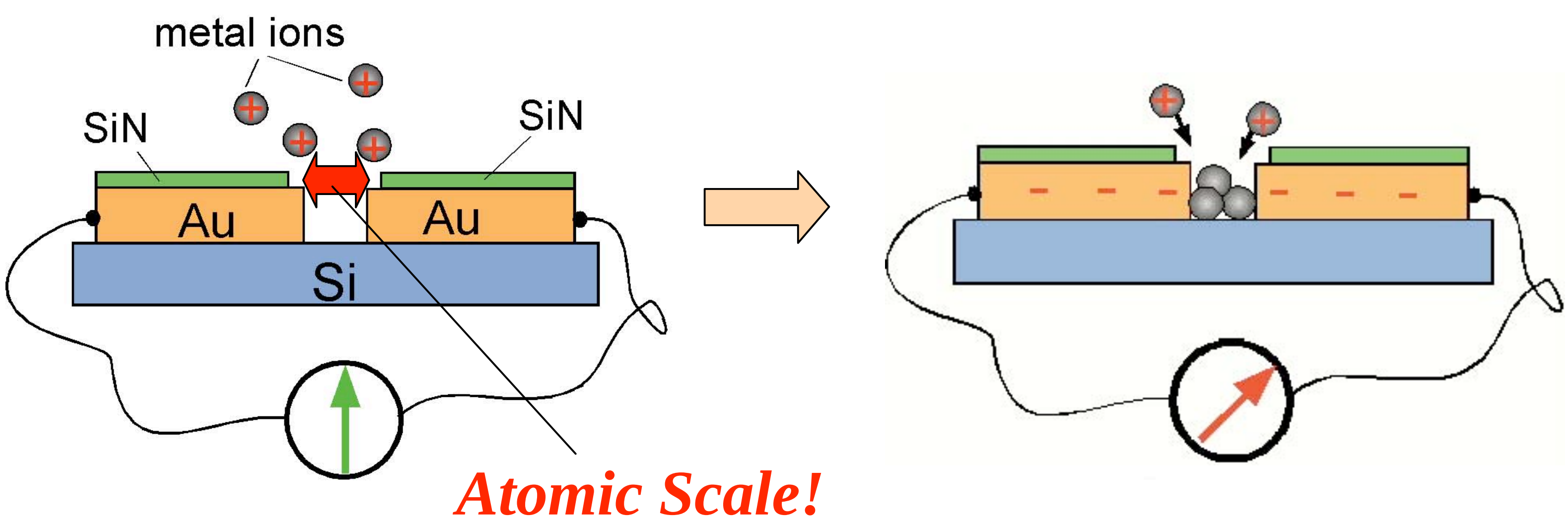
Chad Mirkin, Northwestern



IBM, Zurich

Nanocontact Sensor

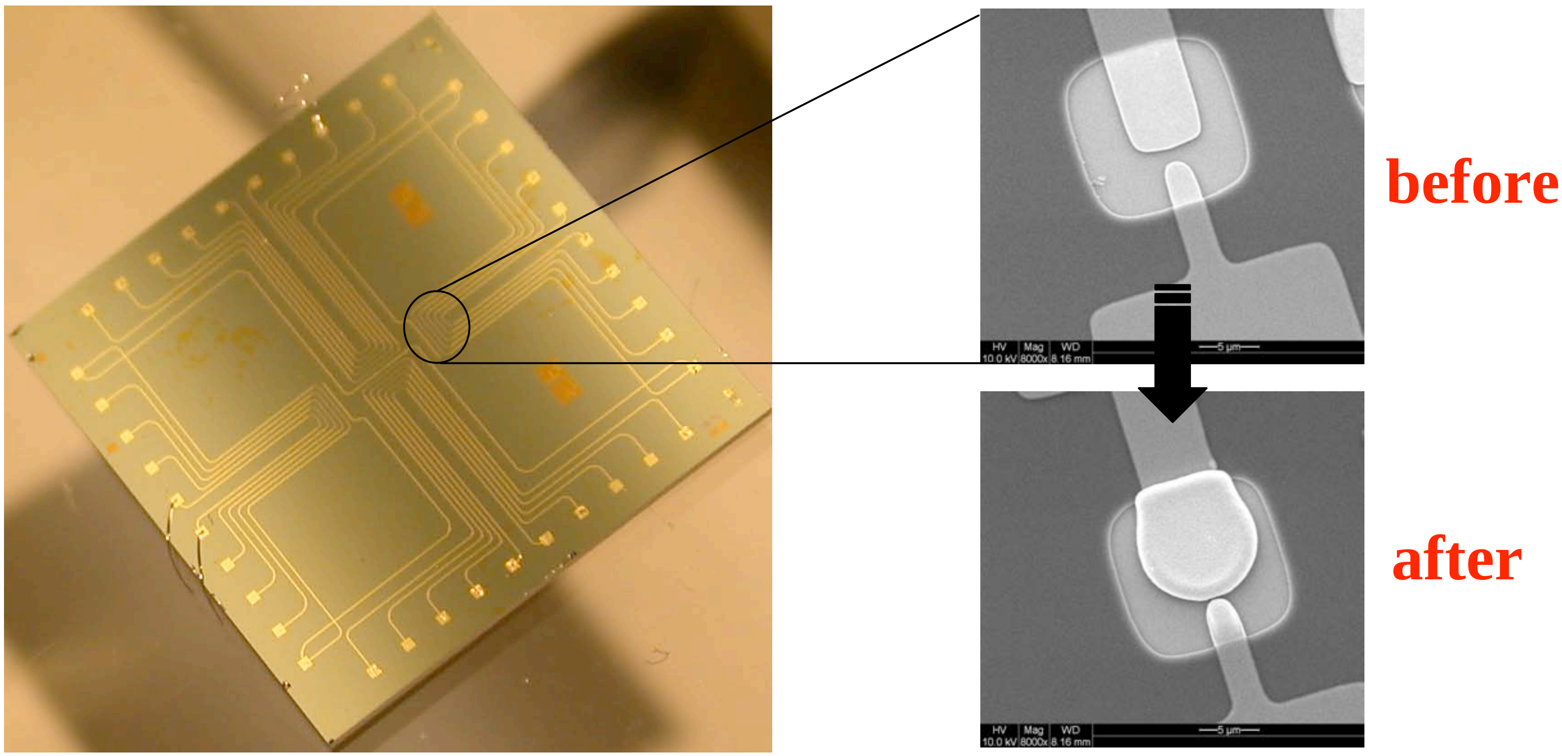
N.J. Tao **(Arizona State)**



Sensitivity:

The electrodes are separated with an atomic-scale gap,
so **a few ions can be detected**.

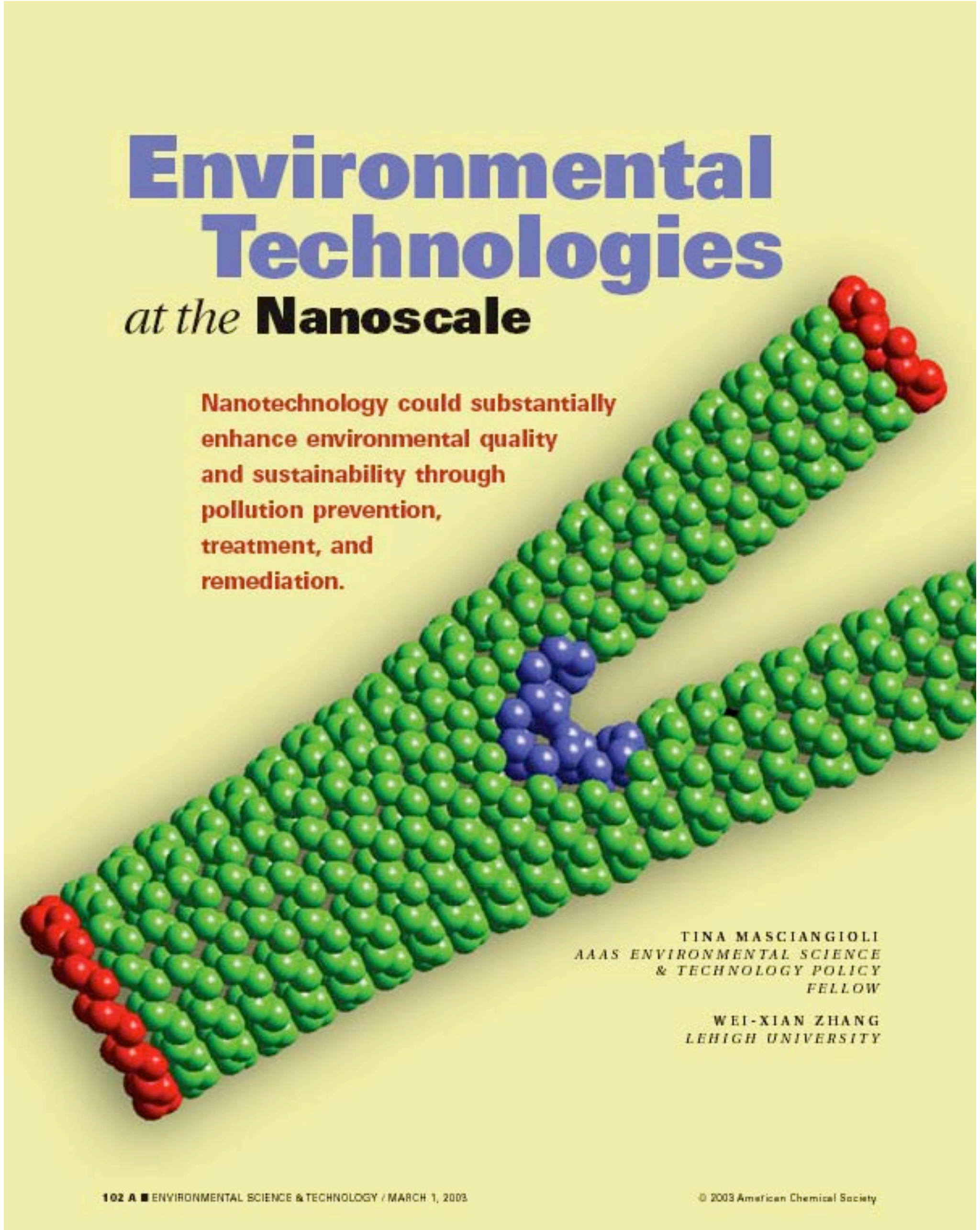
An Array of Atomic-Scale Gaps



Si_3N_4 / Au / SiO_2 / Si

SEM images

N.J. Tao (Arizona State)



Environmental Technologies *at the* Nanoscale

Nanotechnology could substantially enhance environmental quality and sustainability through pollution prevention, treatment, and remediation.

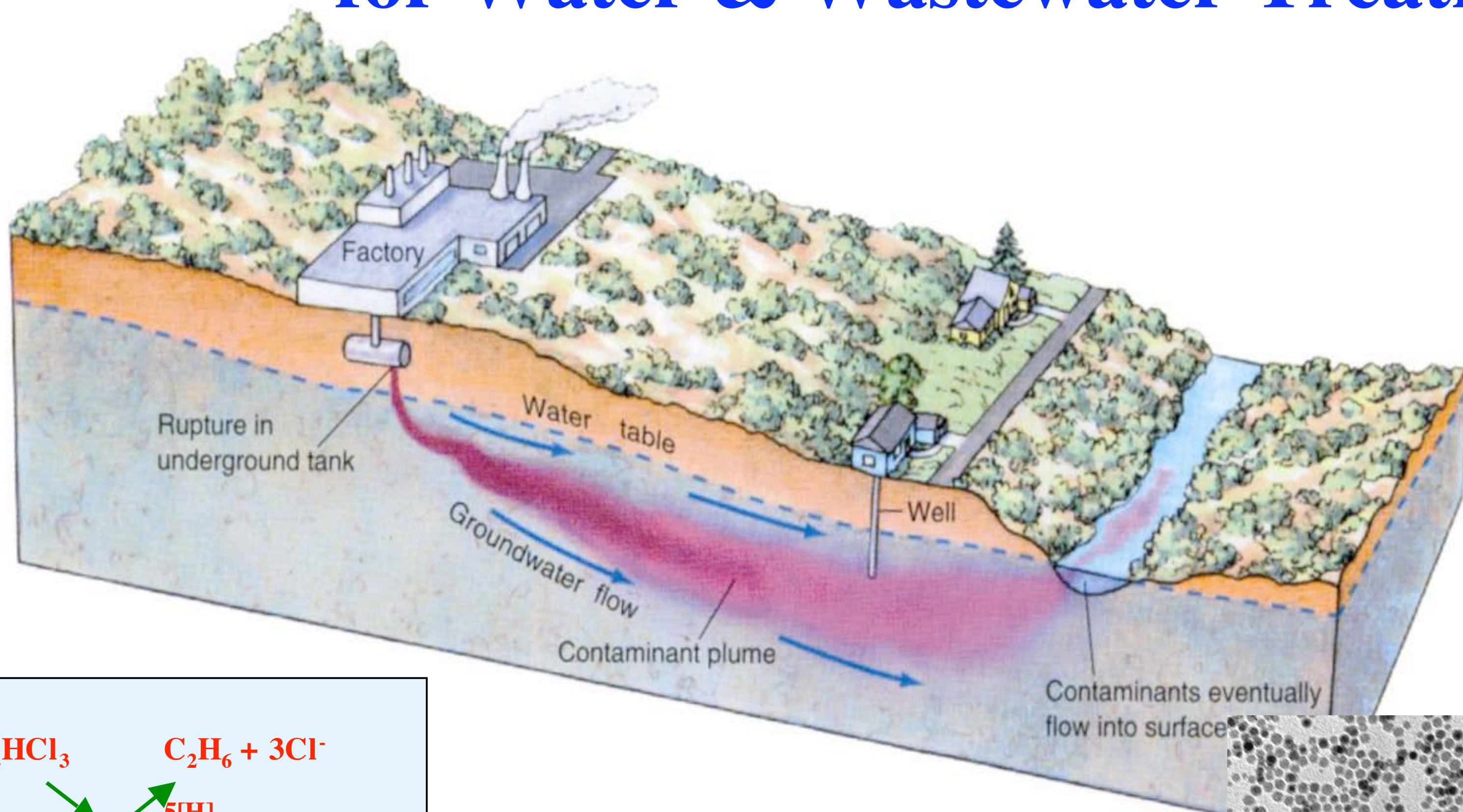
TINA MASCIANGIOLI
AAAS ENVIRONMENTAL SCIENCE & TECHNOLOGY POLICY FELLOW

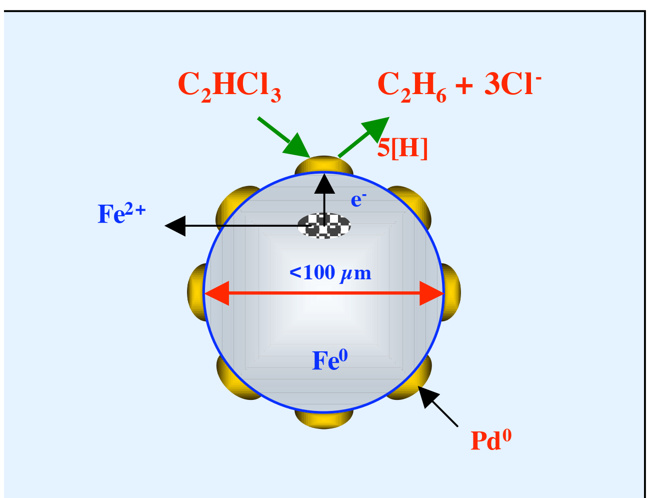
WEI-XIAN ZHANG
LEHIGH UNIVERSITY

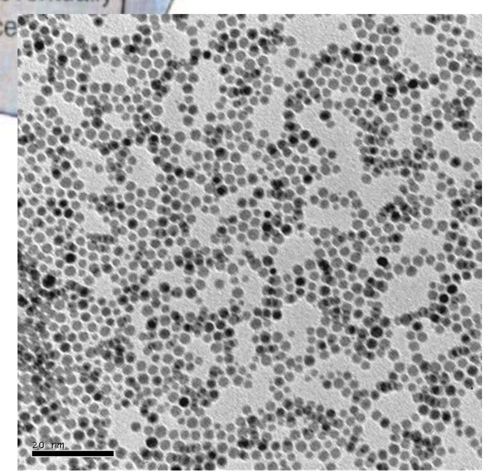
ES&T Feature Article
March 1, 2003
ES&T, 2003, 37 (5),
73A - 112A

Iron Nanoparticles

for Water & Wastewater Treatment







Advantages of Nano Remediants

Highly mobile

Highly Reactive

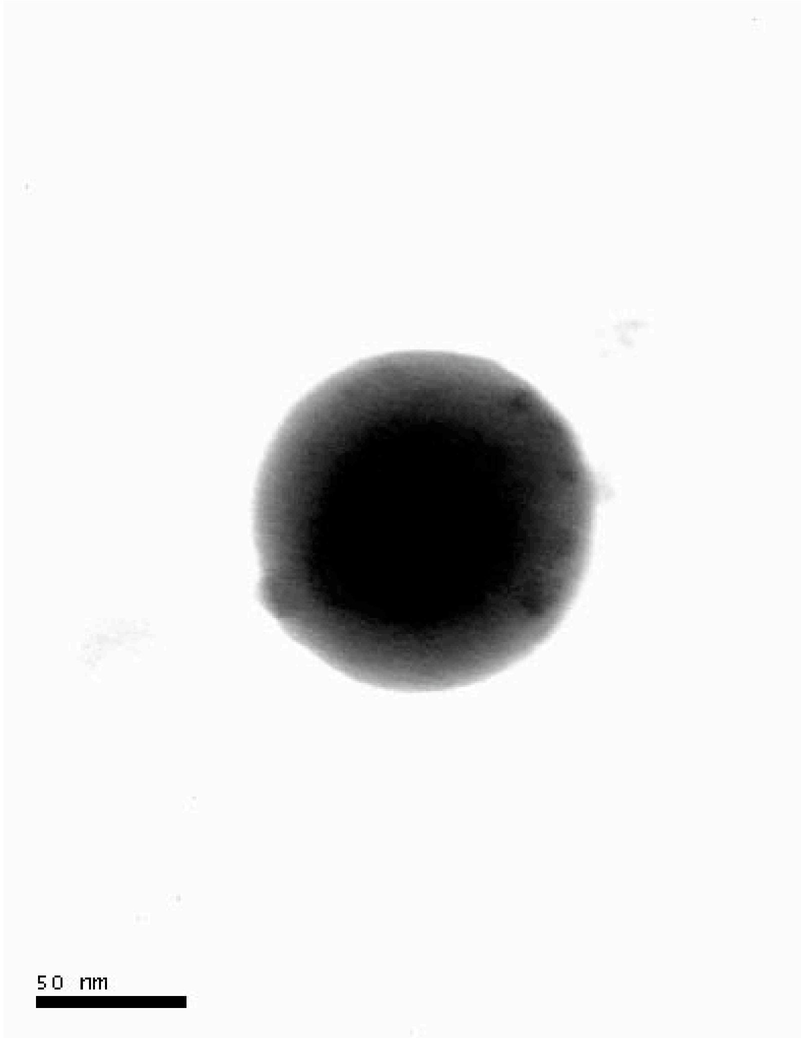
Shorter cleanup time & lower cost

A little history …

- **Summer 1995 - original concepts**
- **July 1996 - Sodium borohydride method**
- **April 1997 - 1st paper (ES&T)**
- **Summer 2000 - 1st pilot test**
- **> 15 projects so far in U.S.**

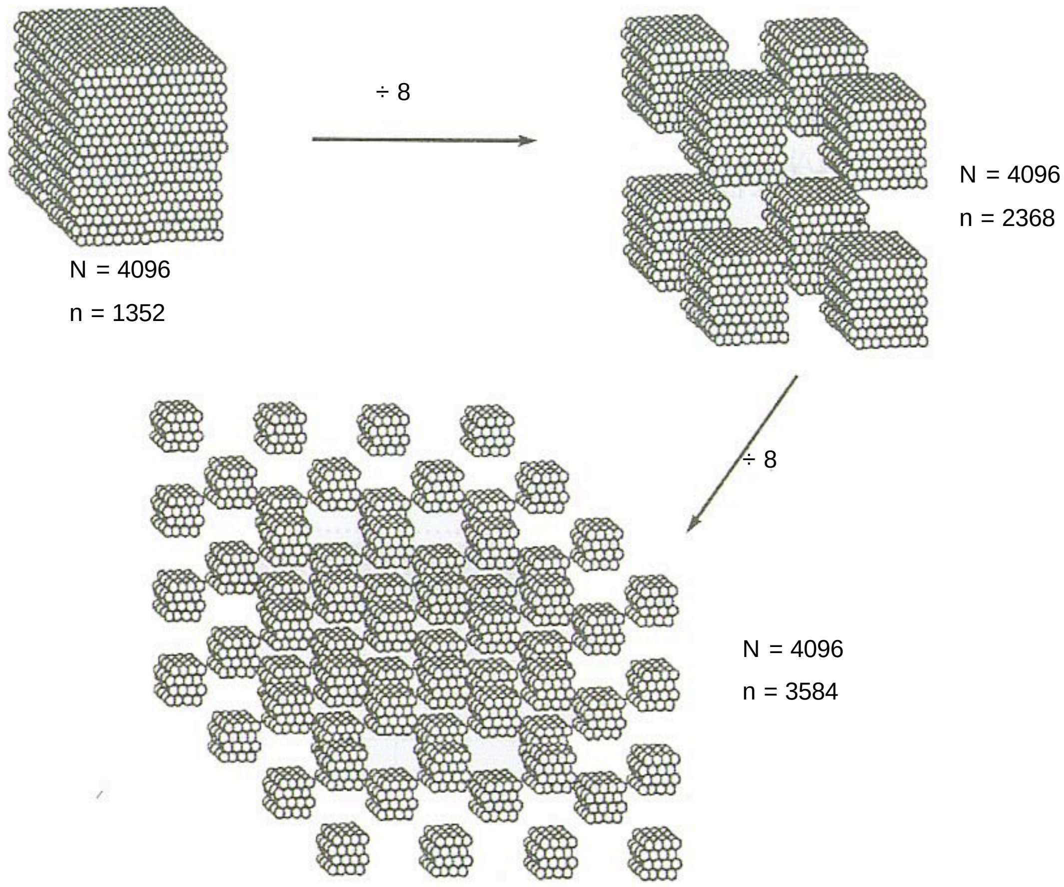
Nano Iron

- Effective reductant
- Widely used in PRBs
- Nontoxic
- Cheap

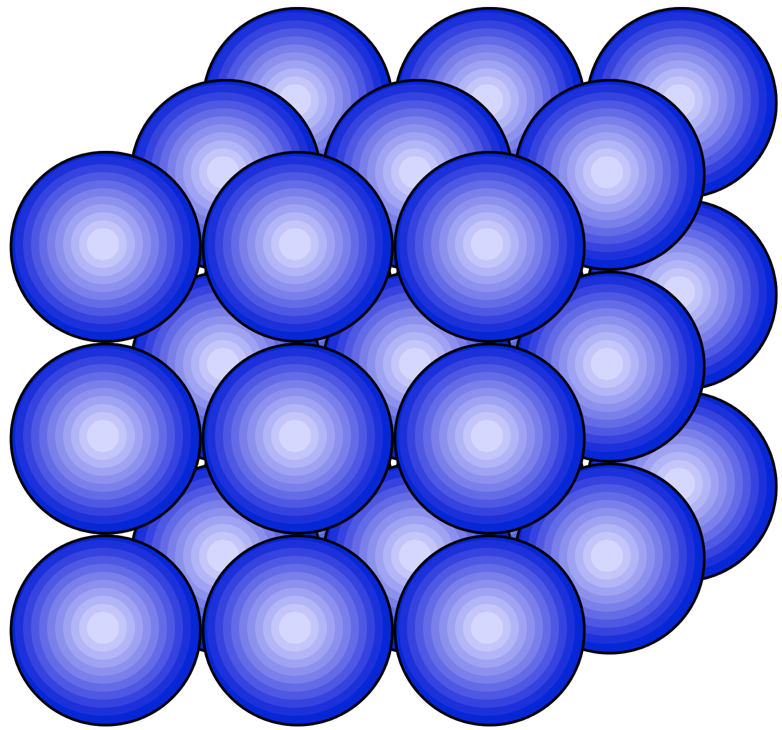


Key property - Efficient Electron Donor

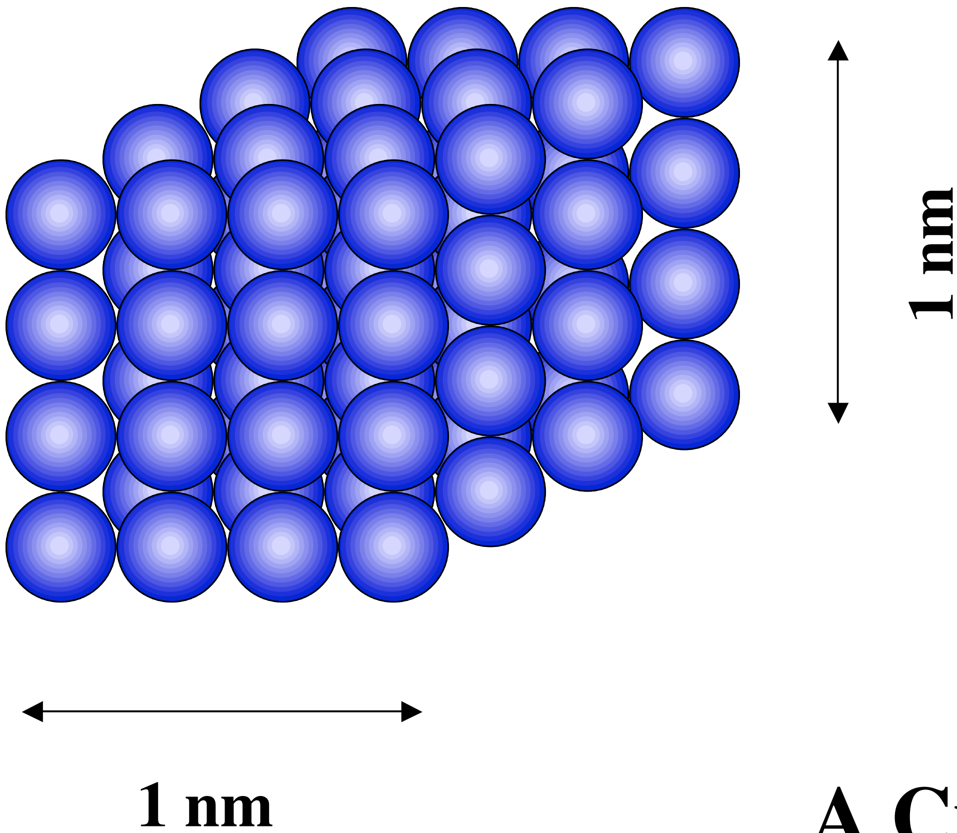
$$Fe^0 \rightarrow Fe^{2+} + 2e^-$$



N: number of total atoms, n: number of surface atoms

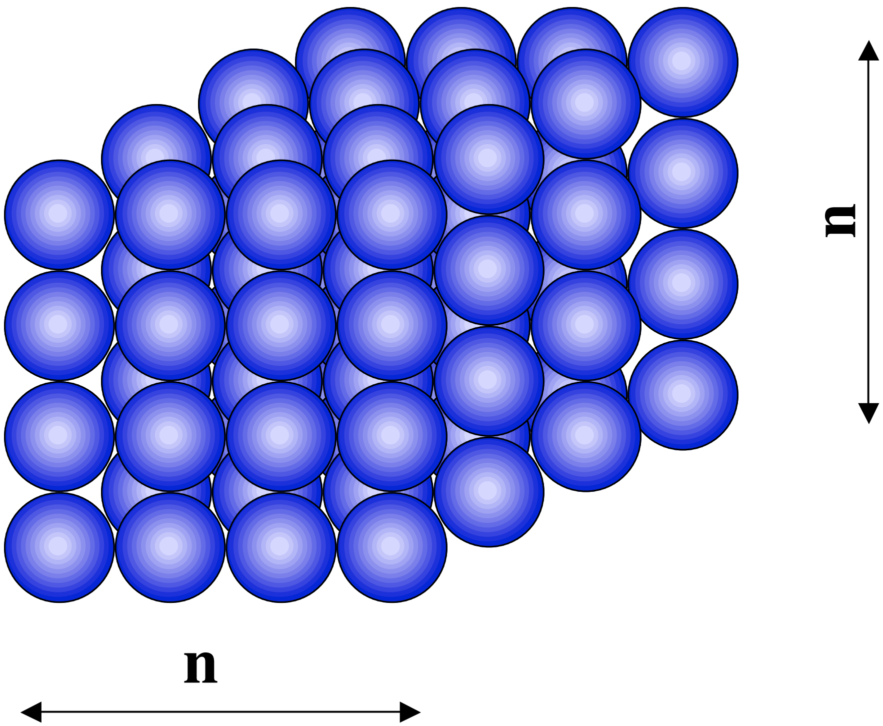


27 Fe atoms - 26 (93.3%) on surface



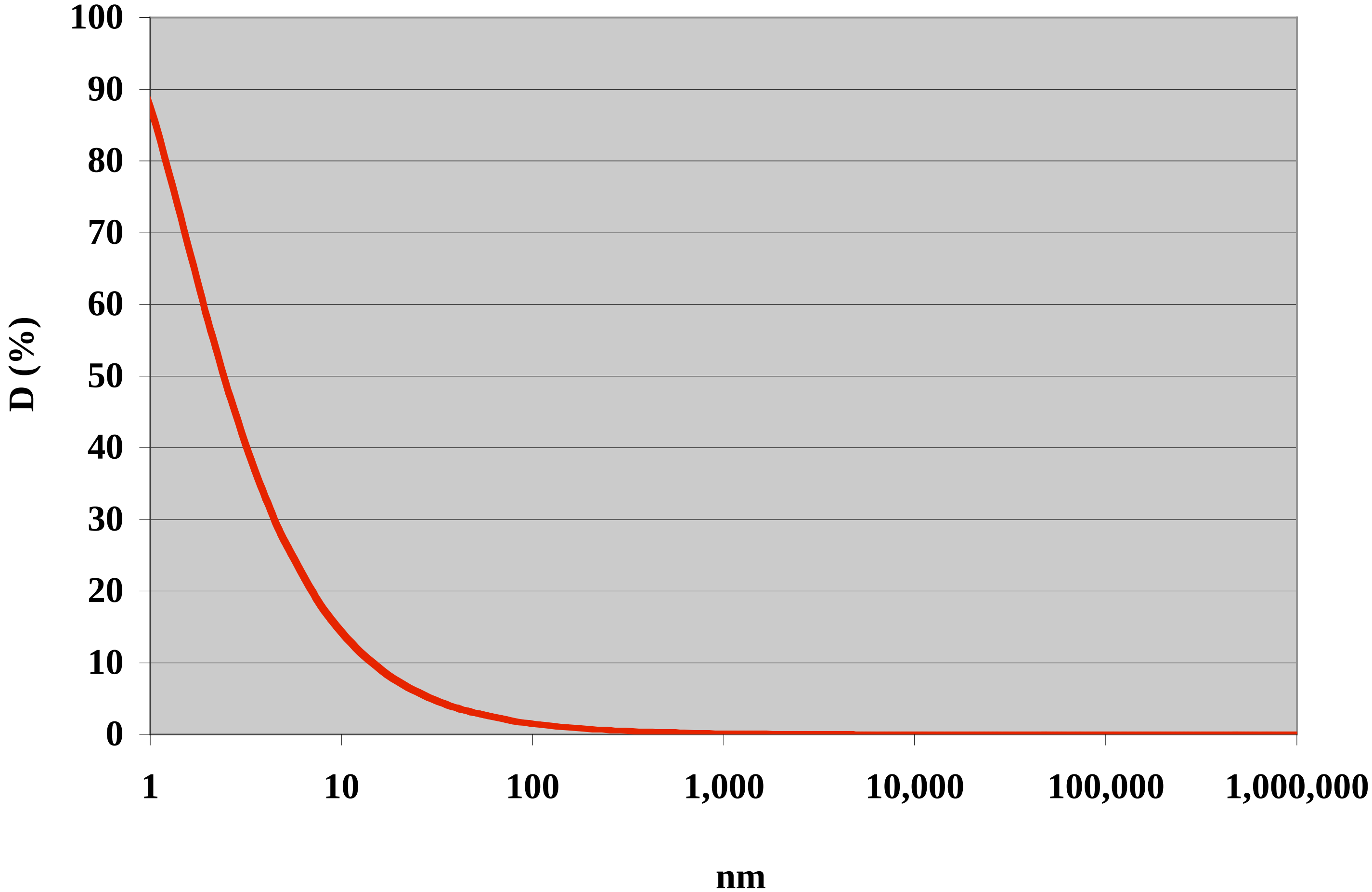
A Cube of 64 Fe atoms
56 (87.5%) on surface

Surface Atoms



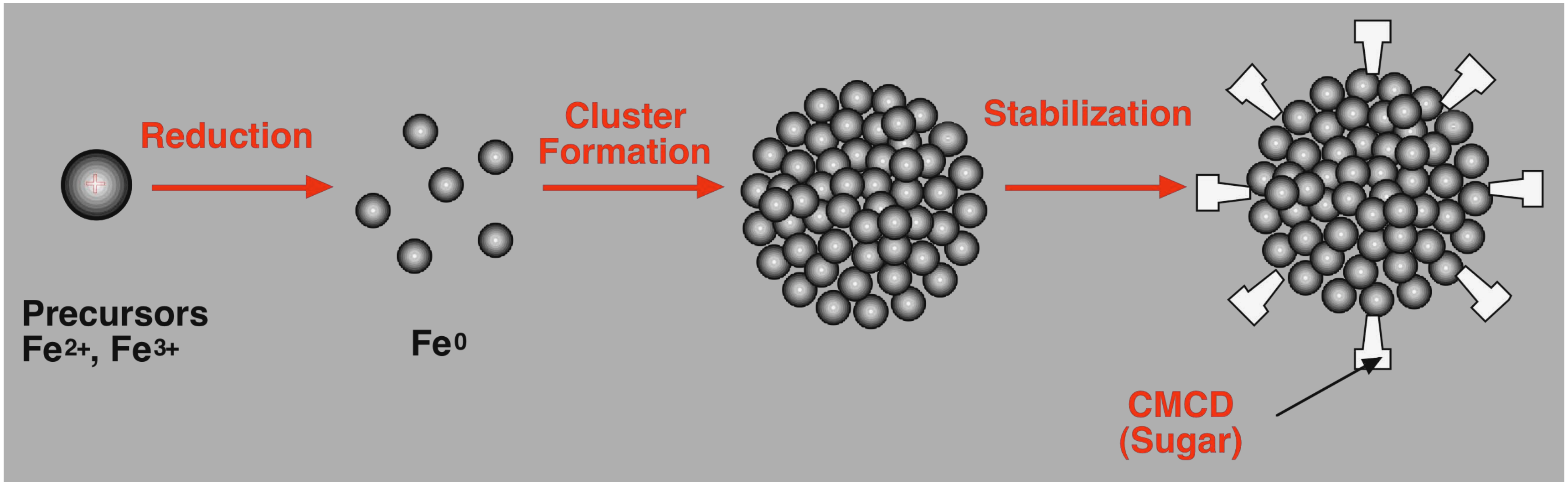
$$D = \frac{\text{number of surface atoms}}{\text{total number of atoms}} = \frac{2n^2 + (n-2)[n^2 - (n-2)^2]}{n^3} \cdot 100$$

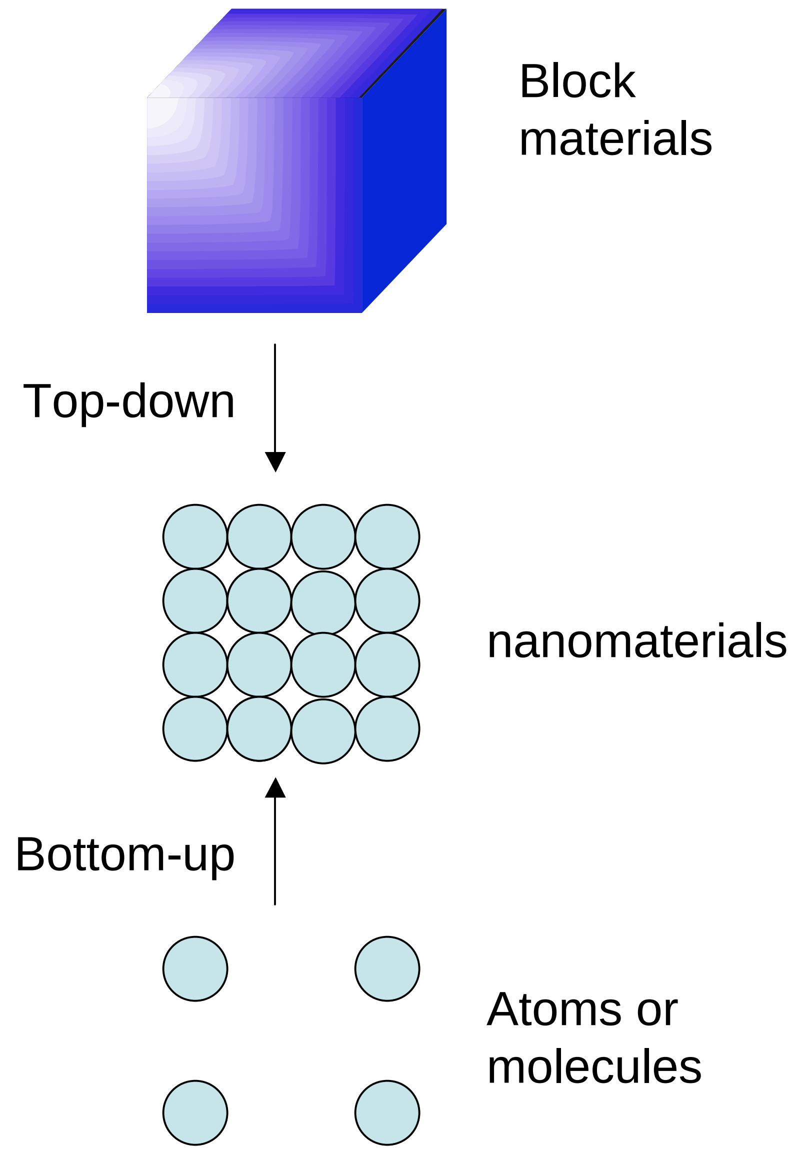
% Atoms on Surface



Calculations for Fe

Methods of Synthesis



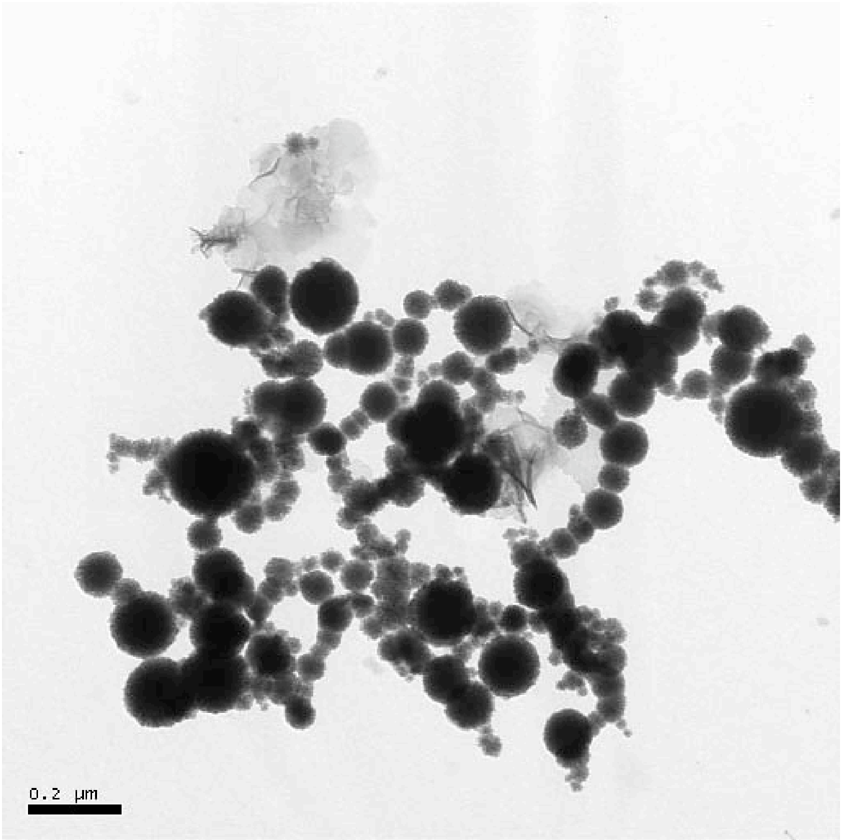

Block
materials
Top-down
nanomaterials
Bottom-up
Atoms or
molecules

Nano Iron for Remediation

- Materials Chemistry
  - Synthesis
- Environmental Chemistry
  - Contaminant degradation
- Geochemistry
  - Fate and transport

Properties of Nano Fe

- **Size range**: 10-100 nm
- **Mean Size**: 60 ± 15 nm
- **Specific surface area**
  - 10-50 m^2/g
- **Zeta potential**
  - 10 to -30 mV



Properties of Nano Fe

Nominal Reaction Rate (Ω)

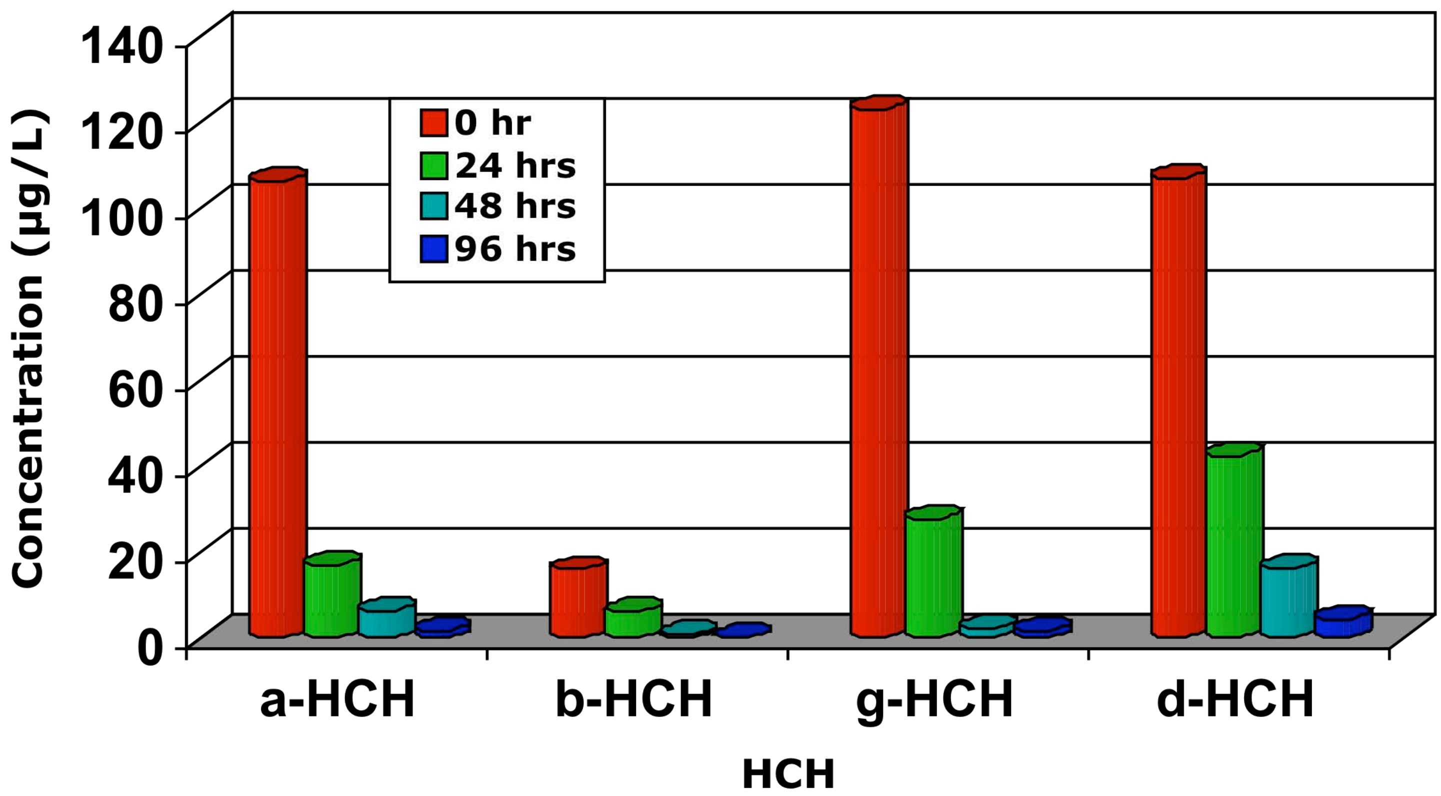
0.1-1 mg TCE/g nanoFe/hour

@ 22°C

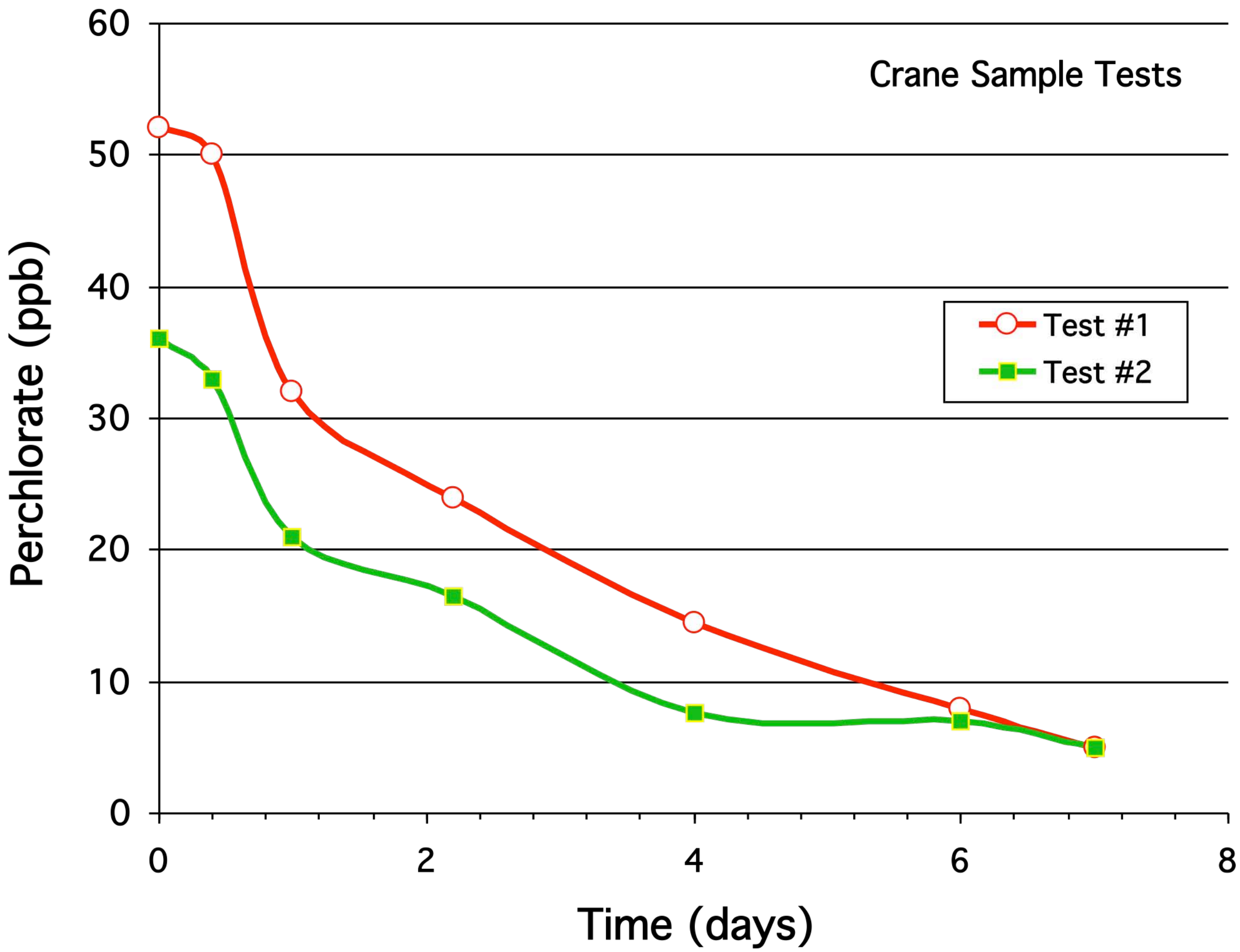
@ 1-100 mg/L TCE

@ pH=7

Lindane (HCH, $C_6H_6Cl_6$)
(Sample from Jacksonville, FL)



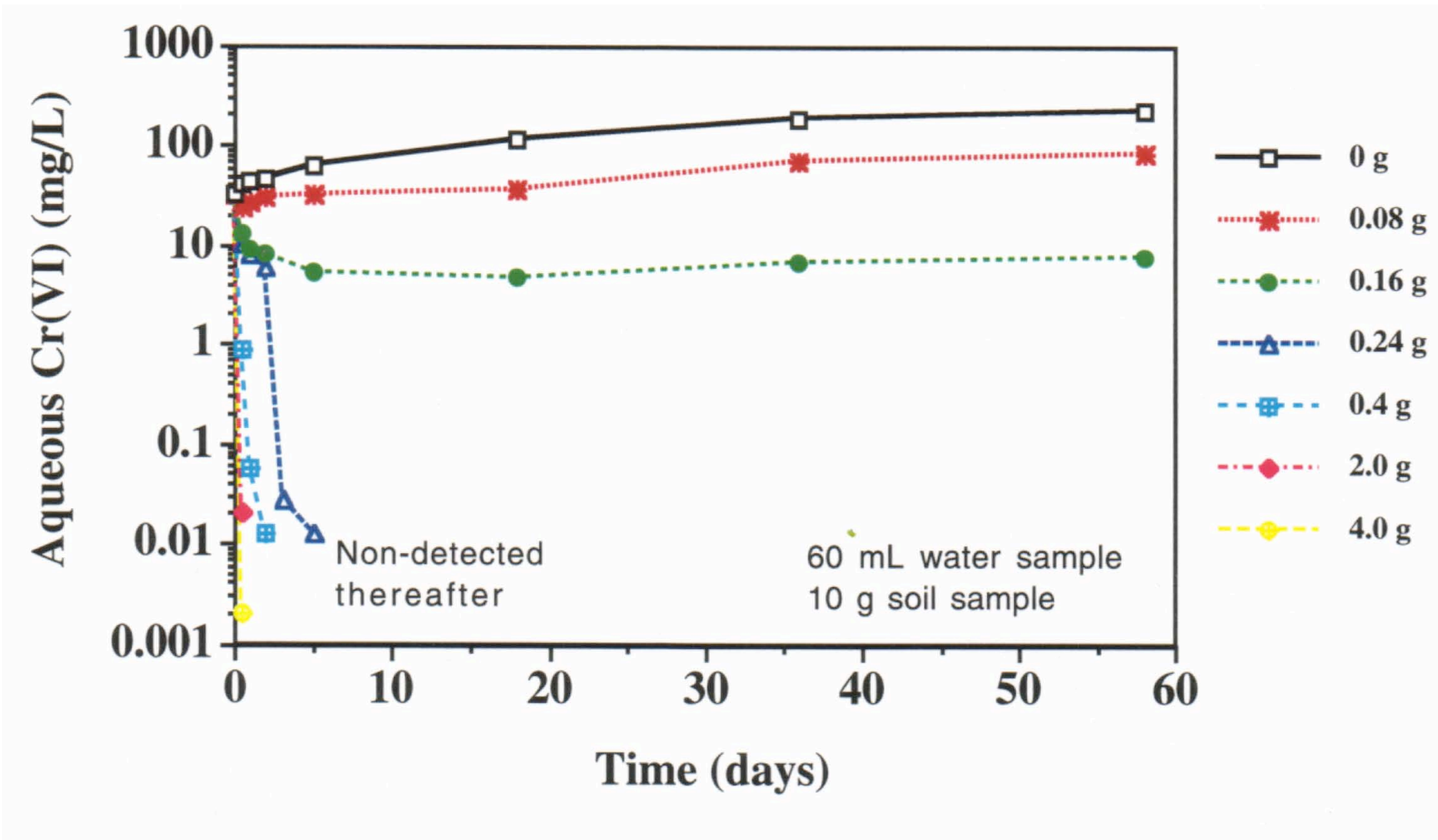
Perchlorate (ClO_4^-)
(Sample from Phoenix, AZ)



Cr(VI)Reduction

COPR Samples from an industrial site in NJ

Aqueous Cr(VI) - 43.38 mg/L, Soil Cr_T - 7,725 mg/kg, pH = 11

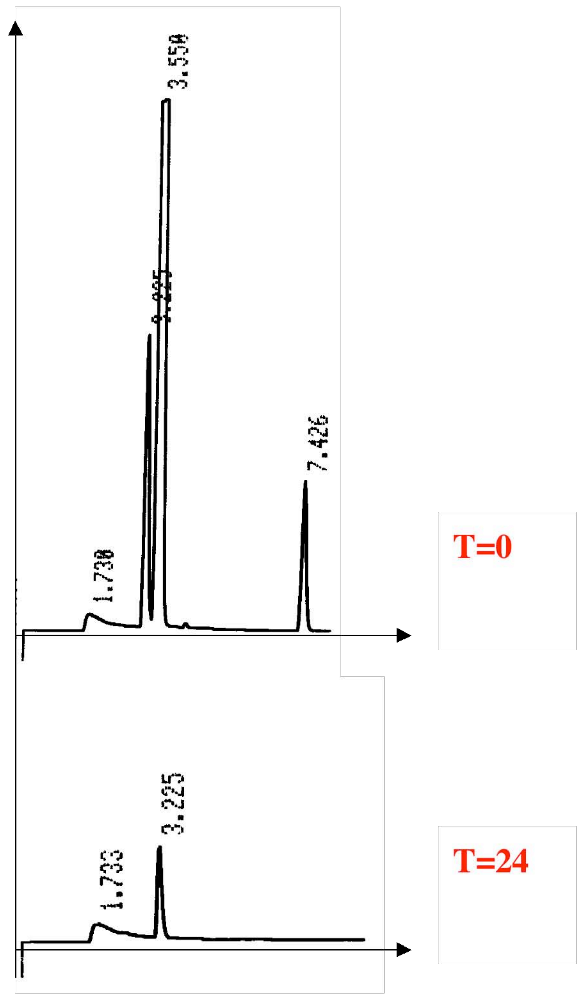


Cr(VI) Reduction/Immobilization

	Micro Fe (~10 μm)	Nano Fe (~50 nm)
Rate	0.0063 mgCr/m²/min	0.157±0.018 mgCr/m²/min
Capacity	1.53-1.75 mg Cr/g Fe	84.0-109.3 mg Cr/g Fe

Carbon Tetrachloride (CT)

(CCl_4, 14.5 mg/L, S. Charleston, WV)



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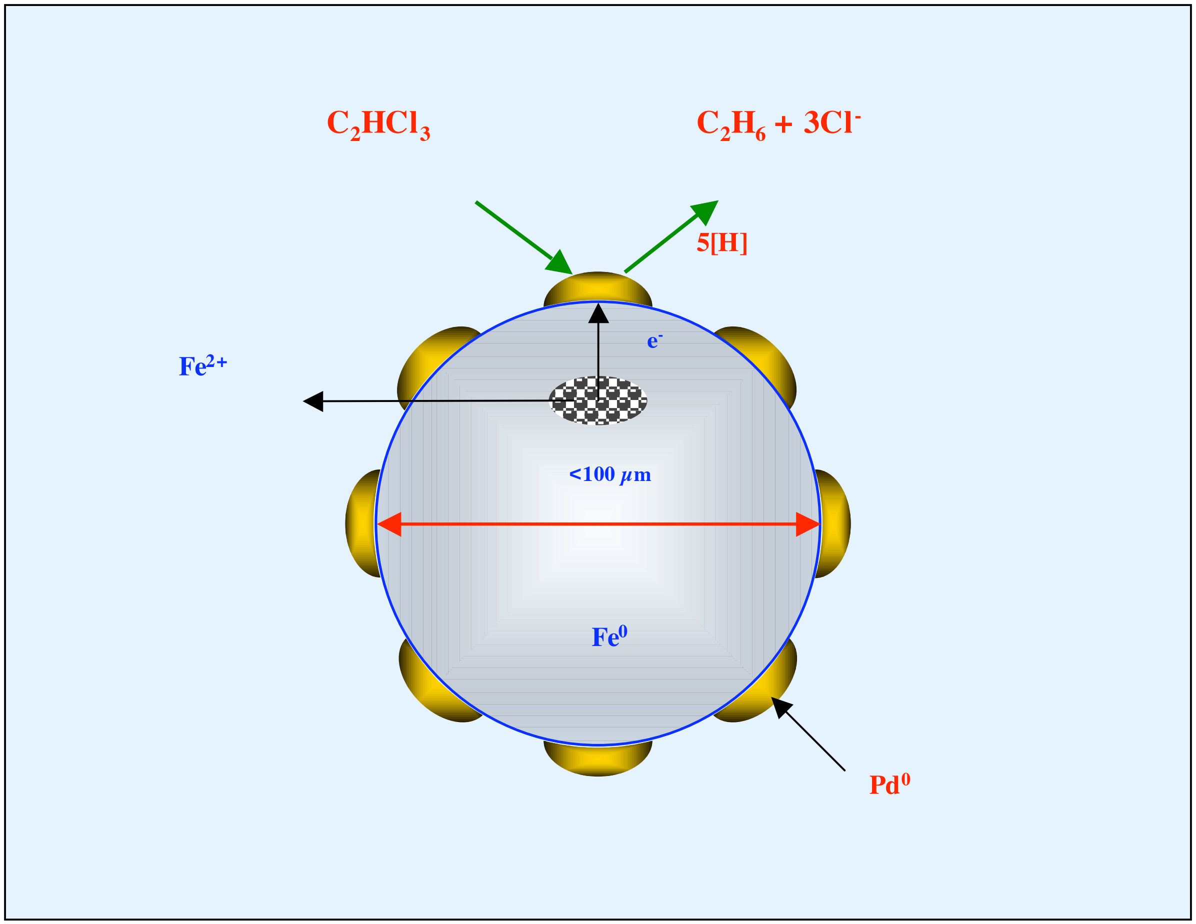
Contaminant Degradation

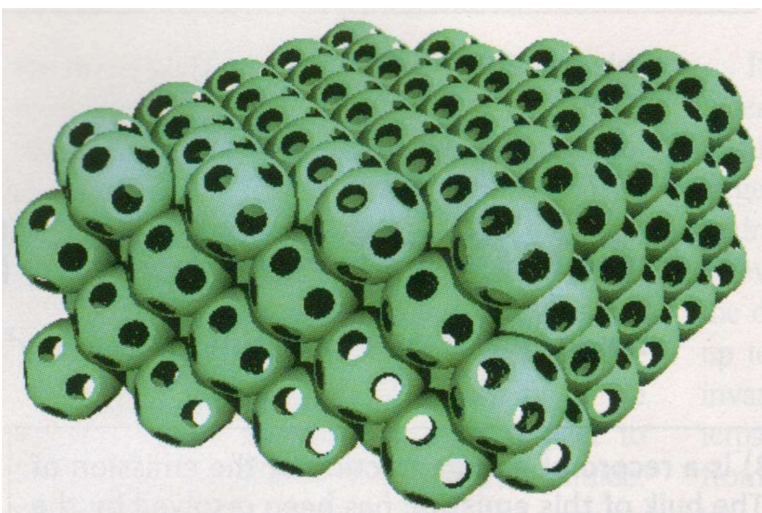
Chlorinated Methanes	**Cr(VI)**
Chlorinated Ethenes	**Pb(II)**
Chlorinated Ethanes	**Ni(II)**
Chlorinated Benzenes	**Cd(II)**
PCBs	**Perchlorate**
Lindane (HCHs)	**As**

> 100 compounds tested at Lehigh so far

Enhance Activity by Catalysts



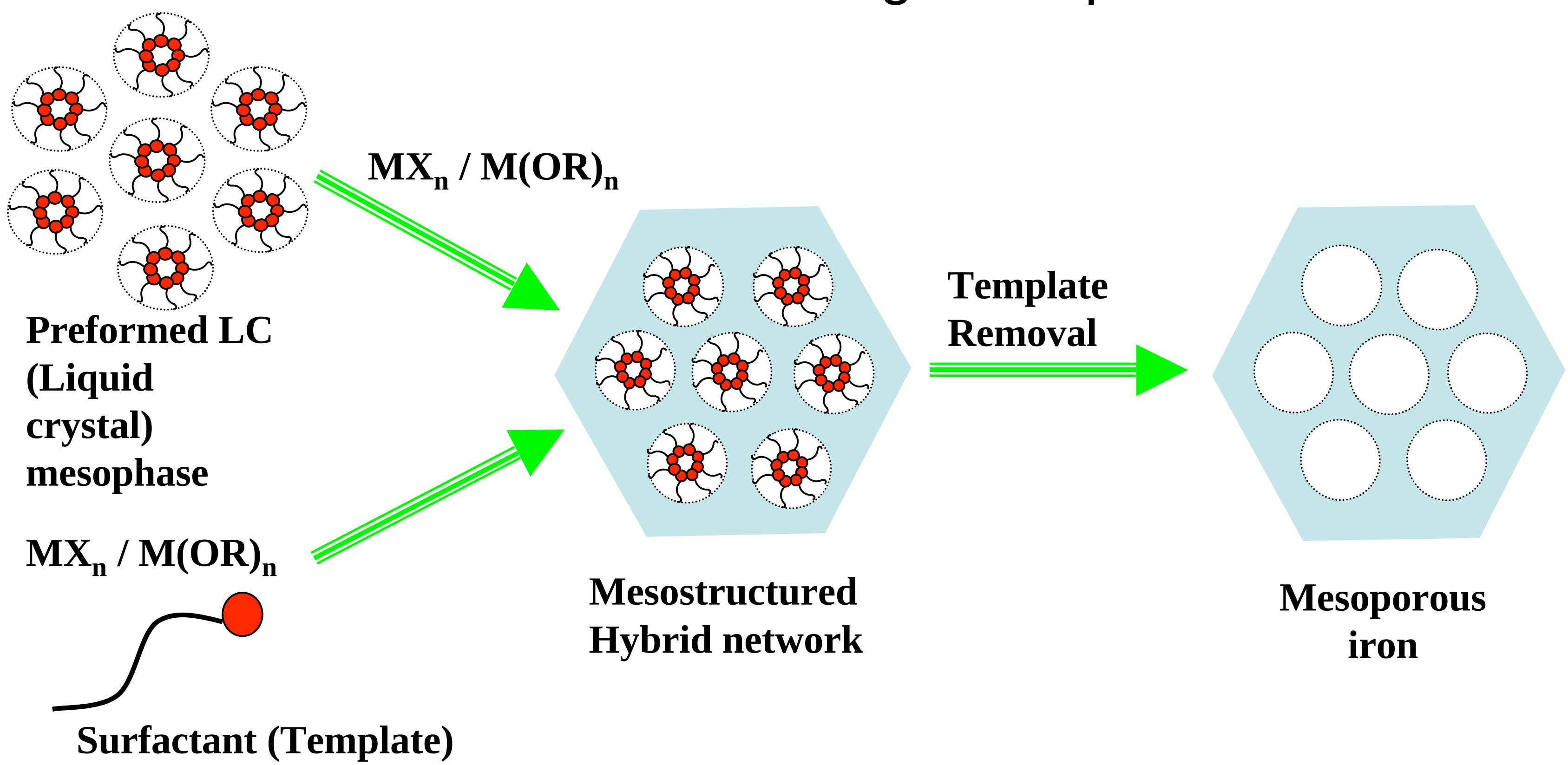
Enhance Activity by Porous Nanoparticles



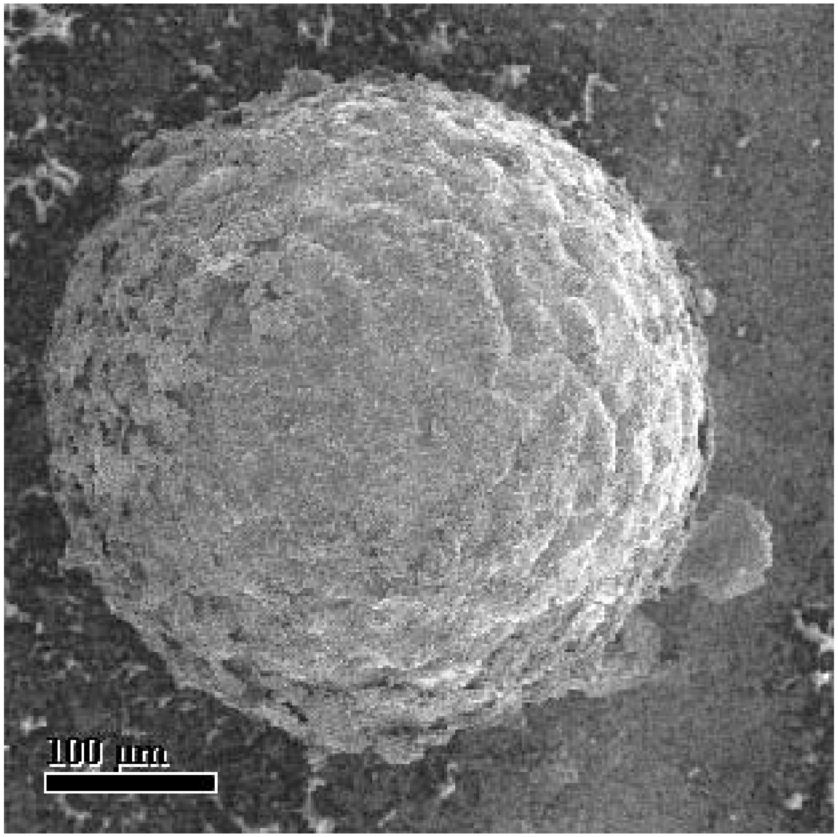
- Large surface area
- Better hydraulics
- High mobility

Synthesis of Porous Nanoparticles

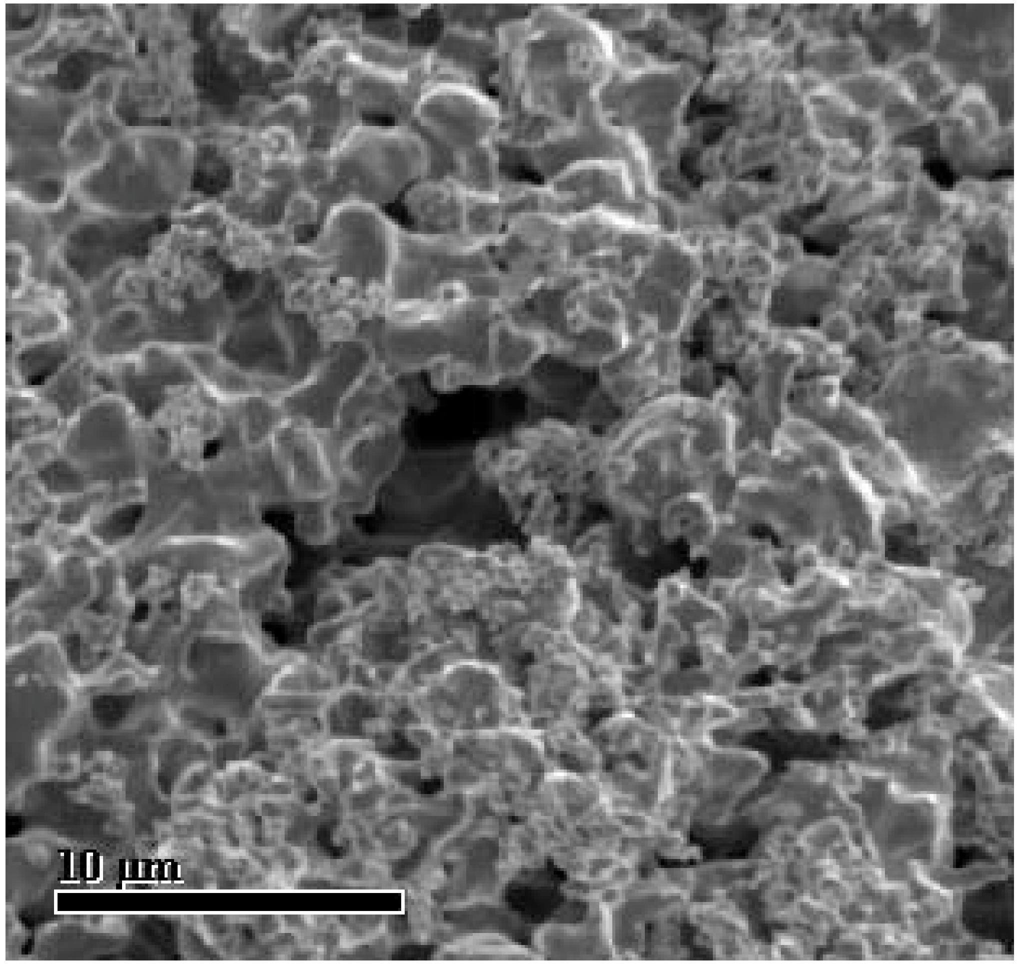
Self-assembling Template



Template-directed Synthesis



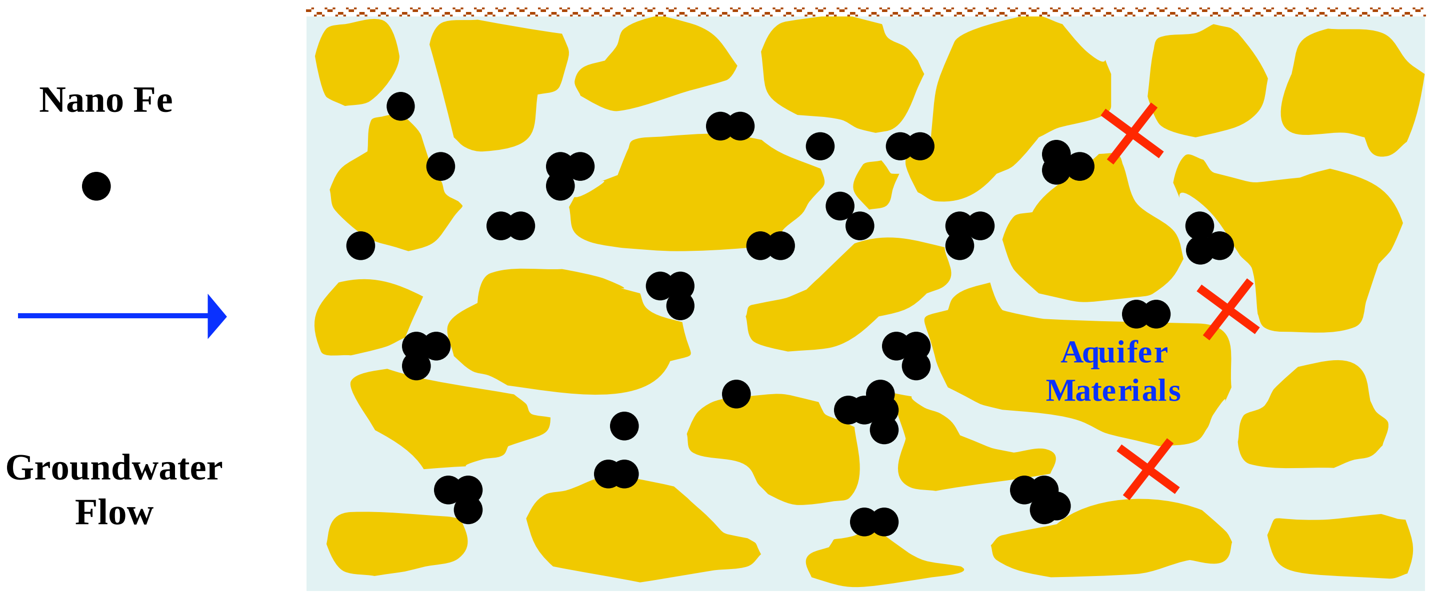
0.4 mm


10 µm

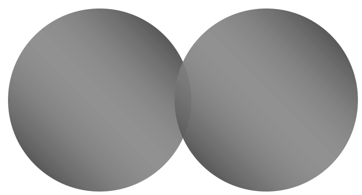
Surface Areas

Fe	SSA (m^2/g)
Aldrich (~0.4 mm)	0.0012
BASF (~1 μm)	1.5
NanoFe (60 nm)	20-40
Nanoporous	142-250

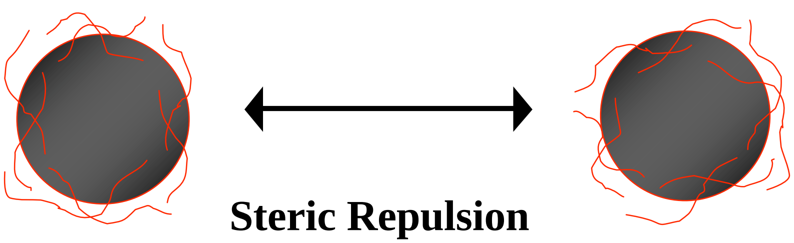
Manipulate Nanoparticle Mobility



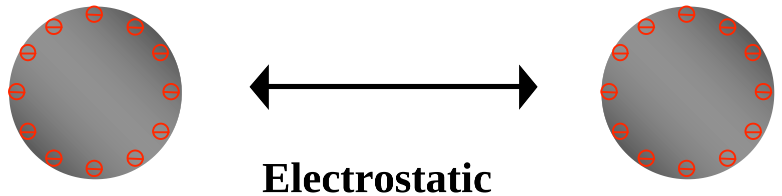
Dispersion



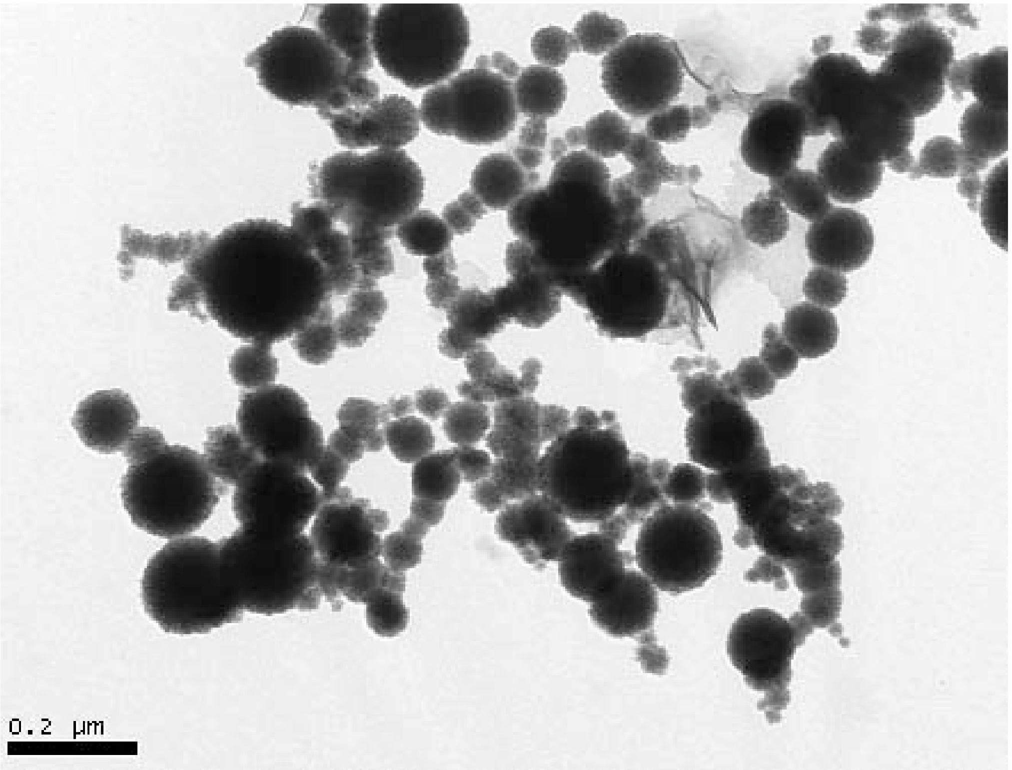
Attachment



Steric Repulsion

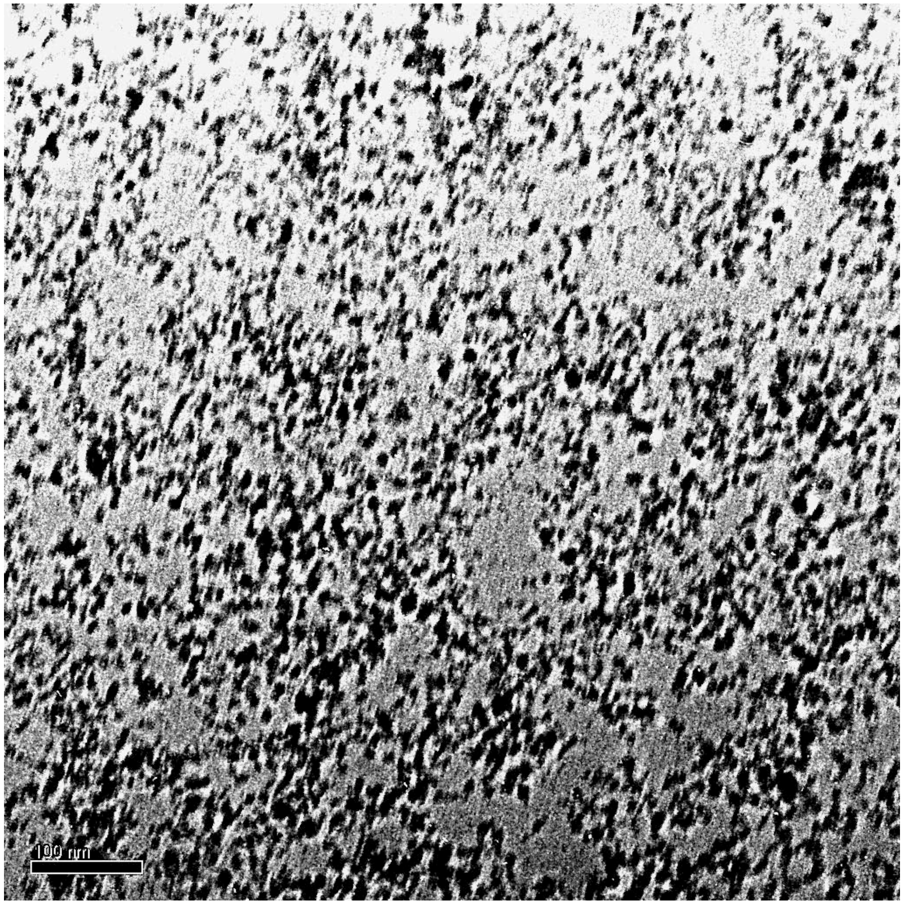


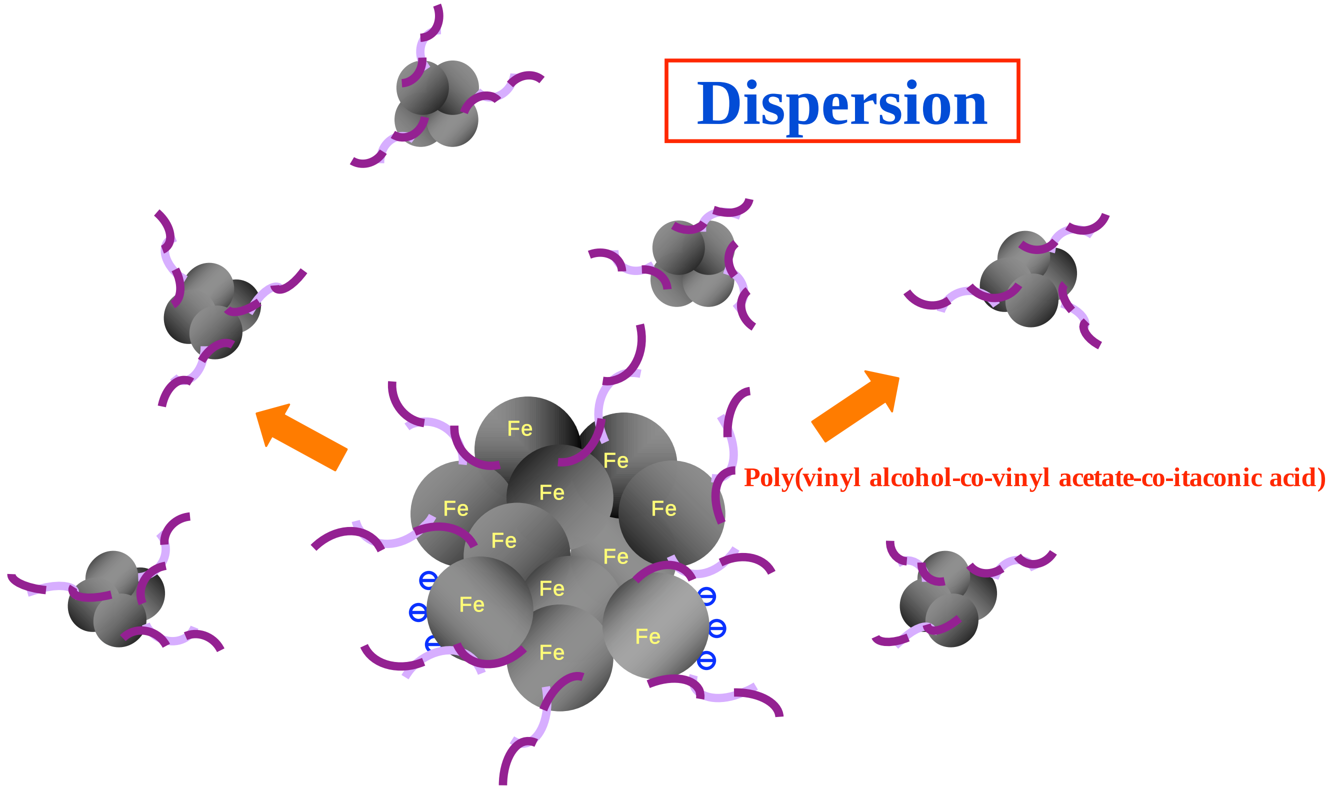
Electrostatic Repulsion



Dispersed Nanoparticle

Original Nanoparticle





Iron Nanoparticle Aggregates

COSTS

Iron Filings
$0.5/kg
<10 m^2/kg
<20 m^2/dollar

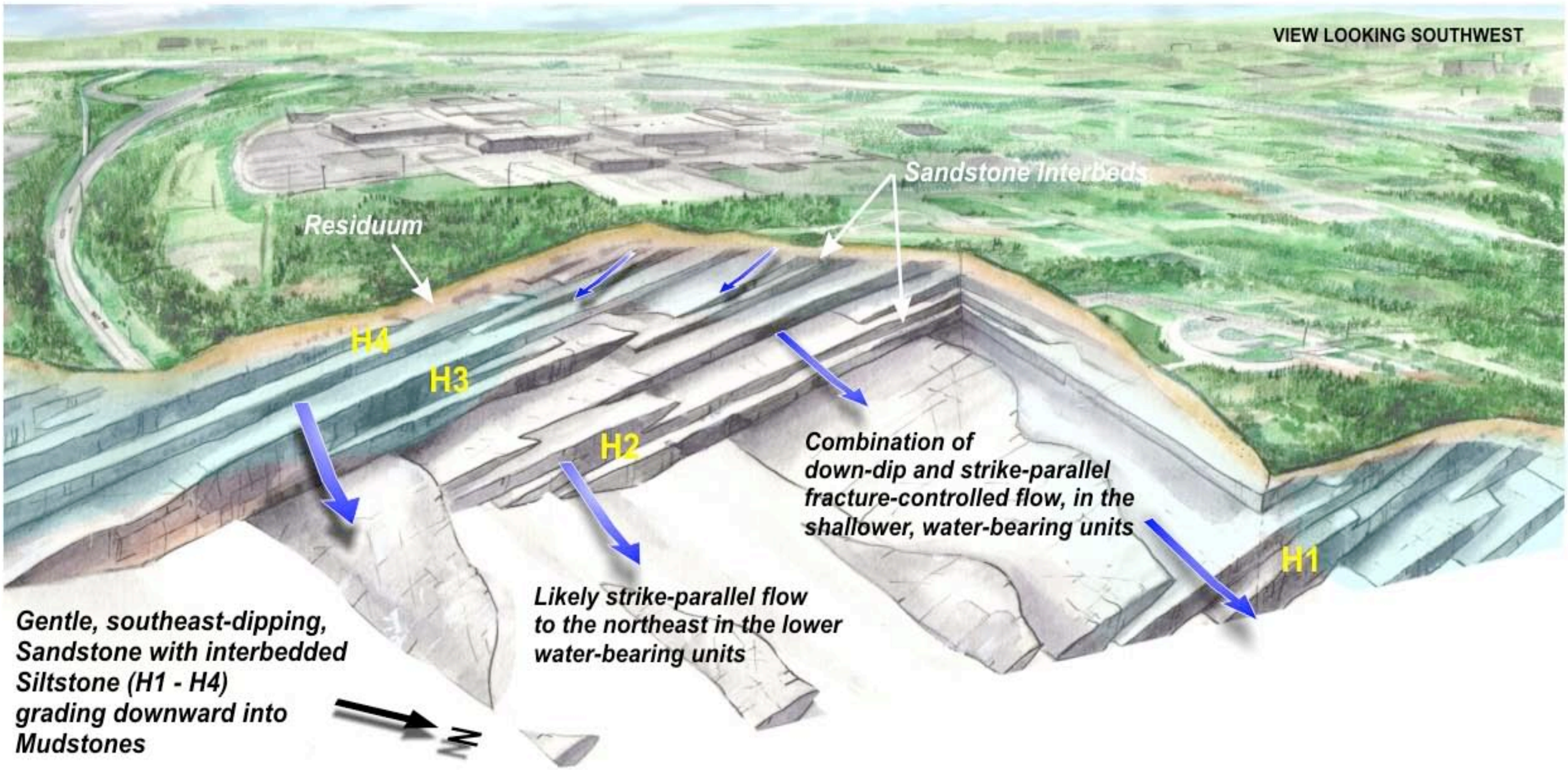
COSTS

Iron Filings	**Nano Iron**
\$0.5/kg	~\$25/kg
<10 m^2/kg	~25,000 m^2/kg
<20 m^2/dollar	**~1,000 m^2/dollar**

COSTS

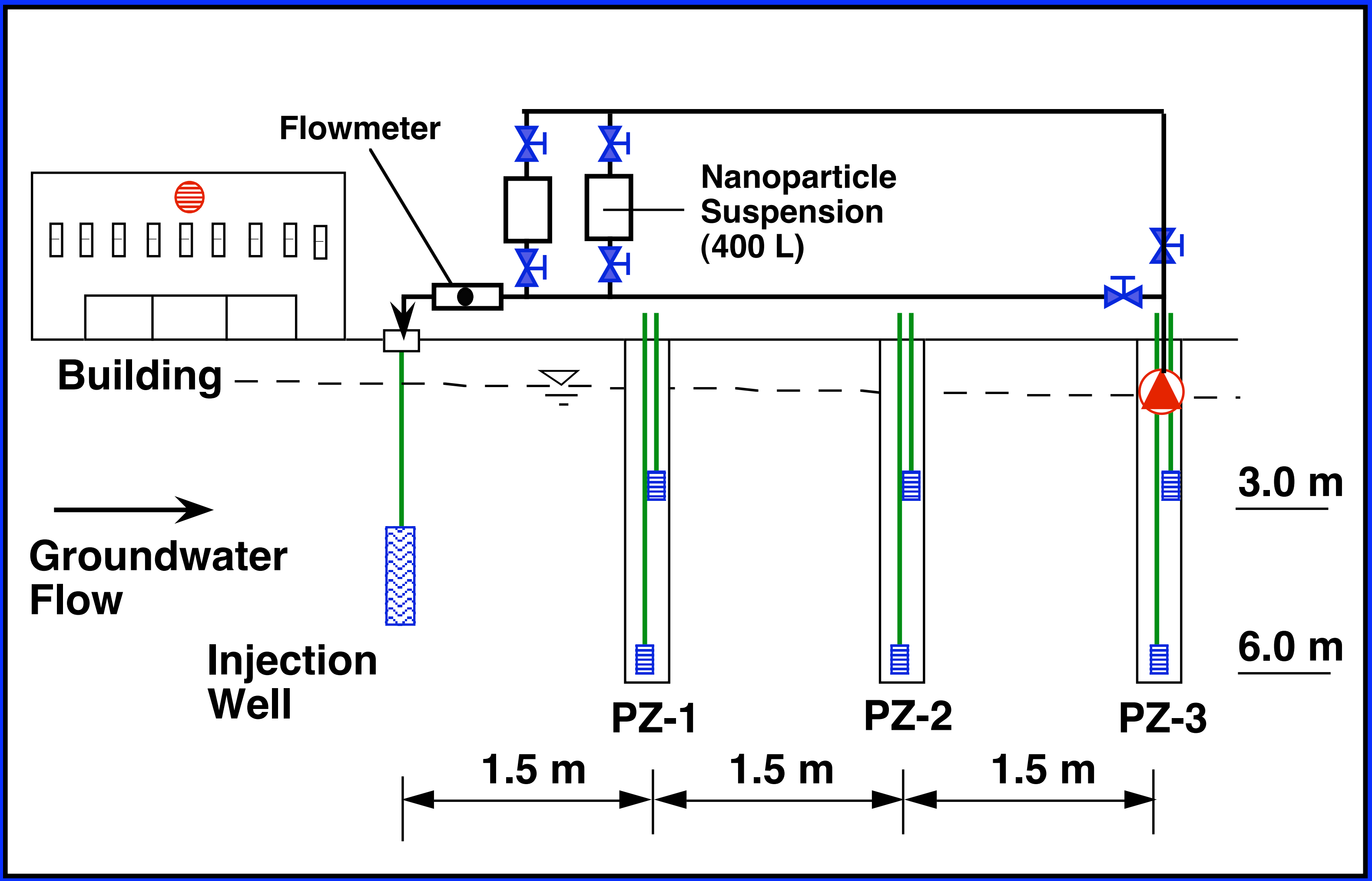
Iron Filings	Nano Iron	Porous Iron
$0.5/kg	~$25/kg	~$50/kg
<10 m^2/kg	~25,000 m^2/kg	~200,000 m^2/kg
<20 m^2/dollar	**~1,000 m^2/dollar**	**~4,000 m^2/dollar**

Conceptual Geologic and Hydrogeologic Model

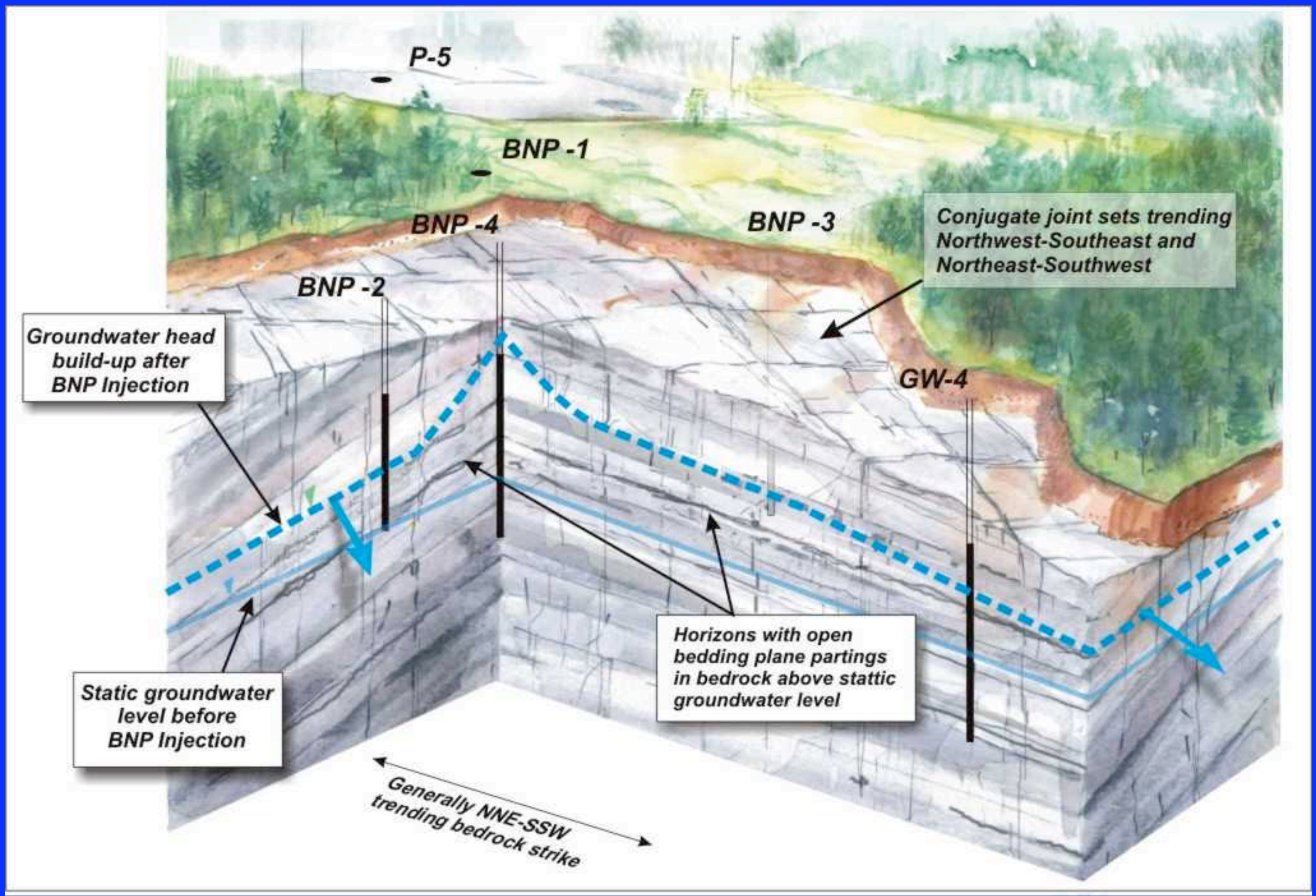


Field Applications

(11 projects so far, >10 Planned for 04')



Conceptual Model

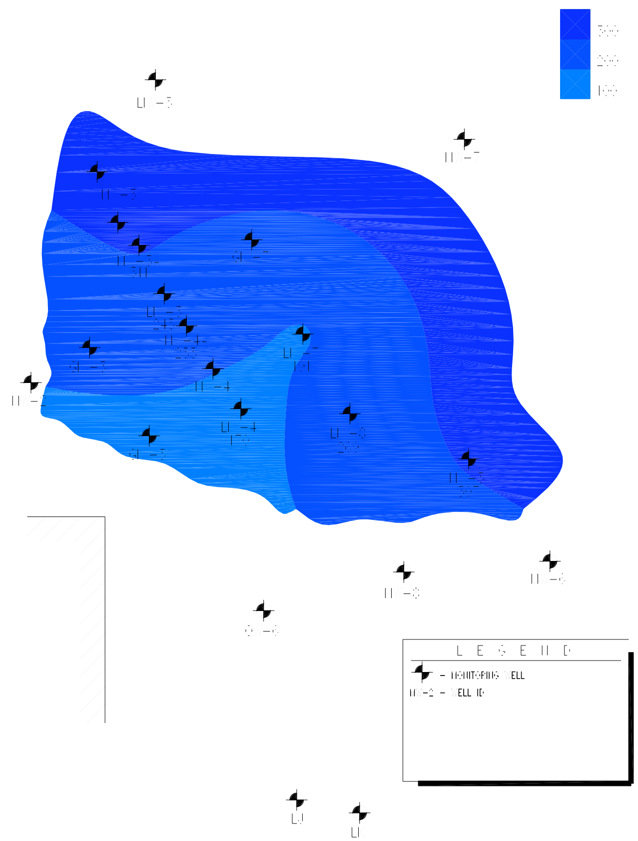


The Nano Fe Slurry
(1-2 g/L)

Test Set-up

ORP 2/4/02

Before Nano Fe Application

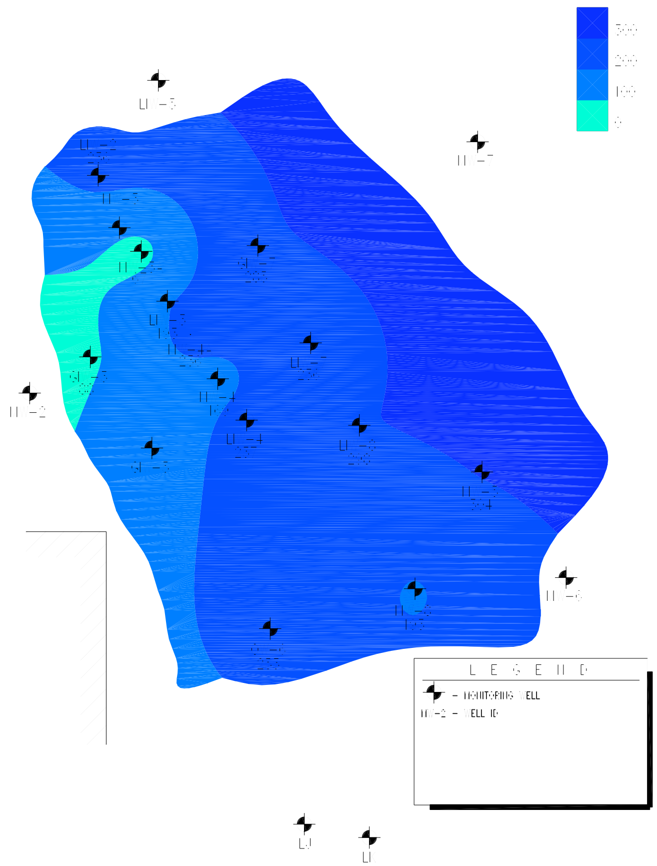


Oxidative Environment

+100 to + 400 mV

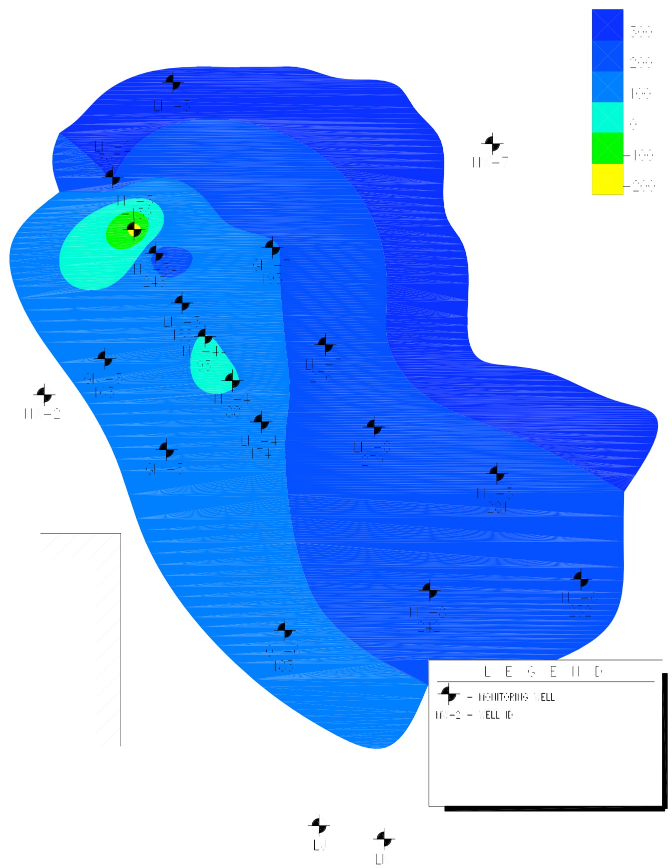
ORP 2/11/02

Right after Nano Fe Application



0 to + 400 mV

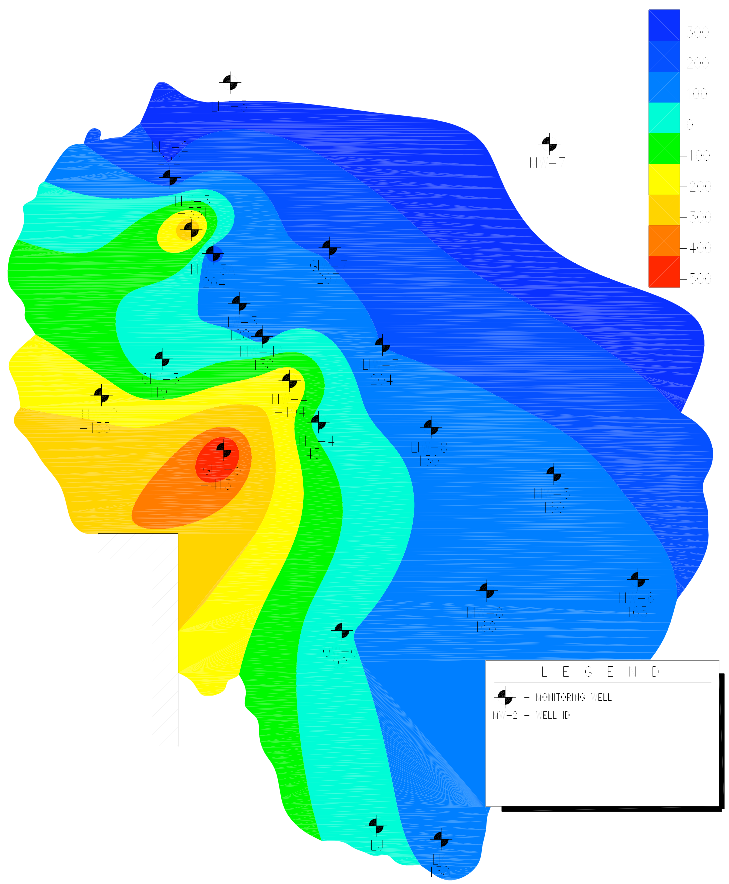
ORP 2/19/02



1 week after Nano Fe Application

-200 to + 400 mV

ORP 3/4/02

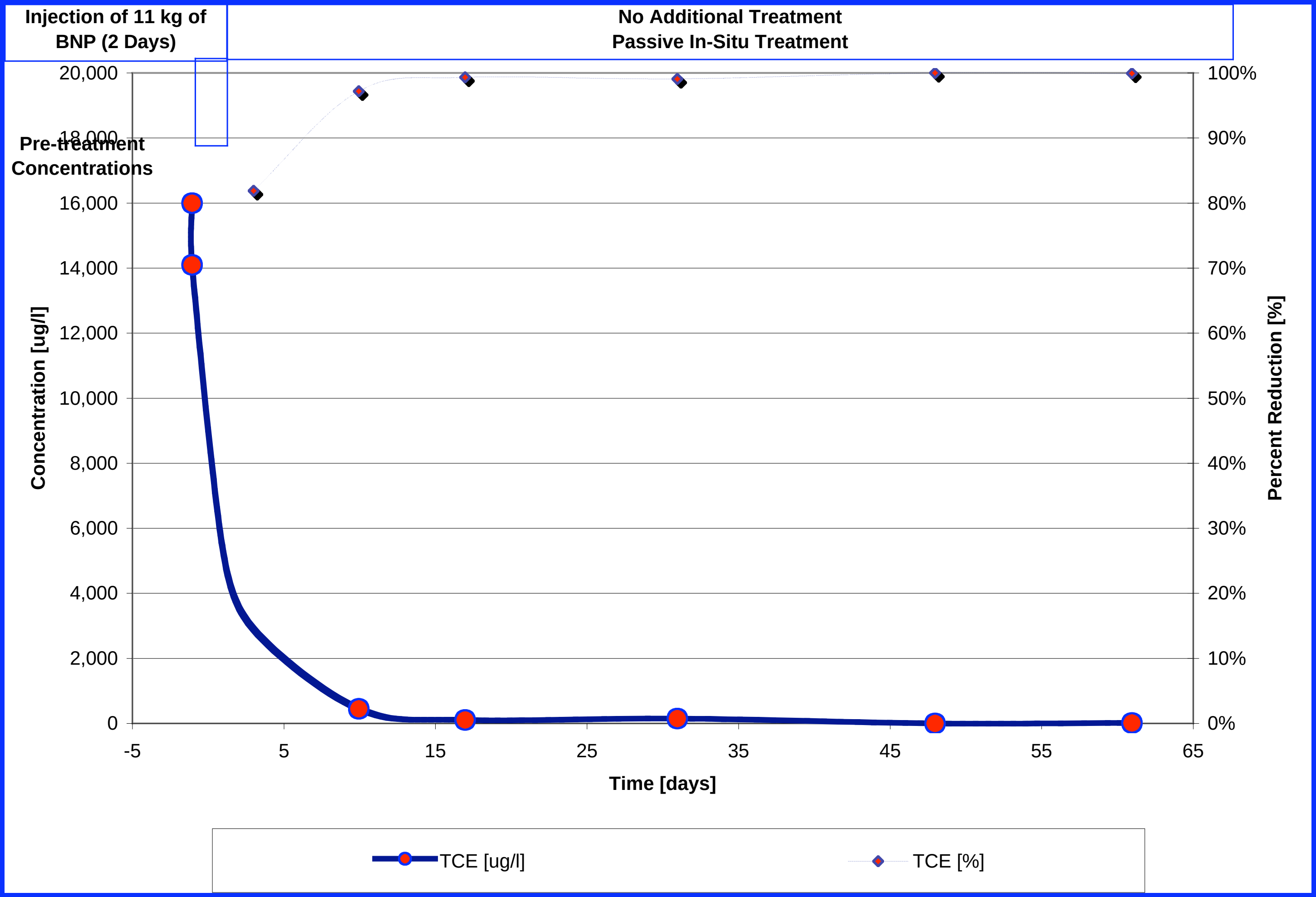


3 weeks after Nano Fe Application

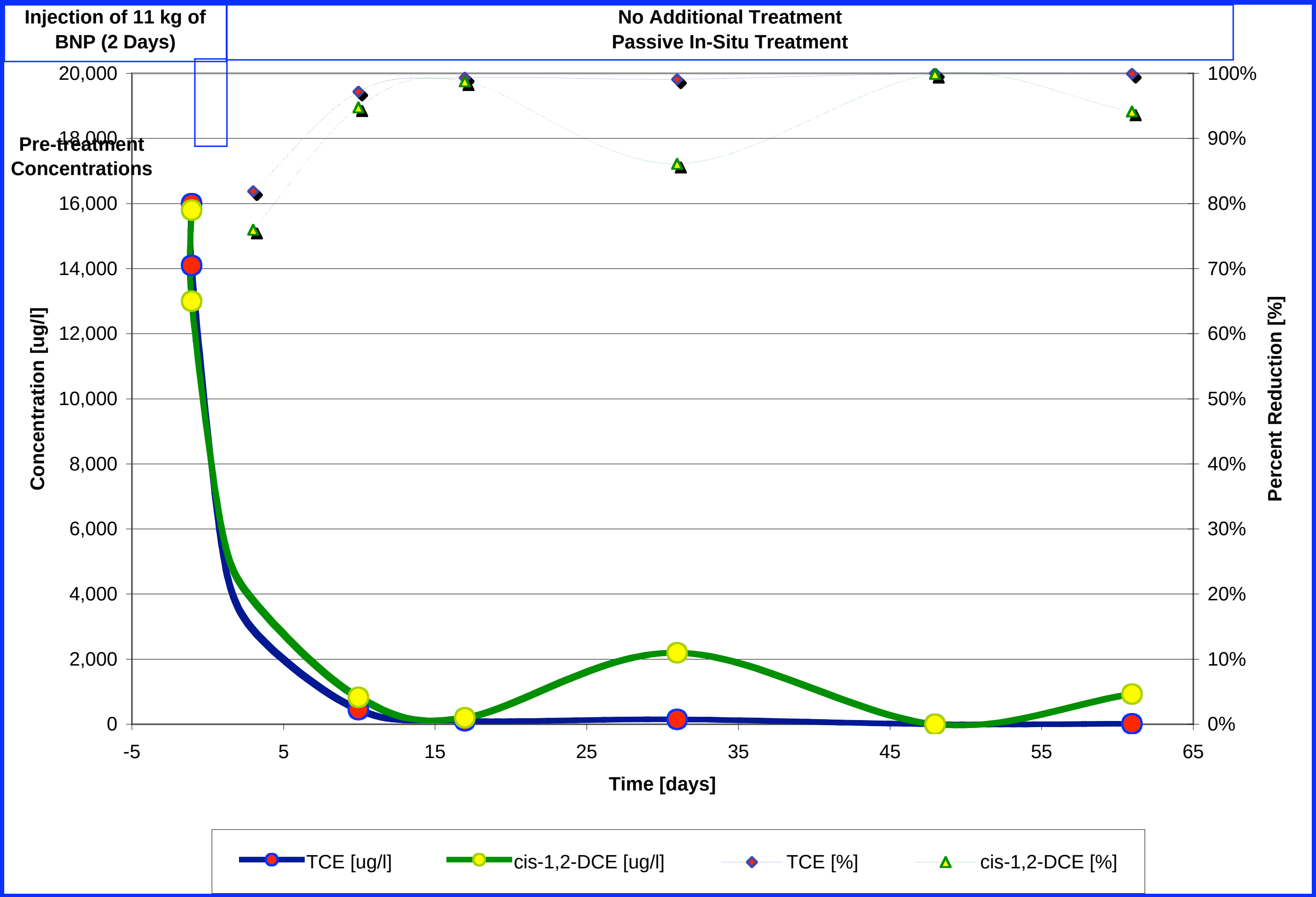
Reducing Environment

-500 to + 400 mV

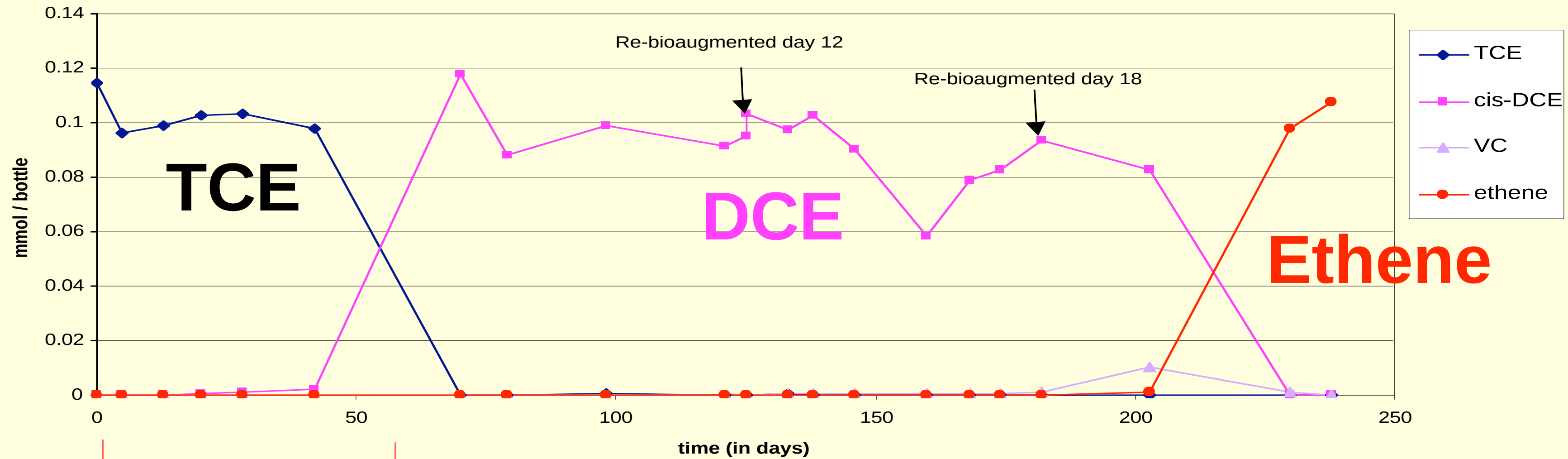
Sampling Results
TCE - MW-4



Sampling Results
TCE and cis-1,2-DCE at MW-4

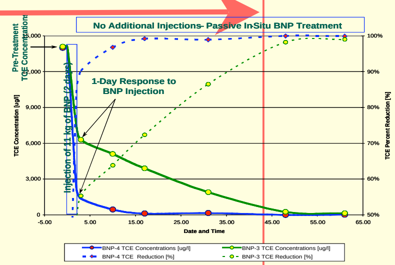


Comparison: Bioremediation - and Nano Fe



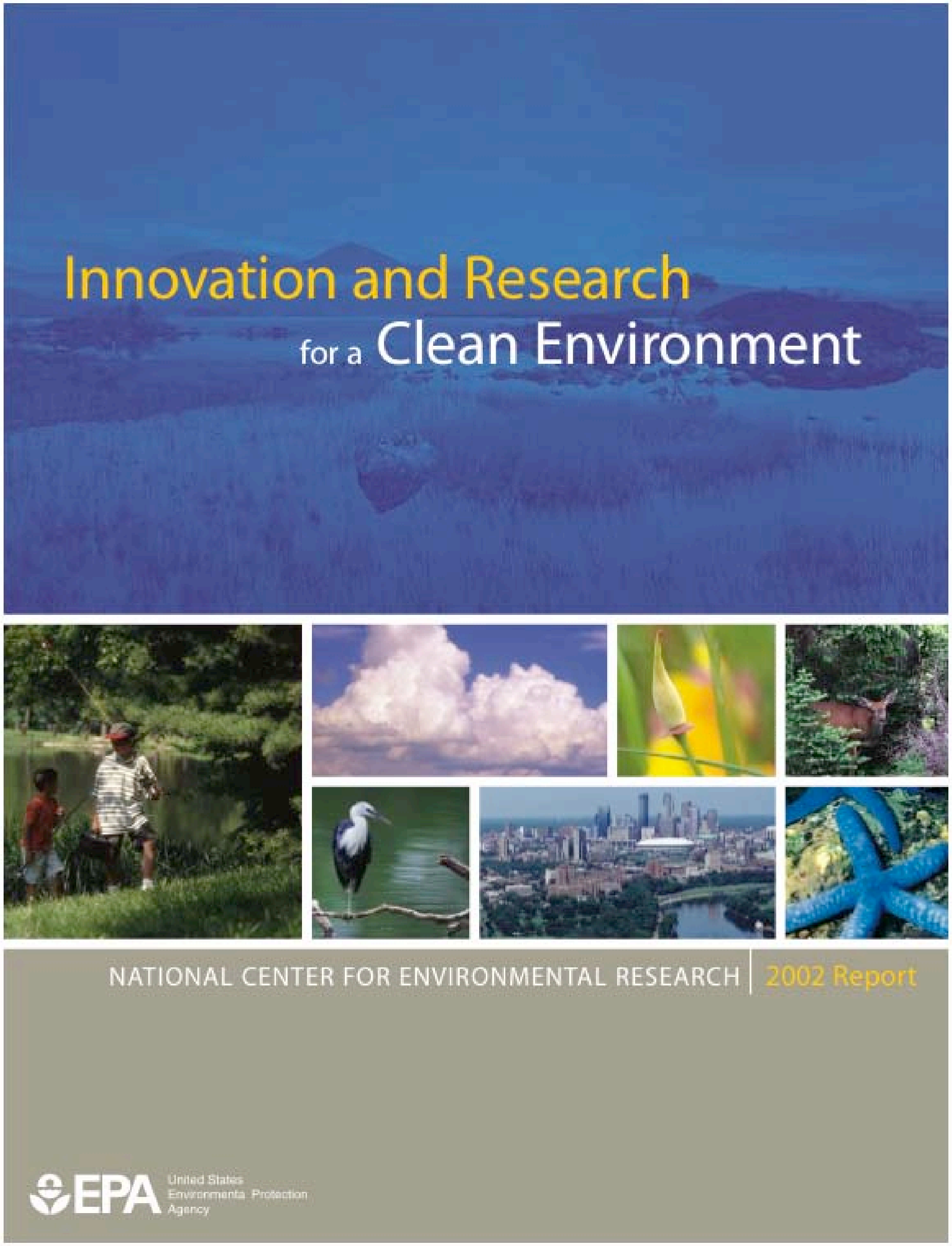
Bioremediation

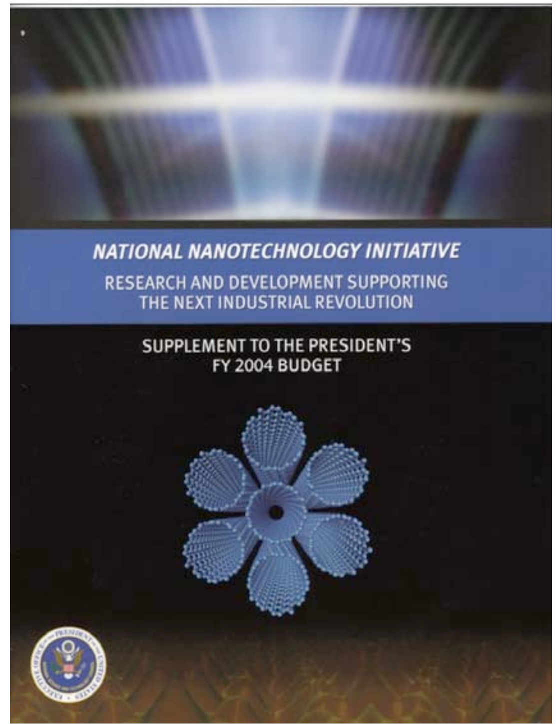
60 Days



Nano Fe

60 Days





More on:

NY Times
USA Today
WSJ
>20 others


TV PG
MAR 19, 2002

Thanks

Questions ?