RICE

# Nanotechnology and Nuclear : One Case Study

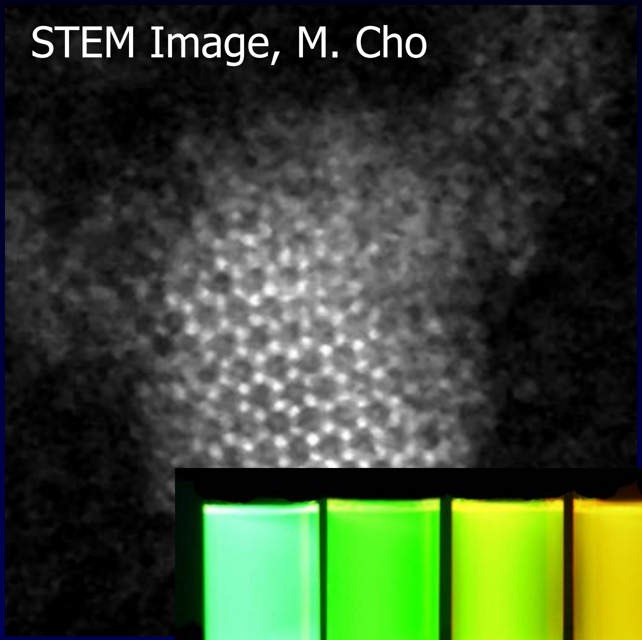
Rice University

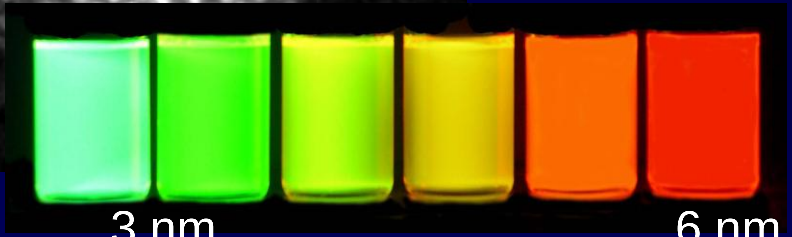
Professor Vicki Colvin

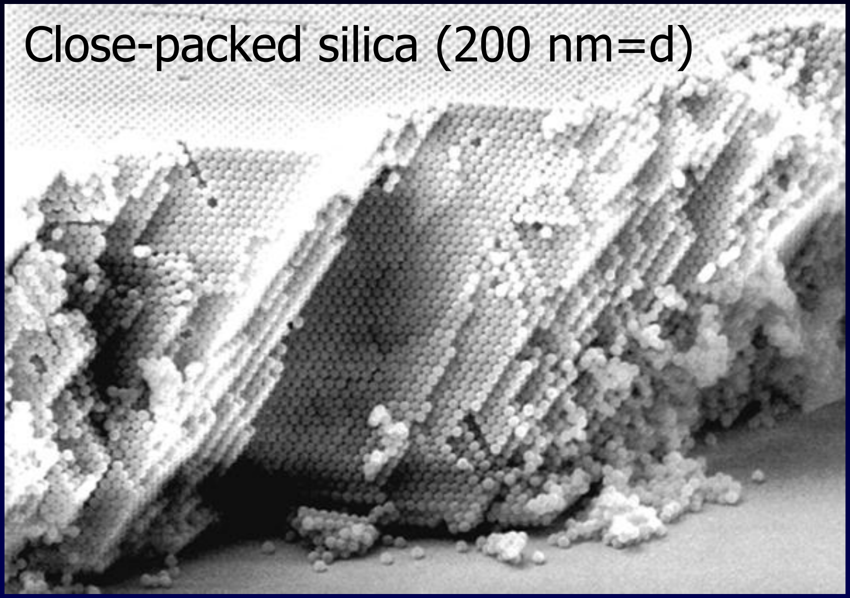
Pitzer-Schlumberger Chair of Chemistry

http://www.rice.edu

# Features of Nanoparticles: The Hammer




- They are very, very small
- Their properties are size-dependent
- They can assemble into larger structures

# The Needle in the Haystack: The Nail

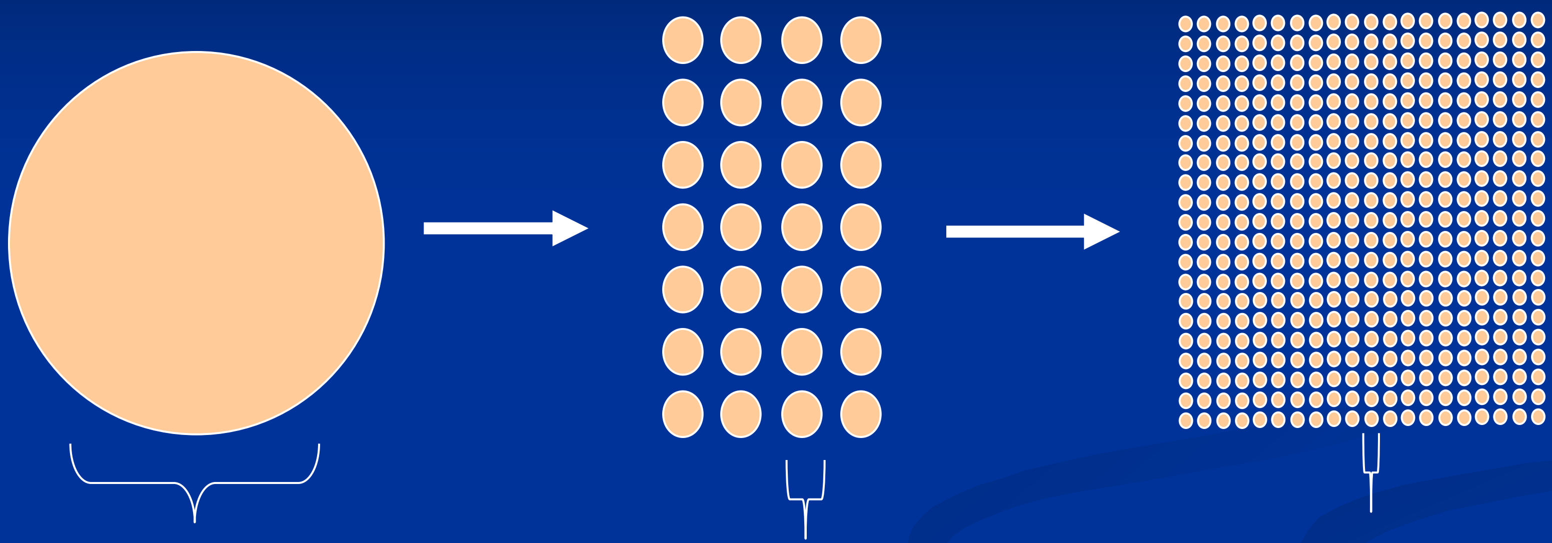
*Can we concentrate Uranium from soils so that it can be analyzed and reclaimed?*

IARPA
BE THE FUTURE

IC Postdoctoral Research Fellowship Program
Research Institutes • National Laboratories • Universities

Dr. John Fortner

# Small stuff, huge surface



100 micron
9 square cm

1 micron
3 square meters

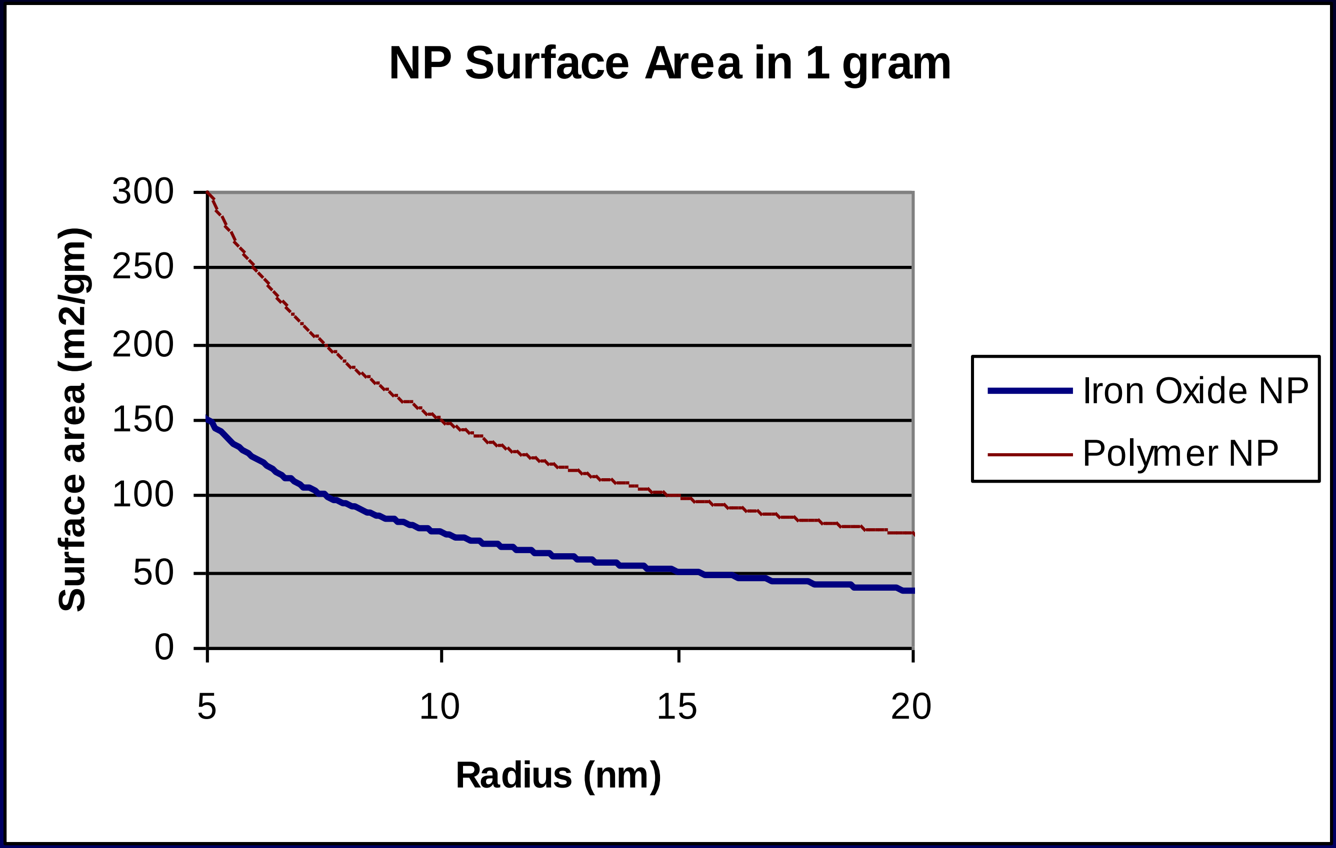
10 nm
300 square meters

**One hundred particles**

**One billion particles**

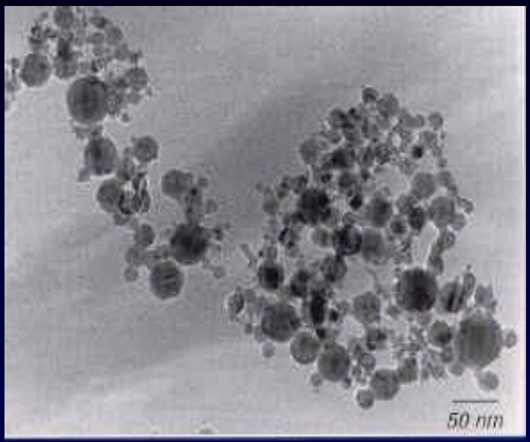
**One hundred trillion particles**

# Nanoparticles: Super Small




Surface area in 1 gram ~ $4 \pi r^2 / (4/3 \pi r^3 \cdot \text{density})$

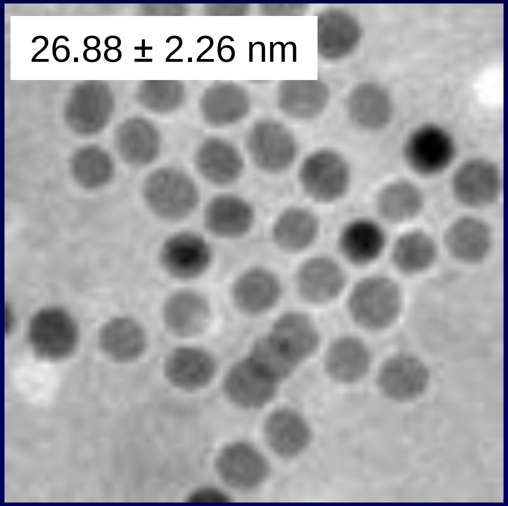
# With that much surface: surface matters

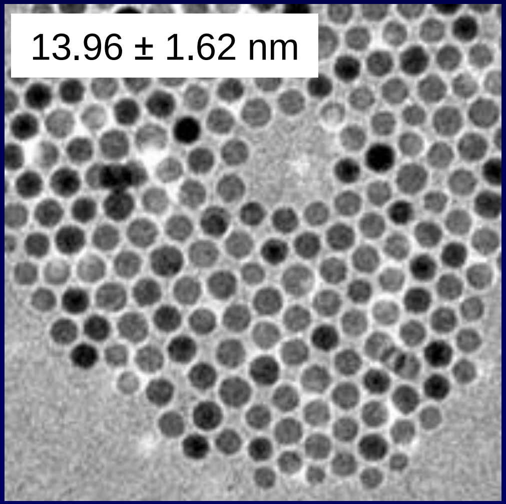


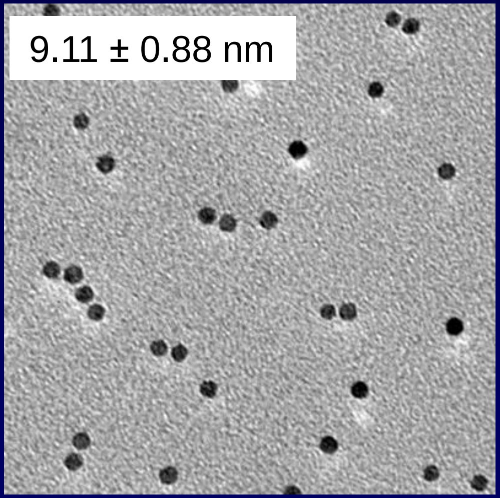

From Kemico, avg size 20 nm

Commercial nano-oxides have problems

- Agglomerated → poor magnetic separation
- Larger nanoparticles → lower sorption
- Bad size distribution → no optimization



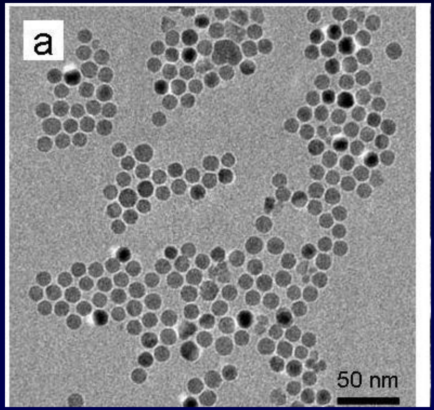

*W. Yu, V. L. Colvin, Chem. Comm. (2004)*

# High Technology through Low Tech Manufacturing

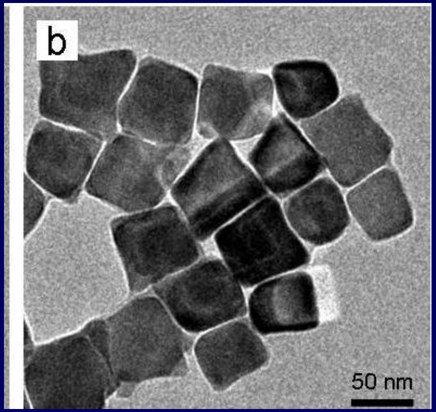
| Precursor | Surfactant | Solvent |
|---|---|---|
| FeOOH<br>(Iron Oxo Hydrate) | Oleic acid<br>((9Z)-octadec-9-enoic acid) | ODE<br>(1-octadecene) |

Rust


Olive oil soap

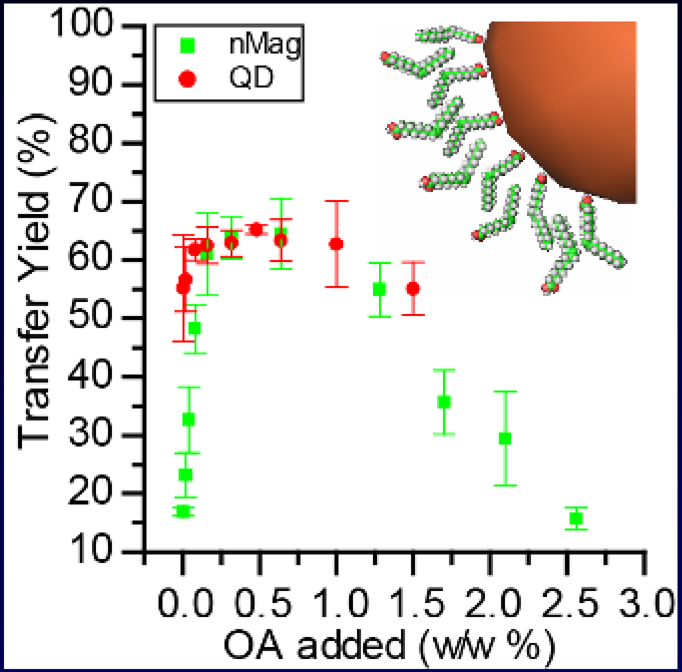



Diesel Oil Diluents



# Surface Stabilization of Materials

*J. T. Mayo and Arjun Prakash*

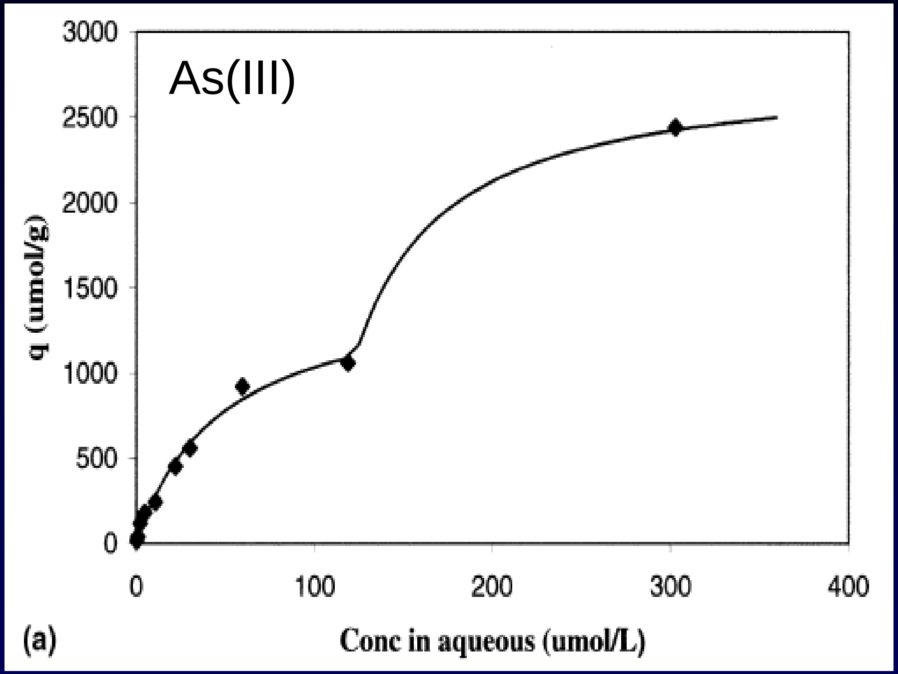



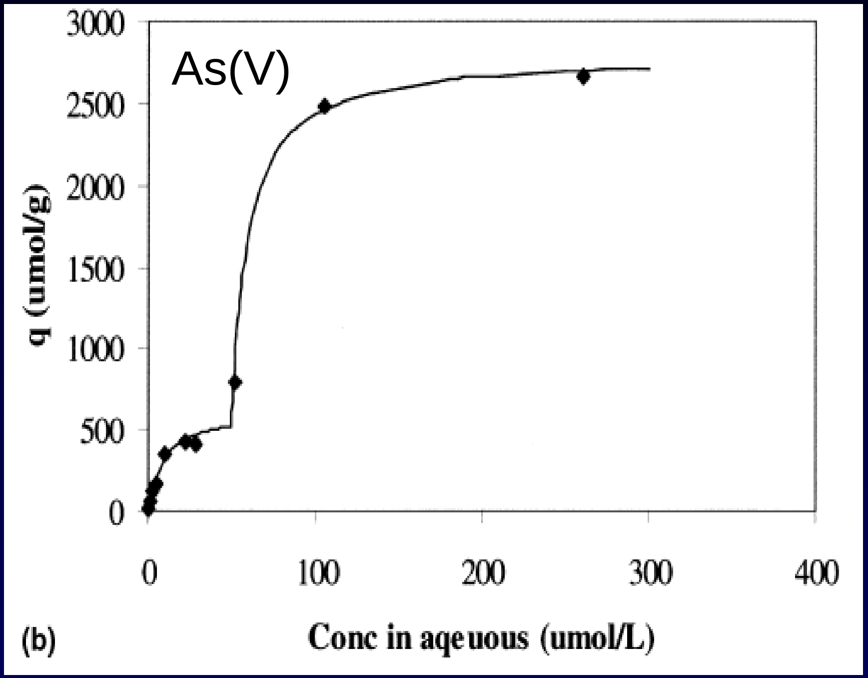

**Oleic Acid Bilayer Stabilization**

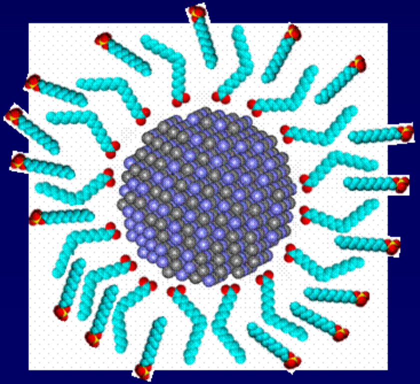
- Fatty acid bilayers – stable suspensions, strong
- Available detergents work well – colloidally stable, weak
- Both options maintain magnetic properties

*Yu, Colvin et al., Chem Comm.; Yavuz, Colvin et al., Science; Prakash, A et al ACS Nano*

# Nano-Iron Oxide: Huge Capacities for Arsenic

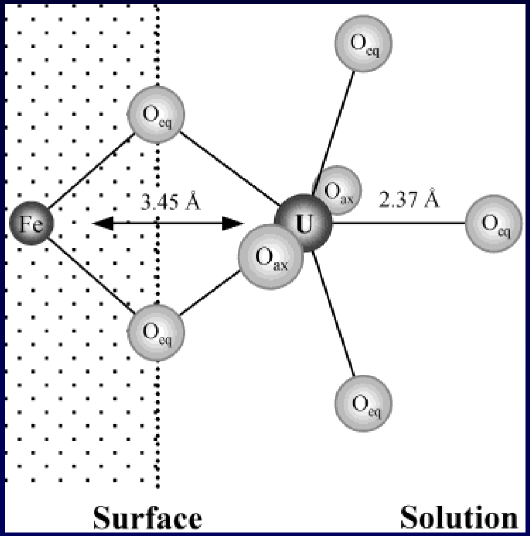


- 10 nm Magnetite can sorb arsenic
- Sorption capacities (▲) of 12 % (w/w)
- 1 gm of sorbent could treat 2000 L of water
- Must be highly crystalline and non-hydrated

# Iron Oxide and Uranium: Strong Interaction




Walter, M., *et al*. Environ. Sci. Technol. **2003**, 37, 2898-2904

Missana, T., U. Maffiotte, and M. Garcia-Gutierrez, *Surface reactions kinetics between nanocrystalline magnetite and uranyl.* Journal of Colloid and Interface Science, 2003. 261(1): p. 154-160.

Missana, T., M. Garcia-Gutierrez, and V. Fernndez, *Uranium(VI) sorption on colloidal magnetite under anoxic environment: Experimental study and surface complexation modelling.* Geochimica Et Cosmochimica Acta, 2003. 67(14): p. 2543-2550.

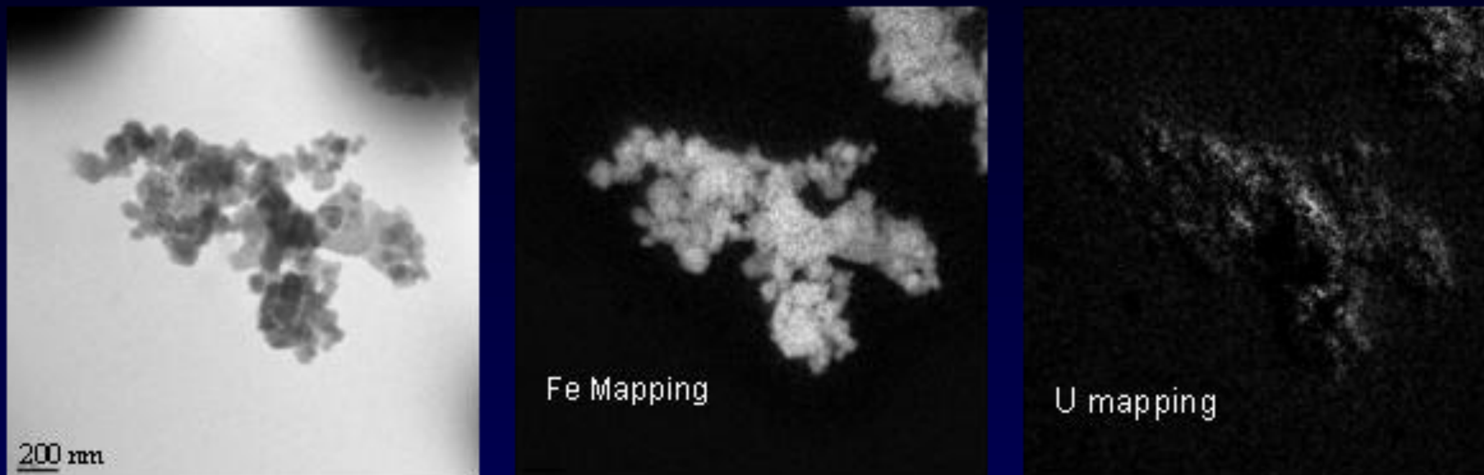
T.B. Scott, G.C. Allen, P.J. Heard and M.G. Randell, *Reduction of U(VI) to U(IV) on the surface of magnetite.* Geochimica et Cosmochimica Acta, 2005.

S. El Aamrania, J. Giménez,  M. Roviraa, F. Secob, M. Grivé, J. Brunoc, L. Duroc and J. de Pablo, *A spectroscopic study of uranium(VI) interaction with magnetite.*  Applied Surface Science, 2007
Waite, T. D.; Davis, J. A.; Payne, T. E.; Waychunas, G. A.; Xu, N. Uranium(VI) adsorption to ferrihydritesApplication of a surface complexation model.*Geochim. Cosmochim. Acta* 1994

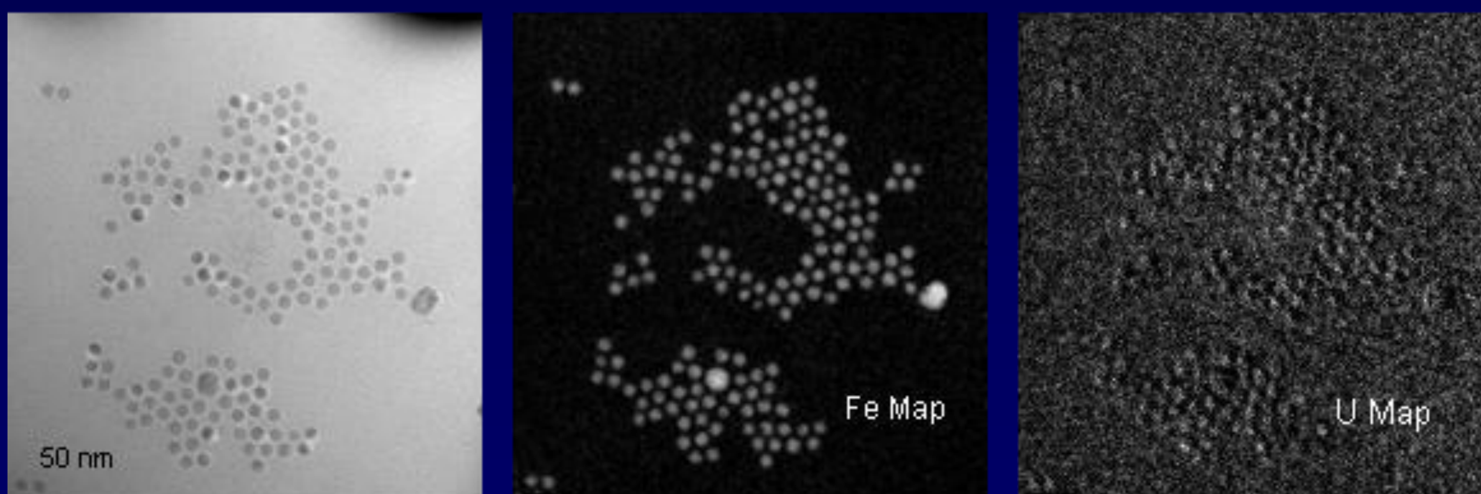
Catalano, J. G.; Brown, G. E., Jr. Analysis of uranyl-bearing phases by EXAFS spectroscopy: Interferences, multiple scattering, accuracy of structural parameters, and spectral differences. *Am. Mineral.* 2004.

# Surface Chemistry Consistent with Iron-Uranyl Complex

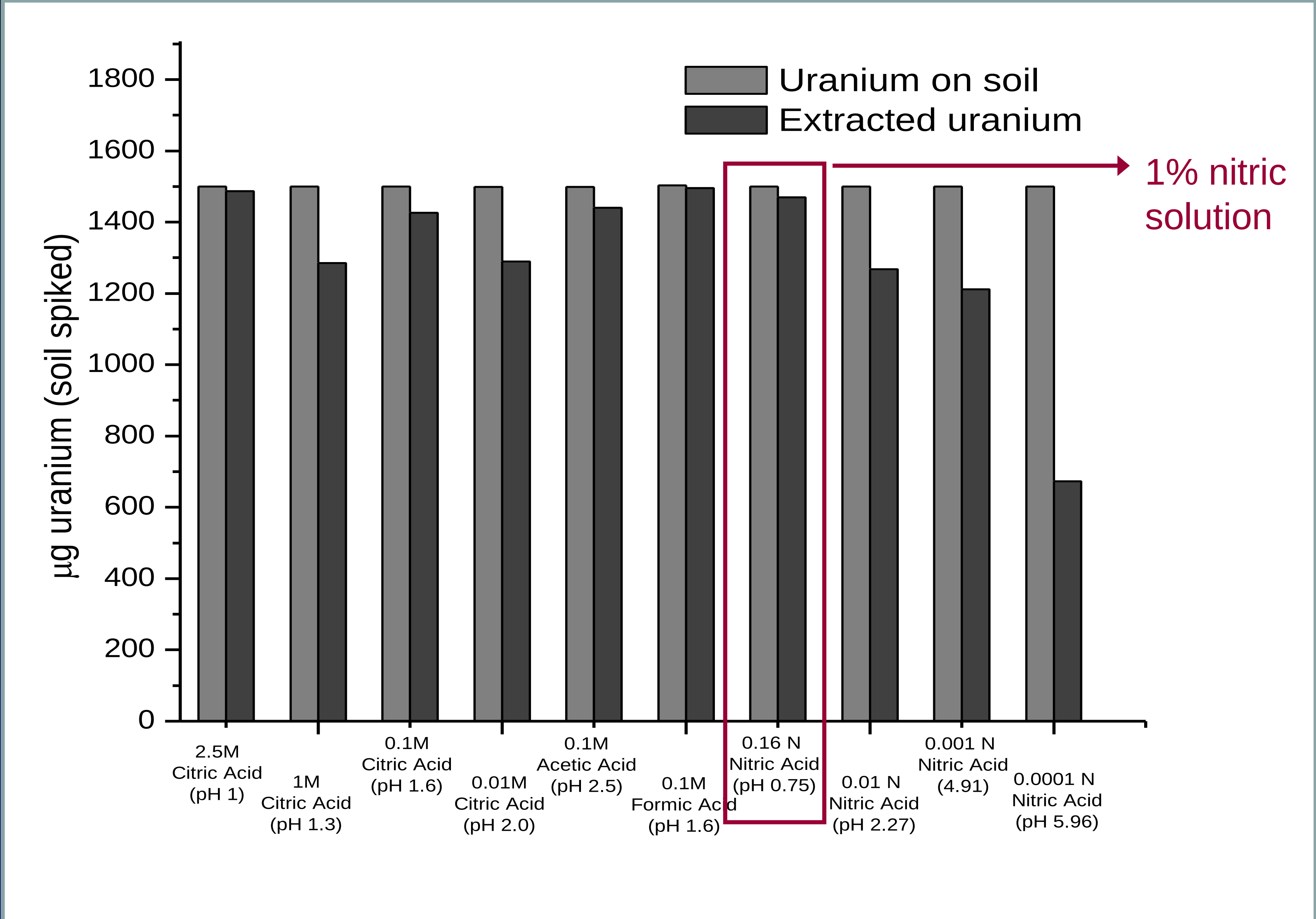
Commercial nMAG



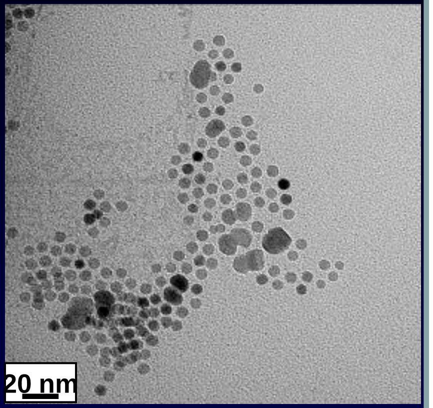

Oleic acid stabilized nMAG

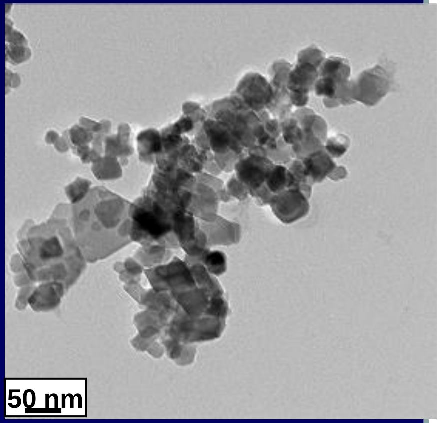


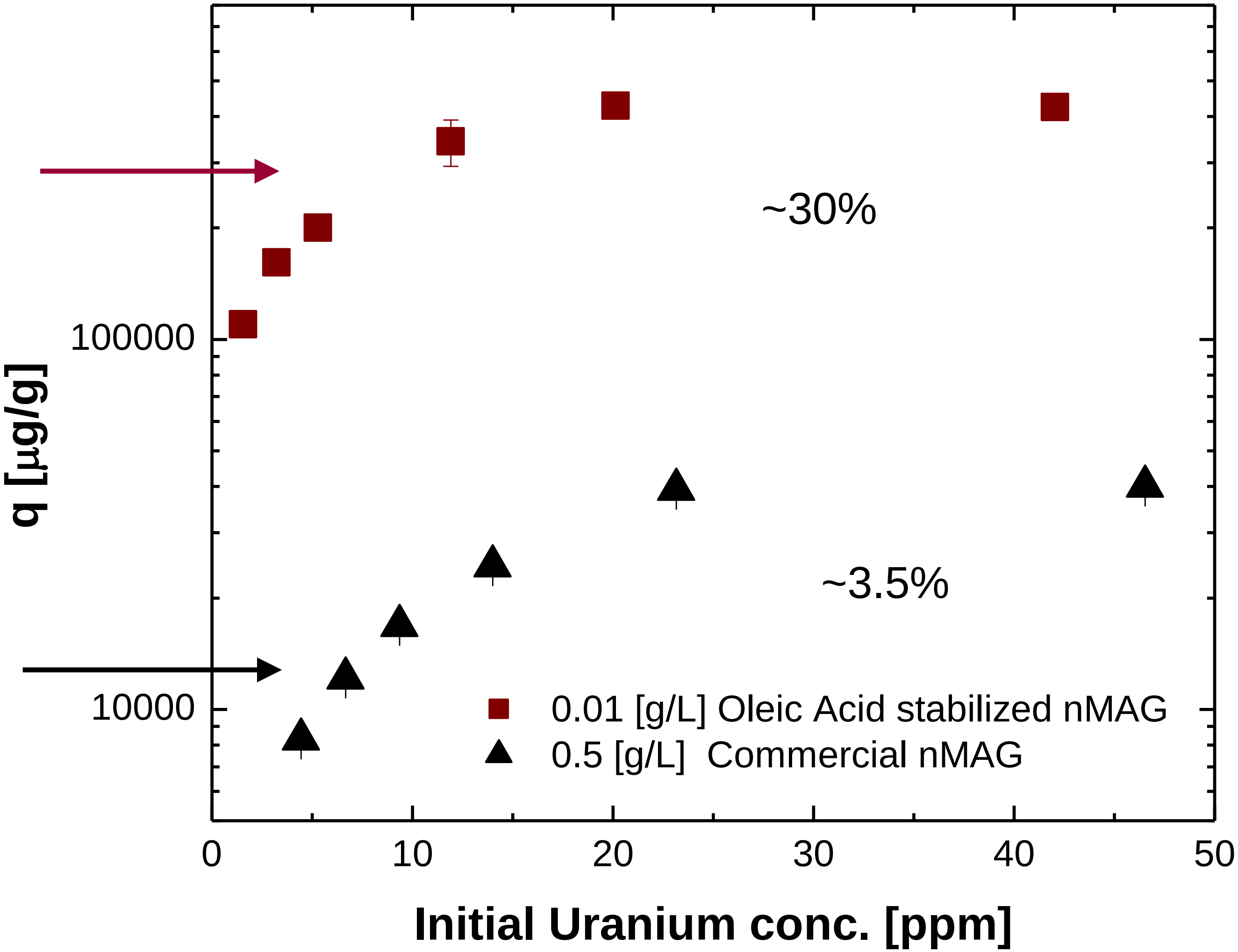
# Iron Oxide: Also Ideal for Uranium Species



# Theoretical Sorption Capacities: 30 w/w %




pH 5, DI Water, 12 hrs

# Aqueous nMAG-Uranyl Sorption: Totals

*Analysis*

## Variable Water Sources

0.05 [g/L] nMAG

| Source | Initial U conc. | U Recovery |
|---|---|---|
| Brays Bayou | 7.45 [ppb] | 75.1±5.0% |
| Ground (well) Water | 4.92 [ppb] | 86.3±20.0% |
| Millipore | 4.83 [ppb] | 99.3±0.1% |

## From Soil (Sandy) Extractions

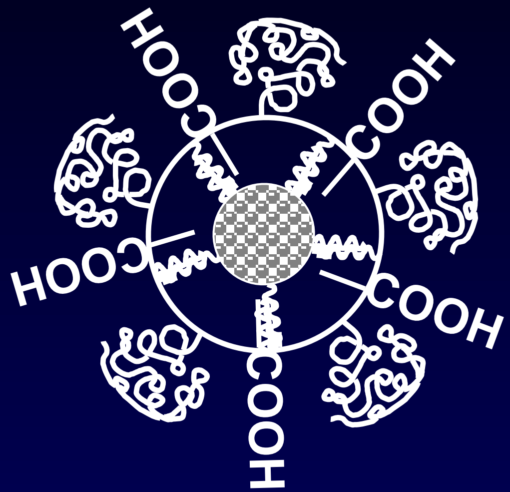
| nMAG conc. | Initial U conc. | U Recovery |
|---|---|---|
| 0.05 [g/L] | 35.1 [ppb] | 99.1±0.2% |
| 0.3 [g/L] | 33.4 [ppm] | 100.4±0.3% |

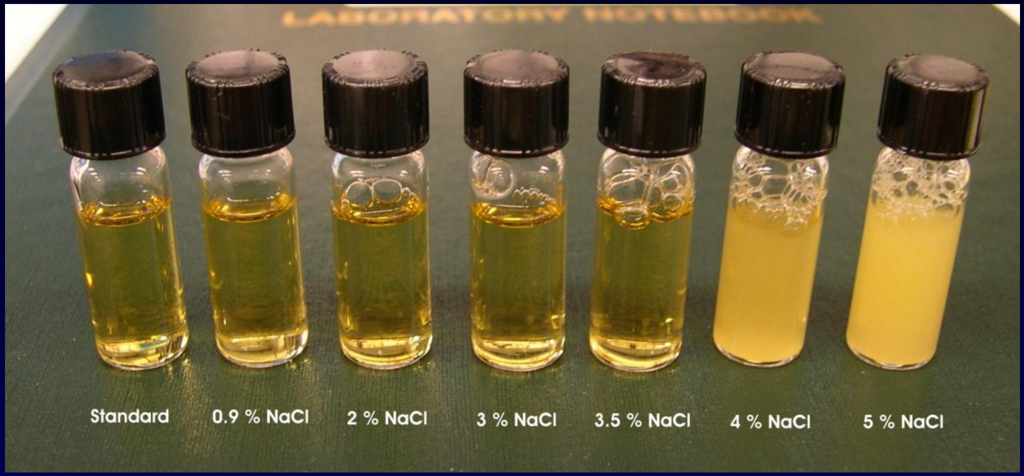
*Reclamation*

| nMAG conc. | Initial U conc. | Max. Sorption |
|---|---|---|
| 0.005 [g/L] | 45.9 [ppb] | 3.40±0.90 [mg/g] |
| 0.05 [g/L] | 58.8 [ppm] | 292±14 [mg/g] |

# Removing Nanoscale Magnetite: Difficult!

***Dr. Cafer Yavuz and J. T. Mayo***



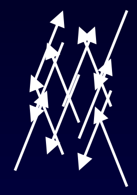

***Iron oxide nanocrystals, in water, variable NaCl***

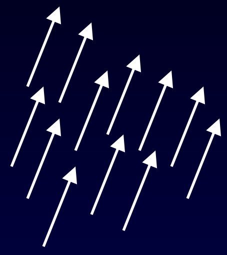
Filtration is energy and capital intensive

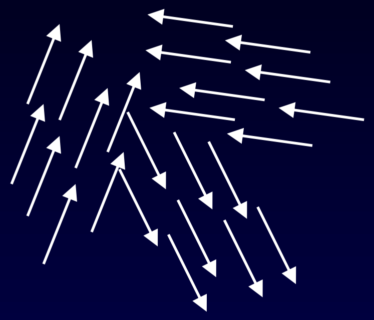
Pressure goes as radius squared

Not viable for rural communities

# Nanoparticles: Size Changes Properties



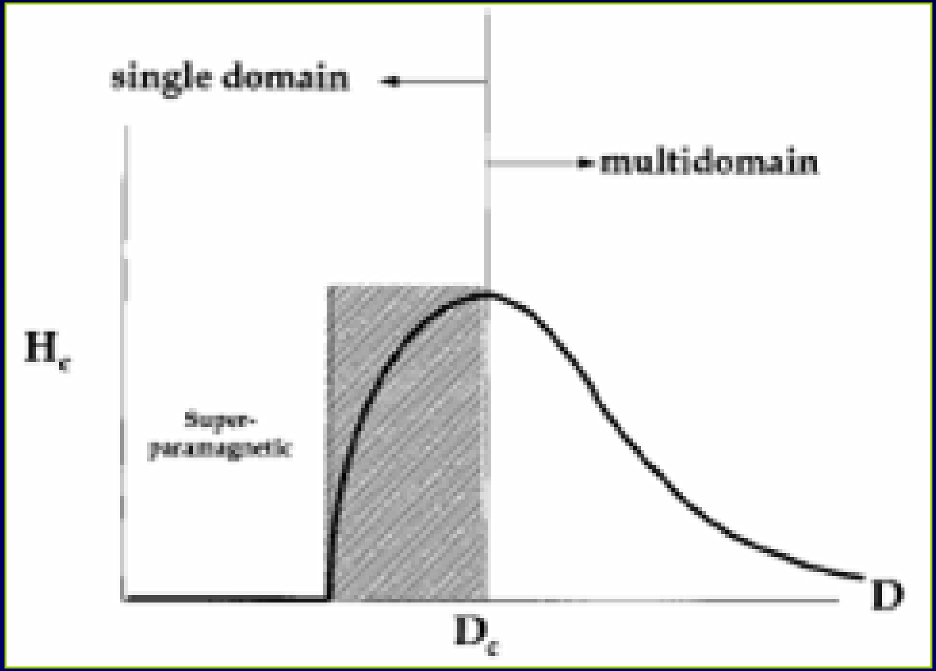




Small cluster: Supraparamagnetic
Easy to magnetize

Larger cluster: Single Domain
Magnetization can shift

Bulk solid: Permanent magnet
Small magnetization



# A Surprising Observation

*Nanocrystals interact with very, very low magnetic fields*

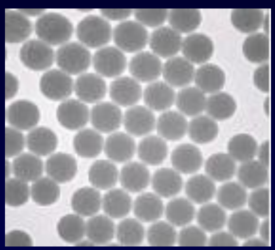

$$F_m = \mu_0 \chi v_p H \nabla H$$

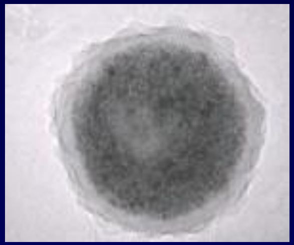
*Much larger in nanocrystalline magnetite*

Yavuz *et al* Science (Nov. 2006); *Cotton et.al.,Separ. Sci. Technol 37 (16): 3755-3779 2002*

# Method to remove magnetic materials

**1 Tesla Electromagnets**
**Narrow bore columns**

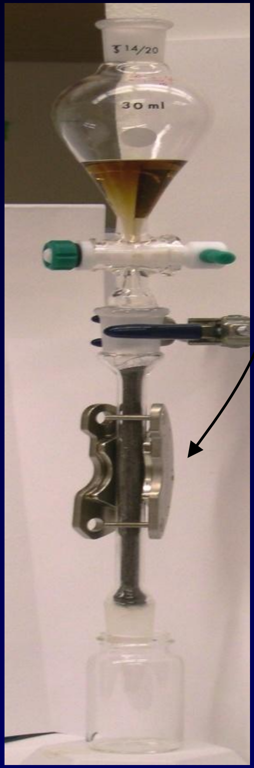


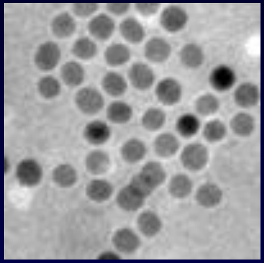


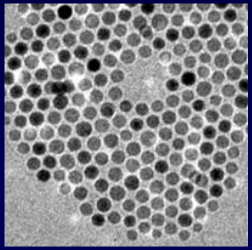
***1 gram = .1 m²***

***Old way***

**100 mTesla**
**Hard drive magnet**





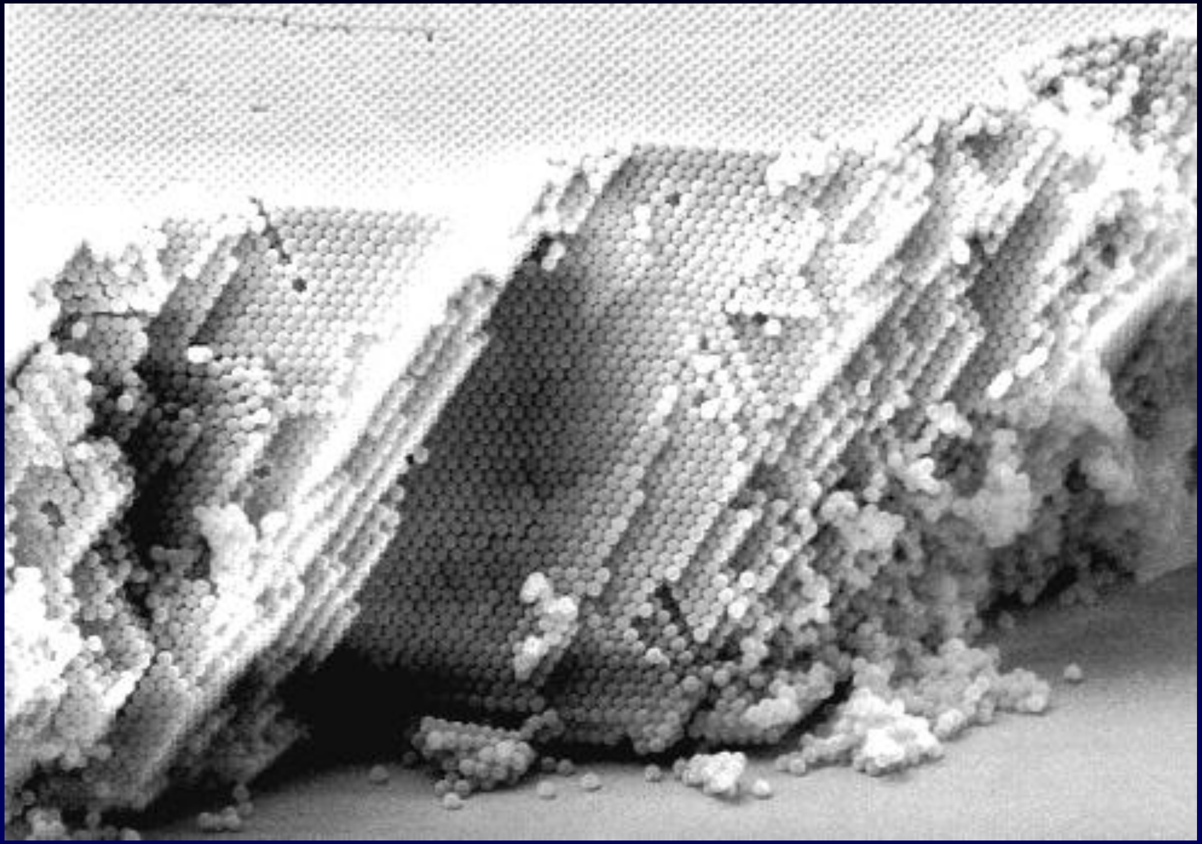
***1 gram = 50 m²***

***New way***

# nMAG Separation: Fast and Low Tech

| Material | Separation | Percent nMAG Removal |
|---|---|---|
| Commercial | 20 nm Filter | 99.9% |
| Igepal® CO-630 | 20 nm Filter | 99.6% |
| Oleic Acid | 20 nm Filter | 98.9% |
| | | |
| Commercial | Magnetic | 99.9% |
| Igepal® CO-630 | Magnetic | 95.3% |
| Oleic Acid | Magnetic | 93.3% |

# Nanoparticles: Assembly Properties

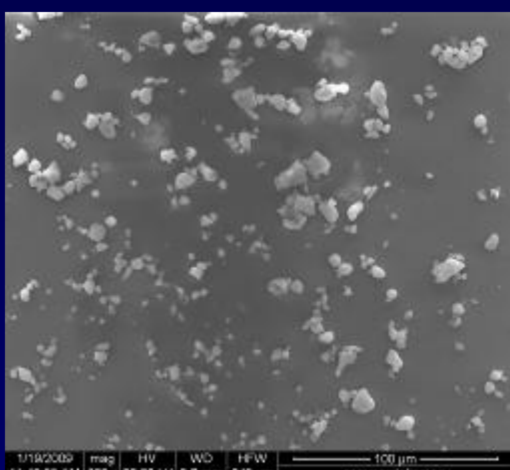


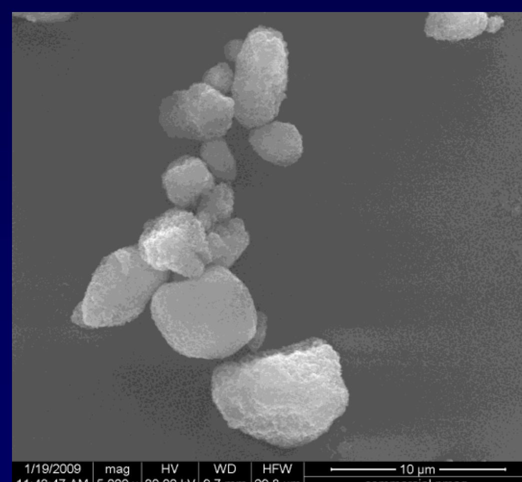
Nanoparticles (200 nm diameter silica, above) will form dense films when diameters are *uniform*

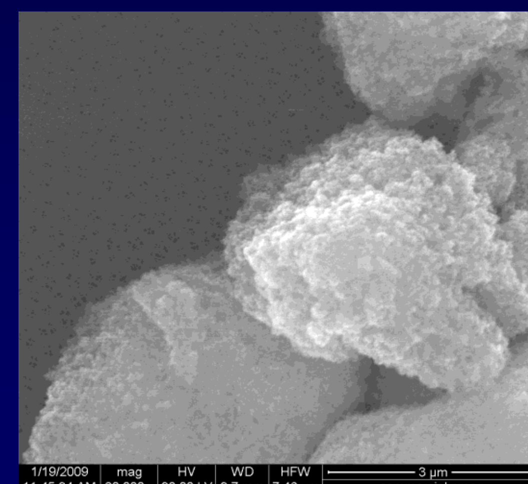
# Uranium on commercial nano-oxides: no counting


Penetration depth of alpha particles < 1 micron, only surface is counted

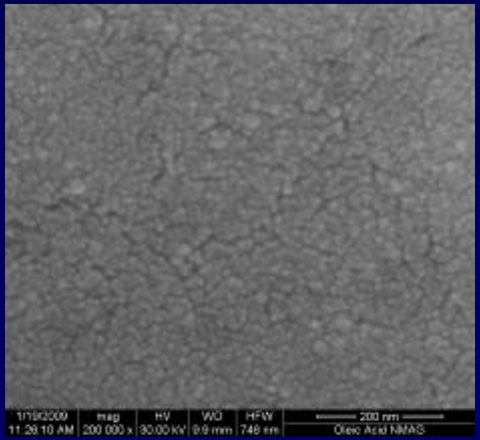
Our ICP

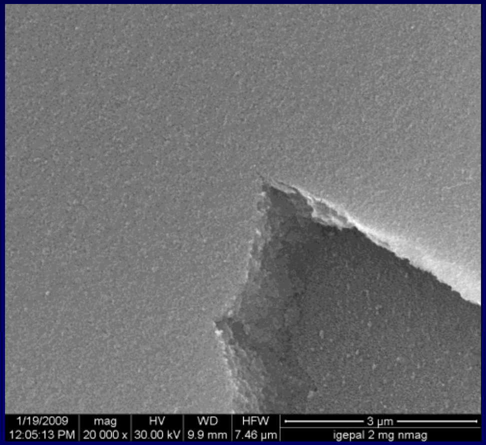


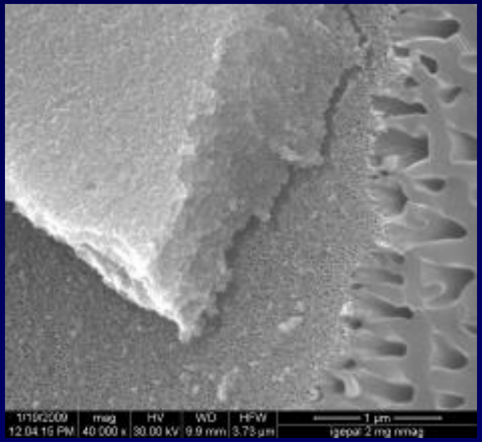



# Unless nanoparticles are uniform: well packed

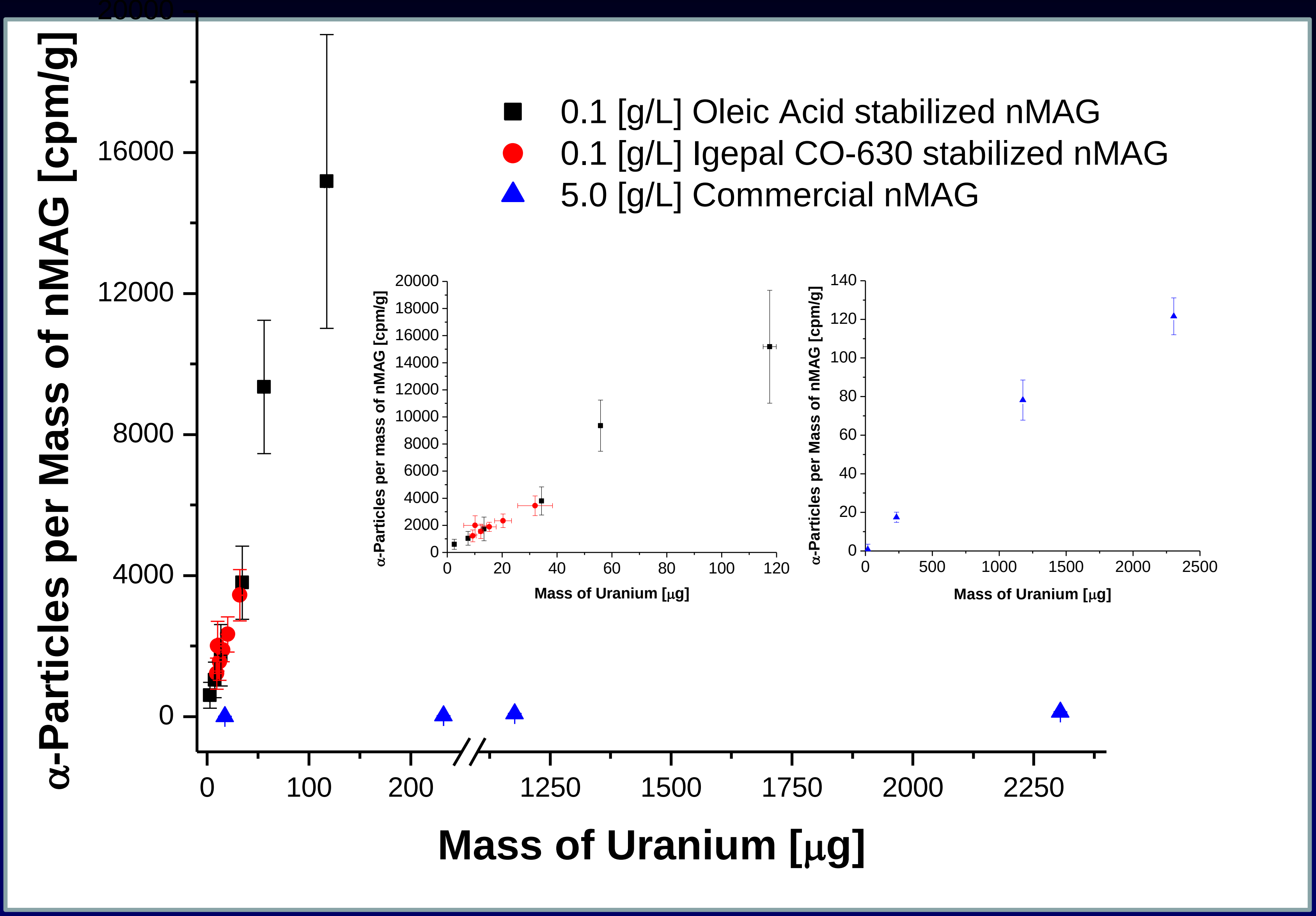





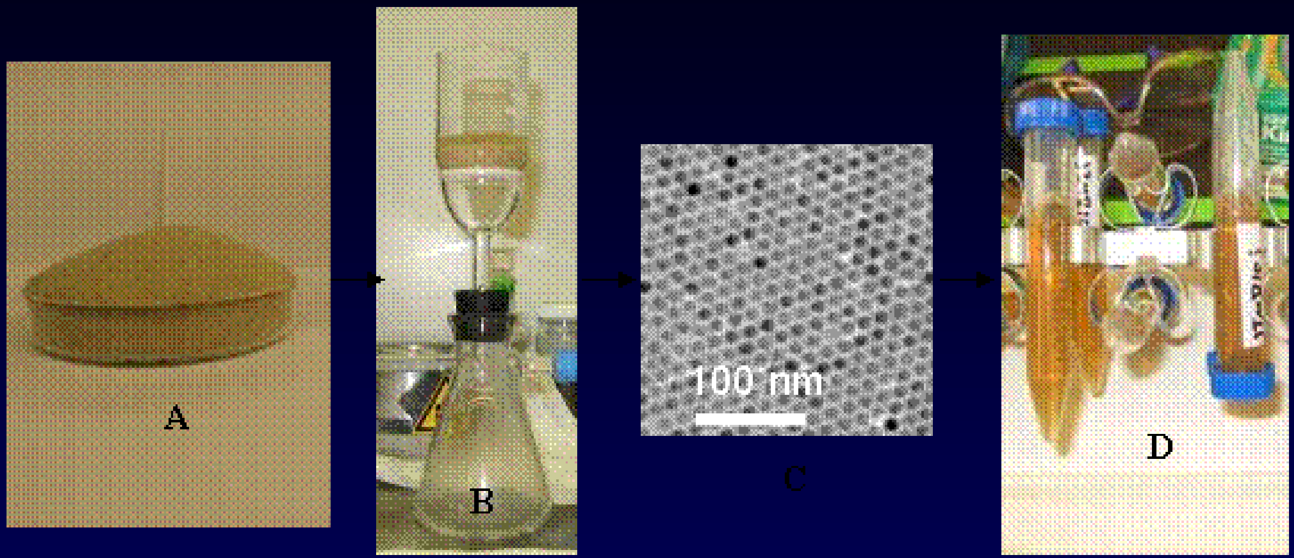




Film of nanoscale magnetite (11.92 nm) stabilized in water with oleic acid bilayer.

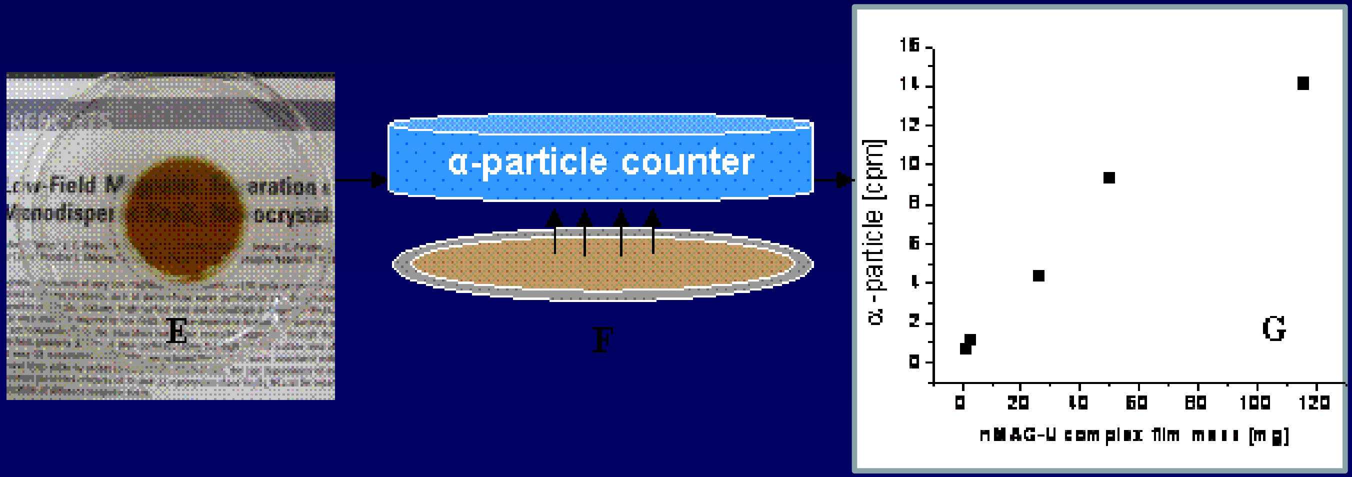
# Ppb level detection in Concentrates



# Ultratrace detection with handheld detector




= x 5




= x >10,000

# The Needle in the Haystack and Beyond

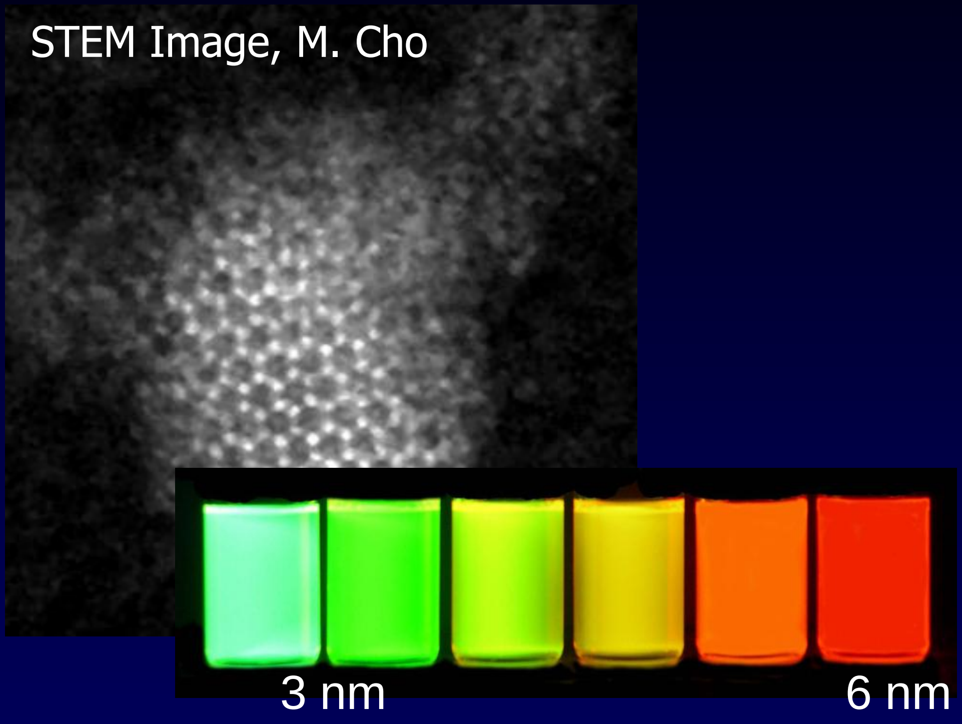
For analysis nanoparticles offer ideal platforms for radionuclides

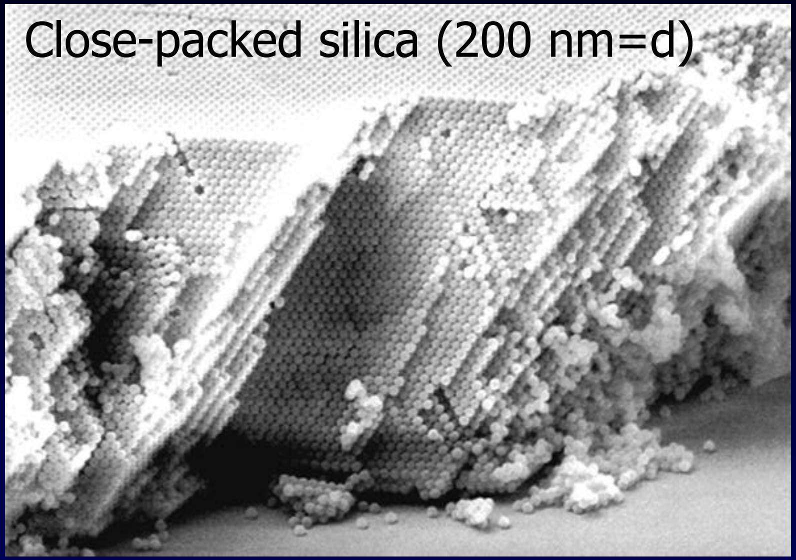
- *Surfaces for other radionuclides*
- *Fast, efficient and simple detection*

For reclamation may also offer similar advantages except

- *Interfering ions in local water*
- *Efficiency of reconcentration*

# The Hammer and Nail Together




- They are very, very small: 30 w/w% sorption
- Their properties are size-dependent: facile magnetic removal
- They can assemble into larger structures: uniform thin films for alpha counting

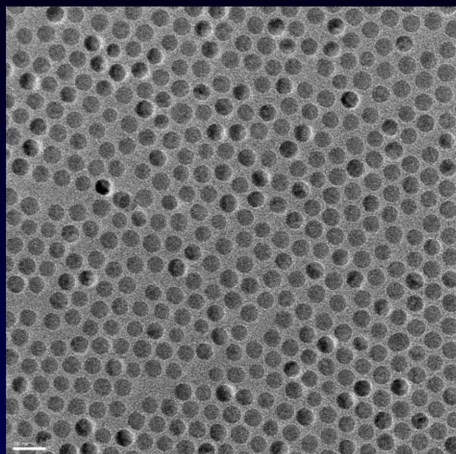
# Other Possible Nails

- Ultrafine and uniform uranium oxide nanocrystals for safe fuels: improve thermal conductivity – find the 'optimal size'
- Nanoscale dopants for steel to improve radiation resistance: nanoparticles can stop crack propagation
- Improved thermal conductivity and mechanical strength in nanoscale composites

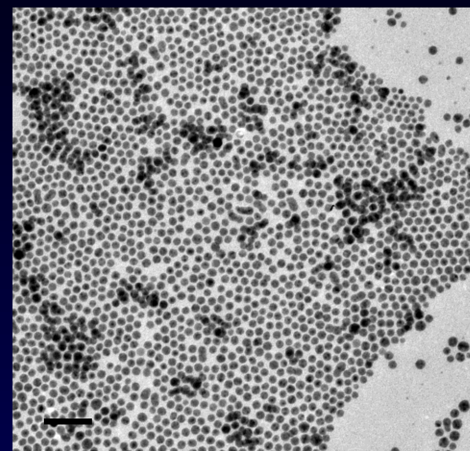
# END

# 'Nano'X: High Surface Area & Tunable Properties

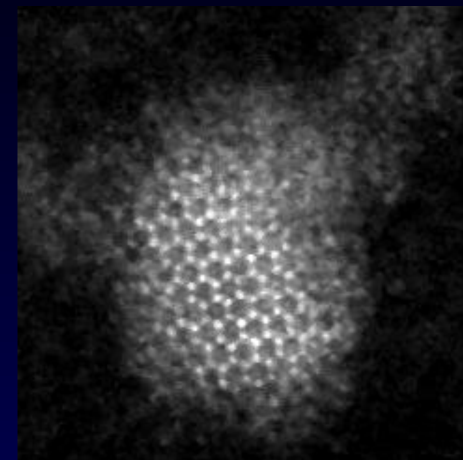
Iron Oxide (~10 nm)

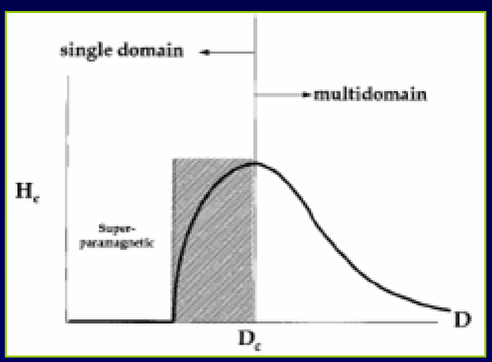


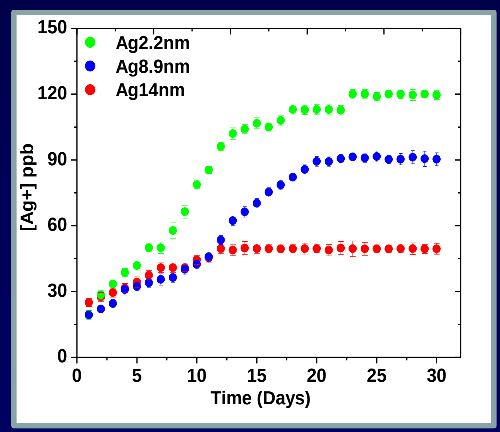
Silver (~ 10 nm)

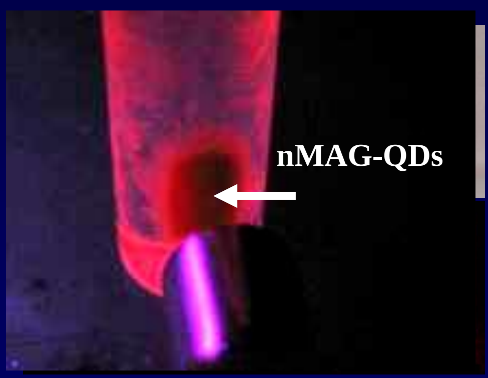


CdSe (8 nm)






**Size-dependent Magnetism**

Arjun Prakash and Seung Soo Lee

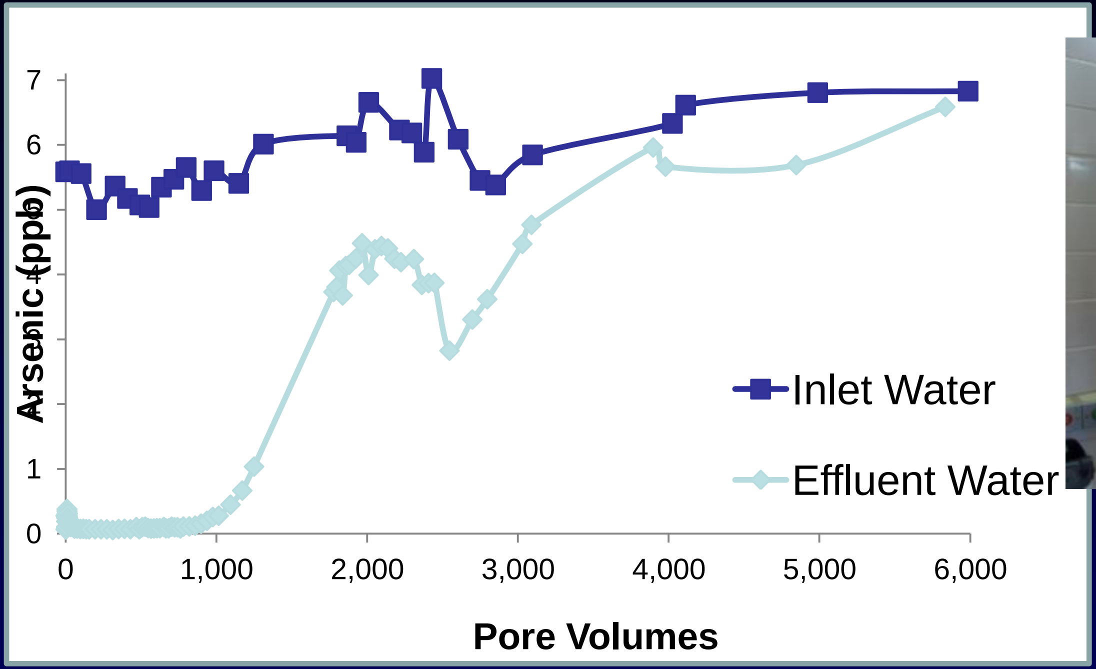
**Size-Dependent Reactivity**

Hema Puppala

**Size-Dependent Emission**

MinJung Cho

# Field Tests: Arsenic Removal Well #4




Scaling-up materials and processes for the field – yes, you still need chemists

Arsenic problem in groundwater wells, limit the city's water supply

Working at remote field sites (above) for in-line filters

First pass – Pipes, fittings, garden sand (Home Depot) plus nanoMagnetite

# About Uranium

(Fun)

44,000 tons mined 2008

$^{235}U$ is the only naturally occurring fissile isotope

All three major U isotopes are alpha (α) emitters

$^{239}Pu$ produced from $^{238}U$ by neutron capture

*Occurrence of Natural Uranium*

| | |
|---|---|
| Blood | Up to 0.5 ppb |
| Bone | 0.2 – 70 ppb |
| Tissue | 1 – 3 ppb |
| Total in Body | 0.01 – 0.4 mg |
| Earth's Crust* | 2 ppm |
| Soils | 0.7 – 11 ppm |
| Sea Water | 3 ppb |

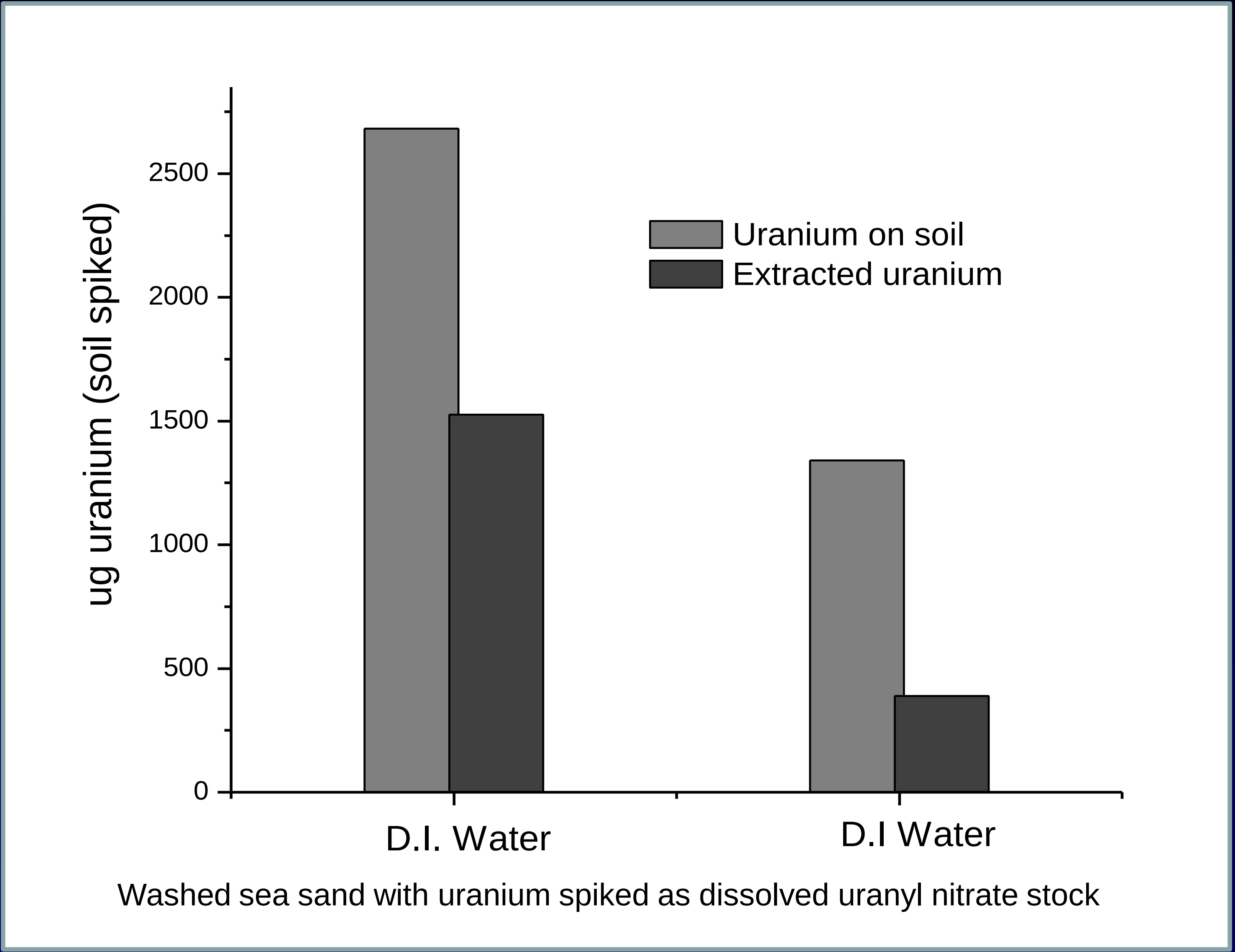
*48th most abundant element

| | Natural Abundance | Half-life |
|---|---|---|
| Uranium-238 | 99.3% | $4.5 \times 10^9$ years |
| Uranium-235 | 0.7% | $0.7 \times 10^9$ years |
| Uranium-234 | 0.005% | $0.245 \times 10^6$ years |

Emsley, J. *Nature's Building Blocks*; Oxford University Press Inc.: New York, 2001

Uranium Oxides:
Uranyl ($UO_2^{+2}$)
Uranite ($U_3O_8$)
Pitchblende ($UO_2$)
Also $U_2O_3$, and $UO_3$

# Environmental Matrices: Uranyl Soil (Sand) Extractions



# EXTRA SLIDES

# Rice Research: Integrative and Interdisciplinary

**Wiess School of Natural Sciences**

- Biochemistry & Cell Biology
- Chemistry
- Ecology & Evolutionary Biology
- Earth Science
- Mathematics
- Physics & Astronomy

**Central Institutes**

- Nanotechnology
- Computation
- Applied Physics
- Biomedical
- Energy

**Brown School of Engineering**

- Bioengineering
- Chemical and Biomolecular Eng.
- Civil & Environmental Eng.
- Computational & Applied Mathematics
- Computer Science
- Electrical & Computer Eng.
- Mech. E and Materials Science
- Statistics

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# Rice: First Mover in High Performance Computing

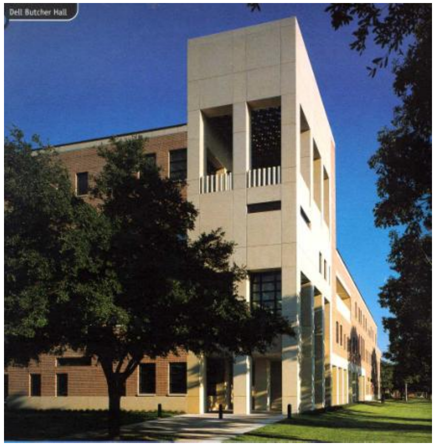
Ken Kennedy

Duncan Hall: Computing

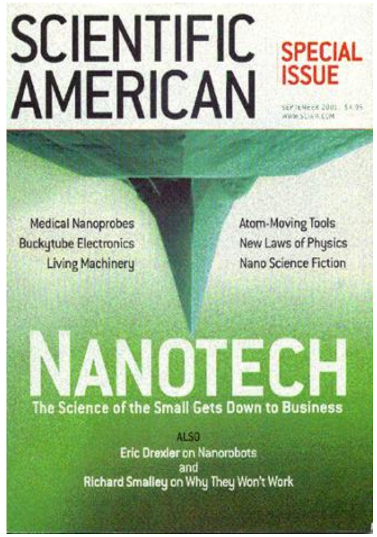

Research Computing Support Group

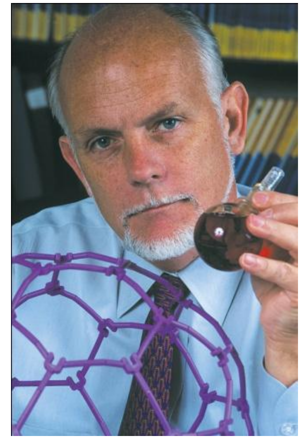
- Ken Kennedy Institute for High Performance Computing
  - One of the first Science and Technology Centers funded by U.S. NSF: 1989
  - Duncan Hall built (1998) and significant faculty hires in HPC
  - National academy members in digital signal processing, parallel computing
  - Current emphasis: visualization, data mining and applications in oil and gas

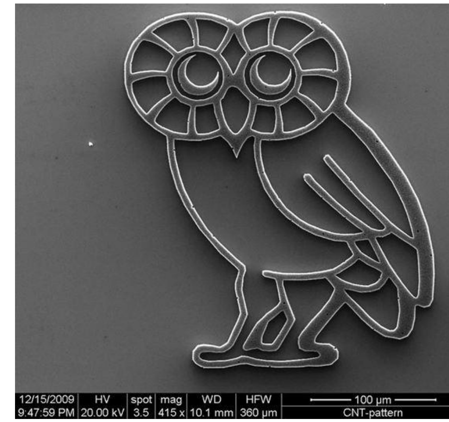
# Rice: A First Mover in Nanotechnology



*Dell Butcher Hall*






## Richard Smalley Institute for Nanotechnology

- Ranked among top five nanotechnology programs in the world[3]
- The first university-sponsored nanotechnology effort (1994!)
- 2 Nobel prizes awarded in 1996 for discovery of $C_{60}$
- Houses one of NSF's national nanotechnology centers: CBEN
- More than 20 nanotechnology faculty, center of gravity is materials

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# Challenges for Research Universities

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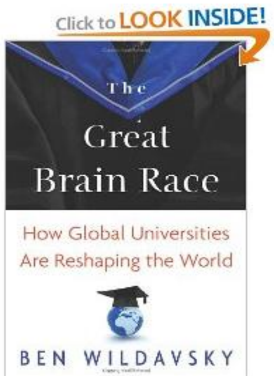
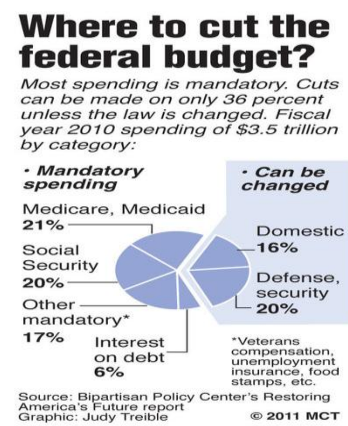



## (A) The globalization of higher education:

- Growing importance of global rankings  and presence
- Our students hired by global, not national, companies
- Competition now global, fewer net research 1 universities

## (B)  Decrease in federal funding for research

- NSF, NIH, DOE: best case -2%, worst case -10%
- Professors writing more grants – success rates 1 in 10
- For Rice, 5% of operating budget from overhead




**Rice Must Seek Unconventional Approaches to Supporting Research and Related Programs**

http://www.rice.edu

# The Future of Research at Rice

What are interdisciplinary grand challenges that:

(A) Truly define the greatest problems of our time
(B) Are of great interest to a large number of faculty
(C) Leverage our historical investments in nano, bio, and computing
(D) Reflect our geographic location and community interests

↓

Energy and the Environment

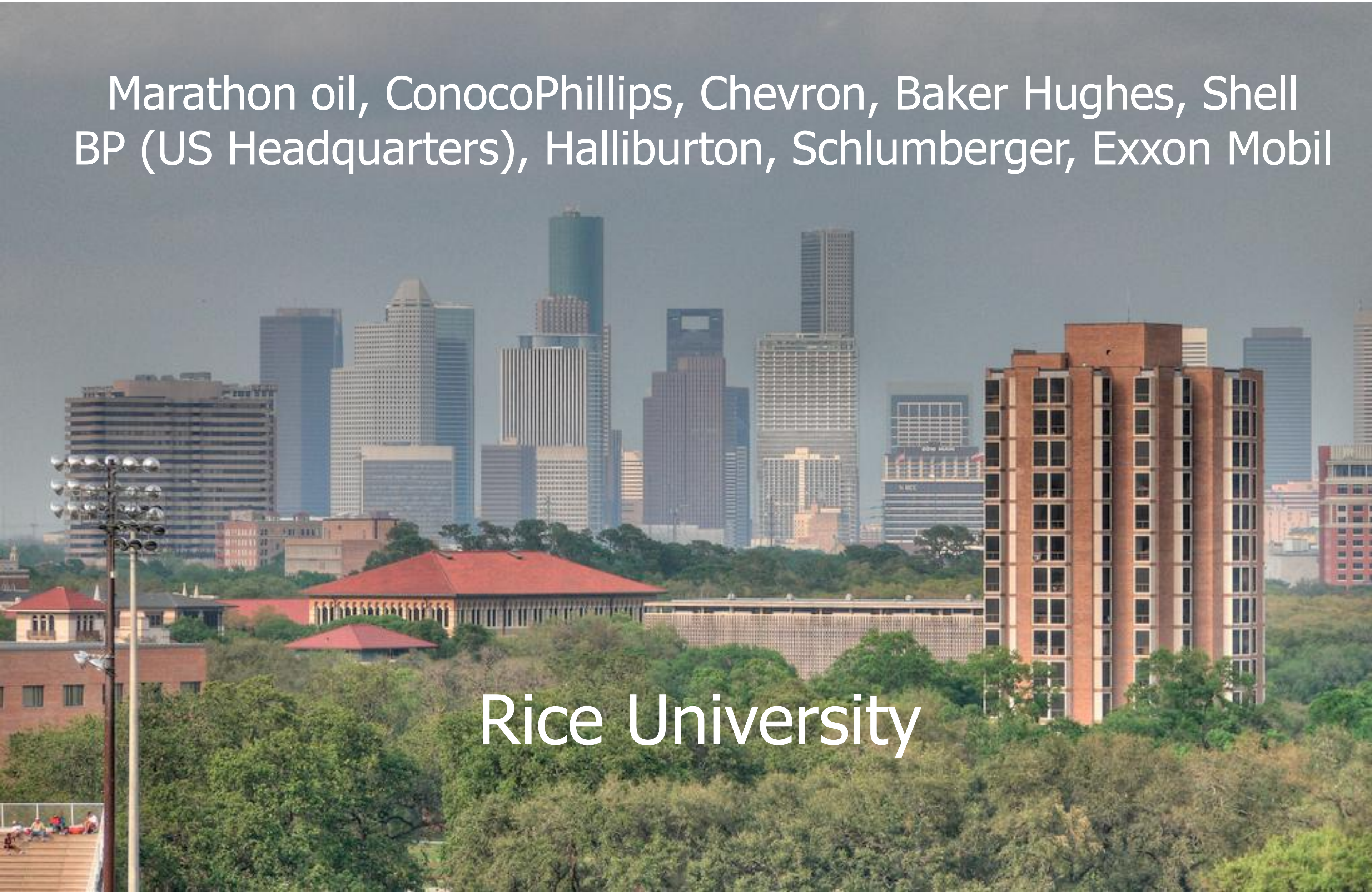
Biology and Biomedicine

# Rice University - Texas Medical Center

*Rice is part of the world's largest medical complex:*

*New Bioscience and Biomedical Research Initiative*

# Rice University – Energy Capital



# Drill-Down to Specifics: Workshops

What are interdisciplinary grand challenges that:

(A) Truly define the greatest problems of our time
(B) Are of great interest to a large number of faculty
(C) Leverage our historical investments in nano, bio, and computing
(D) Reflect our geographic location and community interests

*Energy and the Environment*

*Biology and Biomedicine*

Technology and Science for Greener Carbon

Energy Transitions and Energy Culture

Quantitative Medicine

Physical and Systems Biology

# Energy at Rice :
# *The E-squared Initiative*

Results of a working group, Fall 2010

Faculty workshops fall 2011 and spring 2012

http://www.rice.edu

# Top Ten Problems for Mankind (Smalley)

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# An Insight: The Blue Elephant Slide

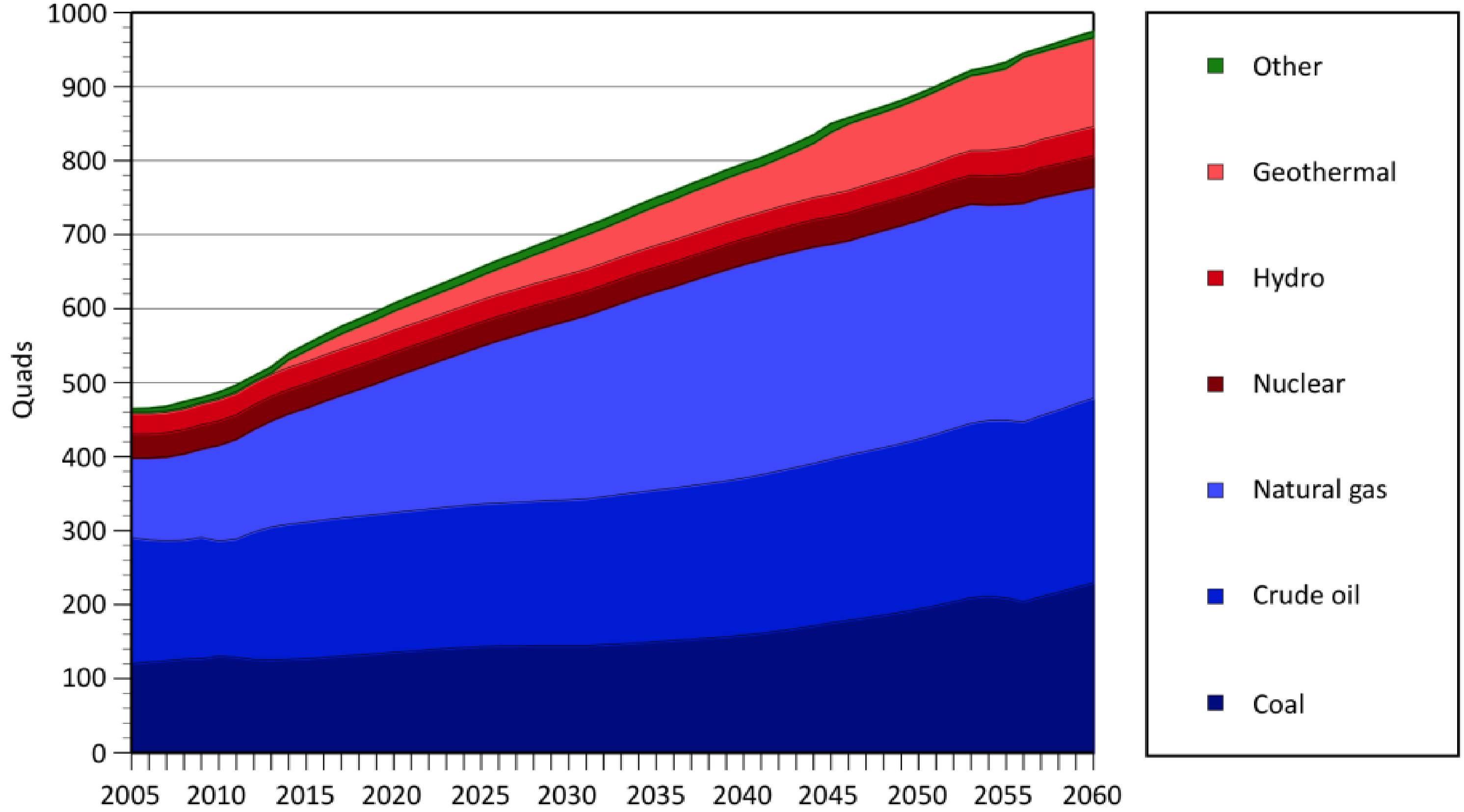
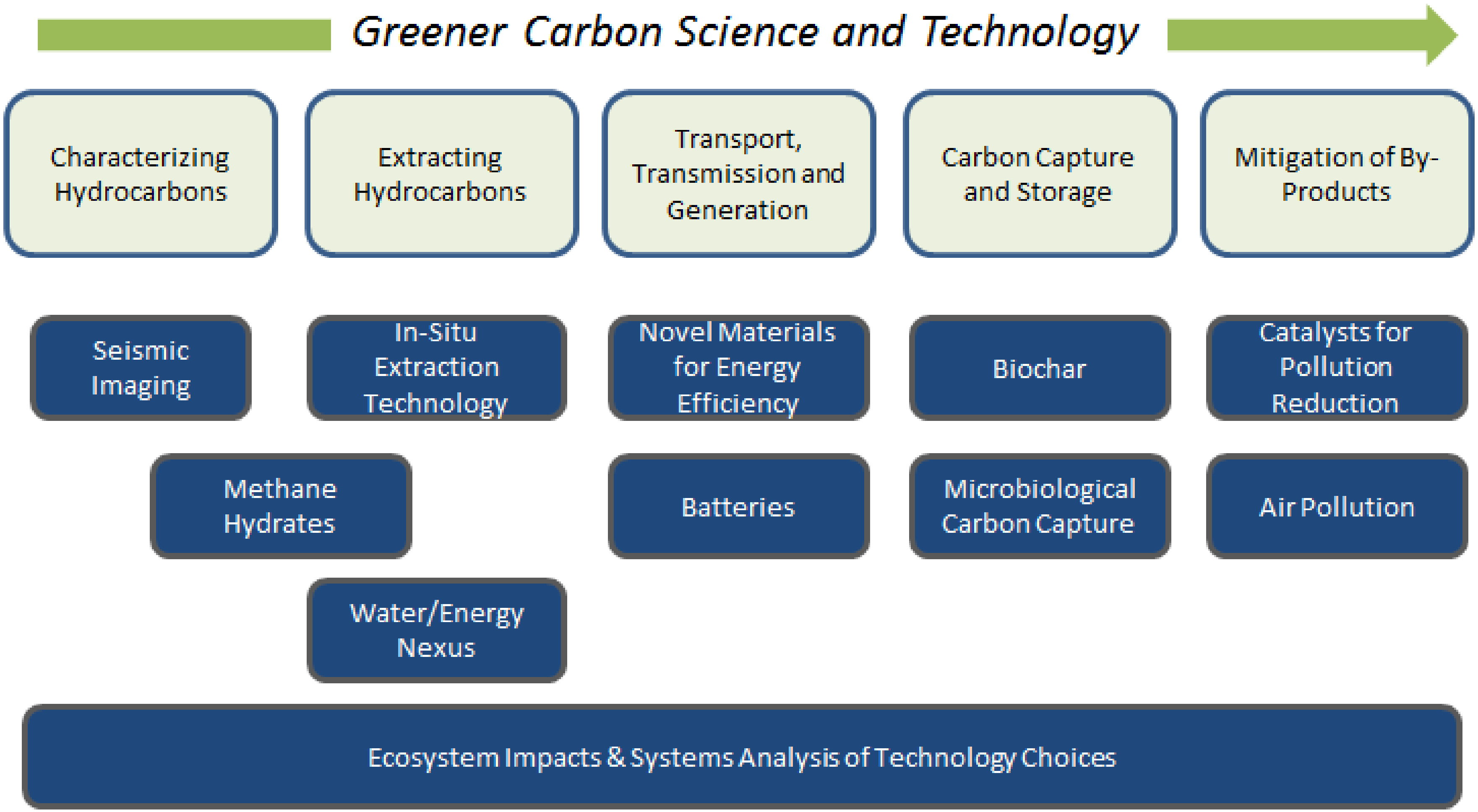



Figure 1. The projected diversity of the global energy supply assuming existing policies. Even the most extreme assumptions only moderately change the anticipated contribution of renewable sources to global energy supply for many decades. (from Peter Hartley Rice Economics)

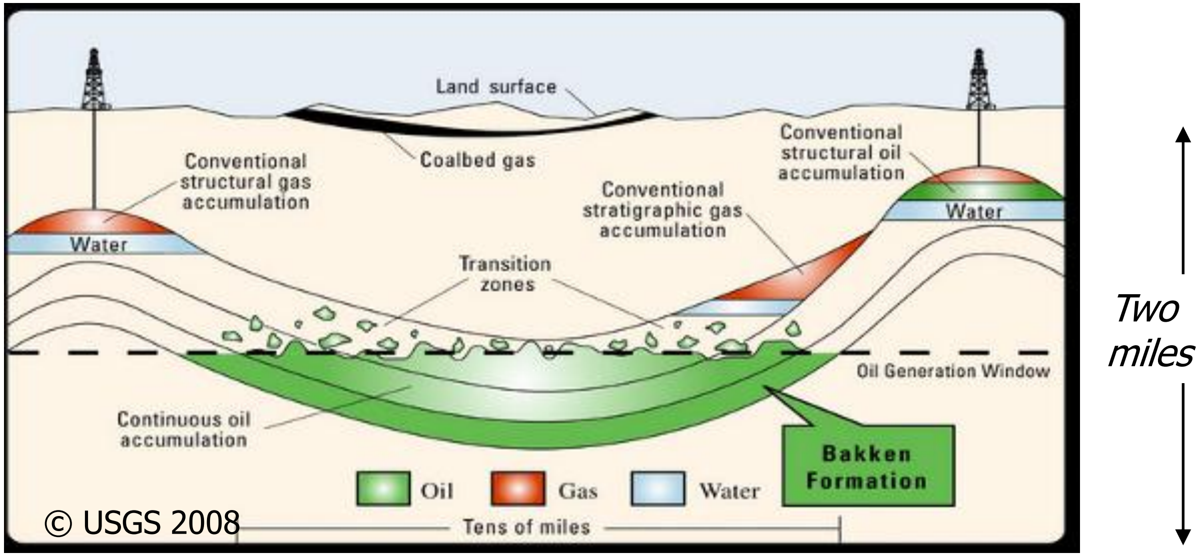
# Greener Carbon: Central to E-squared I



# Nanotechnology: In-situ and reservoir imaging

*Improve information about reservoirs using engineered nanostructures*

- Enhanced nanotracers
- Near borehole sensing
- Contrast for remote sensing
- Self-propelled reporters …




*Challenge 1*: Can nanoparticles fully sample a reservoir? e.g. how can we engineer mobility?

*Challenge 2*: What is the scheme for detecting nanoparticles in the subsurface?

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# Advanced Seismic: Both Computation and Collection

Two images ideally that I could explain briefly :>

- Rice geophysics ranked #12 in country
- Inverse problem consortium
- New NSF grants in imaging and visualization, matched by Chevron

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# Flow Assurance and Chemical EOR

Two images ideally that I could explain briefly :>

- Awards and recognition of Hirasaki ?
- Brine consoritum and xxx consortium
- Increased energy support particulary in heavy oil and unconventional resources

# Water Treatment and Management

Two images ideally that I could explain briefly :>

- Nano-enabled water treatment funded through major federal center
- Other bullet?

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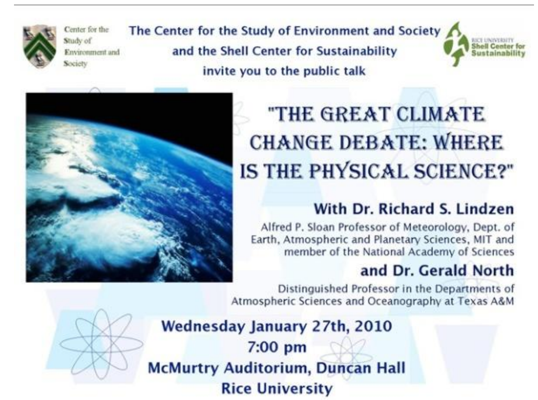
# Responsible Development of Shale Gas: Nascent

- Active policy research in shale gas in Baker Institute
- Very controversial topic, technically complex
- Many opportunities for new technical capabilities

# Center for the Responsible Development of Unconventional Hydrocarbons: An Honest Broker


HUMANITIES RESEARCH CENTER

ICON INTERNATIONAL COUNCIL ON NANOTECHNOLOGY
A partnership for nanotechnology stewardship and sustainability




- Rice has strong history as an 'honest broker' in controversial and technically complex public debates
- Rice's physical location in a large urban center, near major oil and gas companies, make it an instant leader
- Relevant topic for companies: Anthropology and sociology of working productively in complex and alien cultures

# Towards Greener Carbon:
## *A program of the e-squared initiative*


Center for Greener Carbon: a program of the E-squared initiative

- Bullets to be drawn by what I get on the other slides

# Energy at Rice: Now

## Faculty workshop follow-up in November 2011

- Still a “Green Carbon” Emphasis, but Broader
- Identification of best use for institutional funds (e.g. seed monies)
- Over 70 faculty participated (high interest)

## Success stories in early corporate interactions (6 months)

- Master agreement with Baker Hughes in late November
- Brazil partnership with BG group company
- Ongoing relationship development with many others

## Workshop in late March: Planning the E2I Rice Initiative

- Business plan (how to pay for $1 million in general infrastructure)
- Operations plan (how the organization will operate)
- Governance plan (how it will be governed)

# Rice University: Future Strategy and BP


Energy research

Biomedical research


Global Partnerships

***Why Rice University?***

***A shared interest in making energy production and transmission sustainable.***

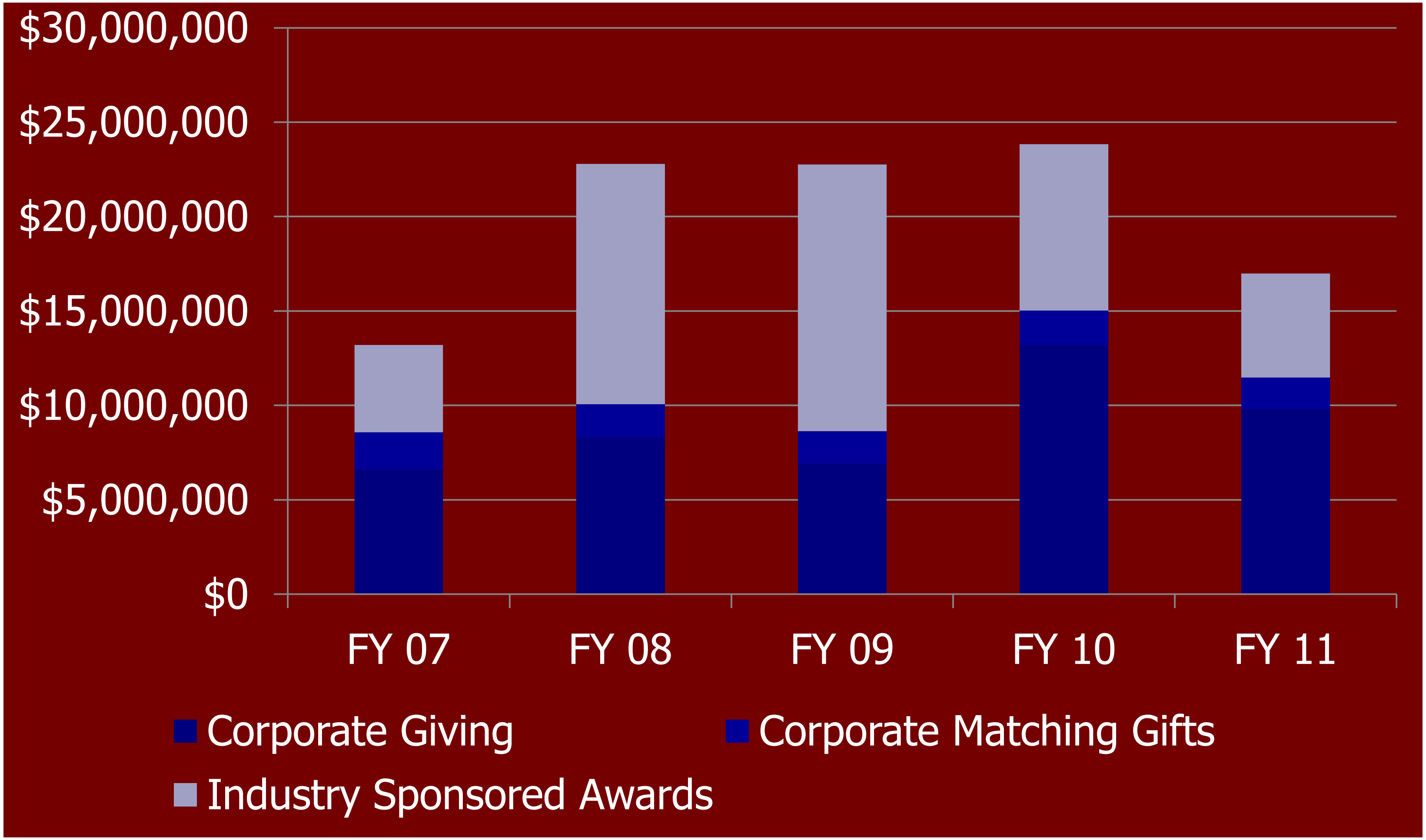
RICE

bp

# Rice University: The agenda for the day

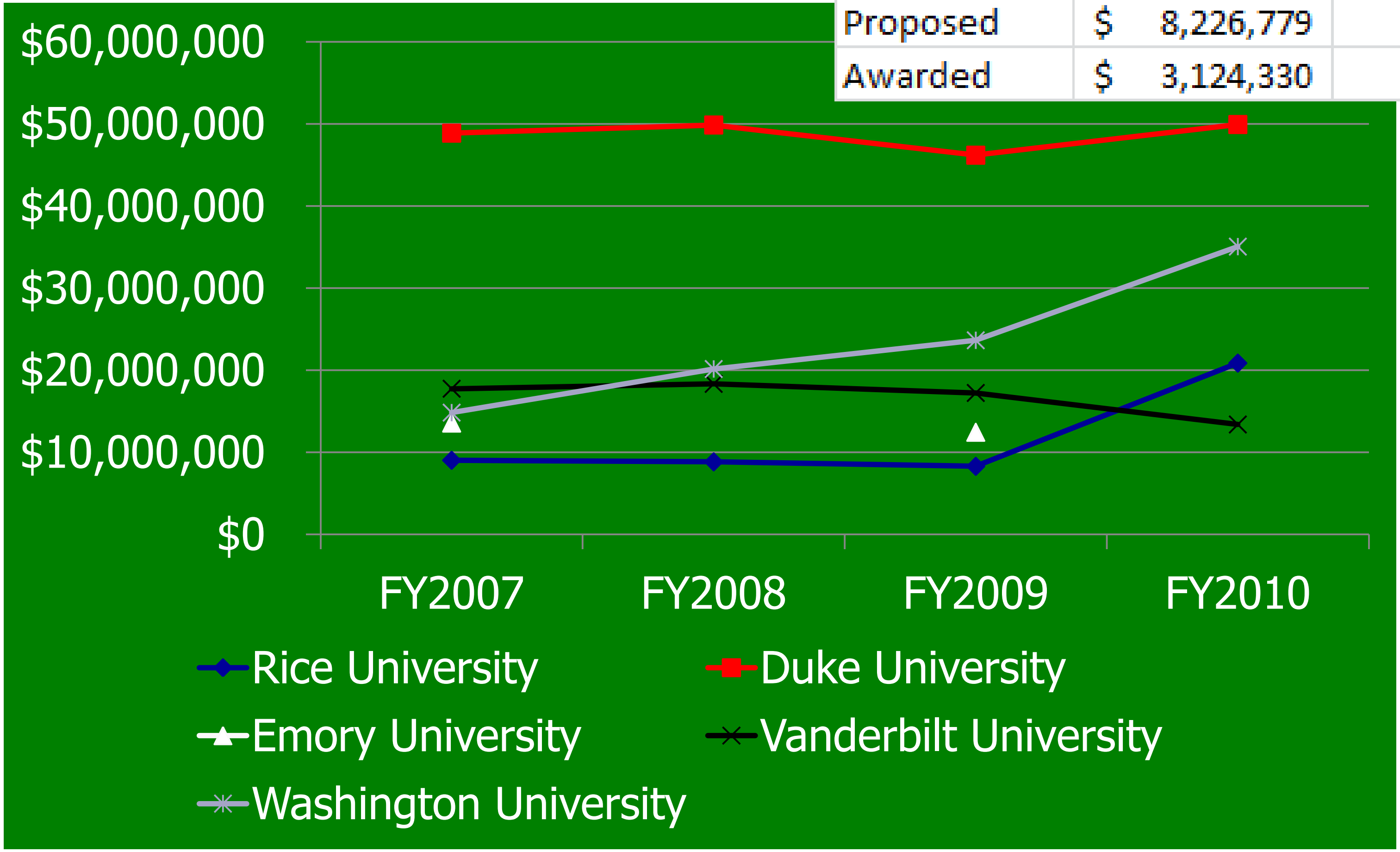
Please reproduce a mini-version of the agenda here

# Rice's Existing Industrial Support



# Rice: Real Opportunity for Growth

**Total* Corporate Giving FY2007-FY2010**




| FY2011 Industry Proposals and New Awards | | | |
|---|---|---|---|
| Proposed | $ 8,226,779 | 75 | |
| Awarded | $ 3,124,330 | 40 | |

*Includes cash, in-kind, and matching gifts; Source: Council for Aid to Education



RICE

# Our Strategy for Corporate Relations

Mission: To structure corporate interactions around "master agreements" that link to multiple areas on campus

We do this by:

- Corporate Council: 3Rs
- "Tiger  Teams" to translate interest into commitment
- Data Sharing: Campus Connector; Newsletters
- Swifter negotiations on industry agreements
- Reorganization of Center for Career Development

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# Master Agreements: A Stepping Stone

**Awareness**

- Career Fairs
- Interviews

**Involvement**

- Industry Affiliates/ Advisory Programs
- Research Grants
- Internships
- Software Grants

**Support**

- Hardware Grants
- Workshops/ Seminars
- Student Organization Sponsorships
- Departmental Philanthropic Support
- Guest Lectures

**Sponsorship**

- **Master Agreement**
- Sponsorship of University Initiatives
- Undergrad Research Support
- Graduate Fellowships
- Outreach Programs
- Support for Proposals for Education (NSF, NASA)

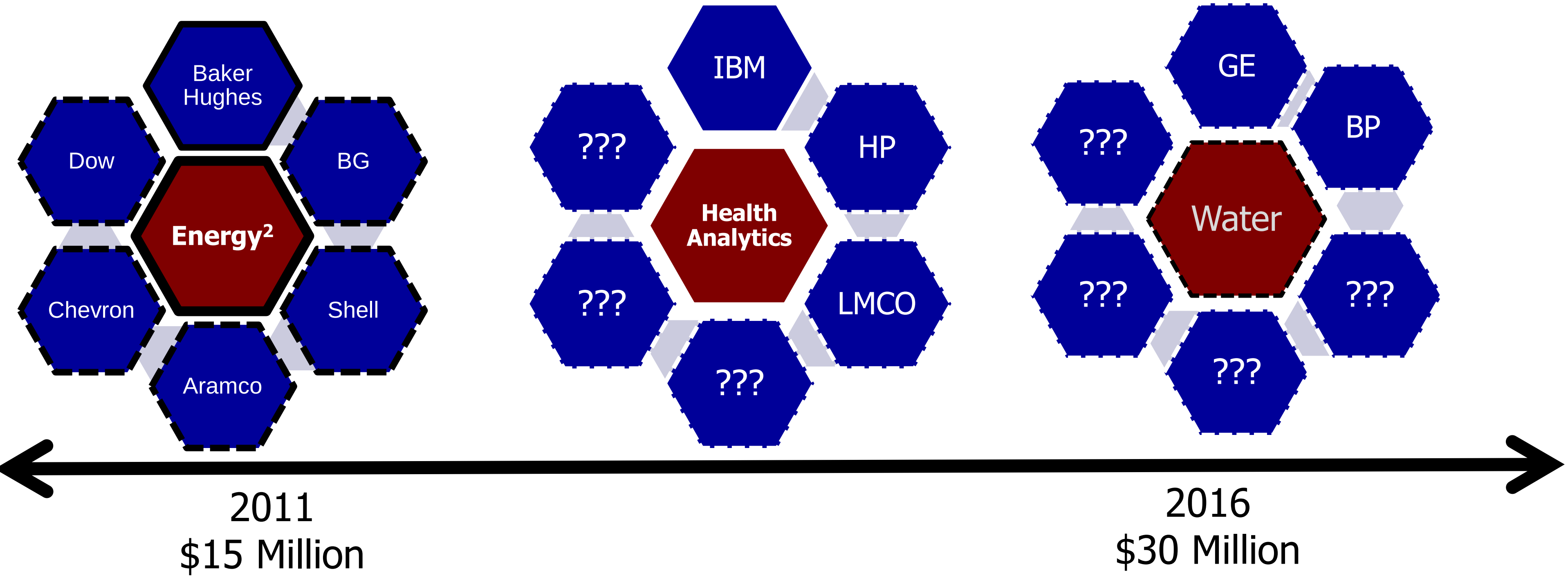
**Strategic Partner**

- **Endowment**
- Executive Sponsorships
- Joint Partnerships
- Major Gifts
- Business Development

Traditional Engagement

University-wide Engagement

# Corporate Engagement: 5 Yr. Vision




- Thematic clusters: nurture cross-company relationships to add value
- Master agreements that integrate programs across campus
- University administration that is efficient and responsive to partners
- Tangible rewards for divisional collaboration in corporate relations

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# Barriers to Corporate Engagement

| Barrier | Response or counterbalance |
|---|---|
| **Little faculty interest in corporate research** | Let faculty drive thematic areas |
| | Offer faculty workshops, seed funding |
| | Declining federal budget will force interest |
| **Internal mistrust of centralized strategy** | Demonstrated success (e.g. Baker Hughes) |
| | Corporate Council and Newsletters |
| | Internal MOU for sharing targets |
| **Access to key corporate decision-makers** | Engage Rice trustees |
| | Increase awareness (e.g. workshops, seminars) |
| **Rice's size: few alumni, narrower** | Identify thematic areas (e.g. don't try to |

# Corporate Engagement with Universities: *A Time of Great Change*

- No longer *ad hoc* : must link to a long-term strategy
- Collaboration and global efforts are now desired
- Industry wants relationships, not just transactions
- Opportunity for innovation in these partnerships


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# Existing and Targeted Master Agreement Partners

- Baker Hughes*
- Lockheed*
- Anadarko
- Aramco Services/Saudi Aramco
- BG
- BP
- Chevron
- ConocoPhillips
- Dow
- ExxonMobil
- GE
- Halliburton
- IBM
- Intel
- Kinder Morgan
- Marathon
- Schlumberger
- Shell
- Statoil
- Total

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# Key strategic questions

- What level of engagement is appropriate for Rice?
- Why Rice?
- How can Rice best communicate what it has to offer to companies?
- What kind of deals is Rice willing to offer?
- How can Rice organize itself internally to best support effective corporate engagement?
- What risks need analysis?
- How do we measure performance?

# Challenges and Opportunities

Strengths

- Excellent faculty working in areas of corporate interest
- Top tier students
- Prestigious institution
- Neutral convener
- Marriage of Technical and Policy Expertise

Weaknesses

- No consistent track record
- Small recruiting pool
- Key faculty may get overcommitted
- Varied and competing points of contact
- Barriers to internal collaboration

Corporate Engagement

Opportunities

- Increasing international ties
- Location in Houston (energy, bio, medical, Fortune 500)
- Strong ties to government, industry, and community leaders

Threats

- Increasing competition as federal funding decreases
- Move towards in-kind versus cash contributions
- Established energy institutes

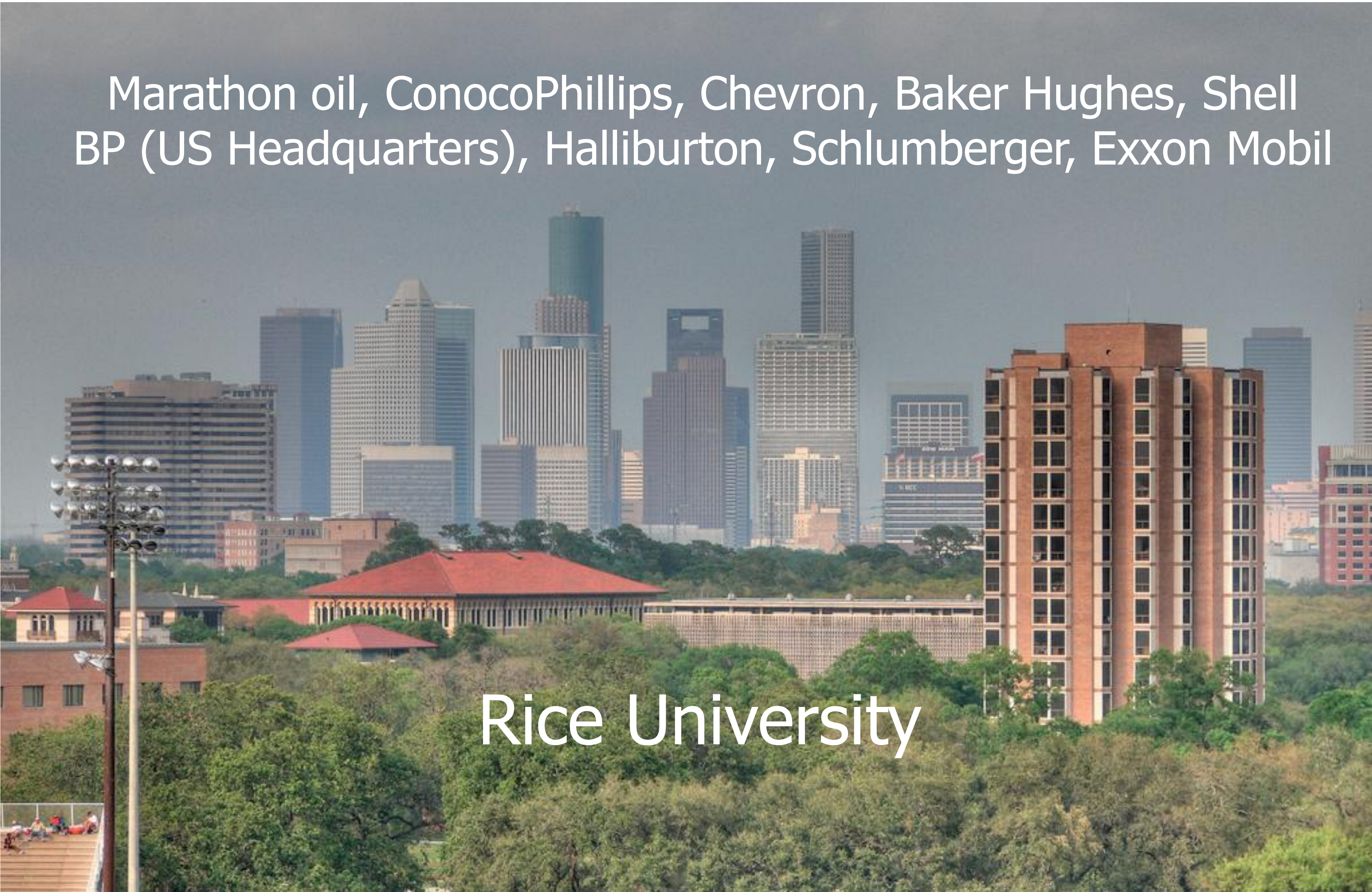
# The Value Proposition

| For Companies | For Rice |
| --- | --- |
| • Talent acquisition<br>• Research tied to business solutions<br>• Business opportunities<br>• Employee/Executive Training<br>• Consultants<br>• New Technologies<br>• Positive PR<br>• Neutral convener | • Funds to support projects, programs, research, events<br>• Real-world problems<br>• Internship and career opportunities<br>• Licensees<br>• In-kind donations<br>• Access to specialized facilities<br>• Clients for Professional Masters and Exec Ed Programs |

# Case Study: Baker Hughes

| Collaboration Areas | Agreement Enhancements |
|---|---|
| • Sponsored Research<br>• Undergraduate Student Design<br>• Baker Institute<br>• Visiting Scholars Program<br>• Professional Development<br>• International Graduate Fellowship Program<br>• Internships | • Discount on indirect costs<br>• Allowance of days for reviews of publication<br>• Arbitration for dispute resolution<br>• Allowance of days for Intellectual Property review |

# Rice University – Energy Capital



# New Research Initiatives at Rice

- Energy research – cross-disciplinary studies of energy transitions and the sustainable and innovative use of hydrocarbons
- Biomedical research – develop nanomedicine and quantitative biology as tools for detecting and curing disease
- International partnerships – orient campus programs towards natural partners in China, Brazil and Mexico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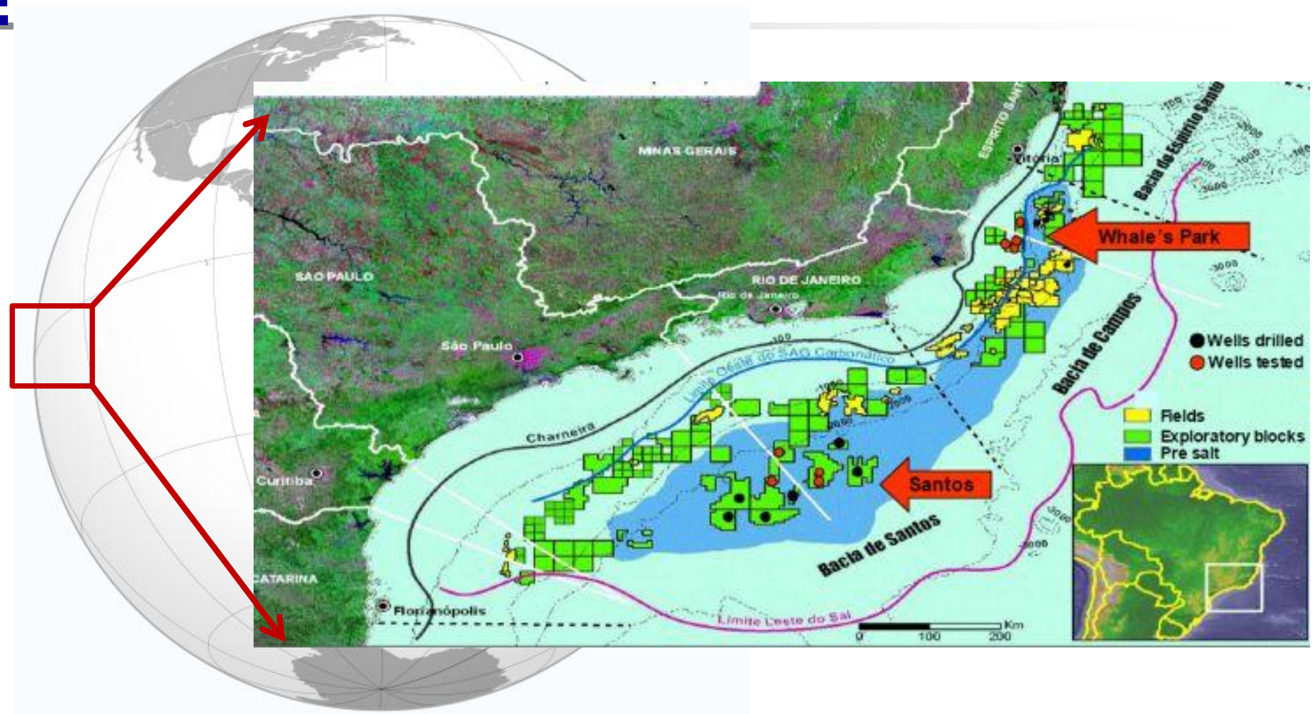
*In Brazil, Rice finds a natural intersection of our international and energy research strategies*

# Why Brazil?




- **9th largest economy, one of the fastest growing in the world**
- **Energy industry has increasing interest in Brazil (pre-sal fields above)**

**Rice has a first mover advantage in Brazil among U.S. un**

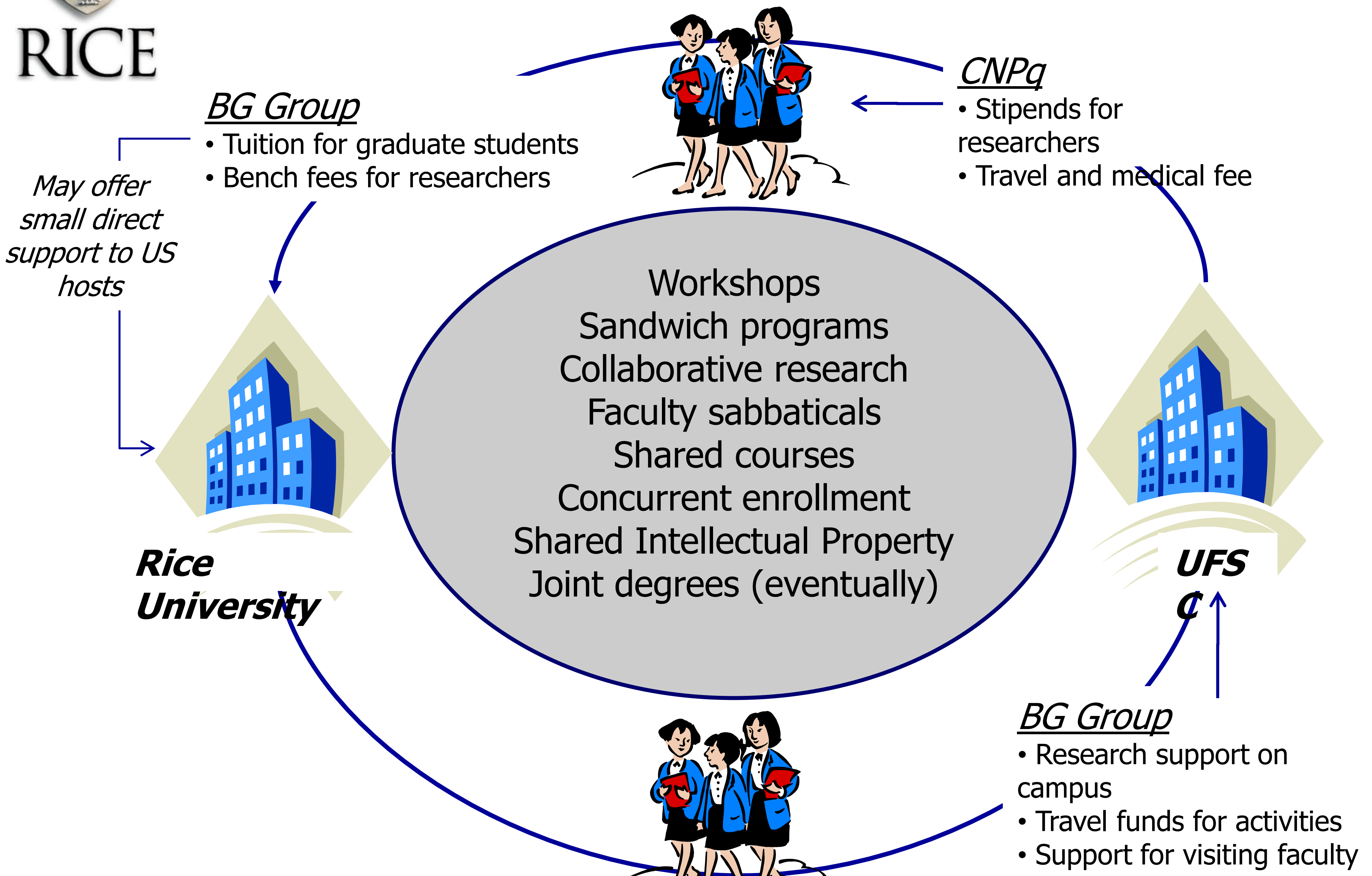
# Support Programs with Government $$

anp
Agência Nacional
do Petróleo,
Gás Natural e Biocombustíveis

*The 'research obligation': 1% of all off-shore profits must return to higher education in Brazil*

- Focus Rice-Brazilian University research collaborations in energy
- Make these collaborations appealing to the Brazilian government
  - Focus on researcher exchange (Dilma's "Science without borders" program)
  - Find ways to get industry matching funds into government exchanges
  - Emphasize entrepreneurship and the innovation culture
- Plan for growth: the obligation will increase substantially in 10 years

# Towards Academic Supercenters: Transnational and Thematic



# A Specific Program: UFSC-Rice

*We are putting in a proposal to a O&G company (BG), and the Brazilian national science foundation (CNPq) which will bring ~$1.5 million in annual support plus a steady supply of Brazilian researchers to Rice.*

**Graduate students**

B razilian graduate students supported by CNPq and their Rice costs by BG. UFSC pays for our students to exchange.

**Post-doctoral researchers**

B razilian post-docs supported by CNPq and their Rice costs by BG. UFSC pays for our post-docs to exchange.

**Faculty**

B razilian faculty have mini-sabbaticals at Rice and one Rice faculty per year spends 8 weeks at UFSC.

# Value of Strong Rice-Brazil Programs

(1) The next generation of energy leaders in a vital emerging economy will have deep connections to Rice

(2) Non-traditional funding for faculty research in interdisciplinary areas such as energy and water

(3) Programs in Brazil provide a persuasive answer to the question 'Why Rice?' for potential industry partners

Our Brazil strategy uses international exchange and collaboration to grow our research enterprise

# The Needle in the Haystack Problem

*Can we concentrate Uranium from soils so that it can be analyzed and reclaimed?*

IC Postdoctoral Research Fellowship Program

Research Institutes · National Laboratories · Universities

Dr. John Fortner