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?

Dr. John Fortner
Small stuff, huge surface

100 micron
9 square cm

One hundred particles

1 micron
3 square meters

One billion particles

10 nm
300 square meters

One hundred trillion particles
Nanoparticles: Super Small

Surface area in 1 gram $\sim 4 \pi r^2 / (4/3 \pi r^3 \cdot \text{density})$
With that much surface: surface matters

Commercial nano-oxides have problems

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

From Kemico, avg size 20 nm

26.88 ± 2.26 nm
13.96 ± 1.62 nm
9.11 ± 0.88 nm

### High Technology through Low Tech Manufacturing

<table>
<thead>
<tr>
<th>Precursor</th>
<th>Surfactant</th>
<th>Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeOOH (Iron Oxo Hydrate)</td>
<td>Oleic acid (9Z)-octadec-9-enoic acid</td>
<td>ODE (1-octadecene)</td>
</tr>
</tbody>
</table>

**Precursor**

- Rust

**Surfactant**

- Olive oil soap

**Solvent**

- Diesel Oil Diluents
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


Surface Chemistry Consistent with Iron-Uranyl Complex
Iron Oxide: Also Ideal for Uranium Species

<table>
<thead>
<tr>
<th>Solution Type</th>
<th>pH</th>
<th>Uranium on Soil (µg)</th>
<th>Extracted Uranium (µg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5M Citric Acid (pH 1)</td>
<td>1</td>
<td>1320</td>
<td>1280</td>
</tr>
<tr>
<td>1M Citric Acid (pH 1.6)</td>
<td>1.6</td>
<td>1300</td>
<td>1260</td>
</tr>
<tr>
<td>0.1M Citric Acid (pH 2.0)</td>
<td>2</td>
<td>1280</td>
<td>1240</td>
</tr>
<tr>
<td>0.1M Acetic Acid (pH 2.5)</td>
<td>2.5</td>
<td>1260</td>
<td>1220</td>
</tr>
<tr>
<td>0.1M Formic Acid (pH 1.6)</td>
<td>1.6</td>
<td>1240</td>
<td>1200</td>
</tr>
<tr>
<td>0.16N Nitric Acid (pH 0.75)</td>
<td>0.75</td>
<td>1220</td>
<td>1180</td>
</tr>
<tr>
<td>0.01N Nitric Acid (pH 2.27)</td>
<td>2.27</td>
<td>1200</td>
<td>1160</td>
</tr>
<tr>
<td>0.001N Nitric Acid (pH 4.91)</td>
<td>4.9</td>
<td>1180</td>
<td>1140</td>
</tr>
<tr>
<td>0.0001N Nitric Acid (pH 5.96)</td>
<td>5.96</td>
<td>1160</td>
<td>1120</td>
</tr>
</tbody>
</table>

1% nitric solution
Theoretical Sorption Capacities: 30 w/w %
## Aqueous nMAG-Urananyl Sorption: Totals

### Variable Water Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Initial U conc.</th>
<th>U Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brays Bayou</td>
<td>7.45 [ppb]</td>
<td>75.1±5.0%</td>
</tr>
<tr>
<td>Ground (well) Water</td>
<td>4.92 [ppb]</td>
<td>86.3±20.0%</td>
</tr>
<tr>
<td>Millipore</td>
<td>4.83 [ppb]</td>
<td>99.3±0.1%</td>
</tr>
</tbody>
</table>

### From Soil (Sandy) Extractions

<table>
<thead>
<tr>
<th>nMAG conc.</th>
<th>Initial U conc.</th>
<th>U Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 [g/L]</td>
<td>35.1 [ppb]</td>
<td>99.1±0.2%</td>
</tr>
<tr>
<td>0.3 [g/L]</td>
<td>33.4 [ppm]</td>
<td>100.4±0.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>nMAG conc.</th>
<th>Initial U conc.</th>
<th>Max. Sorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005 [g/L]</td>
<td>45.9 [ppb]</td>
<td>3.40±0.90 [mg/g]</td>
</tr>
<tr>
<td>0.05 [g/L]</td>
<td>58.8 [ppm]</td>
<td>292±14 [mg/g]</td>
</tr>
</tbody>
</table>
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

Diagram showing the change in magnetic properties with size:
- Single domain
- Multidomain
A Surprising Observation

Nanocrystals interact with very, very low magnetic fields

\[ F_m = \mu_0 \chi \nabla H \times H \]

Much larger in nanocrystalline magnetite

Method to remove magnetic materials

Old way

1 Tesla Electromagnets
Narrow bore columns

1 gram = .1 m²

New way

100 mTesla
Hard drive magnet

1 gram = 50 m²
## nMAG Separation: Fast and Low Tech

<table>
<thead>
<tr>
<th>Material</th>
<th>Separation</th>
<th>Percent nMAG Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>20 nm Filter</td>
<td>99.9%</td>
</tr>
<tr>
<td>Igepal® CO-630</td>
<td>20 nm Filter</td>
<td>99.6%</td>
</tr>
<tr>
<td>Oleic Acid</td>
<td>20 nm Filter</td>
<td>98.9%</td>
</tr>
<tr>
<td>Commercial</td>
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<tr>
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<tr>
<td>Oleic Acid</td>
<td>Magnetic</td>
<td>93.3%</td>
</tr>
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</table>
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
Film of nanoscale magnetite (11.92 nm) stabilized in water with oleic acid bilayer.
Ppb level detection in Concentrates

- 0.1 [g/L] Oleic Acid stabilized nMAG
- 0.1 [g/L] Igepal CO-630 stabilized nMAG
- 5.0 [g/L] Commercial nMAG
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

STEM Image, M. Cho

Close-packed silica (200 nm=d)
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

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Graphs showing size-dependent properties and emission for different materials.
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

#### Occurrence of Natural Uranium

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Blood</td>
<td>Up to 0.5 ppb</td>
</tr>
<tr>
<td>Bone</td>
<td>0.2 – 70 ppb</td>
</tr>
<tr>
<td>Tissue</td>
<td>1 – 3 ppb</td>
</tr>
<tr>
<td>Total in Body</td>
<td>0.01 – 0.4 mg</td>
</tr>
<tr>
<td>Earth’s Crust*</td>
<td>2 ppm</td>
</tr>
<tr>
<td>Soils</td>
<td>0.7 – 11 ppm</td>
</tr>
<tr>
<td>Sea Water</td>
<td>3 ppb</td>
</tr>
</tbody>
</table>

*48th most abundant element

#### Natural Abundance and Half-life

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Abundance</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium-238</td>
<td>99.3%</td>
<td>4.5x10^9 years</td>
</tr>
<tr>
<td>Uranium-235</td>
<td>0.7%</td>
<td>0.7x10^9 years</td>
</tr>
<tr>
<td>Uranium-234</td>
<td>0.005%</td>
<td>0.245x10^6 years</td>
</tr>
</tbody>
</table>

#### Uranium Oxides:
- Uranyl (UO$_2^{+2}$)
- Uranite (U$_3$O$_8$)
- Pitchblende (UO$_2$)
- Also U$_2$O$_3$, and UO$_3$

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(Fun)

44,000 tons mined 2008

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

All three major U isotopes are alpha ($\alpha$) emitters

$^{239}$Pu produced from $^{238}$U by neutron capture
Environmental Matrices: Uranyl Soil (Sand) Extractions

Washed sea sand with uranium spiked as dissolved uranyl nitrate stock
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
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

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
Challenges for Research Universities

(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 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

Marathon oil, ConocoPhillips, Chevron, Baker Hughes, Shell BP (US Headquarters), Halliburton, Schlumberger, Exxon Mobil
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)
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

Greener Carbon Science and Technology

- Characterizing Hydrocarbons
- Extracting Hydrocarbons
- Transport, Transmission and Generation
- Carbon Capture and Storage
- Mitigation of By-Products

- Seismic Imaging
- In-Situ Extraction Technology
- Novel Materials for Energy Efficiency
- Biochar
- Catalysts for Pollution Reduction

- Methane Hydrates
- Batteries
- Microbiological Carbon Capture
- Air Pollution

- Water/Energy Nexus

Ecosystem Impacts & Systems Analysis of Technology Choices
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?
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
Flow Assurance and Chemical EOR

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

Two images ideally that I could explain briefly:
Water Treatment and Management

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

Two images ideally that I could explain briefly :
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
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

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

Center for Greener Carbon: a program of the E-squared initiative
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 University: The agenda for the day

Please reproduce a mini-version of the agenda here
Rice’s Existing Industrial Support

Corporate Giving
Corporate Matching Gifts
Industry Sponsored Awards

FY 07 FY 08 FY 09 FY 10 FY 11

$0 $5,000,000 $10,000,000 $15,000,000 $20,000,000 $25,000,000 $30,000,000

5/13/2012
Rice: Real Opportunity for Growth

**Total* Corporate Giving FY2007-FY2010**

- **Rice University**
- **Duke University**
- **Emory University**
- **Vanderbilt University**
- **Washington University**

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

2011
$15 Million

2016
$30 Million
# Barriers to Corporate Engagement

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

7/13/2012
61
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
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
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

**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

**Corporate Engagement**
The Value Proposition

For Companies
- Talent acquisition
- Research tied to business solutions
- Business opportunities
- Employee/Executive Training
- Consultants
- New Technologies
- Positive PR
- Neutral convener

For Rice
- Funds to support projects, programs, research, events
- Real-world problems
- Internship and career opportunities
- Licensees
- In-kind donations
- Access to specialized facilities
- Clients for Professional Masters and Exec Ed Programs
## Case Study: Baker Hughes

<table>
<thead>
<tr>
<th>Collaboration Areas</th>
<th>Agreement Enhancements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sponsored Research</td>
<td>• Discount on indirect costs</td>
</tr>
<tr>
<td>• Undergraduate Student Design</td>
<td>• Allowance of days for reviews of publication</td>
</tr>
<tr>
<td>• Baker Institute</td>
<td>• Arbitration for dispute resolution</td>
</tr>
<tr>
<td>• Visiting Scholars Program</td>
<td>• Allowance of days for Intellectual Property review</td>
</tr>
<tr>
<td>• Professional Development</td>
<td></td>
</tr>
<tr>
<td>• International Graduate Fellowship Program</td>
<td></td>
</tr>
<tr>
<td>• Internships</td>
<td></td>
</tr>
</tbody>
</table>
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

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-salt fields above)
- Rice has a first mover advantage in Brazil among U.S. universities
Support Programs with Government $$

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

**BG Group**
- Tuition for graduate students
- Bench fees for researchers

**CNPq**
- Stipends for researchers
- Travel and medical fee

**Rice University**
- May offer small direct support to US hosts

**UFS**
- BG Group
  - Research support on campus
  - Travel funds for activities
  - Support for visiting faculty

**Workshops**
- Sandwich programs
- Collaborative research
- Faculty sabbaticals
- Shared courses
- Concurrent enrollment
- Shared Intellectual Property
- Joint degrees (eventually)

[http://www.rice.edu](http://www.rice.edu)
A Specific Program: UFSC-Rice

We are putting in a proposal to an 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

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

Post-doctoral researchers

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

Faculty

Brazilian 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?

Dr. John Fortner