IOGCC
Interstate Oil & Gas Compact Commission

Annual Meeting
Santa Fe, New Mexico
November 18, 2008

The Advanced Energy Consortium

Funding and conducting pre-competitive research in micro- and nano- technology for improved subsurface understanding

Paul D. Ching

Bureau of Economic Geology

Jackson School of Geosciences

The University of Texas at Austin

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ADVANCED ENERGY CONSORTIUM

Overarching Question

Why do we leave so much oil in the ground?

Outline

- **What and Why?**
- How?
  - Illuminate and Mobilize
- Who and When?

What and Why

- **What is the greatest target for new oil reserves?**
  - Wrong, but close….

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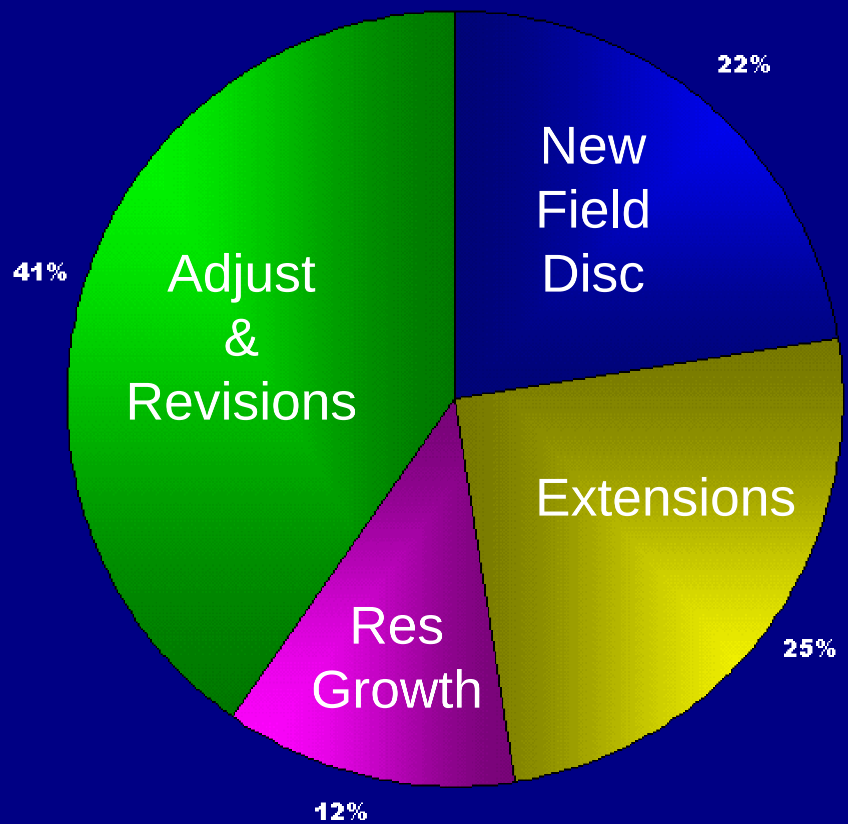
Where are the new reserves?



from DrillingInfo.com

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Where and Why

- **Why EOR?**
  - Because oil will be needed for many (many!) decades, and there remains much oil to be produced
- **Can EOR be improved?**
  - After all of our best efforts, we still leave 30-70% behind.

US Technically Recoverable Resource Potential

Basins / Area	No. Large Reservoirs Assessed	All reservoirs (Ten areas Assessed)		
		OOIP* (Billions Barrels)	ROIP** (Billions Barrels)	Technically Recoverable (Billions Barrels)
Alaska	34	67.3	45.0	12.4
California	172	83.3	57.3	5.2
Gulf Coast	239	44.4	27.5	6.9
Mid-Continent	222	89.6	65.6	11.8
Illinois & Michigan	154	17.8	11.5	1.5
Permian	207	95.4	61.7	20.8
Rocky Mountains	162	33.6	22.6	4.2
Texas: East & Central	199	109.0	73.6	17.3
Williston	93	13.2	9.4	2.7
Louisiana Offshore	99	28.1	15.7	5.9
Total	**1581**	**581.7**	**390.0**	**88.7**

67%

* OOIP=orig. oil in place
**ROIP=remaining oil in place

Source: DOE, Feb. 2006

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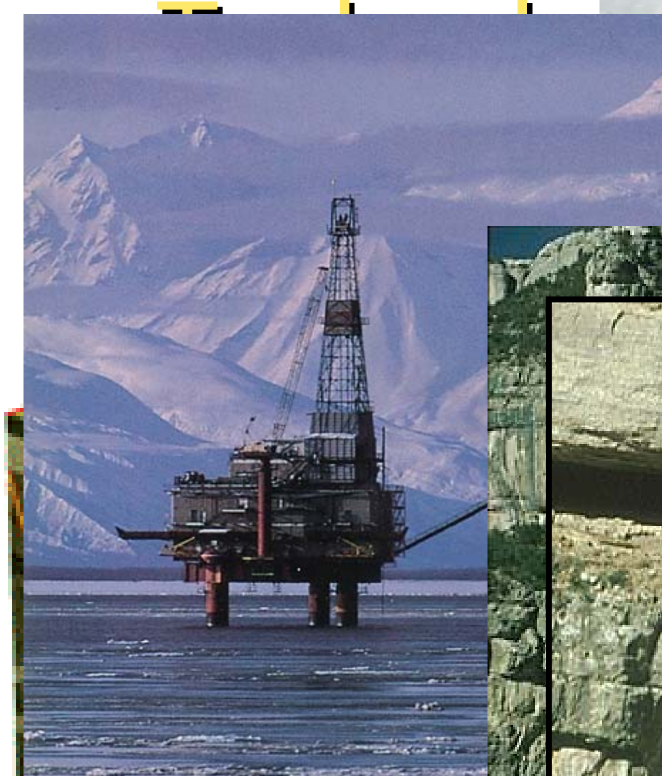
Beyond EOR

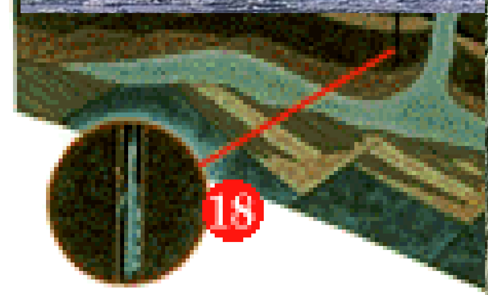
- Reservoir-scale tools are good at measuring matrix properties in the near-well bore environment
- Because we are unable to measure interwell matrix and fracture properties, we rely on approximations
- In most cases, we lack the ability to monitor the inter-well changes in fluid properties that occur as the reservoir is developed and produced
- With greater knowledge of the matrix, fracture, fluid properties and production-related changes, our ability to increase recovery rates should improve

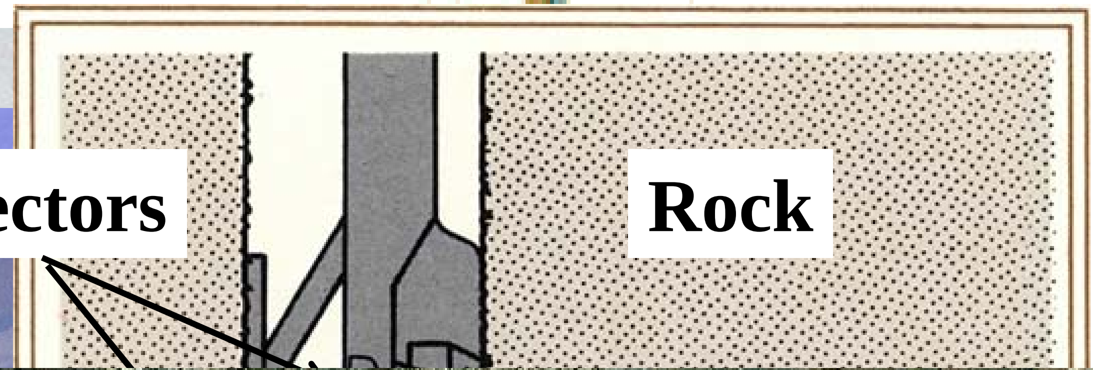
Outline

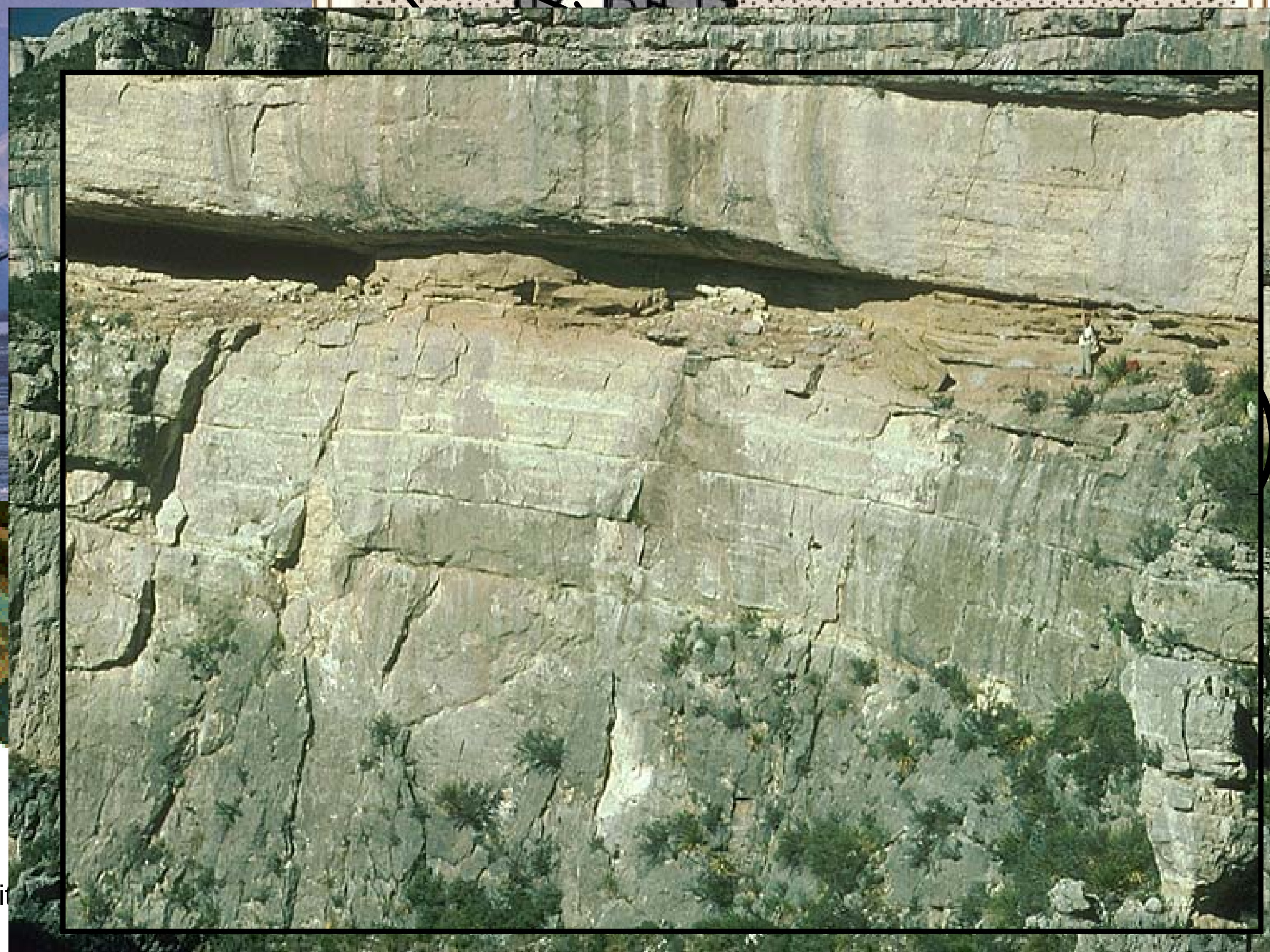
- What and Why?
- **How?**
  - **Illuminate and Mobilize**
- Who and When?

Currer



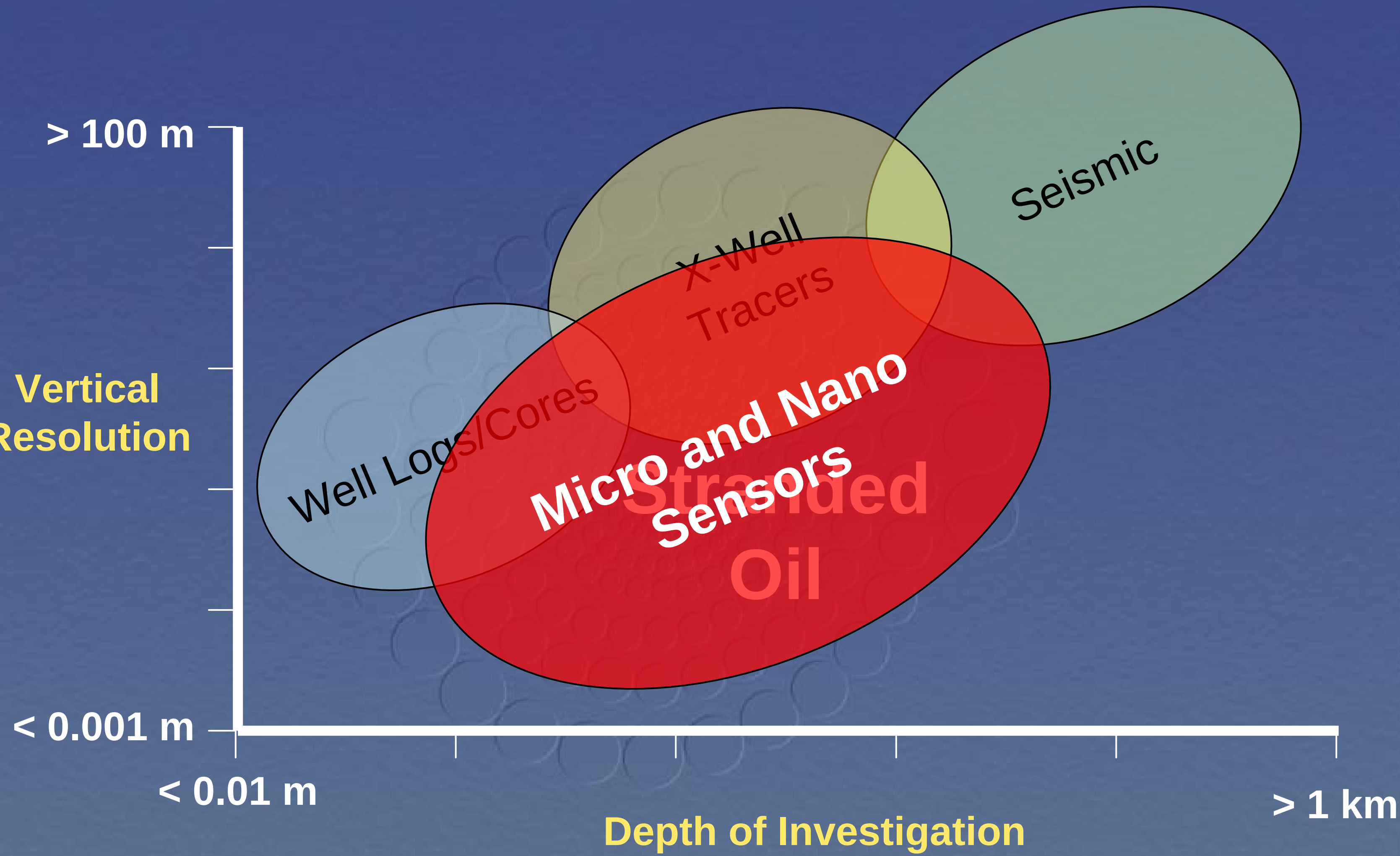






Modified from Chevron Websit

Reservoir-Scale Technologies



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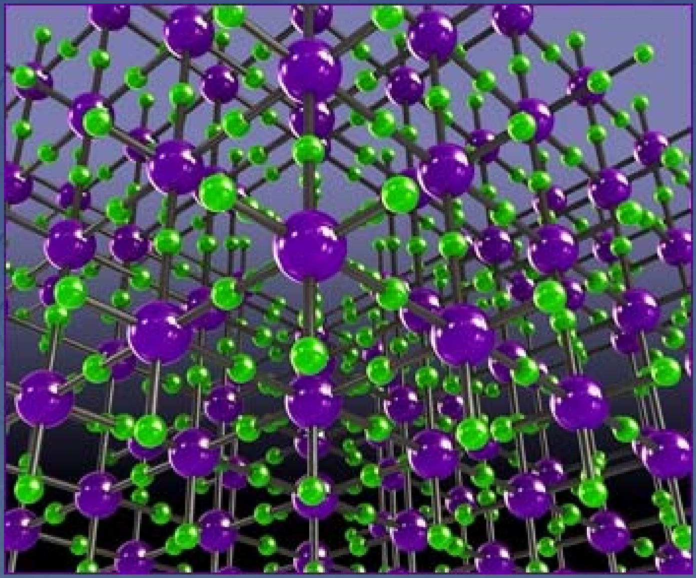
Nanotechnology

Nanotechnology refers to a field of applied science and technology whose theme is the control of matter on the atomic and molecular scale, generally <u>100 nanometers</u> or smaller, and the fabrication of devices or materials that lie within that size range.

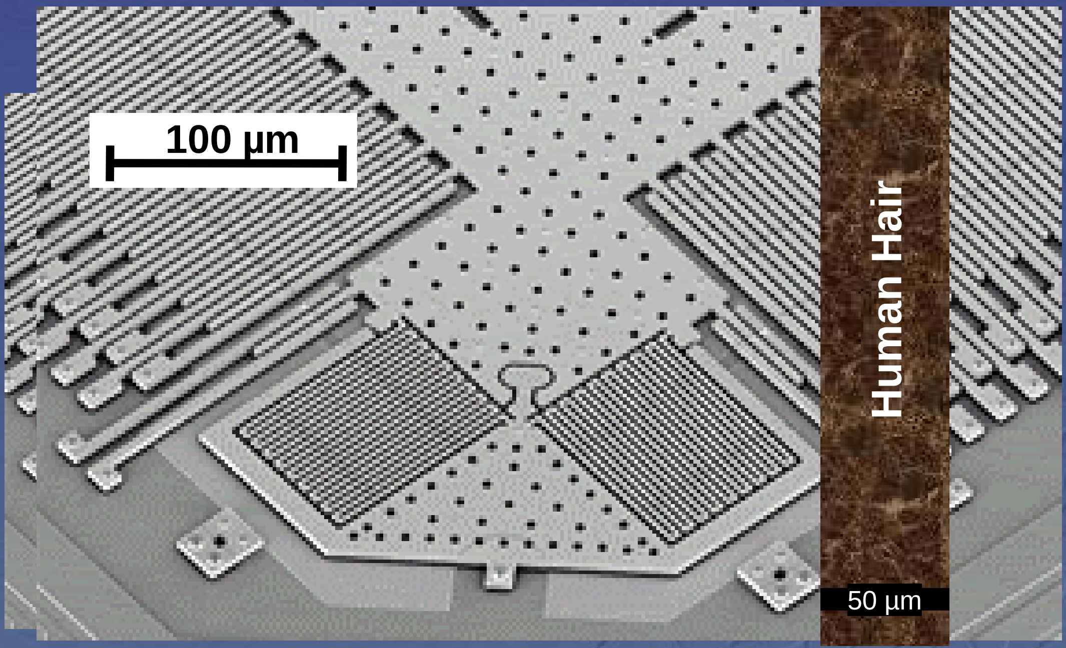


Source NNI

Nanotechnology

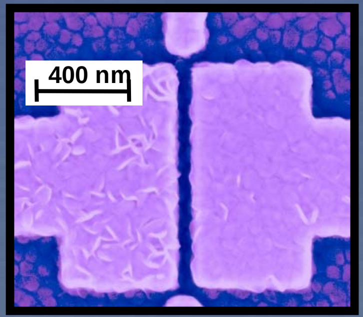
- A nanometer is one billionth of a meter
- Hair is 100,000 nanometers wide
- It's one-tenth the thickness of the metal film on your tinted sunglasses or your potato chip bag
- It's the thickness of a drop of water spread over a square meter
- Almost as wide as a DNA molecule
- It's about how much your fingernails grows each second
- How far the San Andreas fault slips in half a second

NANO Scale



Semiconductor-based sensors. A micro-machined acceleration sensor with thousands of structural elements in less than 1 mm2.

Single pentacene chemical sensor with an active region only ~ 1000 nanometers across.



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Sensor photo: Randy Goodall, Sematech

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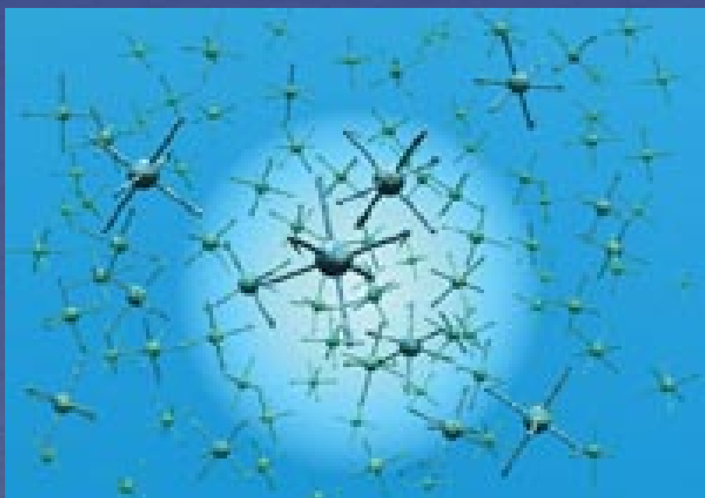
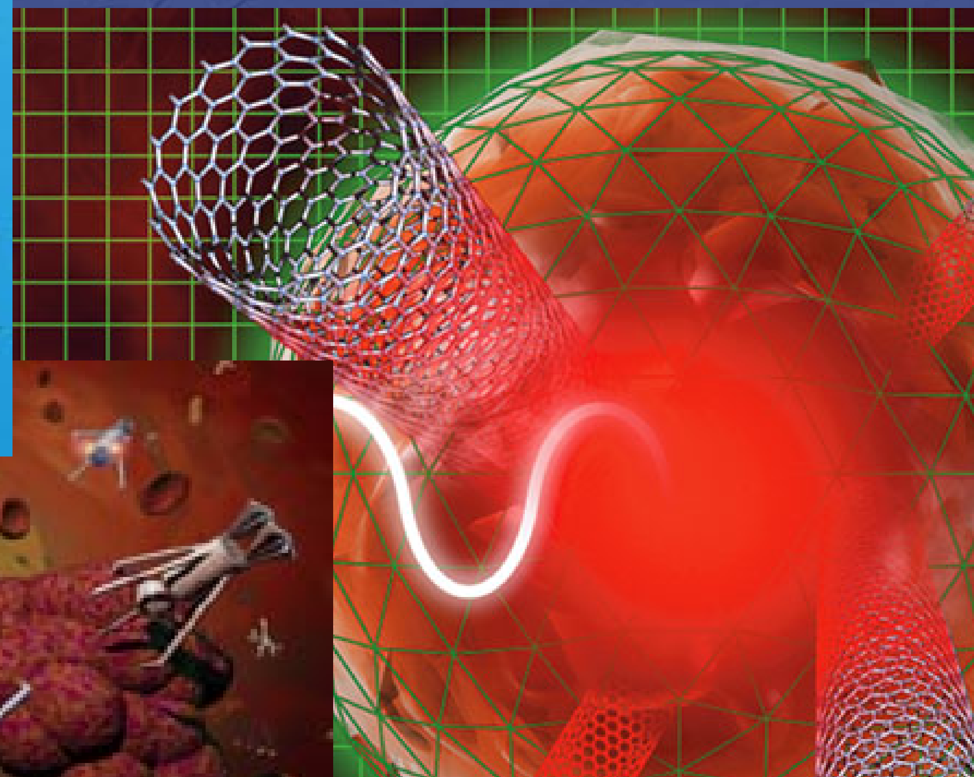
Medical Applications



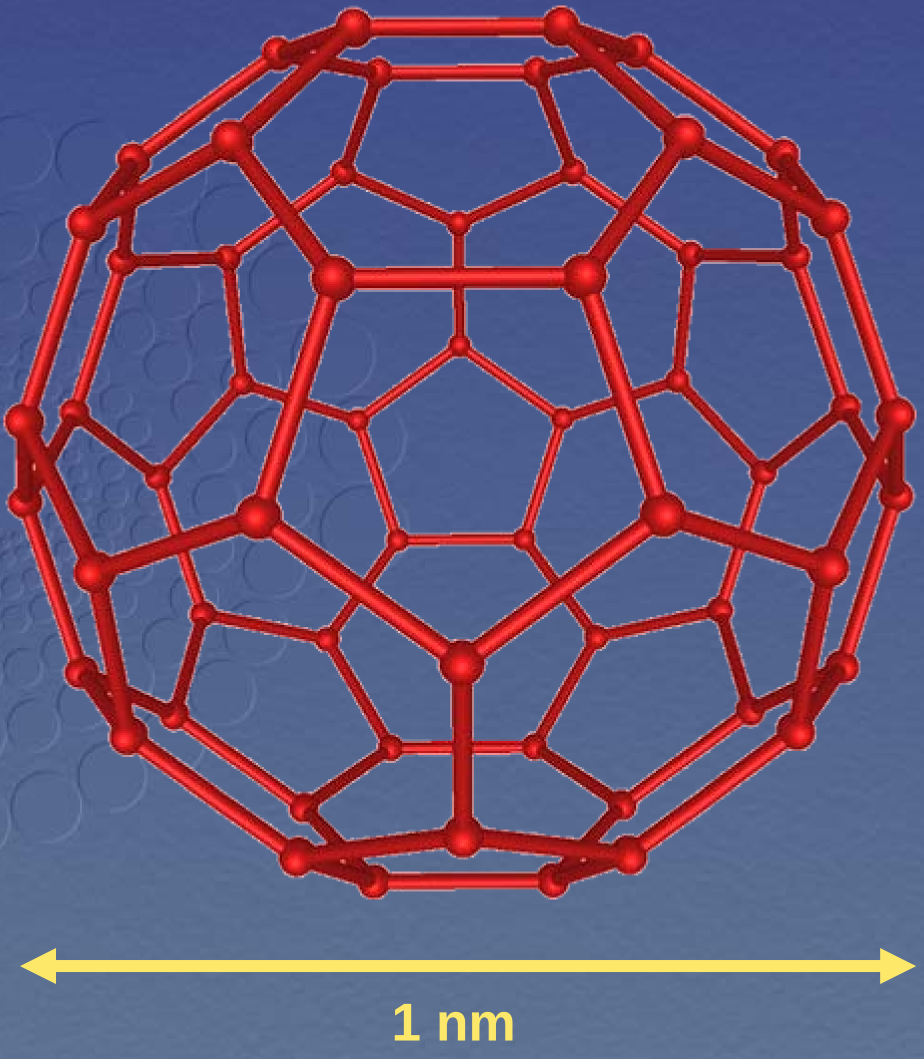
Source NanoTech-Now



Source Readers Digest – March 2008

C_{60} – "Buckminsterfullerene"

- Discovered in 1985 by team including Kroto, Heath, O'Brien, Curl and Smalley
- Kroto, Curl, & Smalley awarded Nobel prize in 1996 for discovery
- Class of carbon molecules includes C_{60}, C_{70}, C_{72}, C_{76}, C_{84} and C_{100}
- Fullerenes found in minerals known as Shungites in Russia
- Van der Waal's diameter C_{60} = 1nm
- C60 in water tends to pick up two more electrons and become an anion (-)
- Active groups can be attached



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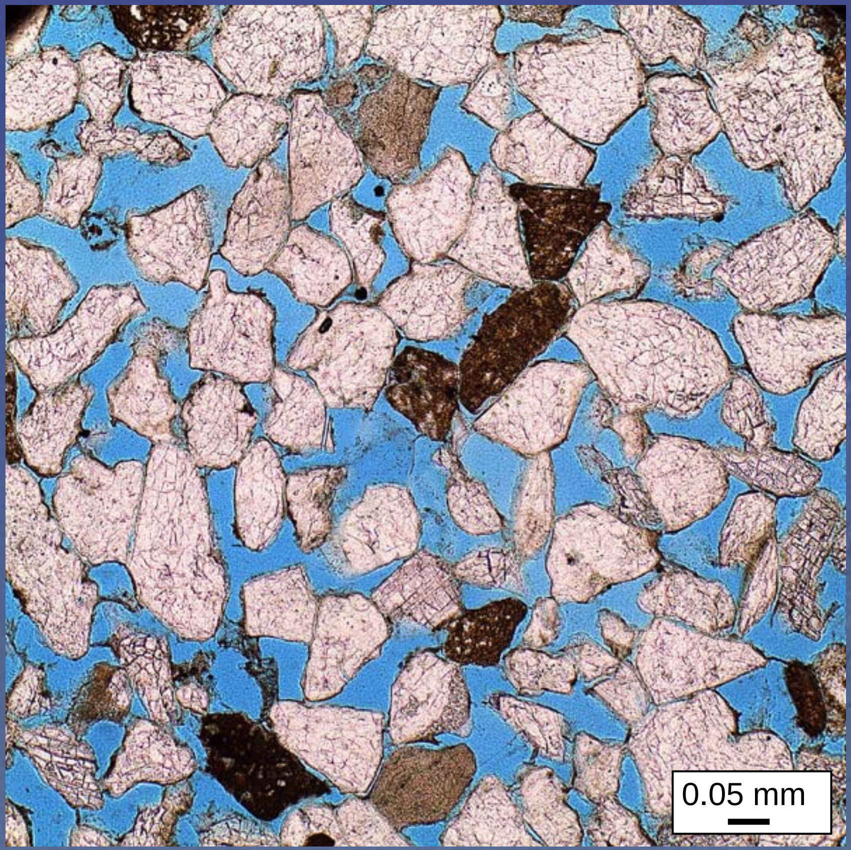
Oil-bearing sandstone porosity



Frio Formation, Liberty Co., Texas 5040 ft.

Micrograph courtesy Robert G. Loucks, BEG

The Oligocene age (31-24 mya) Frio sandstone formation is a major oil-bearing sandstones in Texas and is the principal oil-bearing reservoir in south Louisiana. Oil is often found against traps (faults, salt domes, etc)

Porosity (blue epoxy) in this formation averages 20 – 30%. Sand control (around wells) can be an issue with such high porosities (>20%) and is controlled by frac (gravel) packing.

Note that pore spaces in this sample can exceed .10mm.

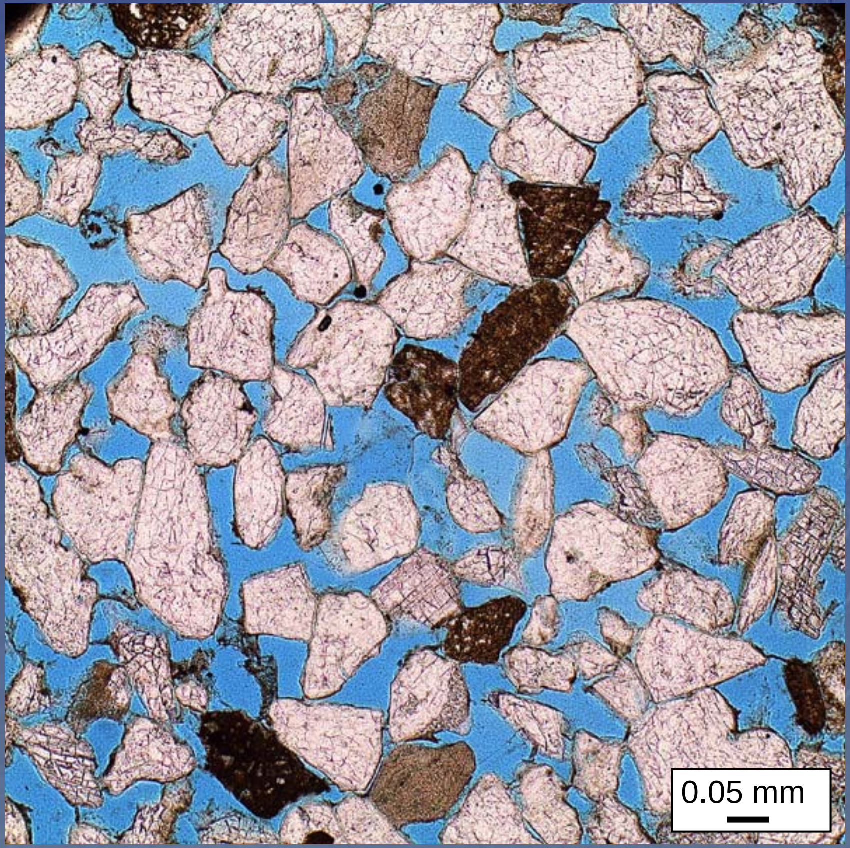
.10mm = 100 microns (µm)

= 100,000 nanometers (nm)

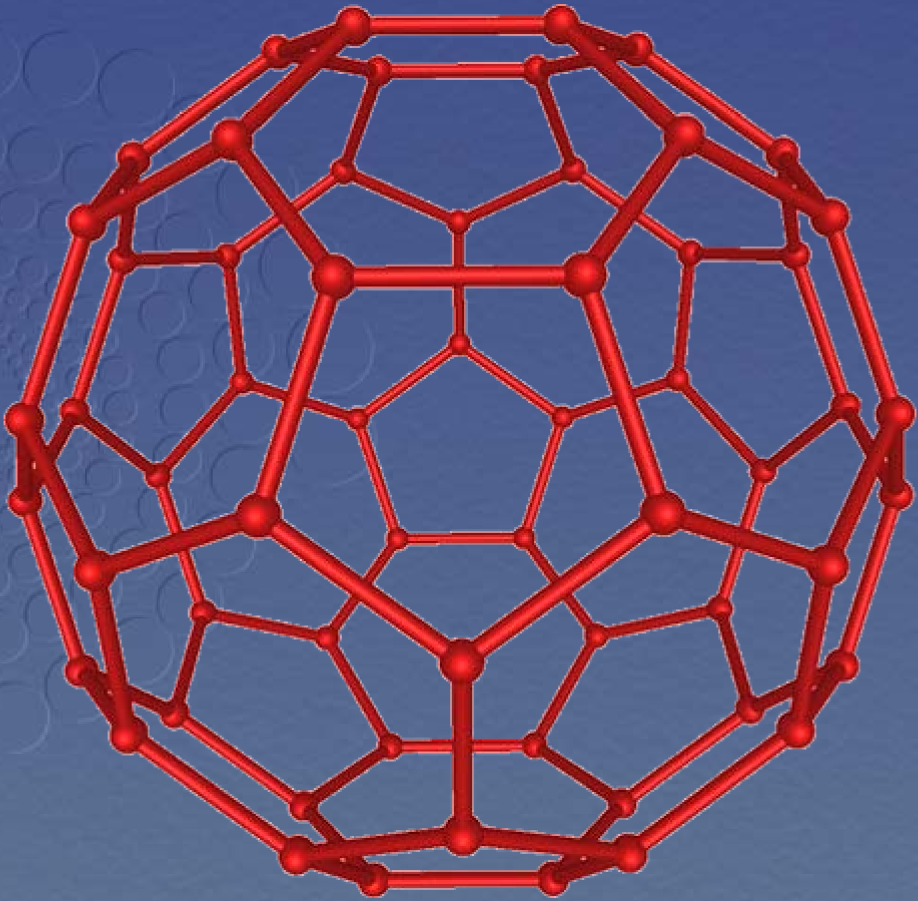
Relative Scale

Frio Sandstone

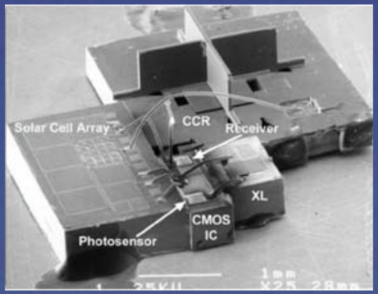
with pores of .10mm = (100,000nm)



C60 buckyball (1nm)



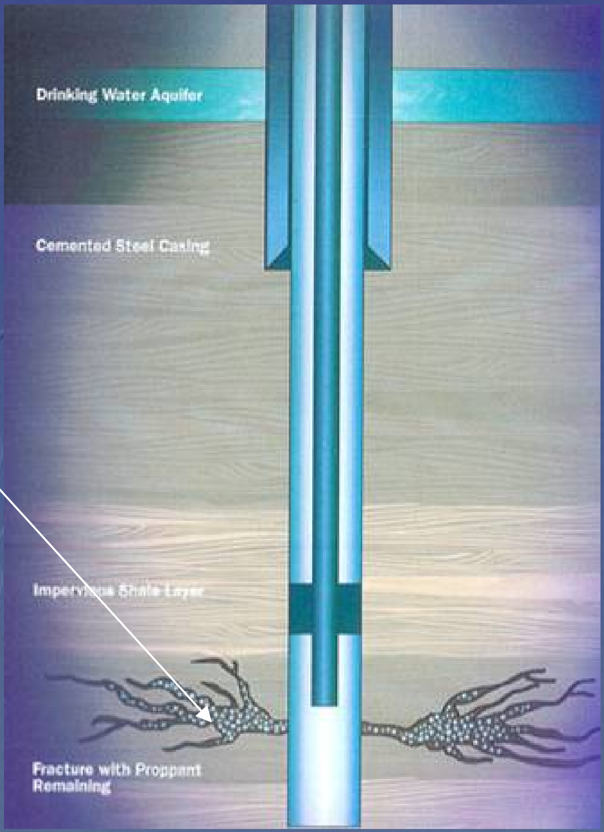
Super Smart Dust?



Source: Kris Pister

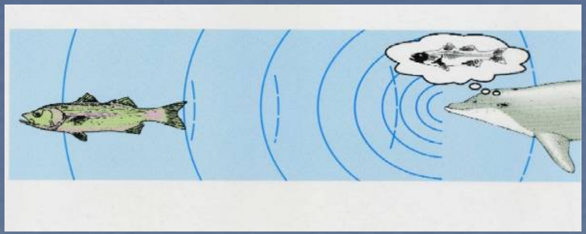
?

Source: ceramicproppant.com



Source: API

We'd like you to inject some nanomaterials that self-assemble down-hole to make smart sensors that spread out through the reservoir, find the oil and tell us where it is - and then, ideally, bring it back to the well bore."



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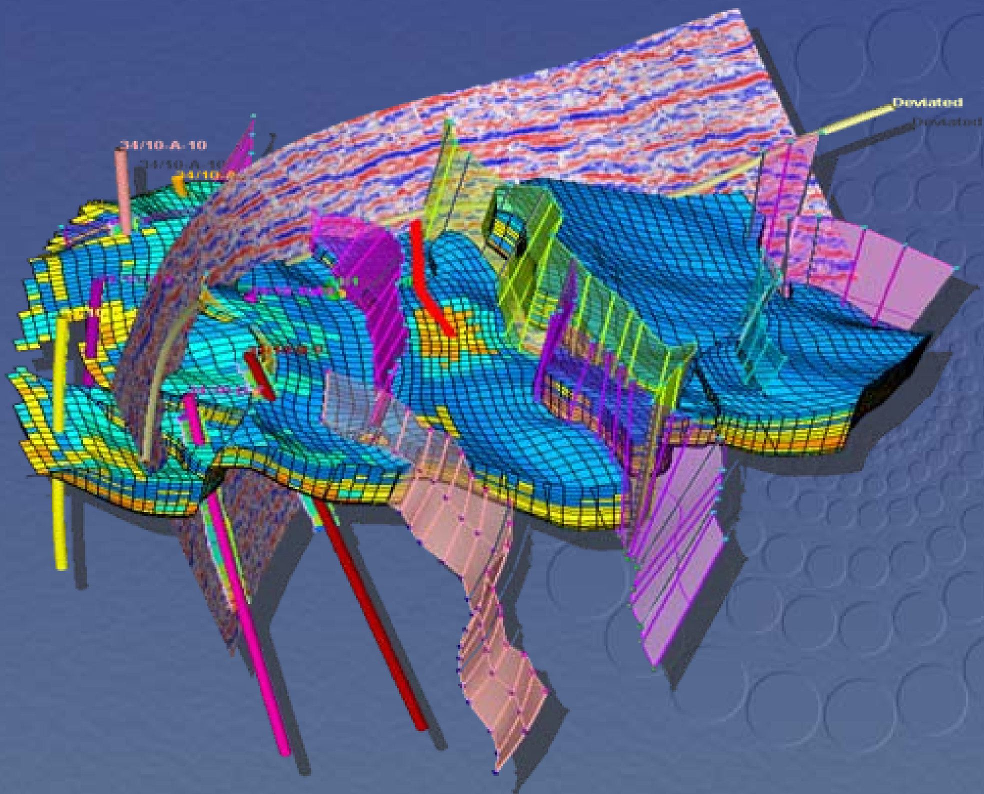
OUTCOME

- PICTURE (Illumination) of subsurface over time
  – Follow the fluids – Reservoir
- SO . . . Can we use "NANO" to obtain a:
  – "more certain" spatial picture ?
- That done !
  – know where the fluids are located
- What "nano" materials (existing and new) can be utilized to increase recovery (extract more)?
  – Change properties, eg, viscosity, wettability, etc
  – Better efficiency of developing, drilling, producing & processing

Micro/Nano sensors that "illuminate" or describe the reservoir:

1) *Chemical & Physical properties of reservoir fluids and rocks beyond the wellbore*
2) *Three Dimensional Distribution of reservoir fluids and rocks*
3) *Dynamic paths of fluids (including all fracture-generated flow paths)*

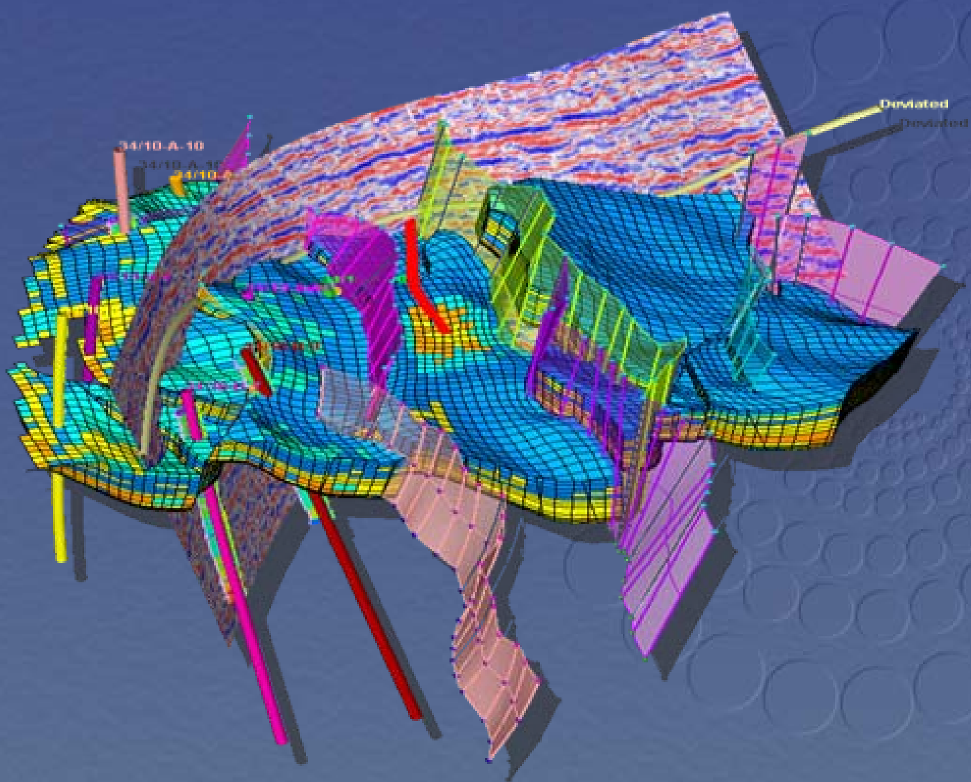
Illuminate



Physical Parameters

- **Pressure** (min/max, mean, dist)
- **Temperature** (min/max, etc.)
- **Permeability** (relative)
- **Porosity**
  - Pore size
  - Pore throat
  - Pore geometry
- **Stress/strain conditions**

Illuminate



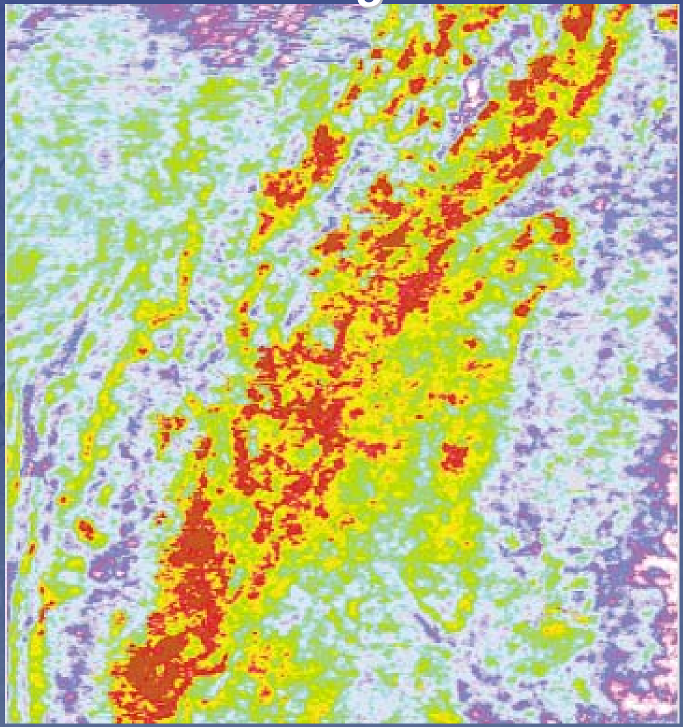
Chemical Parameters

- **Presence of:**
  - Hydrocarbons (oil, natural gas)
  - Water
  - Oil/Water/Gas interface
  - Impurities
    - Corrosives (CO_2, H_2S)
    - Trace Elements
- **Type of hydrocarbon**
- **pH** (min/max, mean, dist)
- **Viscosity**
- **Fluid saturation**
  - So, Sw, Sg
  - Wettability

Illuminate

- ***Spatial distribution of fluids***
  - ***Oil, H_20, natural gas***
  - ***Location of <u>bypassed</u> oil, gas***
- ***Rock formation boundaries***
  - ***Rock layer morphology***
  - ***Reservoir compartments***
  - ***Natural fracture distribution***
  - ***Fault block geometries***
  - ***Artificial fracture geometry***
- ***4-D reservoir pore system?***

2-D slice through reservoir



Courtesy WesternGeco

Dynamic paths of reservoir fluids (4D):

- *What is the natural production fluid flow path?*
- *What is the injected fluid flow path?*
  - *Water flood*
  - *Proppant*
  - *CO_2 / N_2 / etc.*
- *How effective is the fracture production?*
  - *Are the fractures transmitting or blocking fluid flow?*
- *What are the physical/chemical changes?*
  - *Pressures, temperatures, stresses,*
  - *Fluid mixture, pH, viscosity, saturations*

Operating Conditions

(relatively harsh conditions)

- Depths: 5,000 – 15,000 ft
- Temperatures: 30 – 350 ^{o} F
- Pressures: 0 – 8K psi
- pH: 4-8 (acidic)
- Presence of: complicated fluids, water and clays
- Salinity: seawater to very concentrated
- Size (pore throats in rock formations): $\leq 5\ \mu m$
- Additional functional needs:
  - location capability, low power, transmission capability, reasonable cost

Challenges

- Emplacement
  - How to get them into the reservoir
  - How to protect them from this harsh environment
  - How to retrieve them (assuming “passive” sensors
- Telemetry
  - How to transmit a signal
  - 3-D location information from each sensor?
- Communication/Data Acquisition
  - How to retrieve the data
  - How to power
- Data Processing
  - How will the data be effectively processed, analyzed, and used to retrieve more oil & gas
- Economics

Mobilize Remaining Oil

- Lower viscosity of petroleum
- Increase miscibility of petroleum
- Alter wettability in the reservoir
- Alter fluid phase behavior
- Shutoff water production
- Maintain reservoir pressure
- Improve recovery in oil-water transition zones
- Separate water from oil in the reservoir or well bore (in situ)

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Wild Mobilization Ideas…

- Smart propants
- Nano particles as contrast agents
- Nano receivers
- Nano explosives
- Magnetic nano particles for dispersion, retrieval and self-propulsion
- Nano "Heated" particles
- Nano surfactants
- Smart seals
- Nano fluidics
- Nano NMR

Outline

- What and Why?
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  - **Illuminate and Mobilize**
- Who and When?

The Advanced Energy Consortium

- AEC under development for three years
- Developed by Bureau of Economic Geology in conjunction with executive level R&D management of the member companies
- Anti-Trust approval for consortium from Dept of Justice in August, 2007
- Organizational structure and technology focus defined during collaborative meetings with members, UT and Rice University
- January 1, 2008 start up

AEC FOCUS

- Increase oil / gas recovery from new & existing hydrocarbon fields
- "Illuminate" the oilfield
  - **Spatial distribution of the pore system, including reservoir compartments**
  - **Natural fracture system**
  - **Fluid flows through the reservoir**
  - **Fluid saturation (wettability)**
  - **Variations in reservoir pressure, temp, chemistry**
  - **Injection (water flood) distribution and rate**
  - **Effectiveness of seals**

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Mission

The AEC will investigate how pre-competitive research in micro- and nanotechnology, with an initial emphasis on sensors and materials, can create a positive disruptive change in the upstream oil & gas industry.

Partnership

Managing Partner — Bureau of Economic Geology

Technical Partner — Smalley Institute

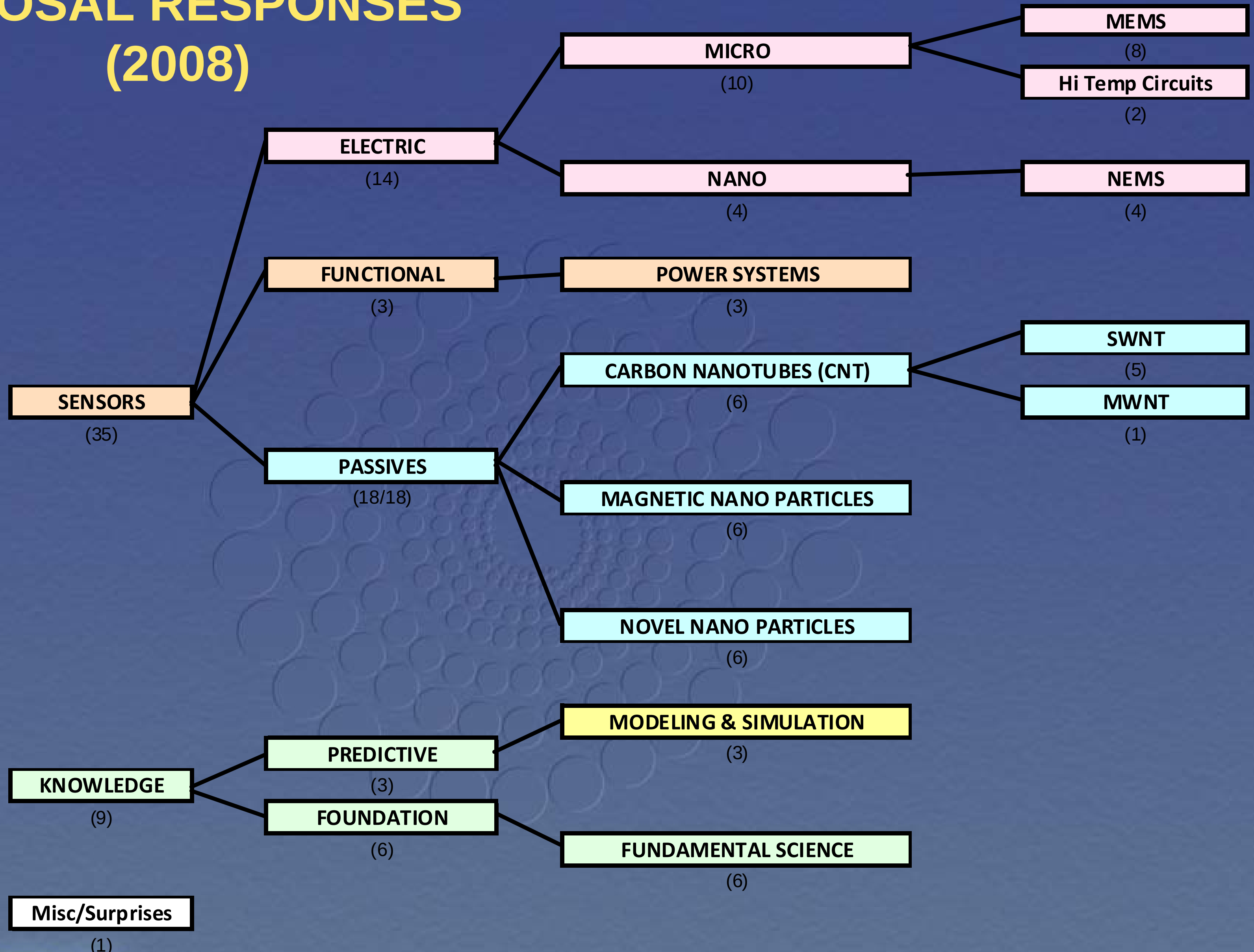
Membership

- BP
- BakerHughes
- ConocoPhillips
- Halliburton
- Marathon
- Occidental
- Schlumberger
- Shell
- Total

Progress and Next Steps

- Pre-Competitive Workshop, May ’08
  – 6 proposals funded
- RFP Summer, 2008
  - 62 proposals received
  - Over 30 institutions worldwide
  - 45 invited for final review
- RFP Review – Finalizing currently
- First Awards January, 2009
  - +/- $6 million expected in funding for FY 09

PROPOSAL RESPONSES (2008)



Overarching Question

Why do we leave so much oil in the ground?

We must contact and then impact the molecules. To that end, nanotechnology holds great promise.

"That's not a *rock*, it's a *reservoir!*"

Fractured Carbonate

Tight Gas Shale

Conclusions

- Nanotechnology can be applied to oilfield applications
- We can build on existing experience from Medical Imaging and Nanofluidics research
- We can envision self-propelled nanosensors
- This is a billion dollar opportunity!

“It won’t be easy”

AEC Contacts

www.beg.utexas.edu/aec

Scott Tinker Director

Scott.Tinker@beg.utexas.edu

Jay Kipper
Associate Director

Jay.Kipper@beg.utexas.edu

Sean Murphy
Program Manager

Sean.Murphy@beg.utexas.edu

Paul Ching
Executive Advisor

Paul.Ching@beg.utexas.edu

Howard Schmidt
Nano Scientist

HKS@rice.edu

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THANK YOU