The Secure Earth Initiative:

Developing a National Research Initiative in the Subsurface Sciences

G.S. Bodvarsson and R. Hertzog

Meeting of opportunity on the Secure Earth initiative
Presented to the National Research Council
Board of Earth Sciences and Radioactive Waste Management

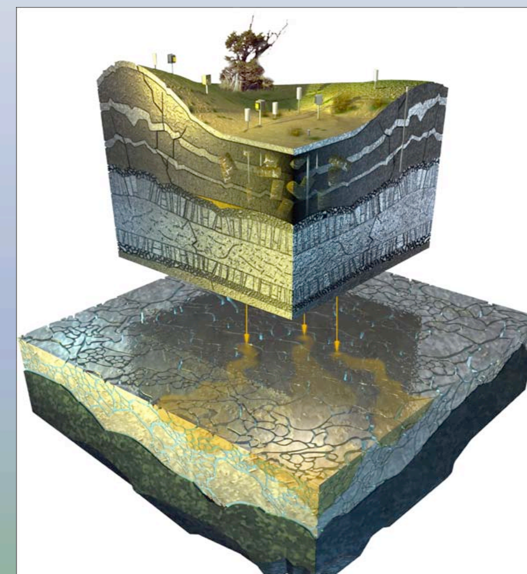
July 14, 2004 – Washington D.C.

Outline

- *Drivers and Basis for Secure Earth Initiative*
  - *Energy outlook and supply*
  - *Environmental security*
- *Vision for Secure Earth*
  - *Goals*
  - *Approach*
- *Scientific Thrust*
- *Implementation*
  - *Research facilities*
  - *Team versus PI approach*
  - *Participants*
- *Summary*

Definition of SECURE Earth

A multi-agency, multi-laboratory, university & industry-supported subsurface geoscience research initiative to address critical energy and environmental problems.



Vision

- *Predictive models can be used to predict and manipulate subsurface processes*
  - *At any space and time scale*
- *Improved measurements and data management is a top priority to scientific discovery and model design*

SECUREarth
urgent solutions to secure earth's future
Scientific Environmental/Energy Cross-Cutting Underground Research

Solving Cross-Cutting PROBLEMS in GeoScience

Environmental Clean-Up
- Natural Attenuation
- Bio/GeoEngineering
- Remediation

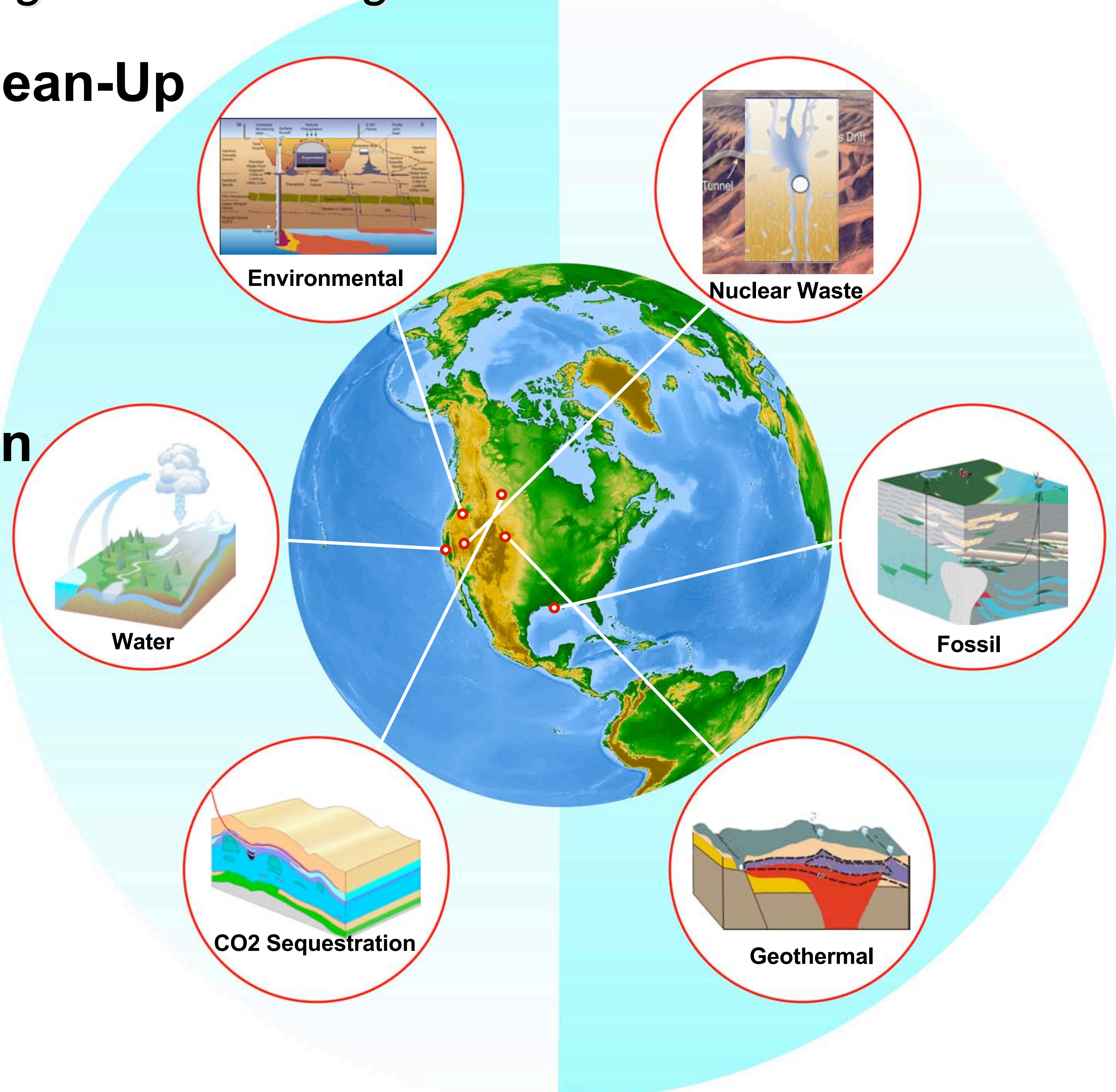
Water
- Recharge
- Quality
- Supply

CO_2 Sequestration
- Storage
- Leakage/"Plugging"
- Sequestration

Nuclear Waste
- Flow Paths
- Transport
- Isolation

Fossil Energy
- Flow Paths
- Enhancement
- Recovery

Geothermal
- Fracturing
- Flow Manipulations
- Production



Earth Sciences Initiatives

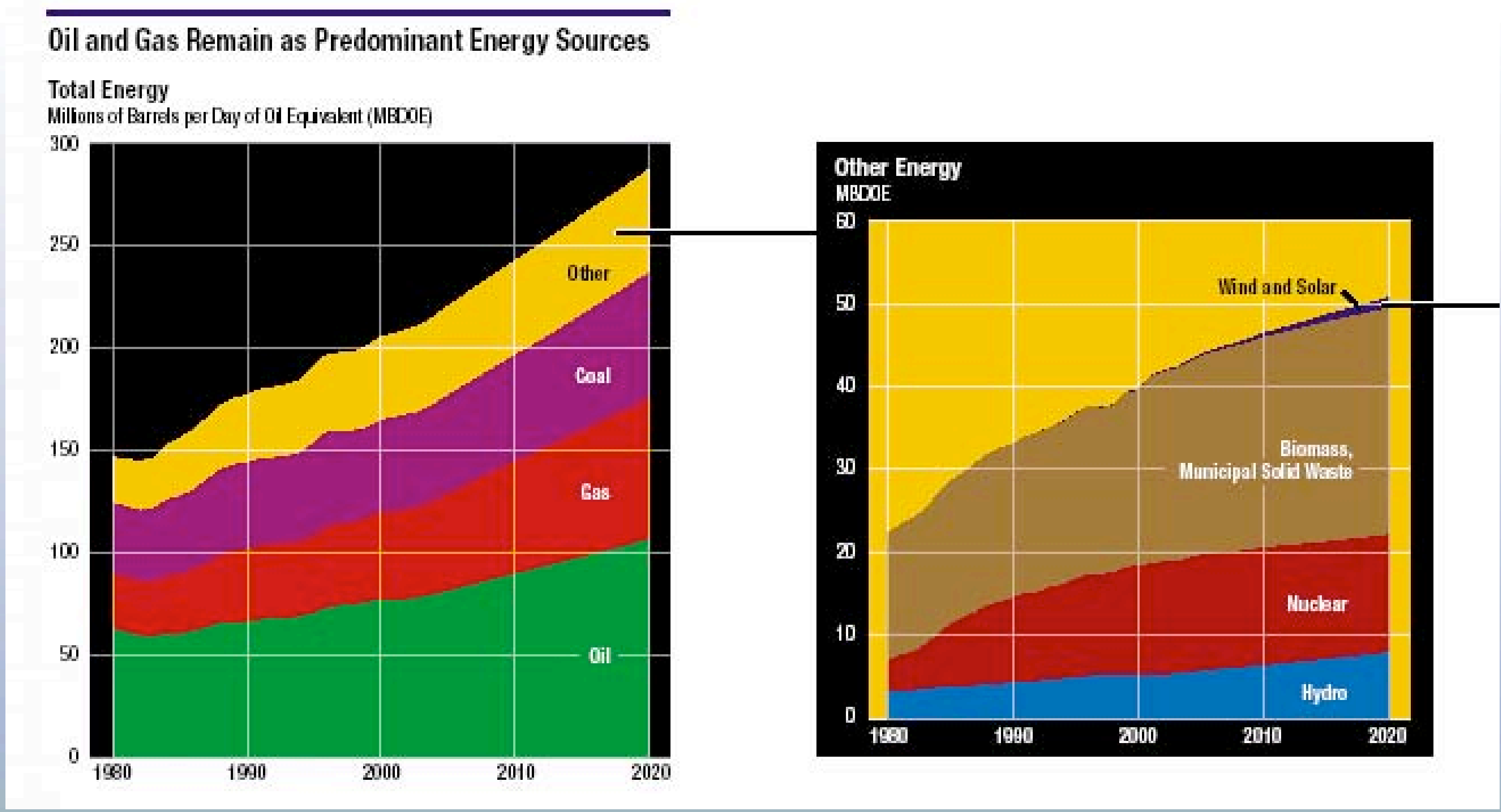
Drivers and Basis for Secure Earth Initiative

The Drivers and Basis for Secure Earth

- *Provide urgent solutions to secure U.S. economic and environmental stability*
  - *Address key critical crosscutting problems that are preventing significant progress in solving energy and environmental issues.*
  - *Quantum leaps to achieve breakthroughs in science and technology*

Energy outlook and supply

http://www.exxonmobil.com/corporate/Citizenship/Corp_citizens



Carbon Emission Growth to 2020

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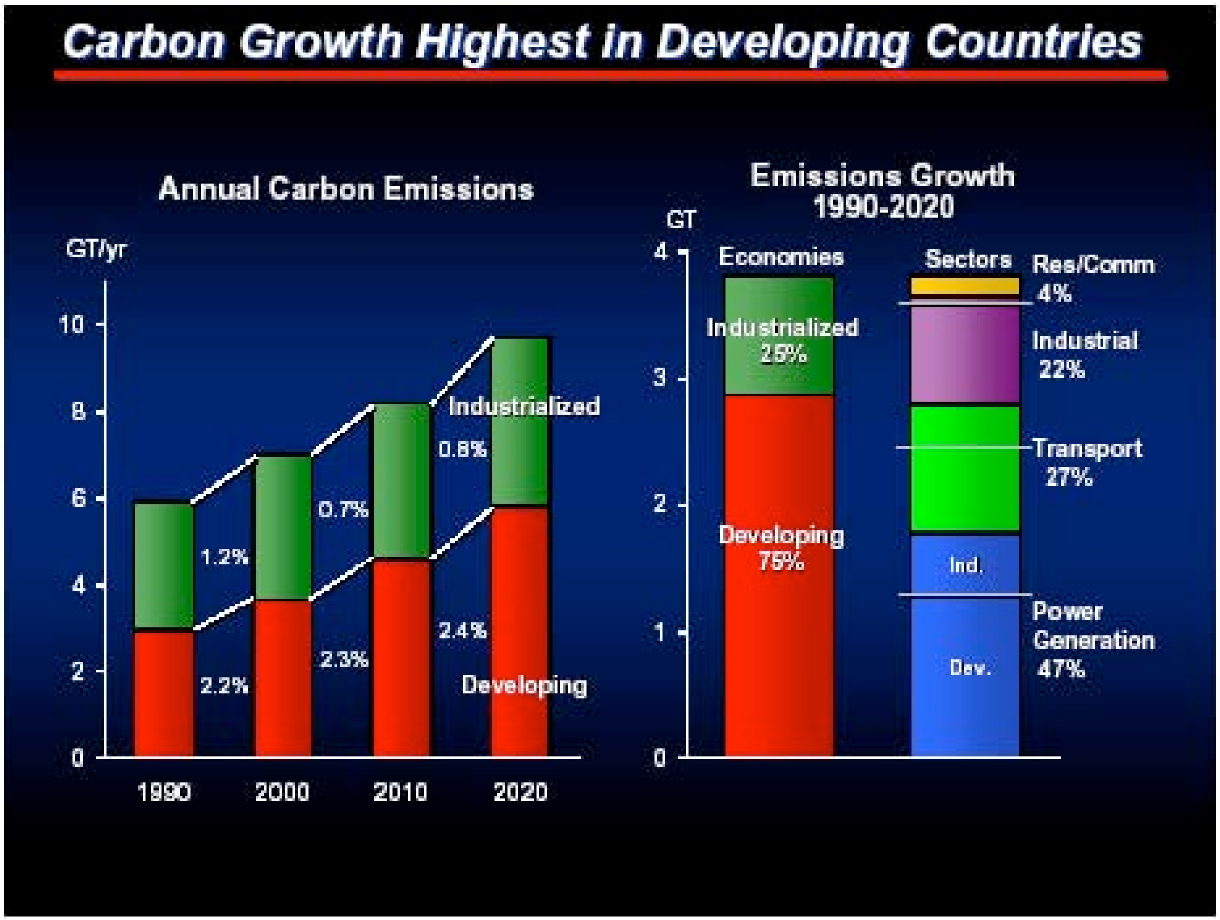


Over 1990-2000 emissions are expected to grow by about 3.8 billion metric tonnes (GT), with roughly 70% of that growth (or 2.7 GT) expected to occur from 2000-2020. From 2000-2020, an even higher share (80%) of the carbon growth will occur in the developing countries.

Energy Outlook

http://www.exxonmobil.com/corporate/Citizenship/Corp_citizens

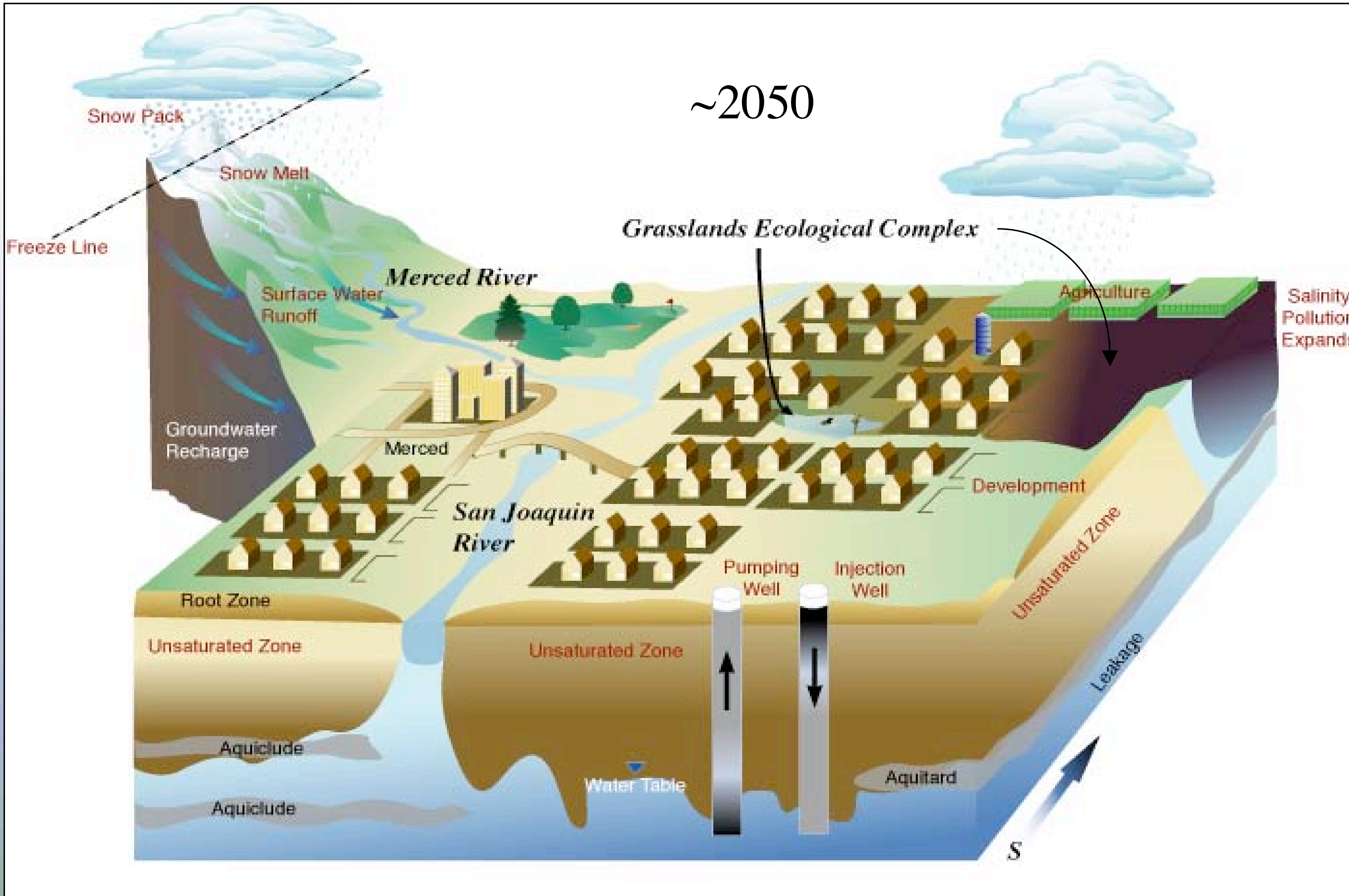
- ***Worldwide energy-demand growth is a key enabler of and closely linked to economic growth. By 2020, the world will need close to 40% more energy, primarily due to increased energy use in less-developed countries, primarily oil and gas, will impact carbon emissions, and investments($200B/yr)***

- ***Renewables will grow quickly, supported by government subsidies, but will contribute only a small fraction of energy supply.***

- ***Meeting this growing demand will require access to resources, technology advances, timely development and the cooperation of host governments.***

- ***We need groundbreaking research to develop a portfolio of energy options. We remain committed to investment in proprietary research.***

Environmental security



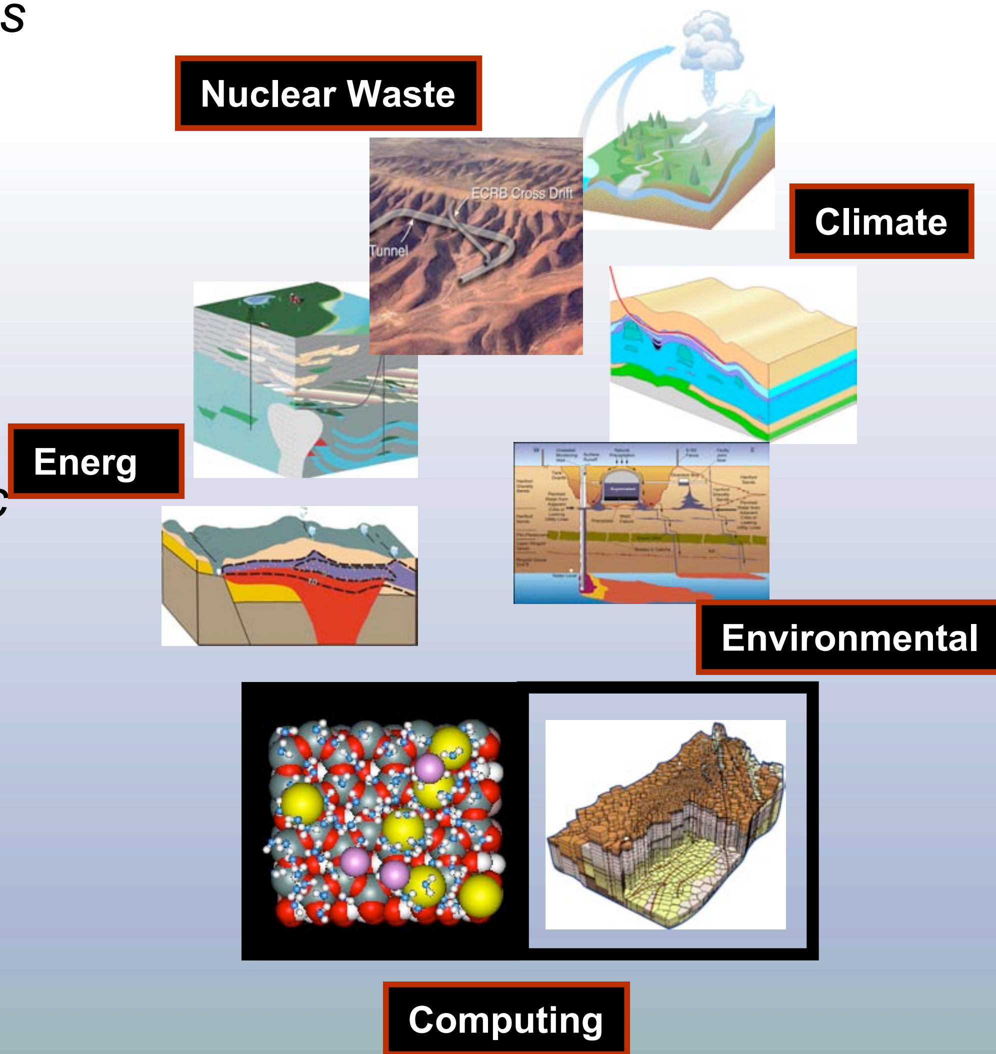
PNNL Slide

Environmental Issues

- ∀ • Need much better understanding of subsurface processes
- ∀ • Develop engineering technology for manipulation of flow patterns, geochemical reactions and ecological processes
- ∀ • Prepare for adverse impacts of natural attenuation by monitoring, process understanding, conceptual and numerical modeling
- ∀ • Understanding of complex geochemical and microbiological processes (organic and inorganic complexes with radionuclides, mercury, heavy metals, and other contaminants)

Secure Earth Summary

- *Focus on critical National needs in energy supply and environmental quality*
- *Initiatives build upon strengths and facilities*
  - *Imaging, computation, fundamental science*
  - *NERSC, JGI, ALS, SNS etc*
- *Link with DOE Initiatives*
  - *Nanosciences*



Scientific Thrust

Long Term Goals:

Develop fundamental understanding of crosscutting, complex, coupled processes that will permit imaging and manipulation of the subsurface for improved management and exploitation

- **Sustainable resource development (water, fossil fuels CO_2 Sequestration, Geothermal)**
- **Environmental remediation**
- **Safe nuclear waste disposal**

Build on Current Research , Not Replace

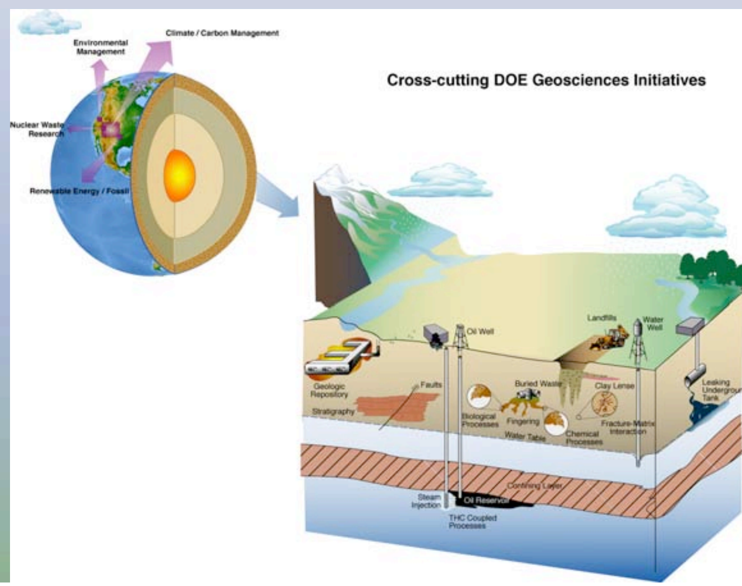
Multi-disciplinary

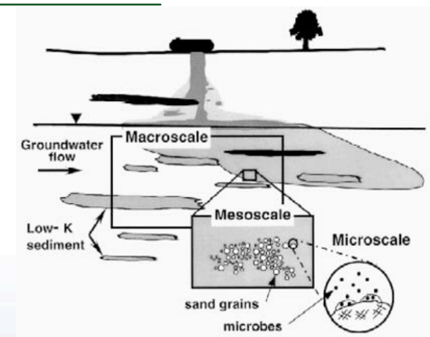
Crosscutting

User focused

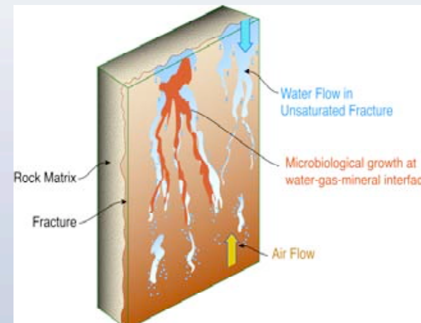
Science Driven

Integrated across theory and practice

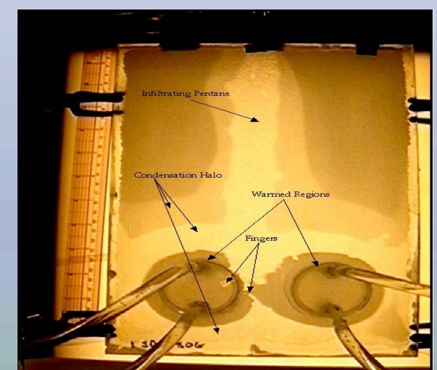




Scaling



Process Prediction



Ecosphere Manipulation

Science Goals–quantitatively predict & manipulate subsurface processes

<u>Barriers to Subsurface Science – we need to know:</u>

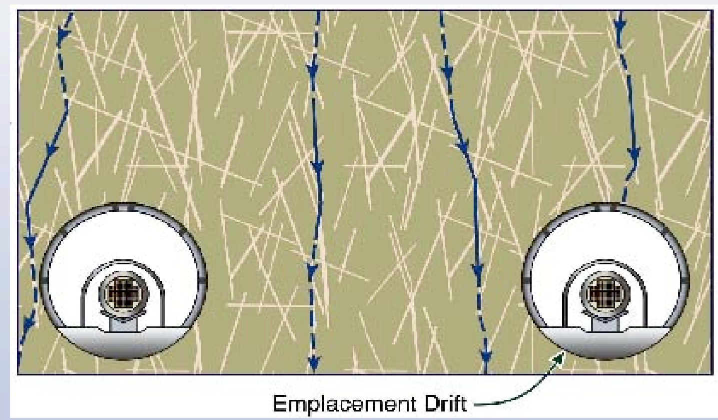
1. *Where are the fluids and what concentration?*
2. *What processes are controlling fate & transport?*
3. *How are coupled processes expressed at different scales and complexities?*
4. *How to study processes non-invasively?*
5. *Are discrepancies between modeled and measured properties due to measurement uncertainties or errors in conceptual models?*
6. *How to revolutionize subsurface data acquisition, information management, and critical knowledge distillation quickly and at low cost?*

Major Obstacles – Energy production

- *Accurate location and identification of fluids (fluid imaging)*
  - *Phase and partitioning (oil, gas , brine, steam, etc.)*
  - *Quantity*
  - *Transport mechanisms/rates*
- *Efficient extraction*
  - *Drilling efficiency and location*
  - *Drilling hazards*
  - *Borehole life*

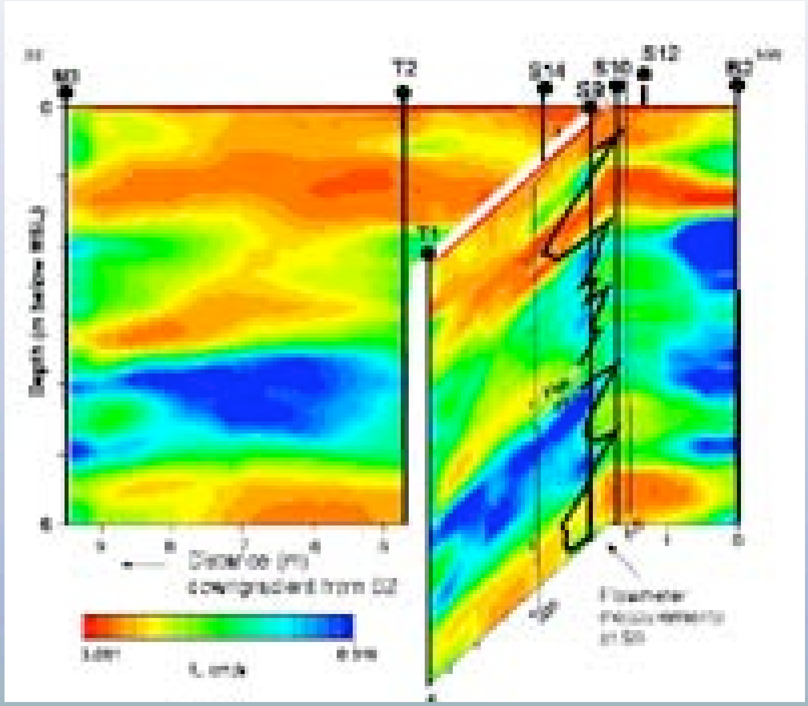
Major Obstacles – Nuclear Waste Disposal

- ***Accurate location and identification of fluid transport mechanisms and pathways***
  - ***Fast pathways versus matrix transport***
  - ***Quantity of fluids***
  - ***Transport/Retardation mechanisms***
- ***Long term prediction of System response due to perturbation of the natural system***
  - ***Effect of thermally driven coupled processes due to radioactive heat output from waste packages***



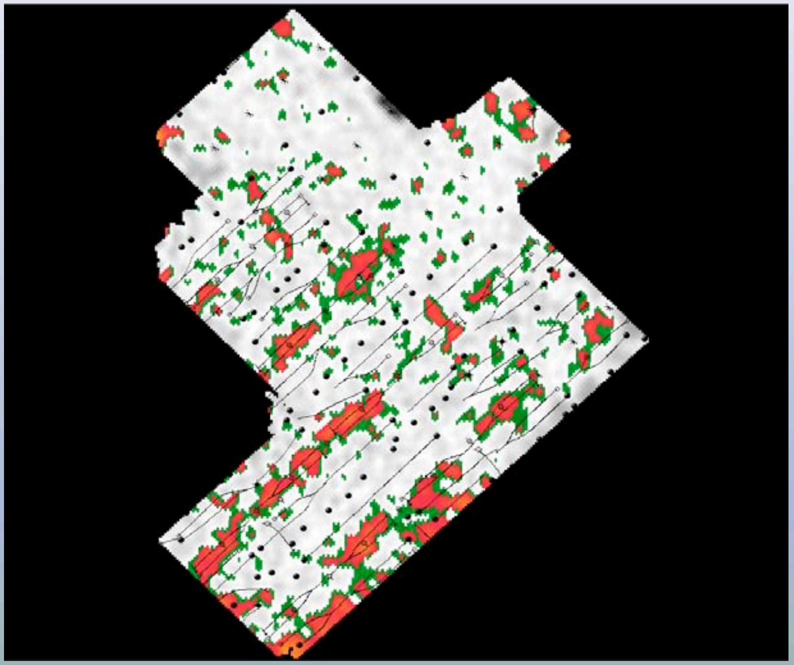
Major Obstacles – Environmental Remediation

- *Accurate location and identification of fluids and contaminants*
  - *Phase and partitioning (DNAPL, water, gas , metals, RN,. etc)*
  - *Relative quantities*
  - *Transport mechanisms*
- *Efficient extraction and/or remediation*
  - *Manipulation of physical chemical and microbial conditions*
  - *Coupled processes understanding*
- *Long term performance*
  - *Leakage/containment*



Major Obstacles – CO_2 Sequestration

- Accurate location and identification of CO_2 and transport mechanisms
  - Phase and partitioning (oil, gas , brine, CO_2, etc)
  - Leakage paths and rates
- Efficient and cost effective containment
  - Total volume and rates of injection
  - Borehole/ reservoir life
  - Monitoring requirements



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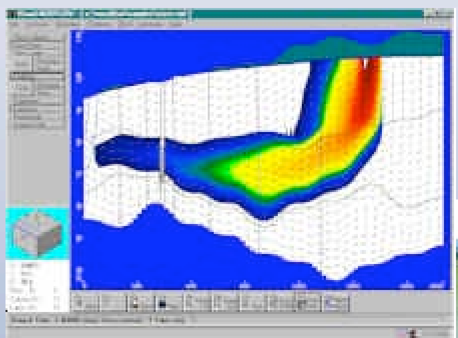
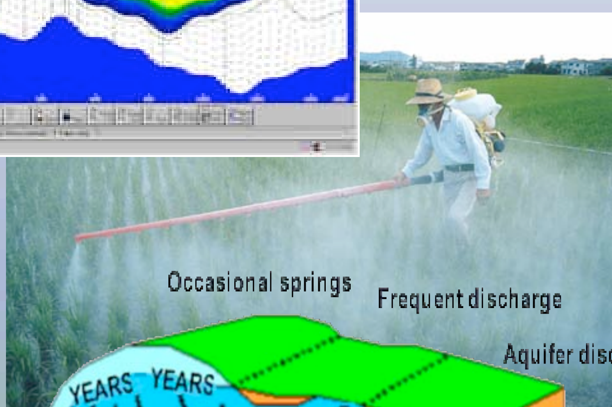
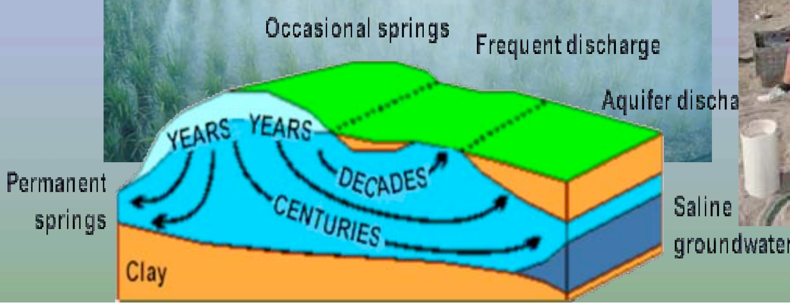
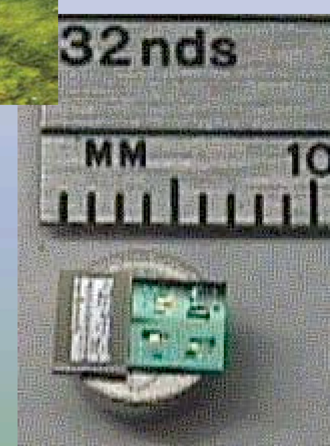
Crosscutting Obstacles

- *Next generation **sensor** development and emplacement*
- ***Imaging** and multi-scale, multi-sensor data integration*
- *Model **prediction** of processes over various length and time scales and **uncertainty** quantification*
- ***Ecosphere manipulation** for sustainable resource development and environmental remedation*









Crosscutting roadblocks in geosciences – Characterization and Predictive Models

- *Natural heterogeneity*
  - *Sensing and imaging systems ("seeing into the earth" with resolution)*
  - *Environmental system properties and dynamics (e.g. fracture flow)*
- *Scaling*
  - *Fracture systems*
  - *Sensing/imaging and modeling (support volumes)*
  - *Conceptual models*
- *Multi-property and coupled process interactions*
  - *Appropriate and adequate theory*
  - *Accurate constitutive equations and parameters*
- *Sensors and data management*
  - *New acquisition capabilities, processing and interpretation of data (e.g. data to information to knowledge)*
  - *Computation and simulations (keeping models "evergreen")*

SECURE Earth Science Strategies

- ***Exploit <u>Enabling Technologies</u> already developed***
  - *Field Research Sites (key data)*
  - *Mesoscale and bench top laboratory facilities (experiments that offer new insights)*
  - *Advanced analytical techniques (to understand chemical and biological processes at the molecular level)*
  - *Comprehensive simulation and new modeling tools*
  - *Visualization and advanced physics-based inversion and computational tools (NSF-CenSSIS)*

Implementation

Societal Goals – Subsurface Science

- *<u>Short term:</u> develop science-based models to forecast subsurface events and consequences – those that affect human safety and lifestyle – knowledge of the consequences of our actions*

- *<u>Long term:</u> beyond prediction, the ability to control events and mitigate extreme scenarios – improve humanity's chance of maintaining a sustainable future*

- *<u>Very-long term:</u> ameliorate our condition on the Earth – develop engineered or alternate natural systems and environments*

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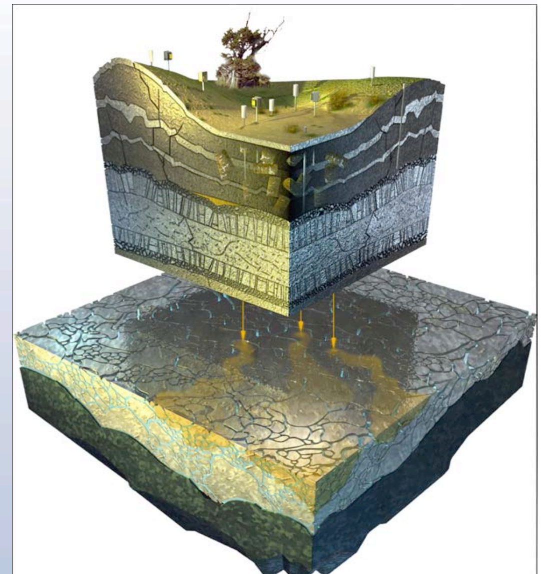
Fact: Current approach slow to develop & deploy solutions

- *Curiosity-driven approach*
- *Principal/single investigator team*
- *Insufficient breadth or scope*
- *Processes are complex and coupled*
- *User/Science community collaboration not involved in defining problem-solution*

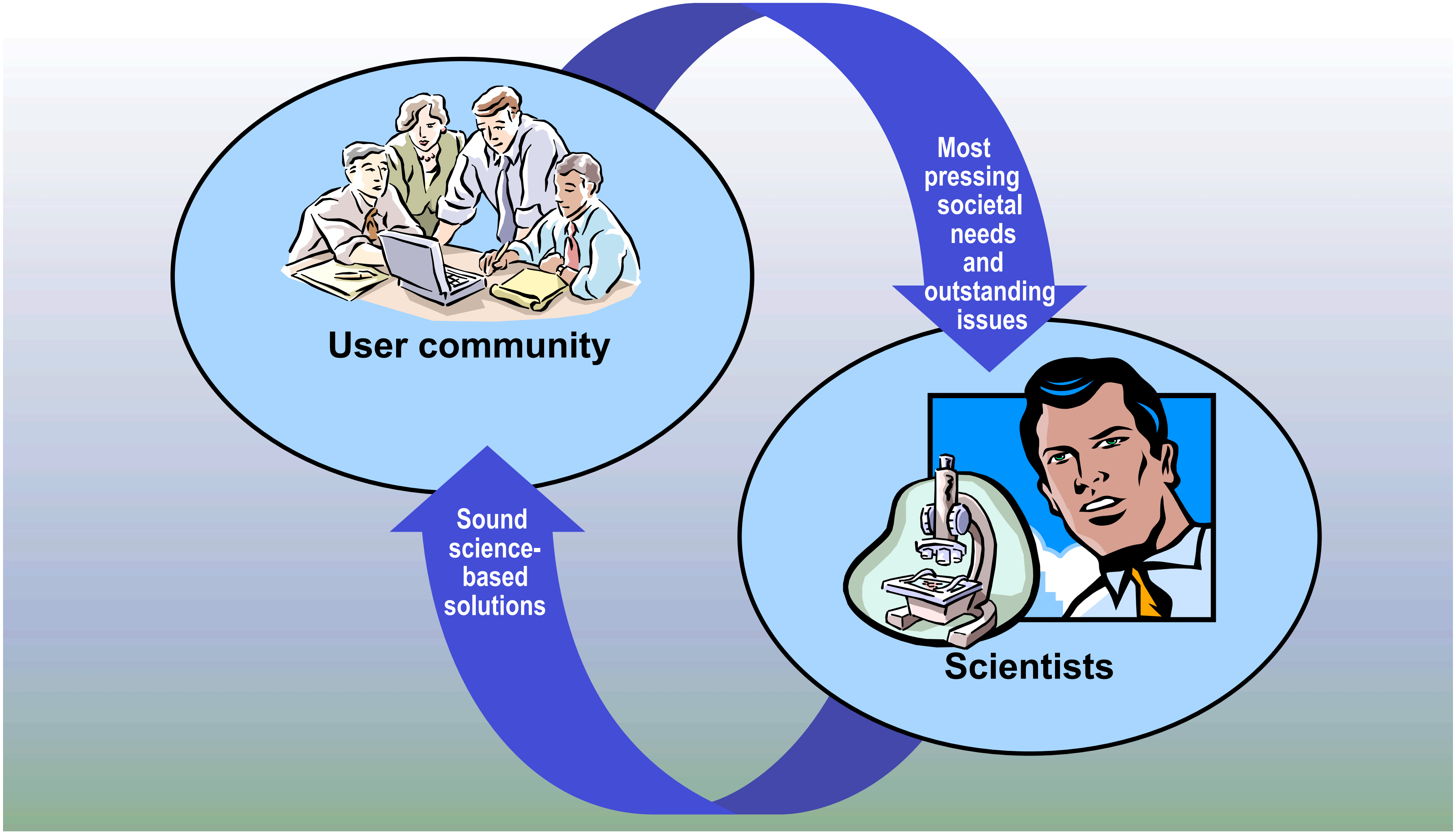


Solution focused research program needed

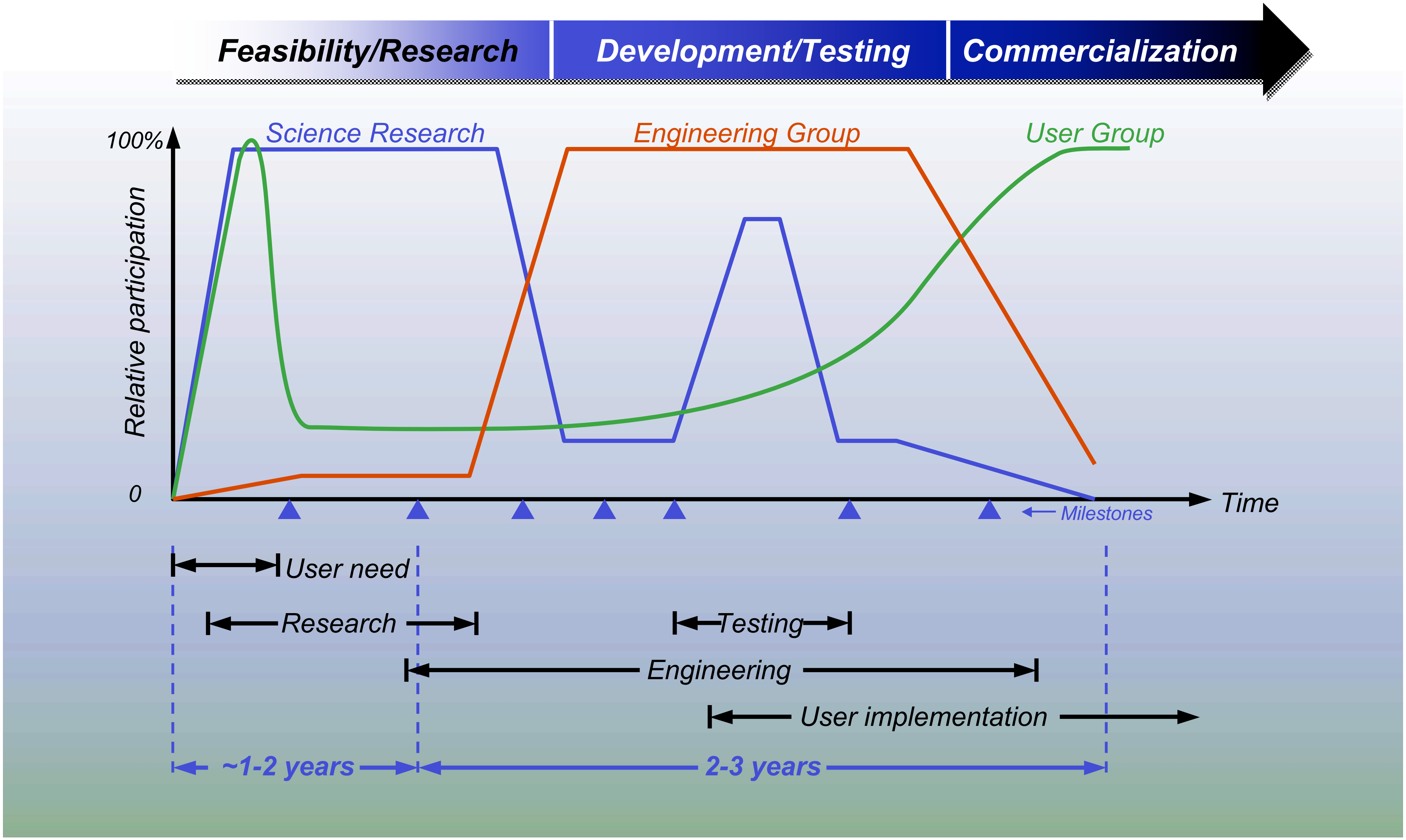
- SECURE Earth – Science driven
- SECURE Earth – User focused
- SECURE Earth – Multi-discipline research
- SECURE Earth – Cross-cutting research themes
- SECURE Earth – Integrated across theory & practice

"Science-driven research must efficiently produce the end-products that are needed by society" EOS 1/20/04

Synthesis of knowledge: better solutions under SECURE Earth



Solution Development Process



Complementary Initiatives

- *Consortium of Universities for the Advancement of Hydrologic Science, Inc (CUAHSI) – NSF (plan/ops: $2-8M/yr and $20M for 2 hydrological observatories)*
- *EarthSCOPE – NSF/NASA ($40-60M/Yr)*
- *Global Water Cycle (GWC) $311 M (2003) NSF/NASA*
- *Energy~Water Nexus*
- *SECURE Earth*

- *Advance hydrologic sciences*
  - *Hydrologic observatories*
  - *Water supply, floods/droughts, ecology*
- *Dynamic geosystem monitoring*
  - *Hazard evaluations*
- *Global water cycle trends*
  - *Basis for regulations*
  - *Flood control, irrigation*
- *Water impact on energy security*
  - *Power, NE/Gen-IV, and Hydrogen*
- *Understand and manipulating subsurface processes*

Program Infrastructure Considerations

- *Evaluate objectives, direction, and success*
- *Input to funding agencies – science community needs*
- *Foster interagency coordination*
- *Funding coordination*
- *Define new program research objectives*
- *Coordinate reporting and review processes*
- *Coordinate research centers and partnerships*
- *Facilitate science integration and technology implementation*
- *Develop and foster education and outreach activities*
- *Promote national and international partnerships – including other complementary initiatives*
- *Conduct workshops to review state-of-the-science and new research directions*

Lessons learned

- *Even at small scales, we cannot adequately predict many processes*
- *Most progress was made using an interdisciplinary team with diverse interests*
- *Most productivity occurs with a mix of hypothesis-driven science focused on a clear application*
  - *Theory, lab/mesoscale, and field investigations*
  - *Manipulation and process-driven research*
- *Research almost always limited by data density (sampling issue) and adequate understanding of coupled processes*
- *Typically resort to deterministic and/or statistical solutions*
- *Always limited by limited (inadequate) theory and technology (need to find ways to overcome these limitations)*

SECURE Earth response

- *Identify process that will pick the critical challenges – those that will lead to the most impact when solved*
- *Process adopted will identify critical roadblocks at each level (system-level, enabling technology level, and fundamental science level) as well as research pathways*
  - *Define work from beginning to end: needs, research, technology development, and user implementation*
  - *Specify how work will be done, not just what will be done*
  - *Specify a productive mechanism that will not hinder creativity*
  - *Recognize that some work solutions are fundamentally impossible*
- *Implement research results*
  - *Appropriate scientific oversight*
  - *Adequate resources*
  - *Involve user community*

What Do We Need To Do?

- *Identify well defined, crosscutting research areas that will clearly have major impacts.*
- *Package these initiatives so that they are readily understood and explained by policy makers.*
- *Define focused-project/program elements and their interrelationships.*
- *High-level champions: Have agency Program Directors write letters of support to the Office of Science.*
- *Congressional delegation brief.*

Need buy in and support by entire Geosciences community

Summary: Roadmap to Implementation

- *Initiated series of problem-defining workshops - 2003*
- *Formed Advisory Committee - 2004*
- *Present concept to NRC workshop to target agencies – 7/12/04*
- *Organize series of workshops on defining critical crosscutting issues - 2005*
- *Formulate “proposal” for submittal to participating programs –*
- *NRC Study of SECURE Earth initiative -2005*
- *Initiate research teams in targeted research areas – 2005-6*

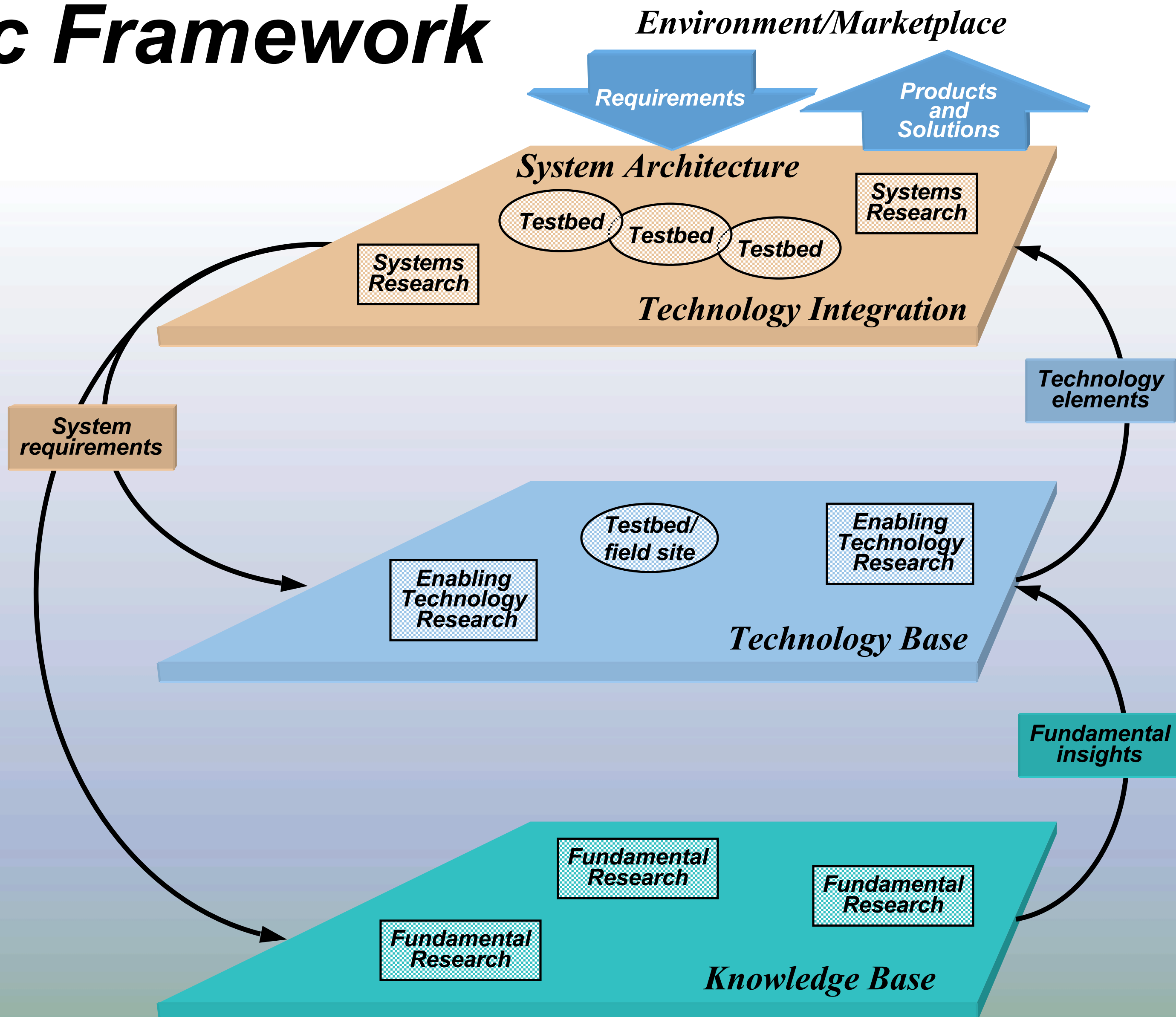
backups

Strategic Framework

Identify societal/market needs, define system and system requirements

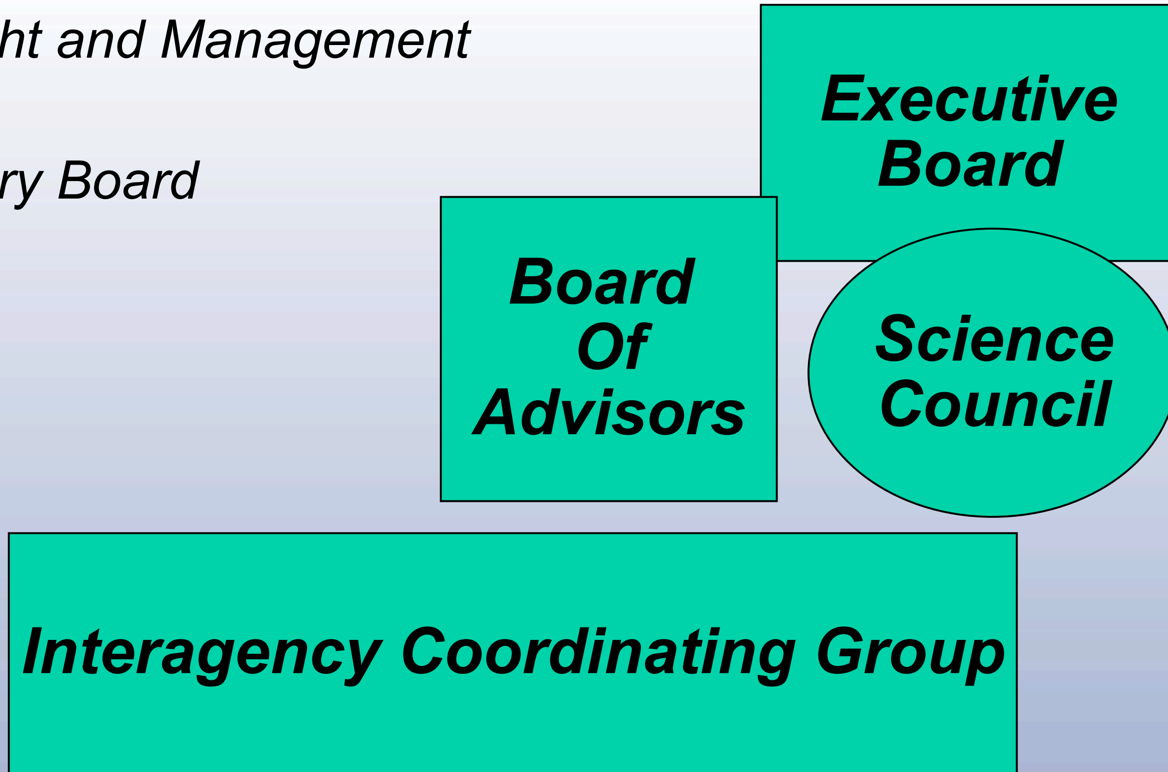
Integrate fundamental knowledge into enabling technology

Develop useful insights from fundamental knowledge



Model A: Earth Scope Model

- Core Teams – Oversight and Management
  - Board of Advisors
  - Interagency Advisory Board
  - Executive Board
  - Science Council
- Partners
  - National Agencies
  - National Labs
  - Universities
  - Industries

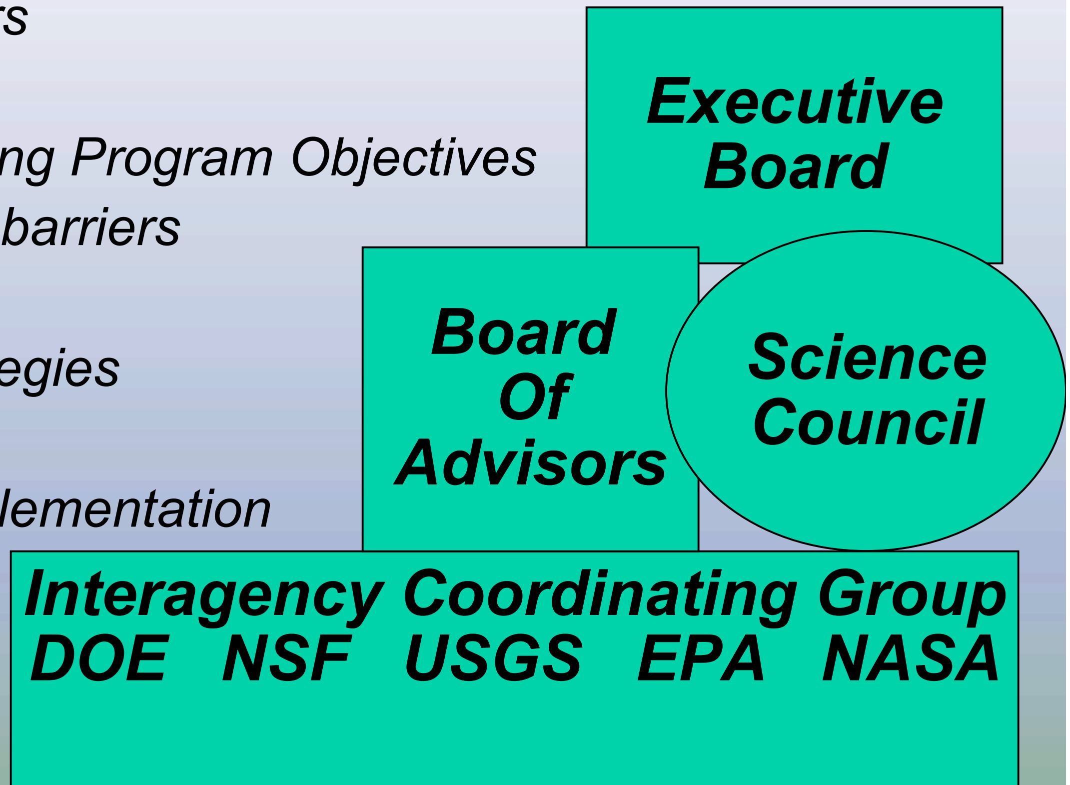


SECURE Earth Science Strategies

- ***Exploit Cross-Cutting Themes***
  - ***Scaling***
  - ***Coupled processes***
  - ***Predictions and limitations***
  - ***Measurements and data accessibility***

Concepts for Organization and Implementation

- *Define User-Research Objectives*
  - *System Level, Enabling Technology, Fundamental Research*
- *Identify/eliminate show stoppers*
  - *Workshops*
- *Identify High-Impact Crosscutting Program Objectives*
  - *Research Goals – address barriers*
  - *Potential outcomes*
- *Industrial Implementation Strategies*
  - *Science and IP issues*
  - *Process for technology implementation*



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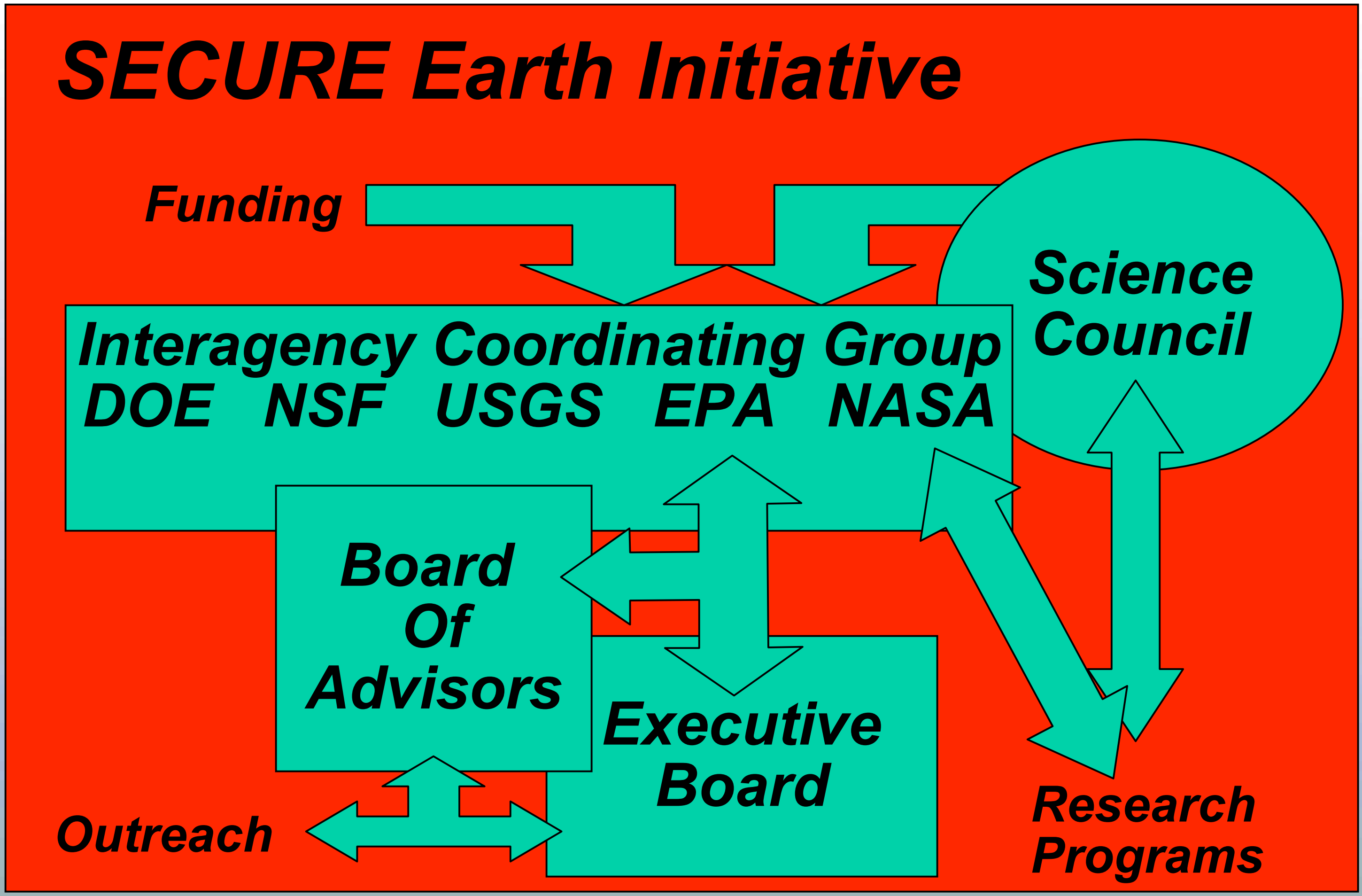

GTL Model

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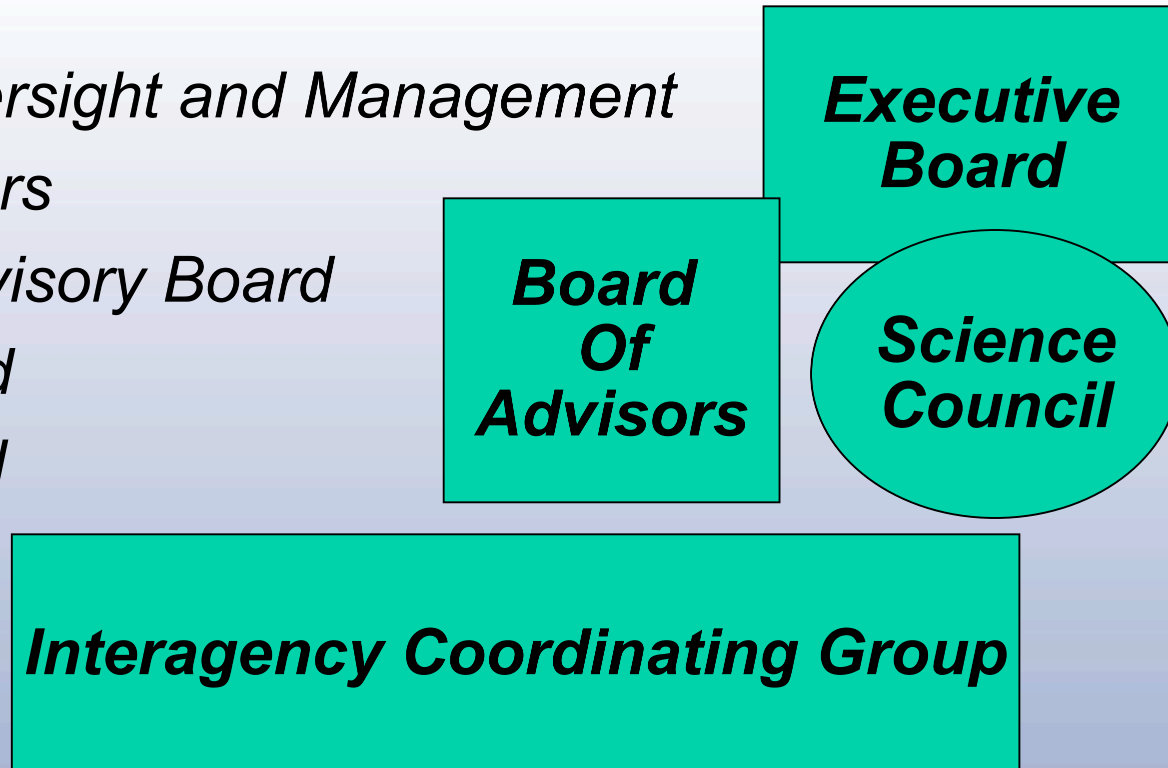
  - Interagency Advisory Board
  - Executive Board
  - Science Council
- DOE Funded



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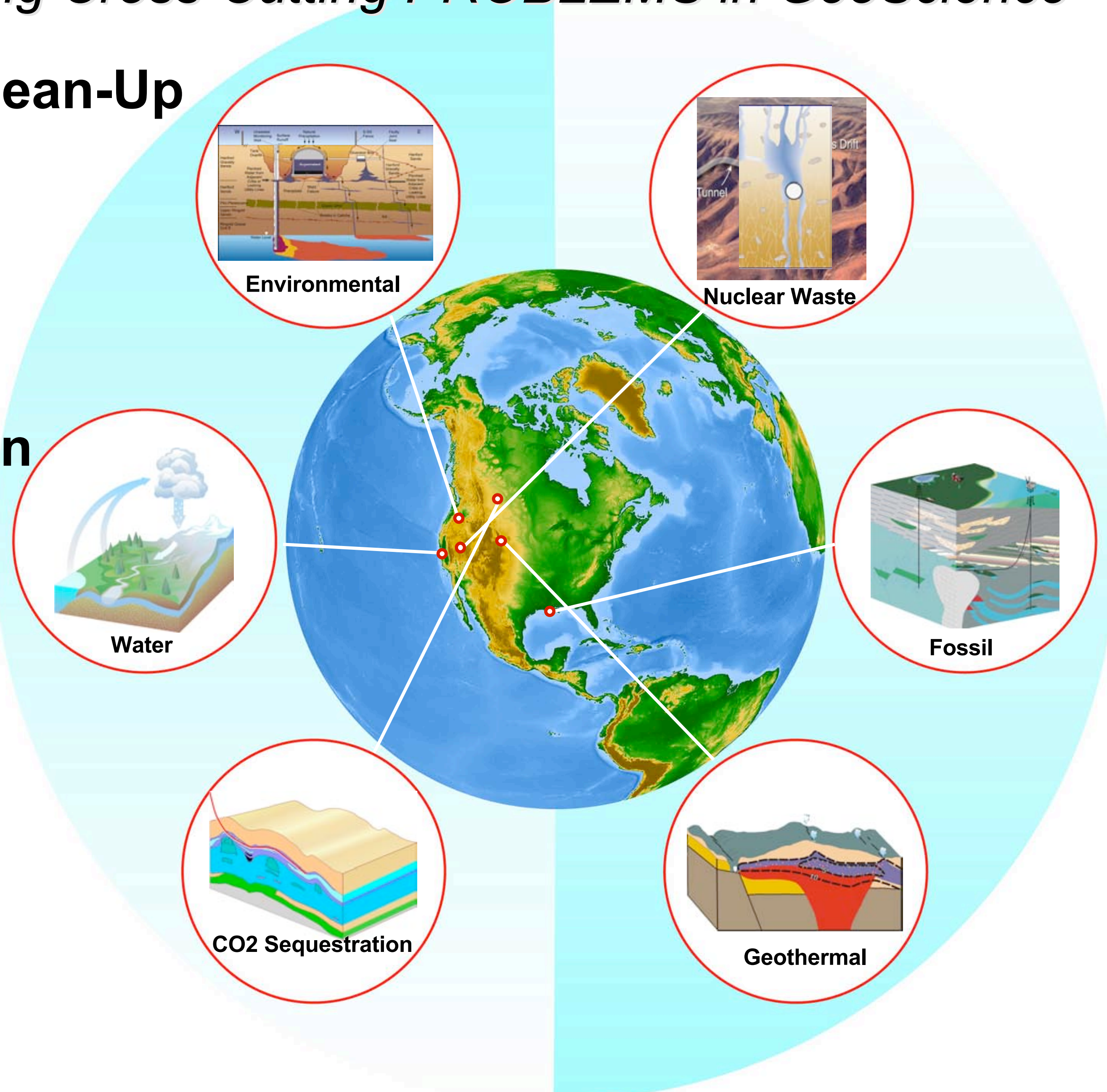


Summary

Backup Slides to reinforce inputs

I'm more concerned with the next 30 to 50 years and with 2 of the 4 horsemen of the apocalypse -- war and famine - that I believe will ride in soon. It's inconceivable to me that we will continue business a usual even for another generation. Demand for oil is just going to overwhelm everything else. The US will not be able maintain peace without wrecking its economy.

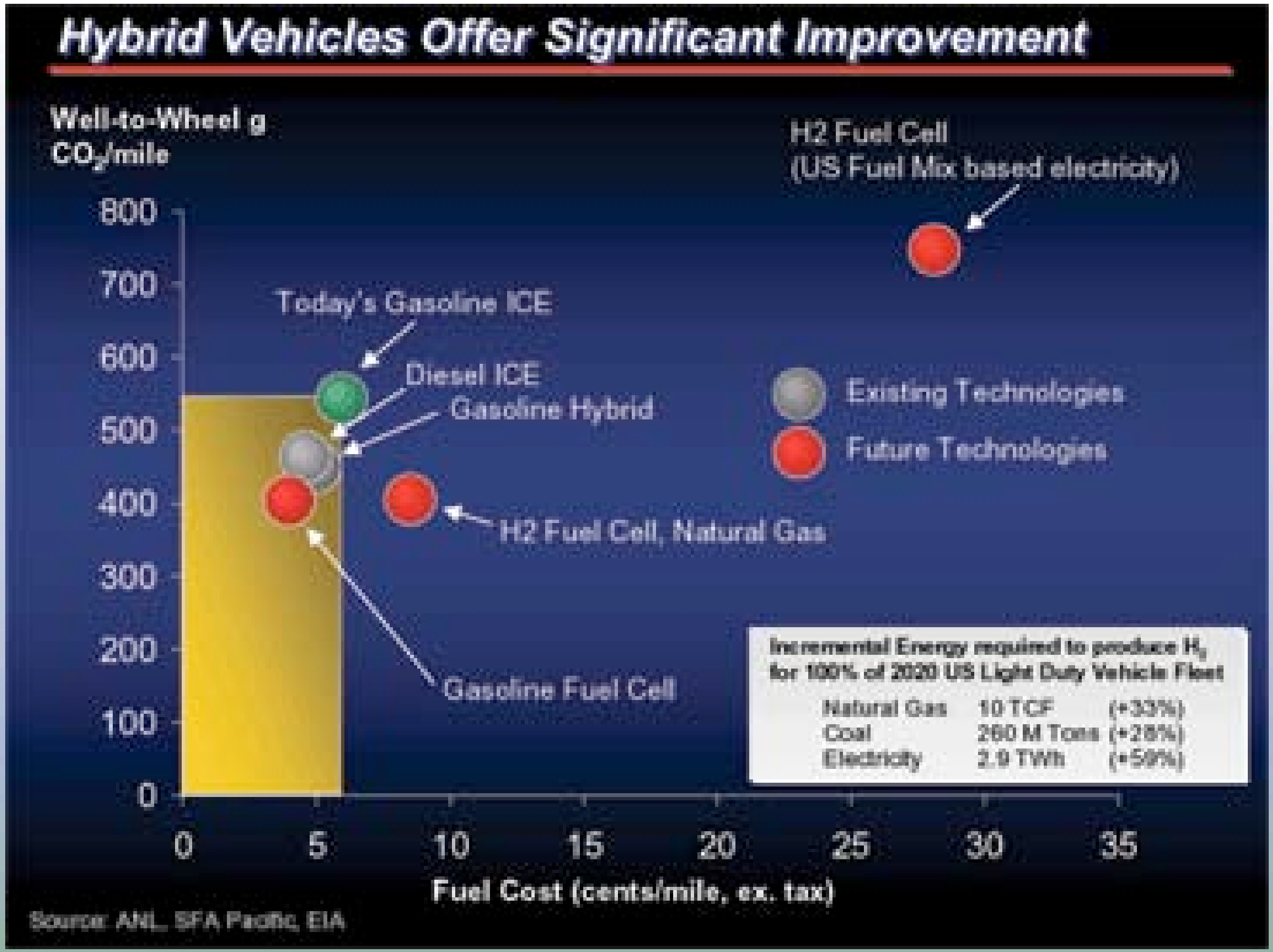
Other countries will militarize and challenge the Pax Americana to guarantee access to oil. Famine will drive Africa to bang on Europe's doors. The East, led by India and China, which will be becoming economic giants and are members of the nuclear club, will clamor for oil. Russia will try to play China and Europe off each other. Japan will get paranoid. Europe will go after something somewhere. Pity the small Asian and African countries with oil. The Middle East will become even more coveted than it is now. Maybe I'm exaggerating, but history does not give me cause to be very optimistic.

I think we have to get much smarter faster than the timescale for climate change would imply. Iran Thomas

Iran Thomas Symposium, Dec 2, 2002 Washington DC

Hydrogen, Boom or Bomb?

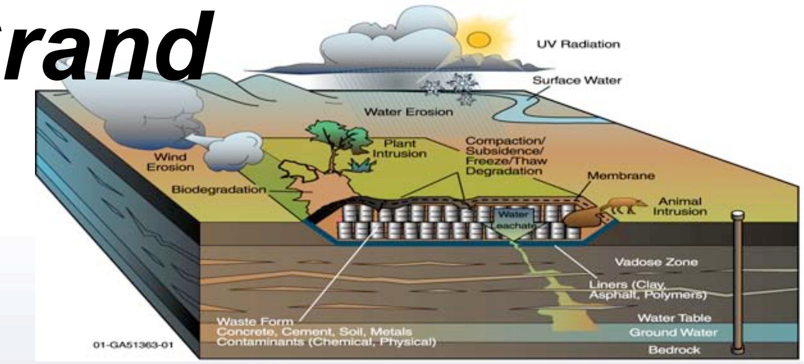
http://www.exxonmobil.com/corporate/Citizenship/Corp_citizens



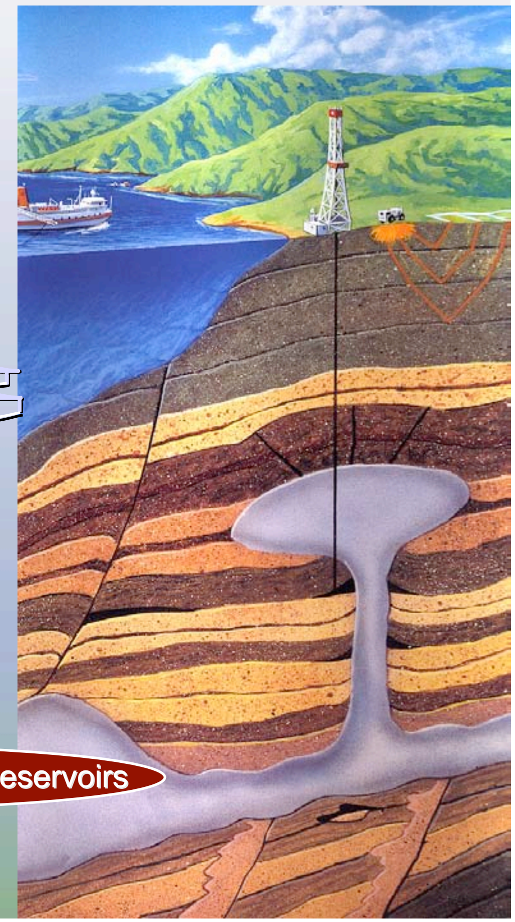
Hydrogen fuel cell vehicles represent an emerging technology with significant cost and supply barriers.

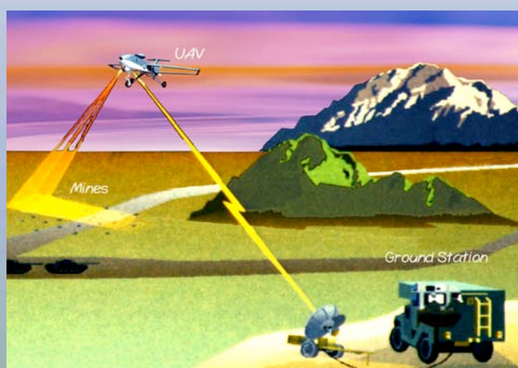
Hydrogen from natural gas offers lower emissions but at a higher fuel cost while hydrogen via electrolysis is worse on both dimensions.

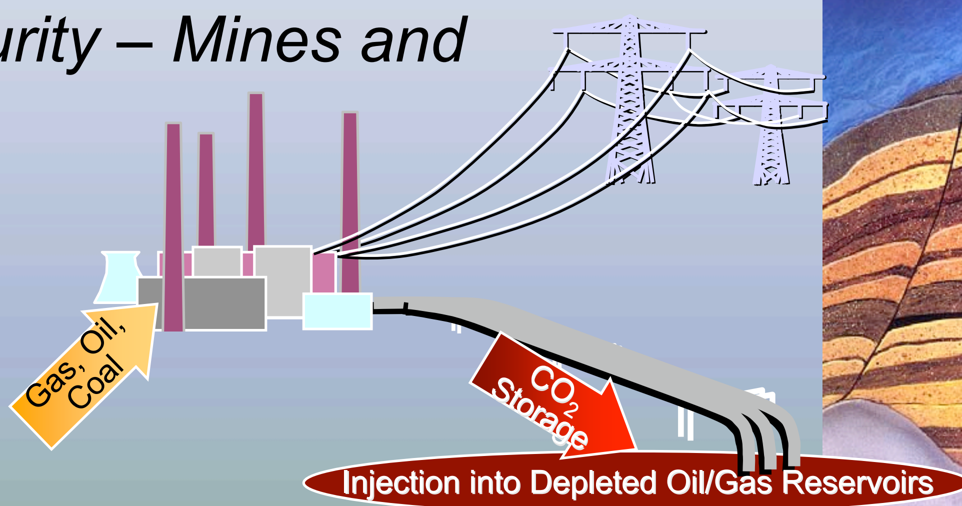
Subsurface Imaging – Grand Challenges



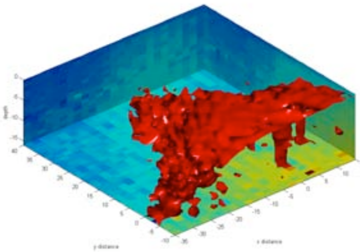
- *DOE Fate & Transport of Contaminants*
- *Resource Development – Geothermal, Oil & Gas*
- *Global Warming – Carbon Sequestration*
- *National Security – Mines and Tunnels*



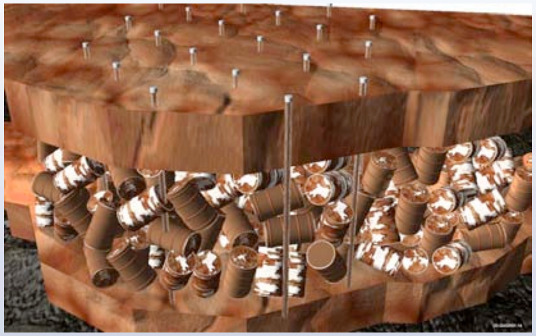




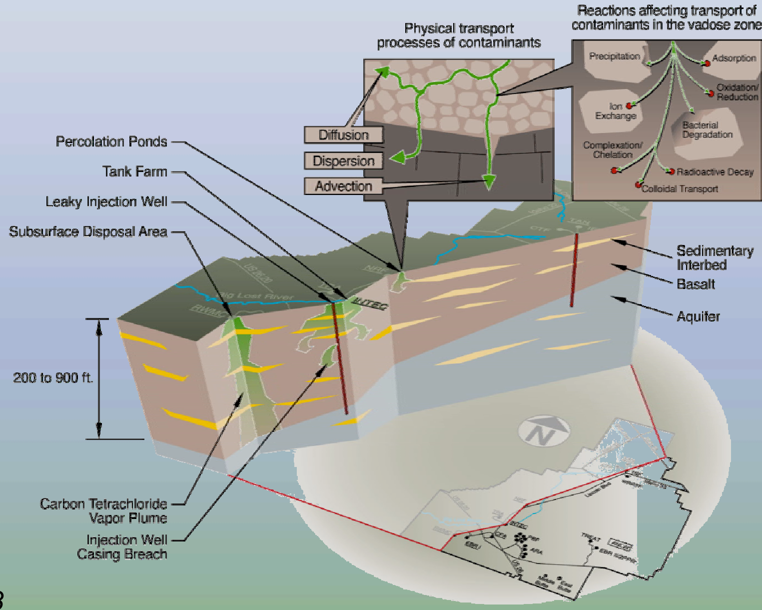
DOE's Grand Challenge: Better prediction of fate and transport of subsurface contaminants



<u>Characterization, Imaging, and Monitoring</u>

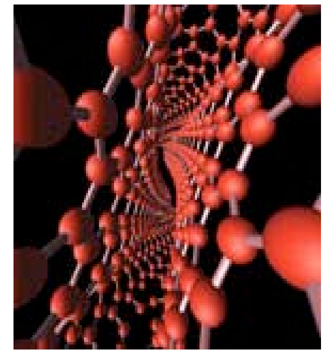


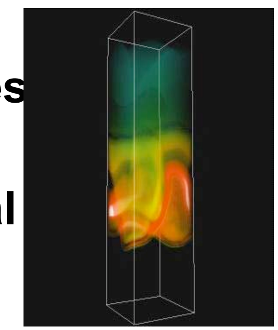
- ***<u>Characterize Waste Sources</u> – For example: buried containers under 6 to 8-ft of clay-soil (DOE-EM)***
- ***Detect and monitor <u>preferred flow paths</u> – identify fractures and inter-bed water (DOE-Office of Science, EM and environmental agencies, Oil & Gas)***
- ***Develop <u>high-resolution 4D images</u> of subsurface processes & properties (DOE-Office of Science, Long-Term Stewardship, Oil & Gas, Mining, DOD & Security Applications)***

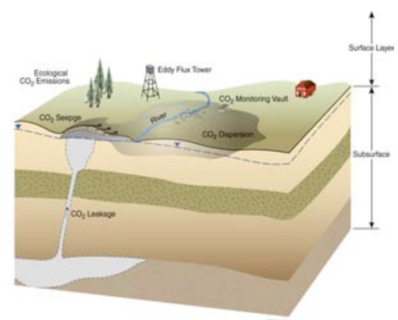


Implementation Mechanism

- Major research facilities focused on critical crosscutting issues
  - Eliminate major roadblocks for improving current and advanced energy production
  - Balance adequate environmental protection with economic growth
  - Use natural analogs for complex process understanding
- Draw on unique expertise and form critical mass through integrated "Manhattan" style projects
  - Nano-scale to macro-scale
  - Integrate diverse expertise to supply innovative and cost effective solutions







The Challenge

Breakthrough needed

Now

Vision

Bypassed production
Mis-positioned wells
Low well productivity
Expensive testing
Reserves uncertainty
Aquifer drive ??

Services - delivery vehicle

Subsurface Sensors

Integration

Reservoir Modeling

Surface sensors

70%+ recovery

Optimal well targeting

Right facilities

Minimum water production

<35%

70%

Environmental Outlook

- **Have resorted to containment rather than cleanup**
- **Current estimates of just DOE cleanup is over $300B (always growing)**
- **Water will be our most precious resource**
- **Current investments in science and technology very limited, most money spent on “cleanup”**

Current Situation

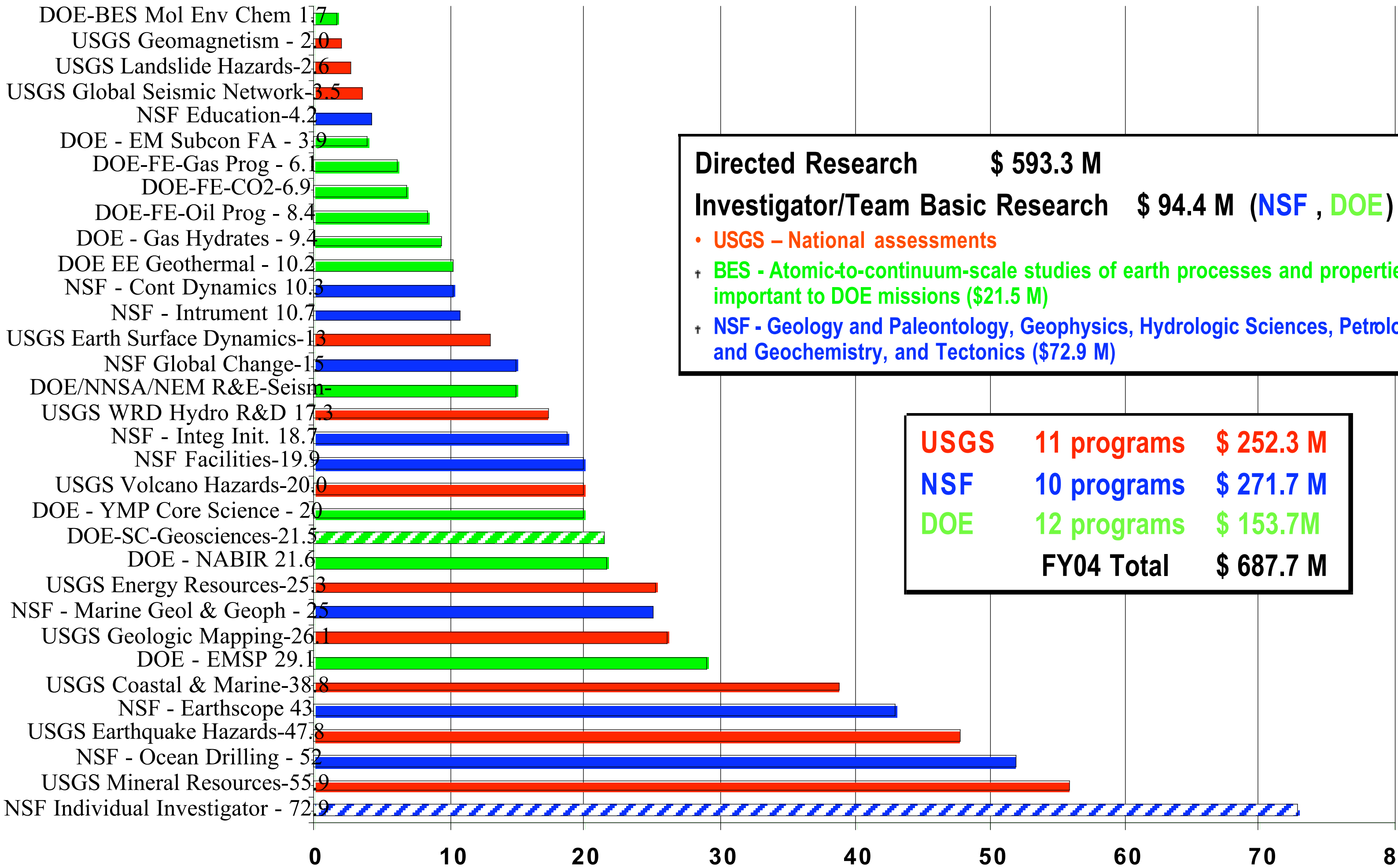
- Even at small scales, we cannot adequately predict many processes
- Most progress was made using an interdisciplinary team with diverse interests
- Most productivity occurs with a mix of hypothesis-driven science focused on a clear application
  - Theory, lab/mesoscale, and field investigations
  - Manipulation and process-driven research
- Research almost always limited by data density (sampling issue) and adequate understanding of coupled processes
- Typically resort to deterministic and/or statistical solutions
- Always limited by incomplete (inadequate) theory and technology (need to find ways to overcome these limitations)

SECUREarth

urgent solutions to secure earth's future

Scientific Environmental/Energy Cross-Cutting Underground Research

FY 2004 National Research Programs in Geosciences



Directed Research $ 593.3 M

Investigator/Team Basic Research $ 94.4 M (NSF , DOE)

- USGS – National assessments
- BES - Atomic-to-continuum-scale studies of earth processes and properties important to DOE missions ($21.5 M)
- NSF - Geology and Paleontology, Geophysics, Hydrologic Sciences, Petrology and Geochemistry, and Tectonics ($72.9 M)

USGS	11 programs	$ 252.3 M
NSF	10 programs	$ 271.7 M
DOE	12 programs	$ 153.7M
	FY04 Total	$ 687.7 M

Basic Energy Sciences