PRIME WORKSHOP

A LONG-TERM E&P INITIATIVE

October 23, 2001
Houston, Texas

Sponsored by:
National Petroleum Technology Office
National Energy Technology Laboratory
U.S. Department of Energy

PRIME WORKSHOP

Disclaimer

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EXECUTIVE SUMMARY

The U.S. Department of Energy's Office of Fossil Energy, through the National Energy Technology Laboratory and the National Petroleum Technology Office, sponsored a workshop on the PRIME Program, a new DOE initiative focused on longer-term, higher-risk basic research on new concepts and/or approaches for exploration and production technology. The workshop's purpose was to get industry input on R&D needs and opportunities in order to facilitate public-private partnerships that provide the public with the economic and energy-security benefits of improved domestic oil production. The workshop, held October 23, 2001 in Houston, Texas, convened over 60 technology developers and users from industry, academia, and the DOE national laboratories.

BACKGROUND

The PRIME (Public Resources Invested in Management and Extraction) Program received initial funding in Fiscal Year (FY) 2002. It emphasizes longer-term, higher-risk research, with the goal of reducing costs, risks, and environmental impacts associated with finding and producing U.S. petroleum resources. Key characteristics are as follows:

- Fundamental applied research;
- 5-10+ year timeframe for the expected R&D products;
- Breakthrough technologies, either entirely new systems and approaches or radical changes to existing systems and approaches;
- Collaboration among industry, universities, national labs, and others; and
- Minimum non-DOE cost sharing of 20%.

The FY 2002 appropriation is $4 million, as initial seed funding for a planned 10-year minimum sustained program effort. There are three program areas: enhanced oil recovery; reservoir characterization and advanced diagnostics and imaging systems (ADIS); and drilling, completion, and stimulation.

WORKSHOP PRODUCTS

The workshop was composed of a plenary session and three smaller work-group sessions. The plenary session covered the PRIME Program areas and a non-DOE perspective by a university bureau director on future industry needs and directions. The three work groups ran in concurrent sessions, with one group each for enhanced oil recovery; reservoir characterization and ADIS; and drilling, completion, and stimulation. Each group addressed the same basic questions.

- What are the barriers and issues to meeting the goals of the PRIME Program?
- What are the R&D opportunities that can overcome these barriers?
- For high-priority areas of R&D, what are the R&D products, resources (dollars, expertise, time, facilities), and collaborations needed to implement the R&D?

In addition to defining R&D areas of opportunity, the work groups also identified a series of key crosscutting issues that relate not simply to the PRIME Program, but to general public-private collaborations. Figure 1 summarizes the results of the three work groups.

THE PATH FORWARD

With FY 2002 as the first year for PRIME Program funding, the workshop products will enable a solid foundation for successful public/private partnering:

- ♦ Guiding program implementation along high-value paths to maximize the impact of the available R&D dollars;
- ♦ Facilitating proactive work with industry, academia, and others on underlying crosscutting issues such as the development and maintenance of critical R&D resources, particularly personnel and laboratory resources; and
- ♦ Applying the results to enhancing the Oil Program mission of increasing domestic exploration and production; enhancing effective stewardship of Federal lands; partnering with independent producers; and facilitating longer-term, higher-risk R&D.

Figure 1. Overview of Workshop Results

In the immediate future, the workshop contributes directly to FY 2002 acquisition planning and the selection of the initial projects in the program's R&D portfolio. Longer term, building upon this portfolio can contribute widespread benefits to industry and the nation's energy security.

I. PRIME: A LONG-TERM E&P INITIATIVE

A. INTRODUCTION

The Department of Energy's Fossil Energy Oil Program plans to initiate a fundamental R&D program in exploration and production technologies during FY 2002. This Public Resources Invested in Management and Extraction Program, PRIME, will focus on longer-term, high-risk research activities emphasizing new concepts and/or approaches that may lead to significant advancements in the state-of-the-art over the next 10 years by reducing costs, risks and environmental impacts associated with finding and producing U.S. petroleum resources. This new initiative differs from the current Fossil Energy Oil Program in that it stresses high-risk research which may require multiple years to develop from the concept phase. Such R&D activities warrant the longer-term investment of resources from which one to several breakthroughs may result in significant advancements in our understanding and subsequent development in technologies applicable to petroleum exploration and production. It is envisioned that a teaming of expertise from academic, private research organizations, and state and federal agencies in collaboration with industry may be needed to focus efforts on overcoming key scientific and engineering hurtles.

This initiative will focus longer-term fundamental R&D in the following broad areas:

- Enhanced oil recovery,
- Reservoir characterization and advanced diagnostics and imaging systems, and
- Drilling, completion, and stimulation technologies.

A general description of each of these broad areas follows with some suggested R&D activities that may be applicable to the goals of the PRIME initiative that are outside current Oil Program activities.

Enhanced Oil Recovery

The production research program has historically targeted oil reservoirs that contain around 200 billion barrels of oil that are potentially recoverable by conventional Enhanced Oil Recovery (EOR) methods. This program has been subdivided into six areas:

(1) chemical methods,
(2) gas flooding,
(3) microbial methods,
(4) heavy oil recovery,
(5) novel methods, and
(6) reservoir simulation.

Each area addresses one or more specific portions of the resource base. However, new technologies and concepts are being developed so there may be new areas which do not fit into the present EOR methods. This initiative is to focus on new technologies with longer-term R&D potential (recovery processes which are only at the "idea" stage) which may help recover additional oil but are currently outside the traditional methods. For example, research areas may include new chemical compounds which may recover oil but are not now available and must be synthesized based on the best available scientific knowledge. Another area may be new processes which will be directed at recovering oil left after waterflood operations but are not a subset of current EOR methods.

Reservoir Characterization and Advanced Diagnostics and Imaging Systems

The advanced diagnostics and imaging systems (ADIS) program currently includes R&D efforts in multiple technologies and methodologies that are used in various combinations during exploration and production to characterize the reservoir and more clearly quantify oil targets, and thus reduce risks and costs associated with the finding, development and production of oil resources. This program includes the development of technologies used to acquire data ranging from pore- to basin-scales. It also includes the effective integration of this information into a multi-disciplinary understanding of the oil reservoir target and associated exploration and production "keys' needed for efficient development and exploitation of oil reserves.

The ADIS program is subdivided into four areas:

(1) Geoscientific measurement, including tool development, data acquisition and analysis techniques for seismic, electrical and electromagnetic, well logging technologies, etc.;

(2) Reservoir description/characterization, including pore- to core-scale studies, fracture modeling, geomechanics, geostatistics and reservoir-specific multidisciplinary studies;

(3) Exploration research, including multidisciplinary approaches to basinal analysis using state-of-the-art technologies and concepts to develop novel exploration and development trend plays within U.S. basins; and

(4) Reservoir geologic and engineering modeling and simulation research including multi-type and multi-dimensional data access, integration and archiving.

Novel R&D approaches may fit in any of these general ADIS program areas. Examples may include science and engineering based concept or idea stage technology development that would further aid in quantifying aspects of oil reservoirs; development of increased understanding of fundamental reservoir characterization principles, processes or techniques; and the development of new methodologies or reservoir characterization.

Drilling, Completion, and Stimulation Technologies

Technologies in these areas have been focused on improving approaches that have been in the oil fields for years. Some of these technologies have been miniaturized, some have been streamlined, and others have been optimized to increase the benefits of using them. The industry is no longer concerned with straight line systems or one-dimensional solutions. The challenges of the future will take dramatic shifts from the current approach to drilling.

The PRIME Program investigates promising scientific ideas that may lead to revolutionary designs for power delivery, significant decreases in weight for drilling systems, major increases in strength and flexibility for downhole materials, robust fluids that are compatible with the most fragile environments, and accurate methods of predicting system behavior in complex situations, whether in use in the field or in research in the laboratory.

Simply drilling to the goal deep in the earth or under thousands of feet of water is not enough. Science must provide benign fluids for the oil field, rendering the operations safer without sacrificing productivity. The stimulation of producing formations to produce despite damage during drilling, creating innovative ways to stimulate some of the most complex reservoirs in the world is a critical need. Prediction, control, and monitoring from remote distances can be accomplished, whether from the surface of the water to deep into the earth or from the home office to the producing well on pristine public land.

B. WORKSHOP PURPOSE AND OUTCOMES

The purpose of the workshop was to produce recommendations for defining specific longer-term R&D needs in exploration and production within each of these three areas. Workshop participants defined the issues, opportunities, and actions needed to help achieve the R&D goals of this new initiative. The workshop results will be used to develop an action plan to serve as a framework for implementing future collaborative R&D activities.

In three breakout groups corresponding to the PRIME Program areas, participants identified:

- Key barriers and issues to furthering development of technologies in each of the areas,
- R&D opportunities to overcome these issues, and
- Action plans identifying technical objectives, actions and products, resources, and collaborative opportunities.

The PRIME Workshop agenda is on the next page. The plenary session presentations are provided in Section II. The detailed products of the three work groups are presented in Section III.

PRIME WORKSHOP: AGENDA

Sheraton North Houston Hotel • Houston, Texas • October 23, 2001 • Sponsored by the National Petroleum Technology Office

TUESDAY, OCTOBER 23, 2001

7:00 a.m.	Registration/Check-in & Continental Breakfast
8:00 a.m.	**Welcome** Bill Lawson, Director National Petroleum Technology Office (NPTO)/National Energy Technology Laboratory (NETL)
8:05 a.m.	**DOE Prime Program** *Overview of the Prime Program* Bob Lemmon, NPTO/NETL *Oil Recovery Technology* Jerry Casteel, NPTO/NETL *Reservoir Characterization – Advanced Diagnostics and Imaging Technologies* Bob Lemmon, NPTO/NETL *Drilling, Completion, and Stimulation Technologies* Rhonda Lindsey, NPTO/NETL
8:35 a.m.	**Overview** Scott W. Tinker, Director, Bureau of Economic Geology, University of Texas at Austin
9:05 a.m.	**Overview of Breakout Sessions: Process and Products** Jim Carey, Energetics, Incorporated
9:15 a.m.	**Breakout Sessions – Brainstorming the Issues** ♦ Oil Recovery Technology ♦ Reservoir Characterization – Advanced Diagnostic and Imaging Technologies ♦ Drilling, Completion, and Stimulation Technologies
10:30 a.m.	*Break*
11:00 a.m.	**Breakout Sessions – Analyzing the Opportunities** ♦ Oil Recovery Technology ♦ Reservoir Characterization – Advanced Diagnostic and Imaging Technologies ♦ Drilling, Completion, and Stimulation Technologies
12:15 p.m.	*Luncheon*
1:15 p.m.	**Breakout Sessions – Defining Action Recommendation Plans** ♦ Oil Recovery Technology ♦ Reservoir Characterization – Advanced Diagnostic and Imaging Technologies ♦ Drilling, Completion, and Stimulation Technologies
3:15 p.m.	*Break*
3:30 p.m.	**Plenary Regroup for Session Report-Outs**
4:15 p.m.	**Wrap-up** Roy Long, NPTO/NETL
4:30 p.m.	*Adjourn*

II. PLENARY SESSION: PRESENTATIONS

This section provides the presentations made by NPTO/NETL Senior Project Managers in the workshop's plenary session. The presentations provide an overview of the program along with detailed information on the three program areas. It also provides the presentation of Scott Tinker of the Bureau of Economic Geology at the University of Texas at Austin.

A. Overview of the PRIME Program and Reservoir Characterization –ADIS
Bob Lemmon, NPTO/NETL

B. Oil Recovery Technology
Jerry Casteel, NPTO/NETL

C. Drilling, Completion, Stimulation, and Operations
Rhonda Lindsey, NPTO/NETL

D. Perspective: Future Needs and Directions
Scott Tinker, Bureau of Economic Geology
University of Texas at Austin

A. OVERVIEW OF THE PRIME PROGRAM AND RESERVOIR CHARACTERIZATION - ADIS

Bob Lemmon, NPTO/NETL

PRIME Initiative - 1

- Public Resources Invested in Management and Extraction (PRIME) technologies
- Emphasizes longer-term, high-risk research activities focused on new concepts and/or approaches
- May lead to significant advancements in the state-of-the-art over the next 10 years
- Reducing costs, risks and environmental impacts associated with finding and producing U.S. petroleum resources

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PRIME Initiative - 2

- Longer-term fundamental R & D in three broad areas:
- 1 - Reservoir Efficiency Processes
- 2 - Drilling, Completion and Stimulation
- 3 - Reservoir Characterization and Associated Diagnostic and Imaging Technologies

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National Petroleum Technology Program

National Petroleum Technology Program: Technology Areas

- Advanced Diagnostics and Imaging Systems
- Emerging Processing Technology Applications
- Advanced Drilling, Completion, and Stimulation
- Effective Environmental Protection
- Reservoir Life Extension and Management
- Crosscutting Program Areas

✓218 active projects as of 9/30/2000.

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Advanced Diagnostics and Imaging Systems Program (ADIS)

Bob Lemmon, Technology Manager

Project Managers

Dan Ferguson	Dan Gurney
Purna Halder	Chandra Nautiyal
Tom Reid	Ginny Weyland

October 23, 2001

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ADIS - Goals -1

- Increase accuracy and resolution of seismic and other geological and geophysical technologies - (field - to - inter well scales)
- Develop new technologies to measure in-situ reservoir fluid and rock properties - (pore - to - near wellbore scales)

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ADIS - Goals - 2

- Develop innovative geologic system models & exploration concepts for analysis of U.S. basins for new and overlooked oil fairways (field - to - basin scales)
- Integrate multiple technology, data sets into refined geologic and engineering models that guide oil field development and management for maximum economic oil recovery

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ADIS Program Organization - 1

- Organizational Structure
  - Geoscientific/Engineering Measurement
    - Electrical and electromagnetic
    - Seismic tool development
    - Seismic analysis techniques
    - Well logging/monitoring
  - Reservoir Description/Characterization
    - Fracture modeling
    - Geomechanics
    - Core/pore-scale studies
    - Geostatistics
    - Basin-specific multidisciplinary studies

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ADIS Program Organization - 2

- Organizational Structure
  - Reservoir Modeling and Simulation
    - Data access
    - Data preservation
    - Field laboratories
  - Oil Exploration Research
    - Basin Analysis
    - General

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Prior ADIS Workshop

- R & D opportunities mainly with seismic focus address:
- 1) Limits on seismic resolution
- 2) Fusion of both dynamic and static data
- 3) Pre-stack inversion and elastic inversion, and tools for S-wave imaging
- 4) Integrating seismic and EM

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Current ADIS Workshop Focus

- R & D Emphasis on, but not limited to, the other aspects of the ADIS program area:
- 1) Reservoir Description - incl. Fracture Detection & Modeling/Geomechanics
- 2) Pore- to Core-Scale R & D and Impacts on Productivity
- 3) Logging Technology & Real-Time Field Monitoring
- 4) Basinal Analysis for New & Overlooked U.S. Oil Trend Fairways for E & P

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Advanced Diagnostics and Imaging Systems Program: Oct. 17, 2001

Organizational Structure:

1.0 Geoscientific Measurement
- **1.1 Electrical and Electromagnetic**
- **1.2 Seismic Tool Development**
- **1.3 Seismic Analysis Techniques**
- **1.4 Well Logging/Monitoring**

2.0 Reservoir Description
- **2.1 Fracture Modeling**
- **2.2 Geomechanics**
- **2.3 Core/Pore-Scale Studies**
- **2.4 Geostatistics**
- **2.5 Basin-Specific - Multidisciplinary Studies**

3.0 Reservoir Modeling and Simulation
- **3.1 Data Access**
- **3.2 Data Preservation**
- **3.3 Field Laboratories**

4.0 Oil Exploration Research
- **4.1 Basinal Analysis**

5.0 General

Organizational Structure:

1.0 Geoscientific Measurement

1.1 Electrical and Electromagnetic

- 00BC15307 Electromagnetic Instruments, Inc./Michael Wilt - Oil Reservoir Characterization and CO2 Injection Monitoring in the Permian Basin with Cross-well Electromagnetic Imaging
- FEW-0011 LLNL/Phil Harben - Oil Field Characterization and Process Monitoring Using Electromagnetic Methods
- FEW-0031 LLNL/Phil Harben - Steel Casing Crosshole Electromagnetic Imaging
- P-23 LBL-Partnership/Ki Ha Lee Extending Borehole Electromagnetic Imaging to Cased Wells (funded under the OGRT forum)
- P-102 LBL-Partnership/Kurt Hihei - Frequency-Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands
- #13-FY01 LLNL-Partnership/Newmark "Autonomous Monitoring of Production"

1.2 Seismic Tool Development

- FEW-2836.6 SNL-Partnership/Bob Cutler - Development of a 3-Component Borehole Seismic Source
- P-24 - LANL/LLNL-Partnership/James Alb right - Advanced Sensor Technology for Microborehole and other Seismic Applications/Microborehole Seismic Instrumentation
- P-40 LLNL-Partnership/Christian Simonson - Acquisition of Borehole Seismic Data Behind Production Tubing/Reducing Certain Seismic Data Acquisition Costs Through Shaped Charges
- P-44 - SNL-Partnership/Robert Cutler - Development of Single Well Imaging Systems
- P-45 LBL-Partnership/Ernie Major - Development of Single-Well Seismic Imaging Technology
- ACTI-003 INEEL/SNL-Partnership/Dave Weinberg - Large Downhole Seismic Sensor Array
- ACTI-053 - LANL-Partnership/Michael Fehler - Improved Prestack Kirchkoff Migration for Complex Structures/Seismic Imaging of Complex Terrain (Gulf of Mexico Subsalt Project)
- ACTI-074 - LLNL-Partnership/Fred Followill - Vertical Seismic Profiling While Drilling
-

1.3 Seismic Analysis Techniques

- 01BC15353 University of Houston/Dr. Marfurt - Development and Calibration of New 3D Vector VSP Imaging Technology; Vinton Sald Dome, Louisiana
- 01BC15354 Stanford University/Dr. Mavko - Seismic and Rock-Physics Diagnostics of Multiscale Reservoir Textures.
- 01BC15356 Rock Solid Images/Dr. Taner - Seismic Attenuation Attributes for Reservoir Characterization.
- 01BC15367 Advanced Resources International, Inc./Dr. Reeves - Development of an Advanced Approach for Next-Generation, High-Resolution, Integrated Reservoir Characterization.
- 00BC15301 Virginia Polytechnic Institute & State Univ./Matthias Imhof - Seismic Determination of Reservoir Heterogeneity: Application to the Characterization of Heavy Oil Reservoirs
- 00BC15302 Univ. of Oklahoma/Thurman Scott - Accoustical Imaging and Mechanical Properties of Soft Rock and Marine Sediments
- 01SW53227 Stanford Univ./Amos Nur - Stanford Rock Physics and Borehole Geophysics Consortium
- 00NT40832 - Prairie View A&M Univ./Innocent Aluka - Integrating P-Wave and S-Wave Seismic Data to Improve Characterization of Oil Reservoirs (funded through HBCU program)
- 98BC15135 Michigan Technology Univ./Wayne Pennington - Calibration of Seismic Attributes for Reservoir Characterization
- ACTI-009 LANL/LLNL/ORNL-Partnership/Leigh House - Testing Advanced Computational Tools for 3D Seismic Analysis Using the SEG/EAEG Model Data Set
- P-103 LBL-Partnership/Kurt Nihei - Frequency Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands
- P-203 - SNL-Partnership/David Aldridge - Inversion of Full Waveform Seismic Data for Three-Dimensional Elastic Parameters
- P-204 - LBL-Partnership/Valero Lorneev - High Speed 3-D Hybrid Elastic Seismic Modeling

- P-205 - LANL-Partnership/Robert Peters - Next Generation Seismic Modeling and Imaging
- #8-FY01 LANL-Partnership/Huang "Innovative Wave-Equation Migration"
- P-225 LBL-Partnership/Majer "Testing and Validation of High Resolution Fluid Imaging in Real Time"
- P-221 LBL-Partnership/Vasco "Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multi-phase Production Data" Oil/Gas

1.4 Well Logging/Monitoring

- 96ER82159 Electromagnetics Instruments, Inc. - Oil Field Induction Resistivity Logging in Steel-Cased Wells (funded under SBIR)
- 99BC15201 Rice Univ./George Hirasaki - Fluid-Rock Characterization and Interactions in NMR Well Logging
- P-87 LANL - Partnership/James Albright - Fluid Identification Acoustic Logging Tool (funded under RLE forum)
- P-100 LANL - Partnership/James Albright - Formation Logging Tools for Microholes (funded under RLE forum)

2.0 Reservoir Description

- 00BC15309 Univ. of Tulsa/Dean Oliver - Mapping of Reservoir Properties and Facies Through Integration of Static and Dynamic Data
- 99BC15203 Southwest Research Institute/Jorge Parra - A Methodology to Integrate MR and Acoustic Measurements for Reservoir Characterization
- P-83 - LBL-Partnership/Don Vasco - High-Resolution Reservoir Characterization Using Seismic, Well and Dynamic Data (funded under RLE forum)
- P-102 LBL-Partnership/Mike Hoverston - Integrated Reservoir Monitoring Using Seismic and Crosswell Electromagnetics

- P-206-INEEL-Partnership/Tim Green - Locating Geopressure Hydrocarbon Reservoirs in Soft, Clastic Sediments Through the Identification of Associated Pressure Seals

2.1 Fracture Modeling

- 01BC15355 The Pennsylvania State University/Dr. Grader - Multiphase Fracture-Matrix Interactions under Stress Changes
- 00BC15308 The Univ. of Texas at Austin/Jon Olsen - Advanced Technology for Predicting the Fluid Flow Attributes of Naturally Fractured Reservoirs from Quantitative Geologic Data Modeling
- 99BC15177 - Reservoir Engineering Research Institute/Abbas Firoozabadi - Research Program on Fractured Petroleum Reservoirs
- 98BC15100 Michigan Technological Univ./James Wood - Advanced Characterization of Fractured Reservoirs in Shallow Shelf Carbonate Rocks - The Michigan Basin
- 98BC15101 Golder Associates/William Dershowitz - Discrete Feature Approach for Heterogeneous Reservoir Production Enhancement
- FEW-A053 - LANL/James Albright - Advanced Seismic Geodiagnostics-Borehole Acoustic Source/Instrumentation for Fracture Mapping

- P-31 LLNL-Partnership/Steve Hunter - Advanced Tiltmeter Hydraulic Fracture Imaging Technology (funded under the OGRT forum)

2.2 Geomechanics

- FEW-4365 - SNL/Larry Costin - Geomechanics for Reservoir Management
- P-200-SNL-Partnership/Mike Stone - Coupled Geomechanical Deformation, Fluid Flow and Seismic

2.3 Core/Pore-Scale Studies

- 00BC15306 Reservoir Engineering Research Institute/Abbas Firoozabadi - Wettability Alteration of Porous Media to Gas-Wetting for Improving Productivity and Injectivity in Gas-Liquid Flows
- 99BC15202 Texas A&M Univ.- Engineering Experiment Station/Ted Watsoh - NMR Characterizations of Heterogeneous Porous Media
- 99BC15204 - New Mexico Institute of Mining and Technology - Petroleum Recovery Research Center/Jill Buckley - Wettability and Imbibition; Microscopic Distribution of Wetting and its Consequences at the Core and Field Scales
- 99BC15205 - Univ. of Texas at Austin/Mukul Sharma - Characterization of Mixed Wettability at Different Scales and its Impact on Oil Recovery Efficiency
- 99BC15206 Univ. of Houston/Kishore Mohanty - Impact of Capillary and Bond Numbers on Relative Permeability
- 99BC15207 Purdue Research Foundation/Laura Pyrak-Nolte - Experimental Investigations of Relative Permeability Upscaling from the Micro-Scale to the Macro-Scale
- FEW ESD99-001 - LBL/Liviu Tomutsa - Imaging, Modeling, Measurement and Scaling of Multiphase Flow Processes

2.4 Geostatistics

- 00BC15303 Univ. of Texas at Austin/Carlos Torres-Verdin - Integrated Approach for the Petrophysical Interpretation of Post- and Pre-Stack 3-D Seismic Data, Well-Log Ldata, Core Data, Geological Information and Reservoir Production Data via Bayasian Stochastic Inversion
- ACTI-065 - LANL-Partnership/George Zyvolski - Unstructured Grids for High Performance Reservoir Simulation/Innovative Gridding (funded under RLE forum)
- FEW-2266(P-32) PNL-Partnership/Mart Oostrom - Improved Prediction of Multiphase Flow in Petroleum Reservoirs

2.5 Basin-Specific - Multidisciplinary Studies

- 01BC15351 Univ. of Texas at Austin-Bureau of Economic Geology/Stephen Ruppel - Multidisciplinary Imaging of Rock Properties in Carbonate Reservoirs for Flow Unit Targeting.

- 01BC15352 Univ. of Texas at Austin-Chemical Engineering Dept./Dr. Torres-Verdin - Characterization of Turbidite Oil Reservoirs Based on Geophysical Models of their Formation.

- 00BC15303 Univ. of Alabama/Ernest Mancini - Integrated Geologic-Engineering Model for Reef and Carbonate Shoal Reservoirs Associated with Paleohighs; Upper Jurassic Smackover Formation, Northern Gulf of Mexico
- 98BC15102 Univ. of Alaska, Fairbanks - Geophysical Institute/Wesley Wallace - The Influence of Fold and Fracture Development on Reservoir Behavior of the Lisburne Group of Northern Alaska
- 98BC15103 Utah Geological Survey/Craig Morgan - Reservoir Characterization of the Lower Green River Formation, SW Unita Basin, Utah
- 98BC15104 West Virginia Univ./Doug Patchen - Reservoir Characterization of Upper Devonian Gordon Sandstone, Jacksonburg-Stringtown Oilfield, NW West Virginia
- 98BC15105 Univ. of Texas at Austin-BEG/Charles Kerans - Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonardian Age) Reservoirs, West Texas and Southeastern New Mexico
- 98BC15119 Clemson univ./James Castle - Quantitative Methods for Reservoir Characterization and Improved Recovery; Application to Heavy Oil Sands

3.0 Reservoir Modeling and Simulation

3.1 Data Access

- 00BC15310 Univ. of Kansas Center for Research, Inc./Lynn Watney - Geo-Engineering Modeling Through Internet Informatics (GEMINI)

3.2 Data Preservation

- 00SW48306 National Academy of Sciences - Preservation of Geoscience Data and Collections
- 99BC15115 American Geological Institute - National Geoscience Data Repository System-Phase III

3.3 Field Laboratories

- 99BC15185 - University of Oklahoma/John Castagna - Gypsy Field Project in Reservoir Characterization

4.0 Oil Exploration Research

4.1 Basinal Analysis

- 99BC15217 California Inst. of Technology/William Goddard - An Advanced Chemistry Basin Model for Petroleum Exploration
- 98BC15117 Univ. of Kansas/Tim Carr - Preparation of Northern Mid-Continent Petroleum Atlas
- 96BC14946 Univ. of Alabama/Ernest Mancini - Basin Analysis of the Mississippi Interior Salt Basin and Petroleum System Modeling of the Jurassic Smackover Formation, Eastern Gulf Coastal Plain
- FEW-P49398 ANL/Thomas Moore - The Use of Predictive Lithostratigraphy to Significantly Improve the Ability to Forecast Reservoir and Source Rocks
- FEW-4340-53 INEEL/Bruce Reynolds - Transportation of Hydrocarbon Indicators by Migrating Formation Waters in Selected Basins of the Four Corners Region

- FEW-FEAC310 ORNL/Bob Hatcher - Southern-Central Appalachians Framework and Controls of Hydrocarbon Generation

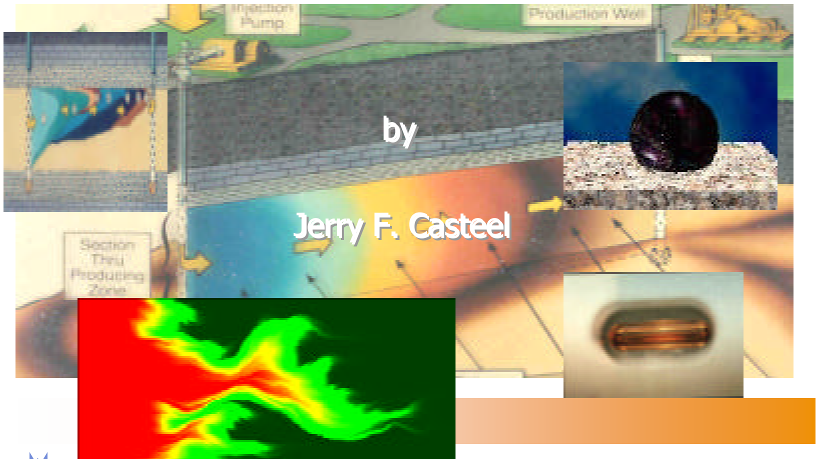
5.0 General

- 98BC15170 National Academy of Sciences/National Research Council - NRC Support to Board of Earth Sciences

B. OIL RECOVERY TECHNOLOGY

Jerry Casteel, NPTO/NETL

Reservoir Efficiency Processes



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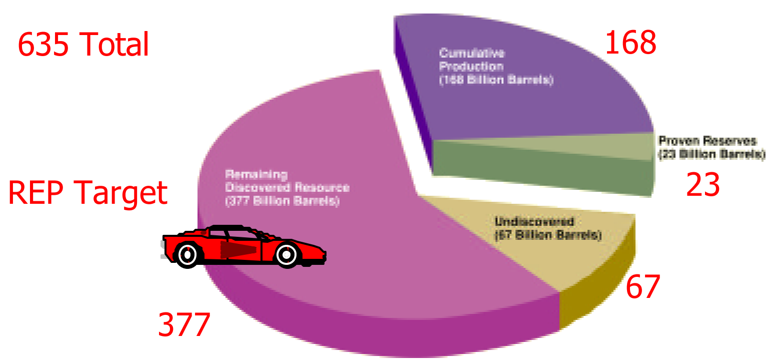
Reservoir Efficiency Processes

Two-Thirds of U.S. Oil Resource Remains after Conventional Production



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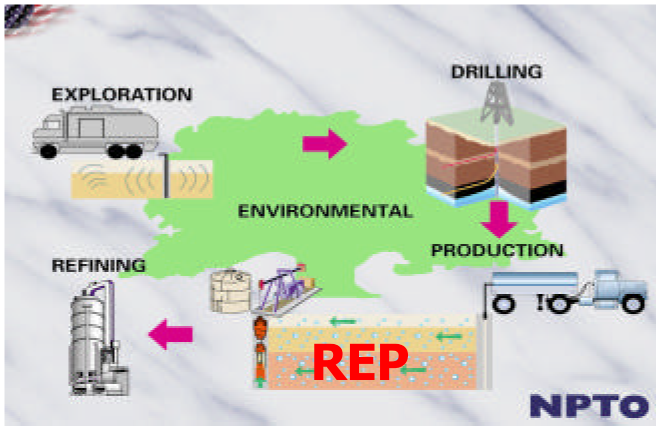
Reservoir Efficiency Processes



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Reservoir Efficiency Processes

- Enhanced Oil Recovery (EOR)
- Tertiary Oil Recovery (TOR)
- Advanced Oil Recovery (AOR)
- Improved Oil Recovery (IOR)

- What is the REP program really doing?

Recover oil from known reservoirs.

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Reservoir Efficiency Processes

- Chemical Methods
- Gas Flooding Methods
- Microbial Enhanced Oil Recovery
- Thermal Methods
- Novel Methods
- Simulation

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Challenges for Chemical Flooding

Surfactant Loss

The Loss of the Surfactant is High due to Adsorption and Partitioning into the Oil and Water

Mobility Control

Difficult to Control the Injection of Chemical

Oil Viscosity

Surfactants formulation difficult with High Viscosity Oils

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Challenges for Chemical Flooding

Brine Concentration

High and Low Brine Concentrations difficult

Temperature

High and Low Temperatures difficult

Clay Content

Various Clays can cause problems

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Challenges for CO2 Flooding

The Minimum Miscibility Pressure (MMP) must be within an acceptable range

The reservoir must be deep enough to allow operation at or above the MMP

Availability of High Purity CO2

Nitrogen and Methane can greatly increase the MMP

Reservoir Heterogeneity

The Low Viscosity of CO2 makes Mobility Control Difficult

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Challenges for CO_2 Flooding

Oil Viscosity

A High Oil Viscosity makes the CO2 Channel and Breakthrough Early

Water Saturation

CO2 will also Dissolve in Water and especially at high pressure

Gravity Segregation

The CO2 tend to go the the Top of the Reservoir

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Challenges for MEOR Flooding

Microbes

Finding Effective Microbes

Microbe Placement

Placing the Microbes and the Nutrient properly

Temperature

Need Temperature Tolerant Microbes

Brine

Need Brine Tolerant Microbes

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Challenges for Heavy Oil Recovery

Recovery

Need More Economical Methods

Sweep Improvement

More Temperature Tolerant Chemicals

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National Petroleum Technology Office

Challenges for Novel Methods

New Methods

Need More Economical Methods rather than improvement of current methods.

NETL

National Petroleum Technology Office

Challenges for Simulation Methods

Faster Methods

More Economical Methods

General Methods

Useful Simulators for Small Operators

National Petroleum Technology Office

Challenges

Are We Going in the Right Direction?

If not what??

National Petroleum Technology Office

Challenges

We are looking for your input:

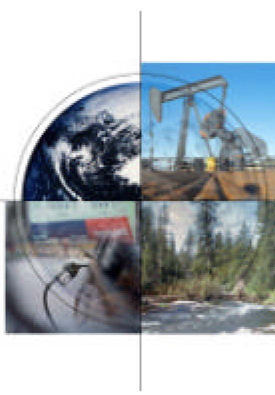
How to recover the oil left behind.

National Petroleum Technology Office

C. DRILLING, COMPLETION, STIMULATION, AND OPERATIONS

Rhonda Lindsey, NPTO

Drilling, Completion, Stimulation, and Operations



Presentation to
PRIME Workshop

October 23, 2001
Houston, Texas

Rhonda Lindsey
National Energy Technology Laboratory

NETL

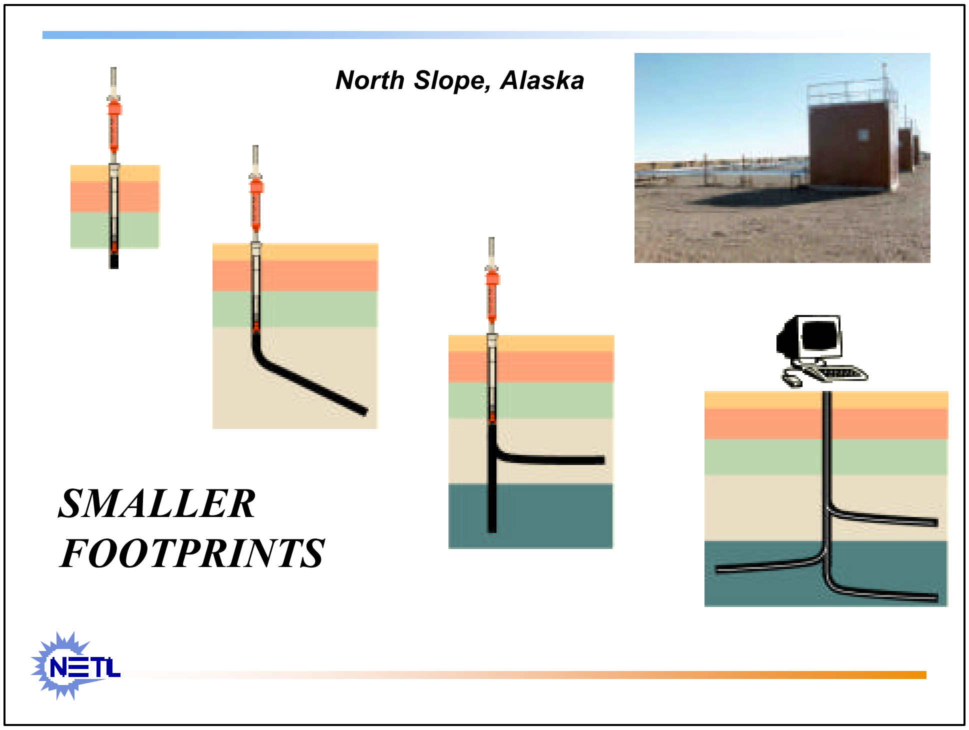
Advanced Technologies Will Play a Crucial Role in Addressing Environmental, Supply, and Reliability Constraints of Producing and Using Fossil Energy

NETL

Advanced Drilling, Completion, and Stimulation Systems

- *Benefits:*
  - ***Reduced drilling costs***
  - ***Minimized formation damage***
  - ***Lowered environmental risks***
  - ***Reduced surface footprint onshore and offshore***
  - ***Improved access to culturally and environmentally sensitive areas through technology***

NETL



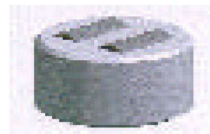
Drilling Systems

- Advanced Cuttings Transport Facility
- TU Drilling Research Program
- Acoustic Telemetry
- 3D Analysis of Induction Logging
- North Slope/Arctic Drilling

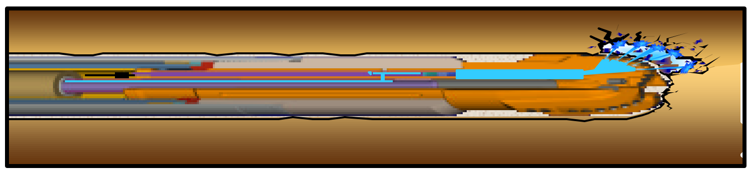
NETL

Revolutionizing the Drilling Industry

- **Microwave processing**
  - No brazing of TSD material
  - Single process instead of three
  - Composite materials for many applications

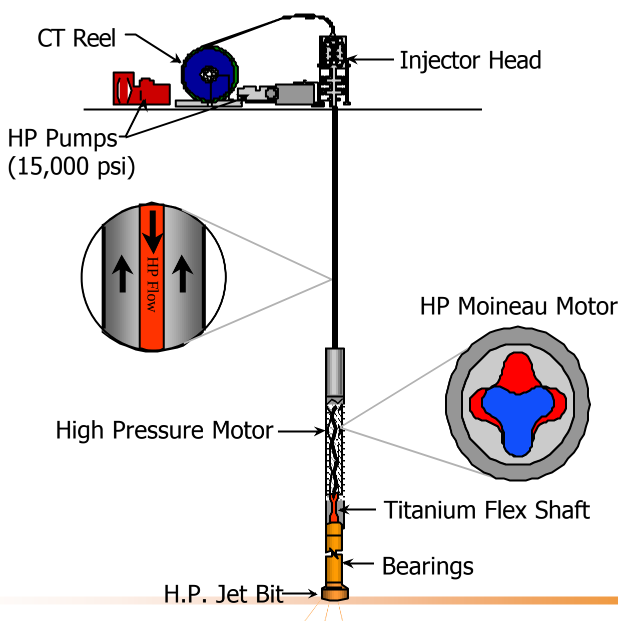


- **Advanced composite drill pipe**
  - Half the weight of steel pipe
  - Extend the capacity of current rigs
  - High speed data communication
- **Jet assisted directional mud hammer**



NETL

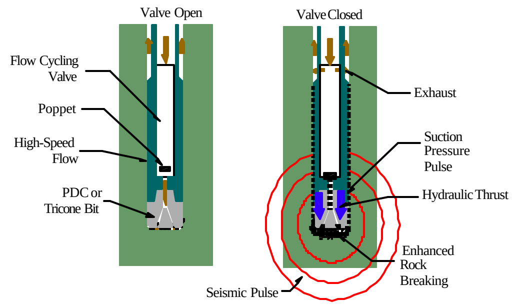
High Pressure Coiled-Tubing Drilling System



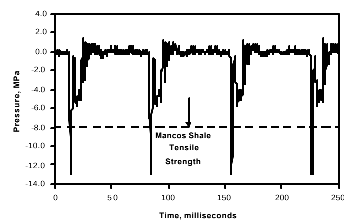
NETL

Suction Pulse Drilling System
(With Seismic Lookahead Potential)

Oscillator Valve



Suction Pulse Train



Tempress Technologies, Inc.

Ultra-Lightweight Cement
Cementing Solutions, Inc.

Objectives
Develop cementing systems using ULHS
- Deep water applications
- Other lightweight applications
- Densities from 13.0 lb/gal to 8.0 lb/gal

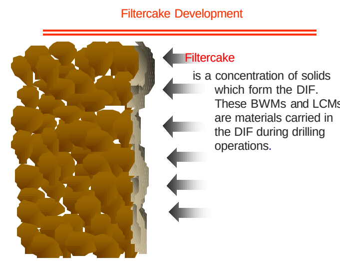
Test physical performance
Compare to conventional systems
- Foamed and non-foamed

Advisory Board
Oil companies
Shell, ExxonMobil
Service Companies
BJ, HES, DS
Special products companies
3M - ULHS
TXI - Cement
Chandler - Testing equipment

Advisory Board Charge
- Help determine testing parameters and cement compositions
- Supply additives for testing
- Advise on direction and applicability
- Provide data and testing
- Assist with demonstration & commercialization

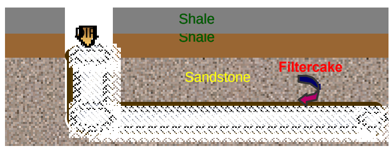
“Development of New Types of Non-damaging Drill-in and Completion Fluids”
Texas Engineering Experiment Station

Objectives:
- Develop new DIF Designs
- Develop kinetic model to simulate filtercake removal
- Combine results of experiments with kinetic model
- Test new DIFs & Models in field applications



Problem Definition: Filtercake Removal is Key to Higher Productivity

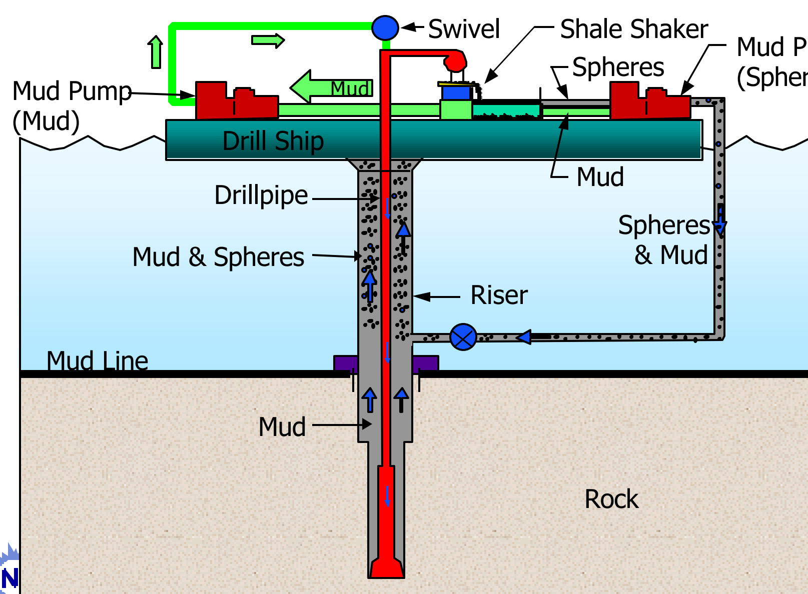
There are no models predicting effectiveness of cleanup treatments



Industry Participants

BP	Phillips
Chevron	Shell
Conoco	TBC Brinadd
Marathon	Texaco

Hollow Sphere Dual Gradient System



Completion Technology

- Optimization of Horizontal Completion
- Ceramic Sealants and Cements
- Cement/Casing Interaction Research
- Cavity-like Completion Technology

NETL

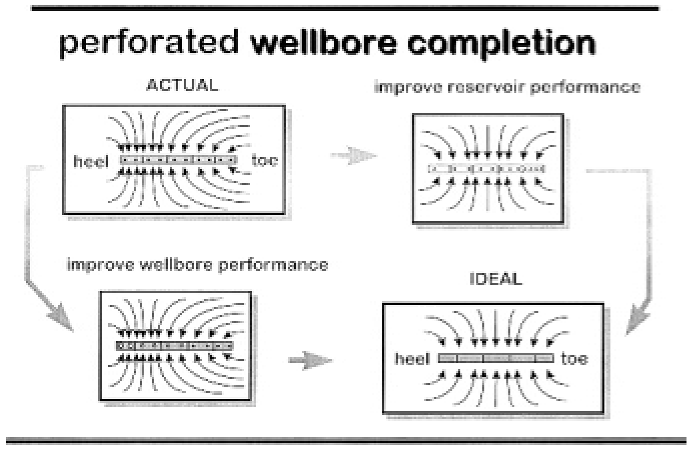
Partnership- Chemically Bonded Ceramic Borehole Sealants

Sets in the presence of hydrocarbons & chlorides!

- pumpable
- drillable
- temperature tolerant
- self-bonding
- bonds to any material except plastic
- uses conventional equipment

NETL

Optimization of Horizontal Completions



<u>Stimulation Technology</u>

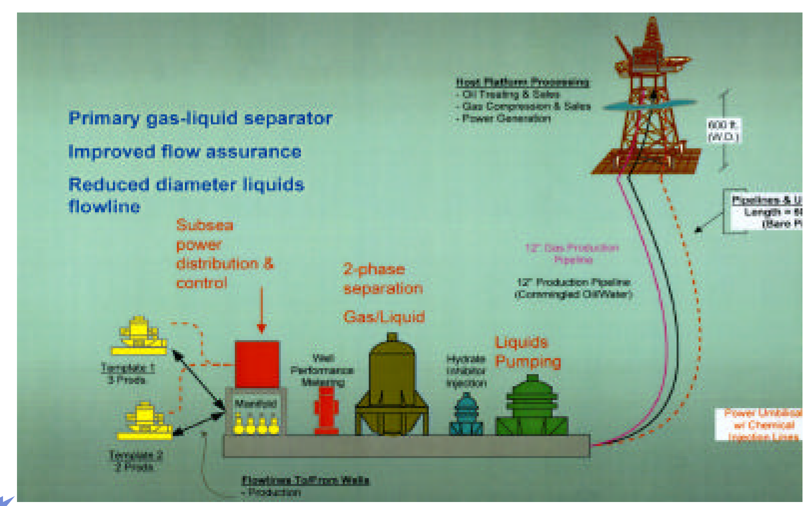
- **In-Well Heating & Stimulation**
- **Seismic Stimulation**
- **Sonic stimulation Tools and Standards**
- **Improved Well Performance JIP**

Operations and Flowability

- Compact 3-Phase Separator
- Subsea Separation Field Test
- Paraffin Deposition and Prediction JIP
- Drill Cutting Injection

Conoco Subsea Processing

(Co-funded ADCS Award)



Proposed for FY02
Deep Trek: Program Elements

- **Program**
  - Industry-driven consortium for university research
  - Cooperative agreements with individual companies, JIPs and Universities
  - National Lab Partnership
  - Onsite Laboratory Work at NETL
- **Technology Areas**
  - Low friction, wear resistant materials & coatings
  - "Smart" systems
  - Advanced sensors/monitoring systems
  - High performance drilling systems

NETL

WWW.NPTO.DOE.GOV

RHONDA LINDSEY

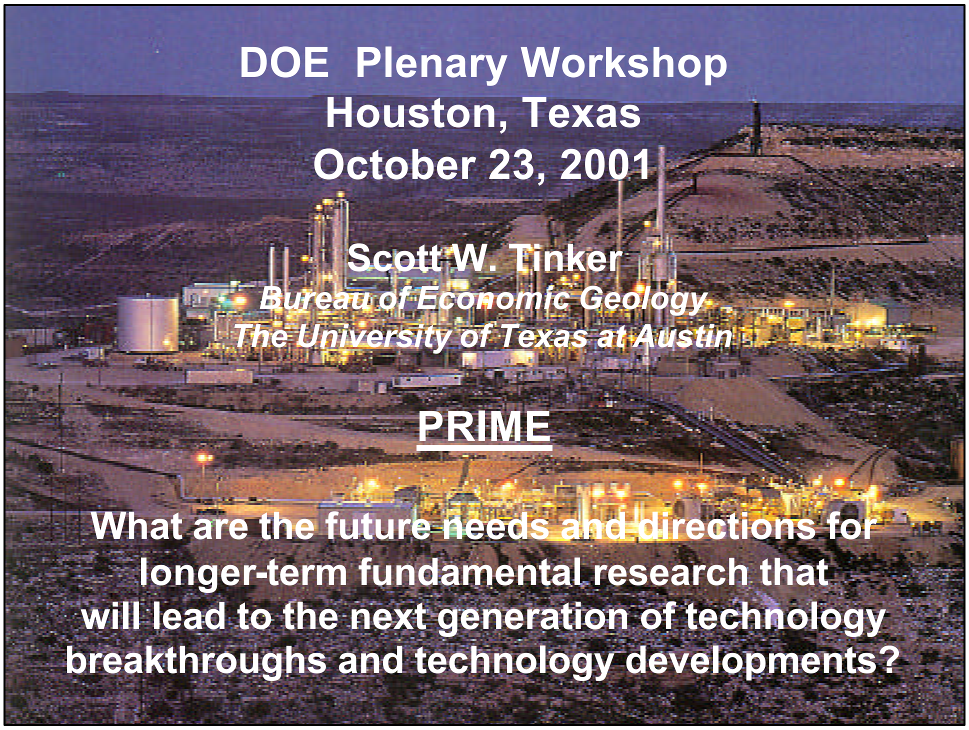
918/699-2037

National Petroleum Technology Office

NETL

D. Perspective: Future Needs and Directions

Scott Tinker, Bureau of Economic Geology
University of Texas at Austin



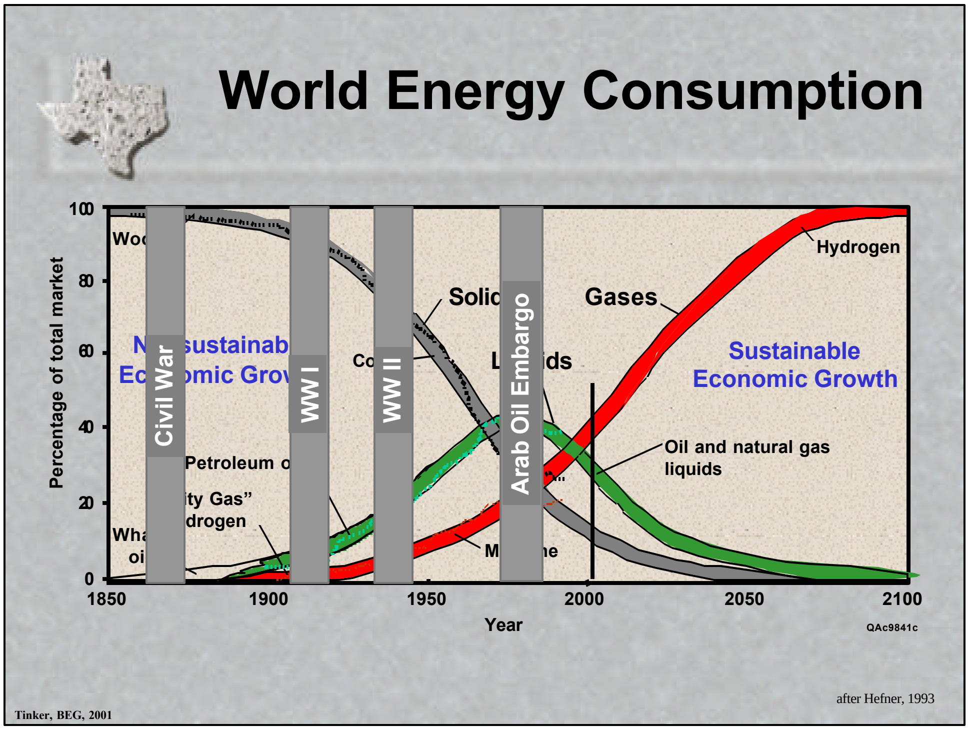
Introduction

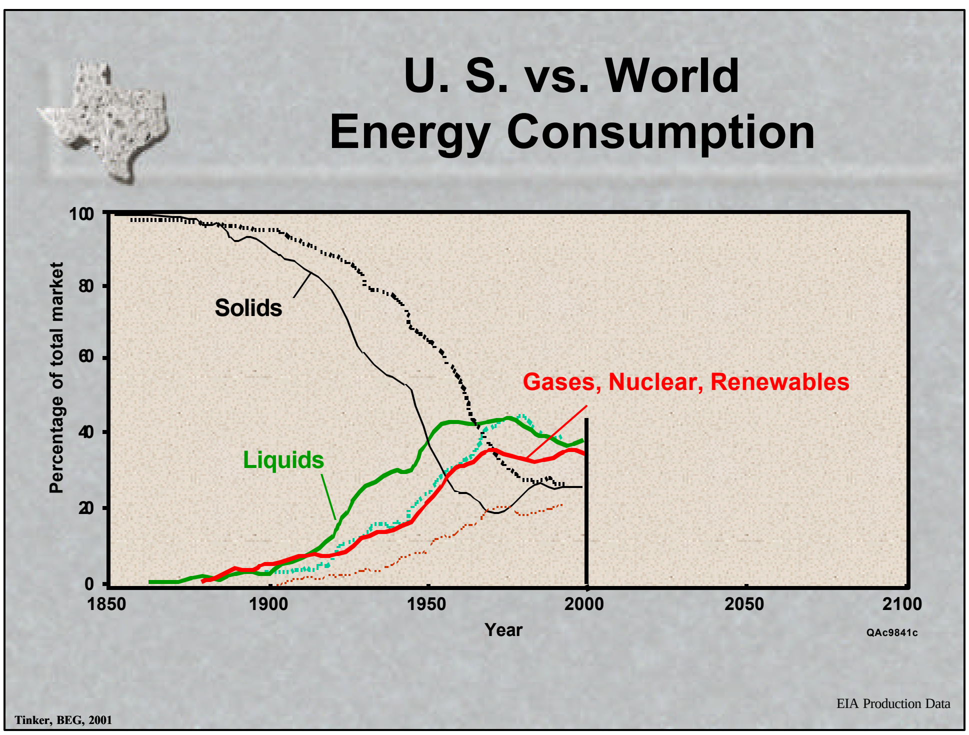
Energy consumption in the U.S can be divided into three periods: prior to 1970s, 1970s through 2000s, post 2000s.

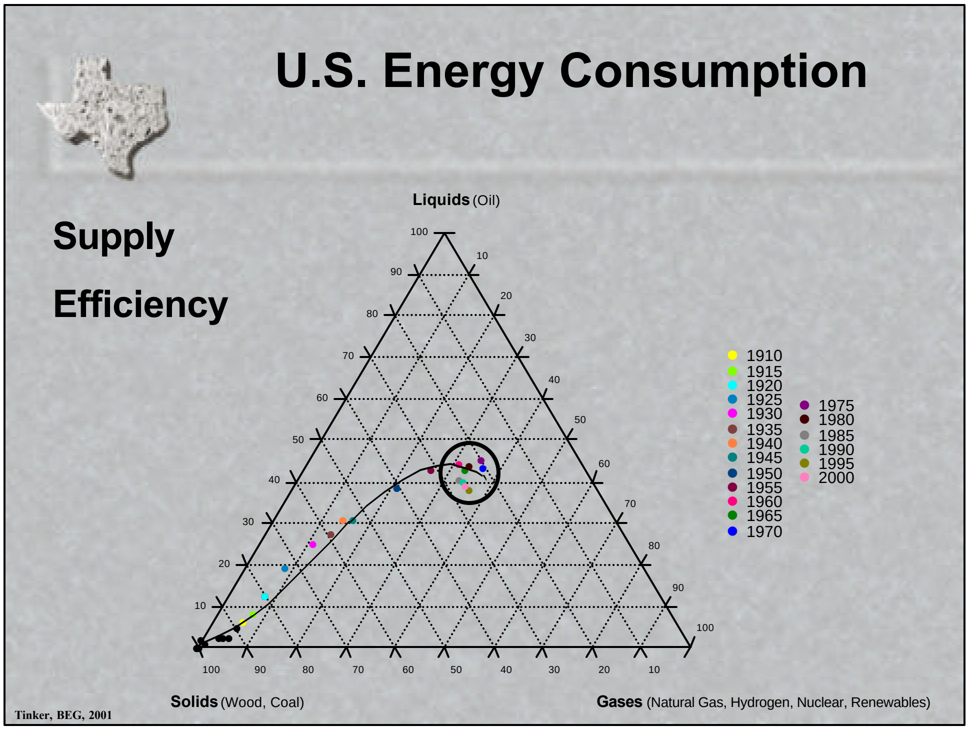
Research and technology have been there all the way, responding as needed to the forces of supply, price, policy, and efficiency.

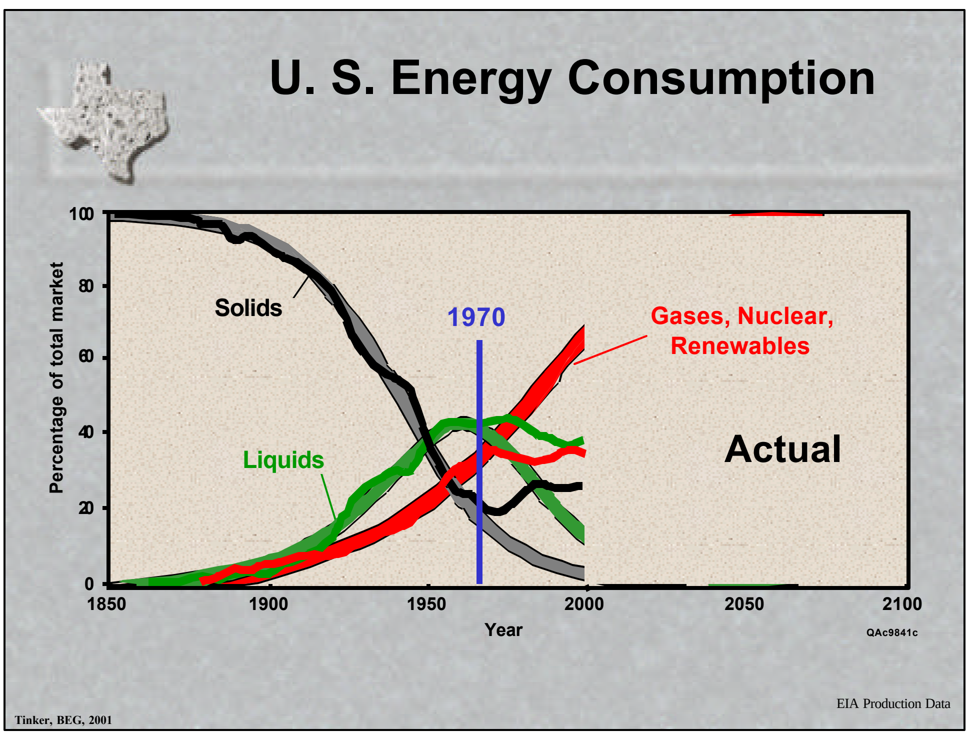
Basic oil research and funding should focus on
- improved assessment for exploration
- advanced characterization for enhanced production
- several other frontier areas.

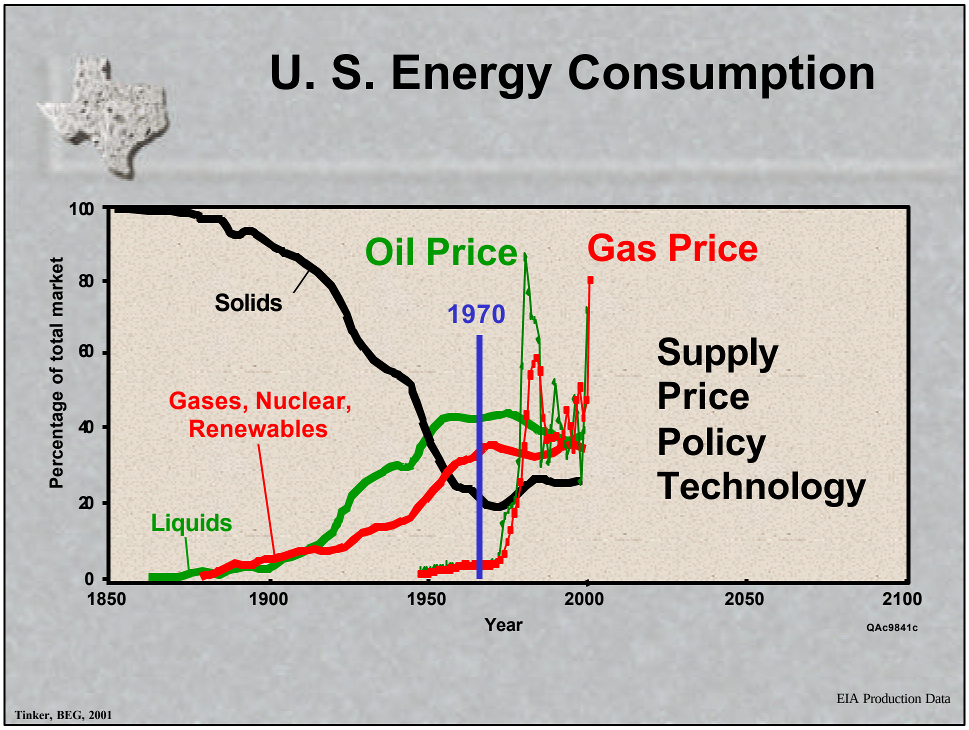
Tinker, BEG, 2001

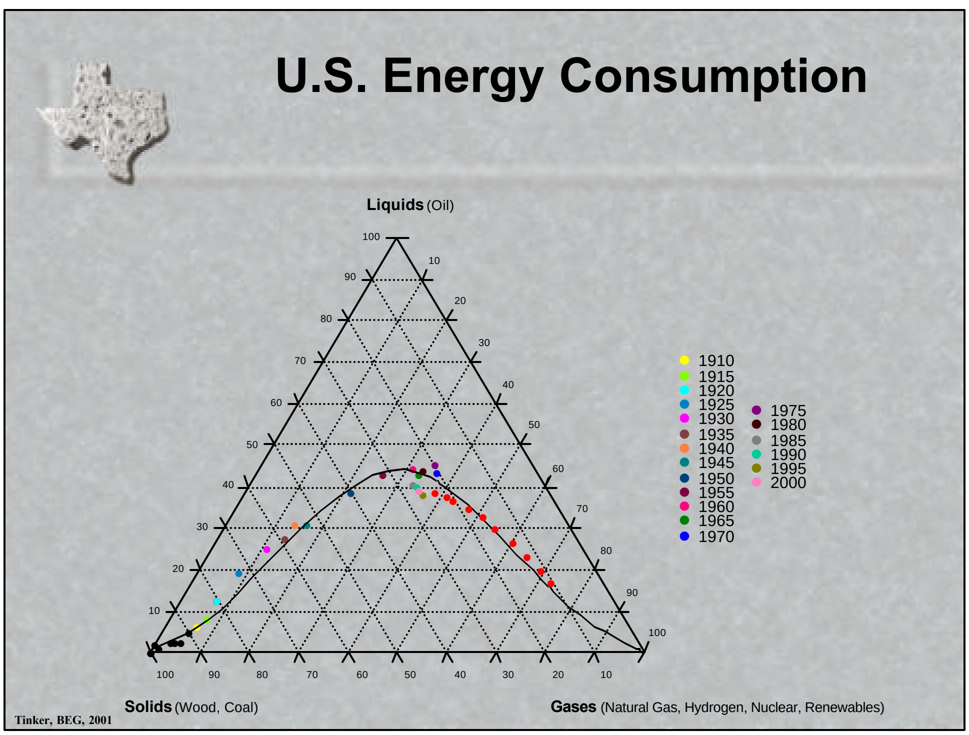

World Energy Consumption
Percentage of total market
Year
Civil War
WW I
WW II
Arab Oil Embargo
Solic
Gases
Hydrogen
Sustainable
Economic Growth
Oil and natural gas
liquids
Petroleum o
ity Gas"
drogen
Wha
oi
Co
L ids
M e
Woo
N sustainab
Ec omic Grov
QAc9841c
after Hefner, 1993
Tinker, BEG, 2001

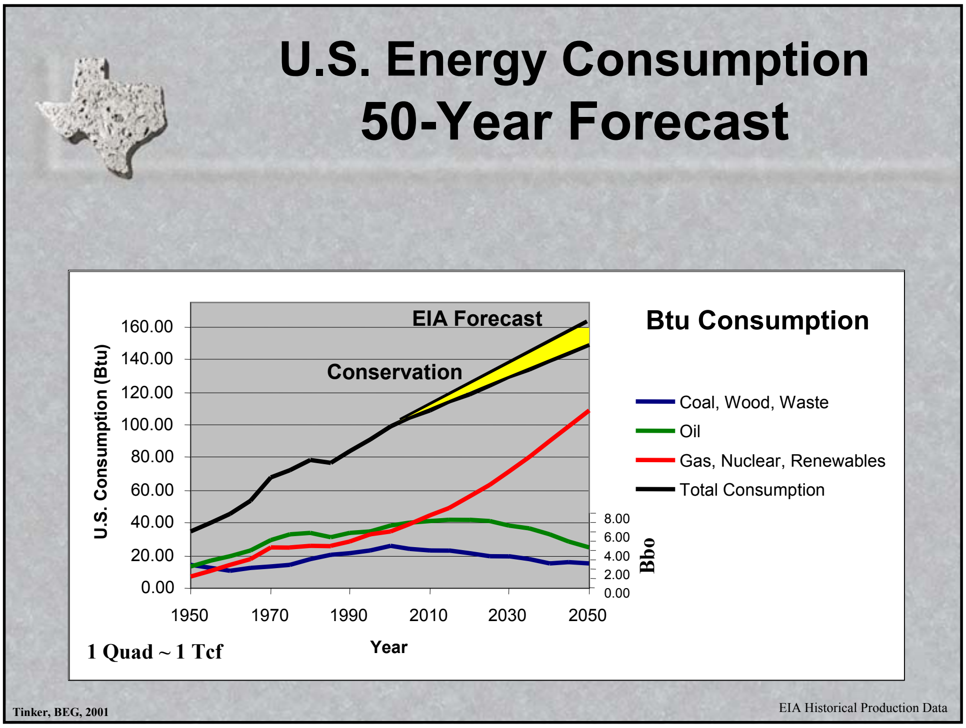

U. S. vs. World
Energy Consumption
Percentage of total market
Year
Solids
Liquids
Gases, Nuclear, Renewables
QAc9841c
EIA Production Data
Tinker, BEG, 2001

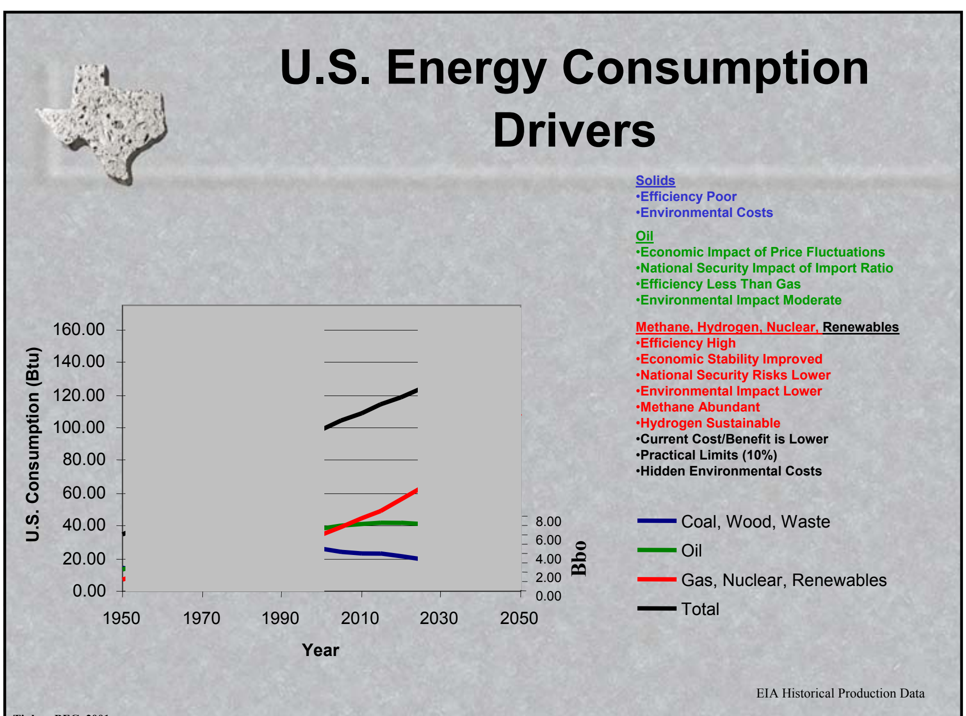

U.S. Energy Consumption
Supply
Efficiency
Liquids (Oil)
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Solids (Wood, Coal)
Gases (Natural Gas, Hydrogen, Nuclear, Renewables)
Tinker, BEG, 2001


U. S. Energy Consumption
Percentage of total market
Solids
1970
Gases, Nuclear,
Renewables
Liquids
Actual
Year
QAc9841c
EIA Production Data
Tinker, BEG, 2001


U. S. Energy Consumption
Percentage of total market
100
80
60
40
20
0
1850
1900
1950
2000
2050
2100
Year
Solids
Oil Price
Gas Price
1970
Gases, Nuclear, Renewables
Liquids
Supply
Price
Policy
Technology
QAc9841c
EIA Production Data
Tinker, BEG, 2001


U.S. Energy Consumption
Liquids (Oil)
Solids (Wood, Coal)
Gases (Natural Gas, Hydrogen, Nuclear, Renewables)
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Tinker, BEG, 2001


U.S. Energy Consumption
50-Year Forecast
EIA Forecast
Conservation
Btu Consumption
Coal, Wood, Waste
Oil
Gas, Nuclear, Renewables
Total Consumption
U.S. Consumption (Btu)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
8.00
6.00
4.00
2.00
0.00
Bbo
1950
1970
1990
2010
2030
2050
Year
1 Quad ~ 1 Tcf
Tinker, BEG, 2001
EIA Historical Production Data


U.S. Energy Consumption
Drivers
Solids
•Efficiency Poor
•Environmental Costs
Oil
•Economic Impact of Price Fluctuations
•National Security Impact of Import Ratio
•Efficiency Less Than Gas
•Environmental Impact Moderate
Methane, Hydrogen, Nuclear, Renewables
•Efficiency High
•Economic Stability Improved
•National Security Risks Lower
•Environmental Impact Lower
•Methane Abundant
•Hydrogen Sustainable
•Current Cost/Benefit is Lower
•Practical Limits (10%)
•Hidden Environmental Costs
Coal, Wood, Waste
Oil
Gas, Nuclear, Renewables
Total
U.S. Consumption (Btu)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
8.00
6.00
4.00
2.00
0.00
Bbo
1950
1970
1990
2010
2030
2050
Year
EIA Historical Production Data
Tinker, BEG, 2001

Oil

Exploration

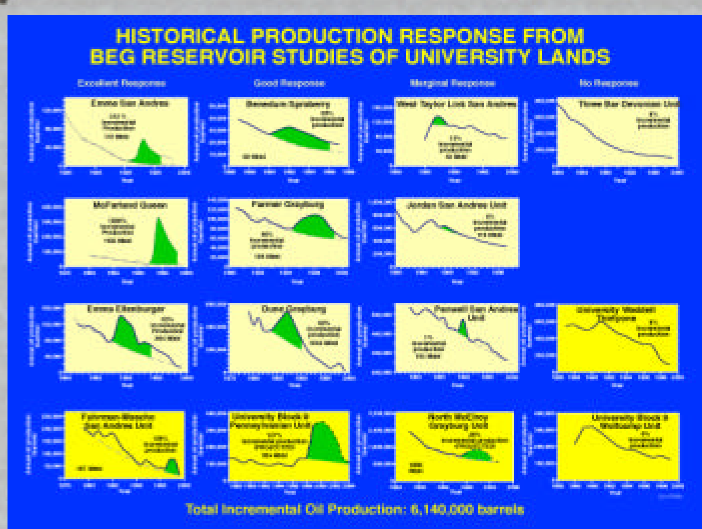
- Access
- Assess

Development

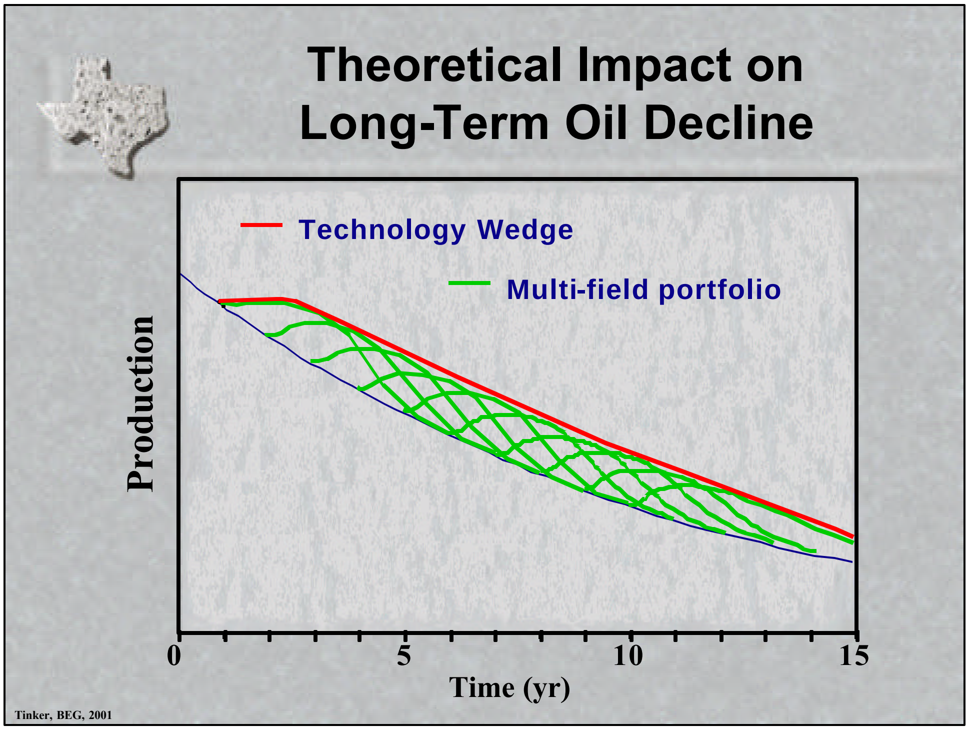
- Reservoir Characterization
- Field Management

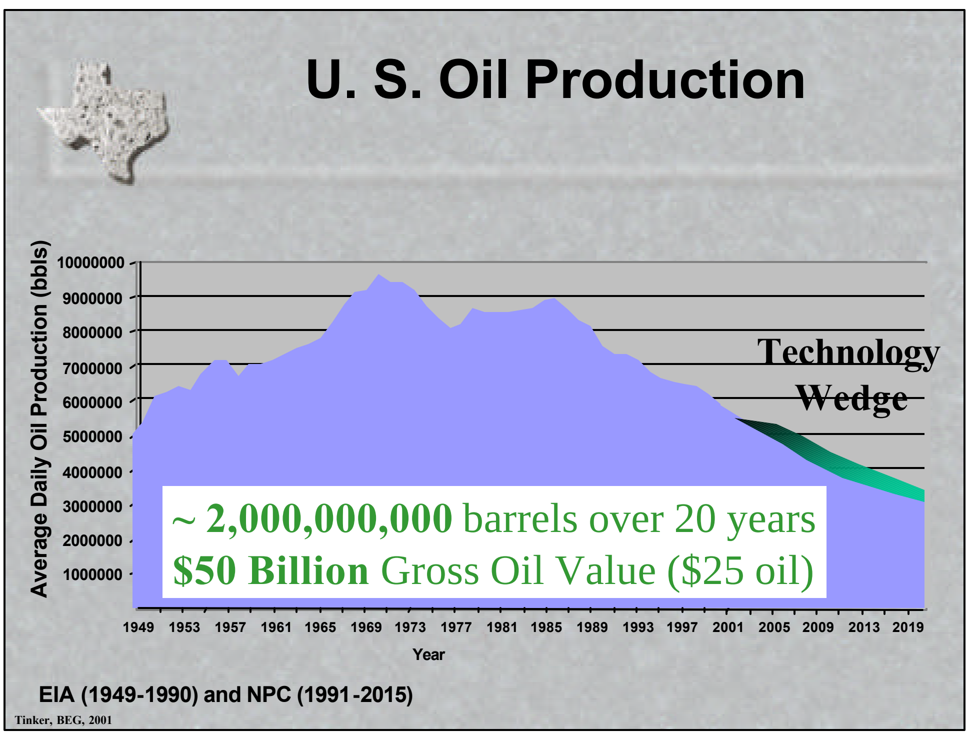
Environment

Impact of Oil Research



Tinker, BEG, 2001

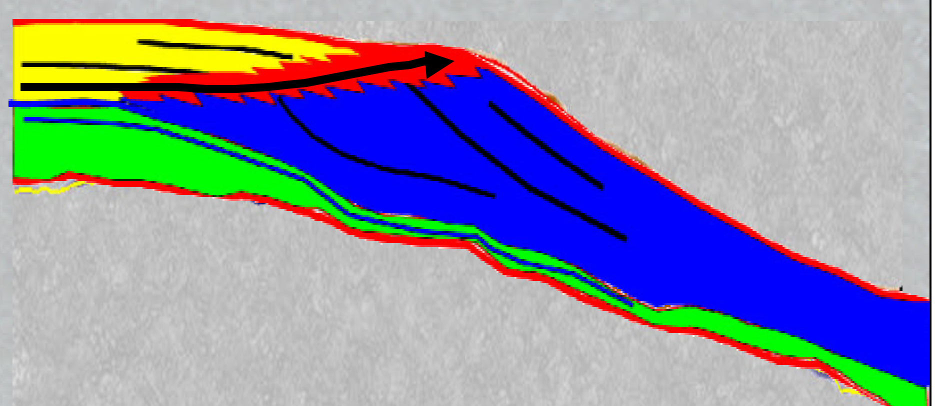

Theoretical Impact on Long-Term Oil Decline
Technology Wedge
Multi-field portfolio
Production
0
5
10
15
Time (yr)
Tinker, BEG, 2001


U. S. Oil Production
Average Daily Oil Production (bbls)
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
Technology Wedge
~ 2,000,000,000 barrels over 20 years
$50 Billion Gross Oil Value ($25 oil)
1949 1953 1957 1961 1965 1969 1973 1977 1981 1985 1989 1993 1997 2001 2005 2009 2013 2019
Year
EIA (1949-1990) and NPC (1991-2015)
Tinker, BEG, 2001

Fundamental Geoscience Research

- High Frequency Stratigraphy: Seismic & Outcrops
- 4C 3D, 4D, and 9C 3D Seismic
- Rock Physics
- 3-D Matrix and Fracture Modeling & Simulation

High Frequency Stratigraphy



Tinker, BEG, 2001

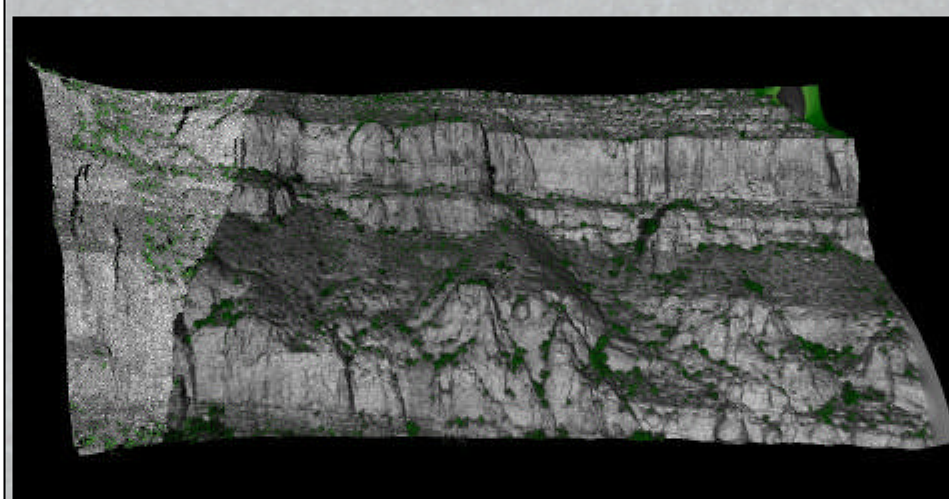
High Frequency Stratigraphy

Ortho-photo draped on DEM

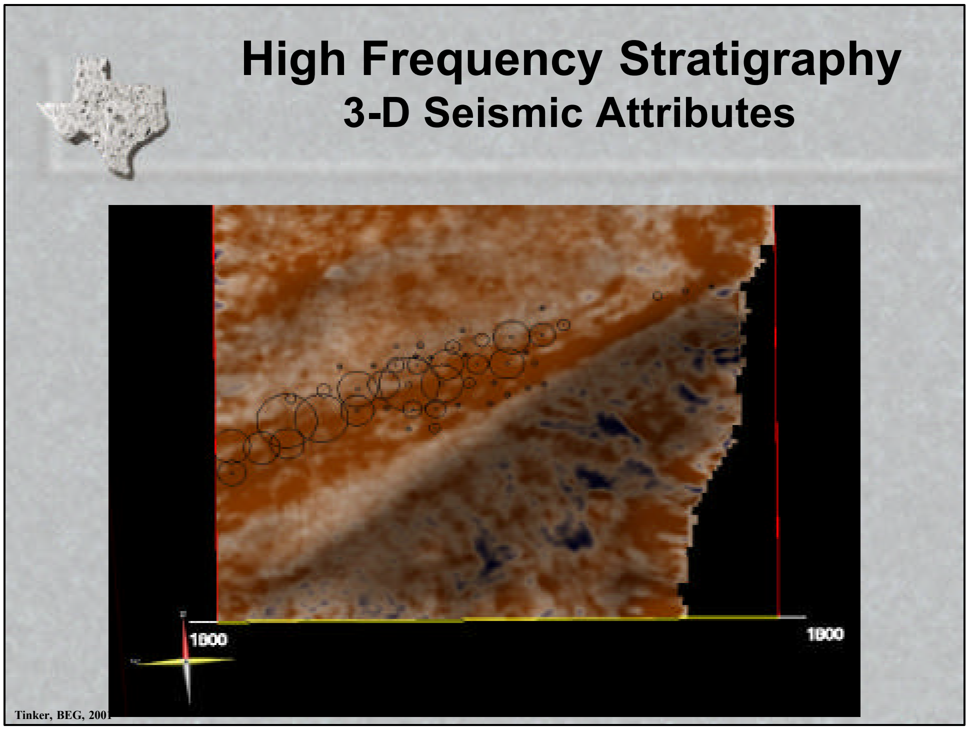
Tinker, BEG, 2001

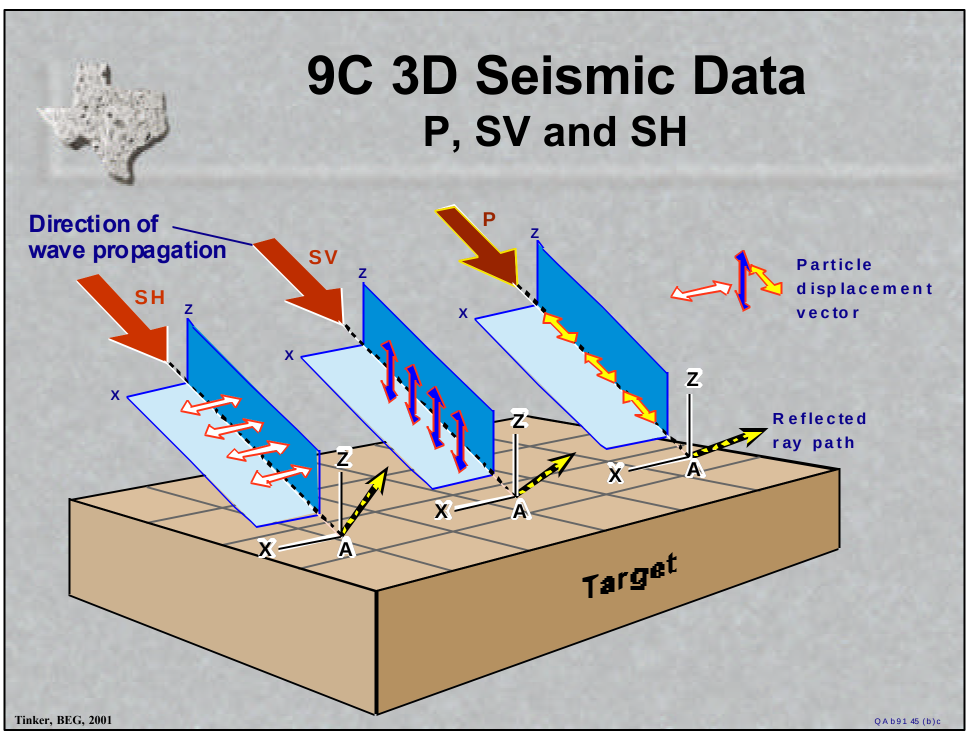
High Frequency Stratigraphy

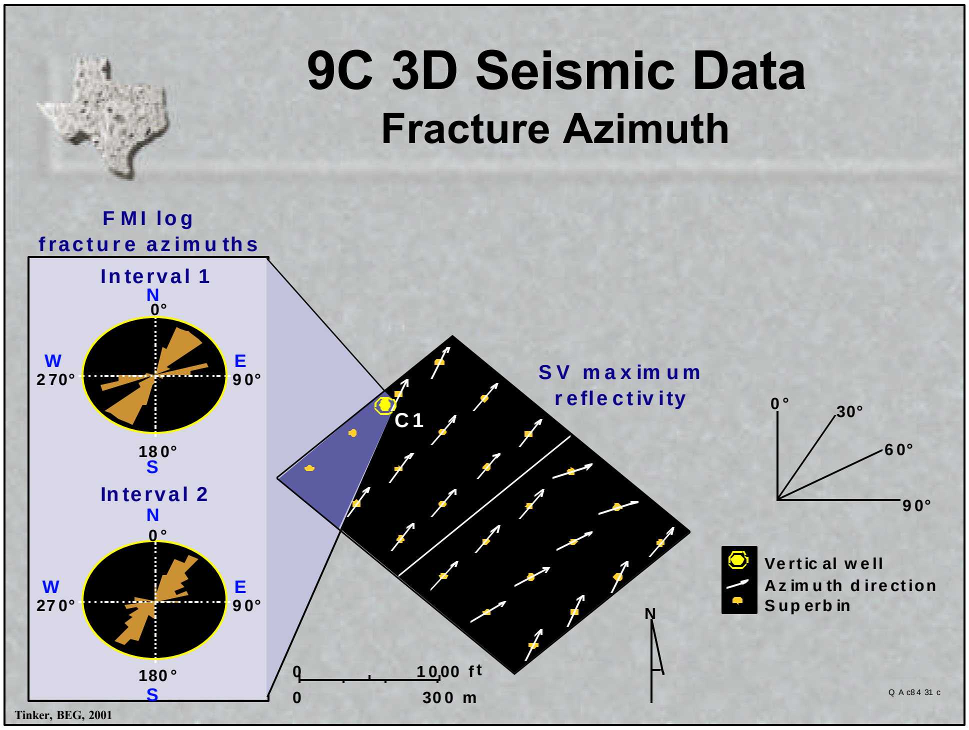
ILRIS Laser Image

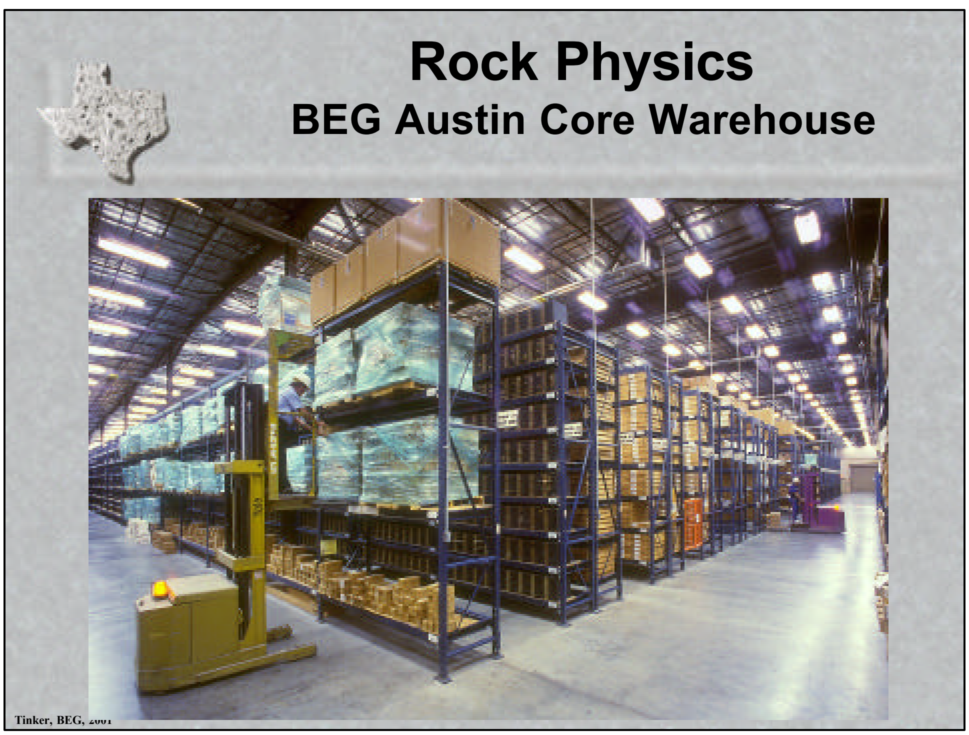


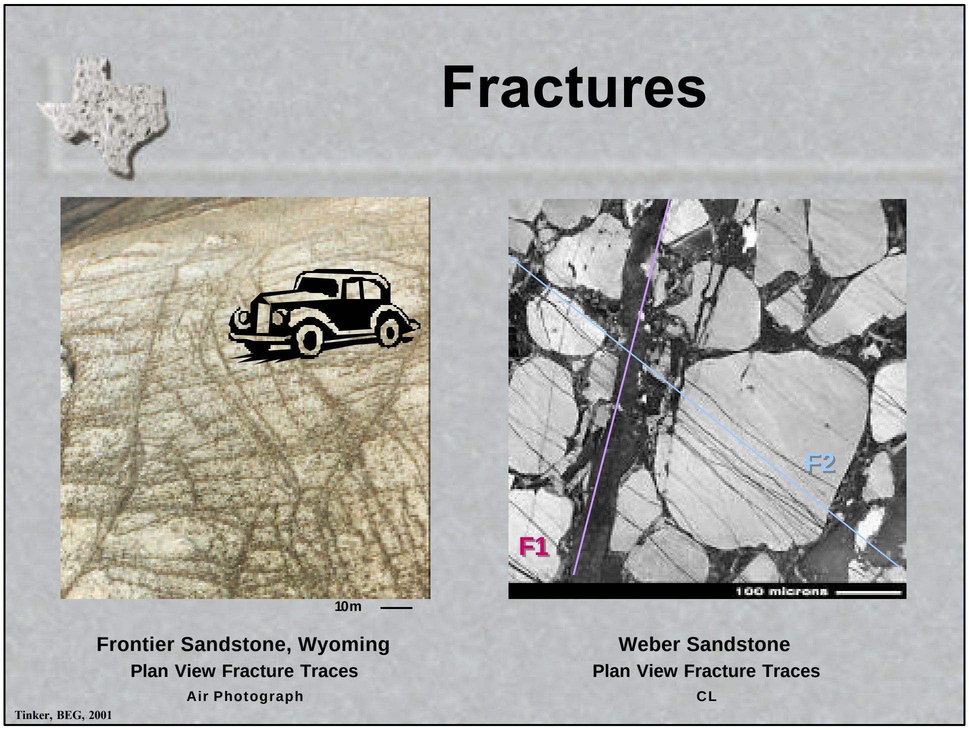
Tinker, BEG, 2001


High Frequency Stratigraphy
3-D Seismic Attributes
1800
1800
Tinker, BEG, 2001

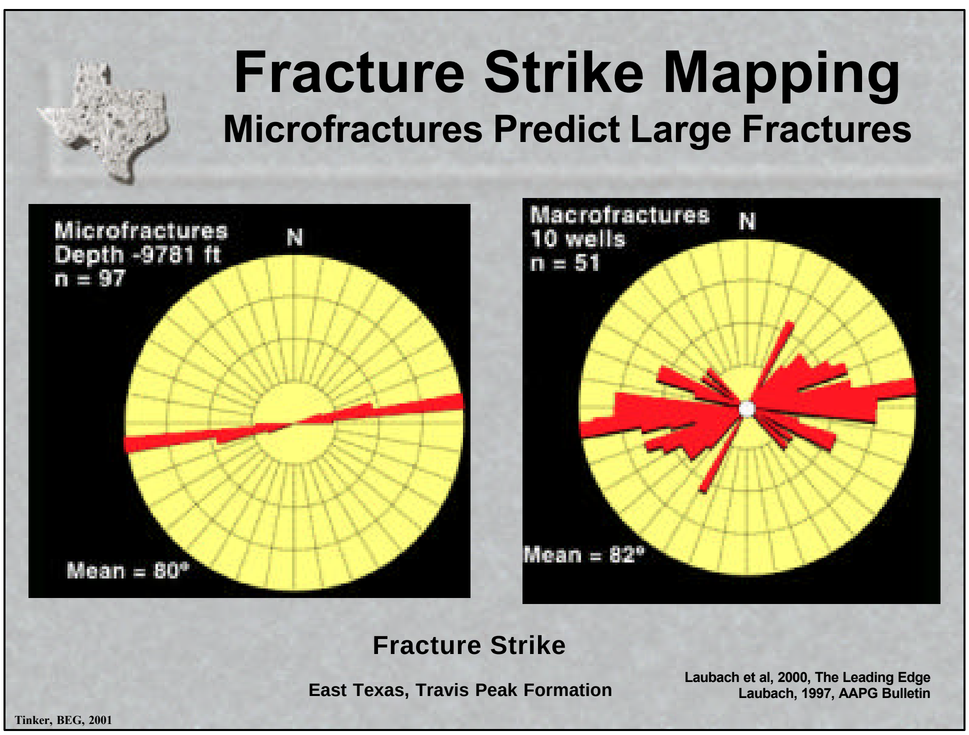

9C 3D Seismic Data
P, SV and SH
Direction of wave propagation
SH
SV
P
Particle displacement vector
Reflected ray path
Z
X
A
Target
Tinker, BEG, 2001


9C 3D Seismic Data
Fracture Azimuth
FMI log
fracture azimuths
Interval 1
N
0°
W
270°
E
90°
180°
S
Interval 2
N
0°
W
270°
E
90°
180°
S
SV maximum
reflectivity
C1
0°
30°
60°
90°
Vertical well
Azimuth direction
Superbin
N
0
1000 ft
0
300 m
QAc8431c
Tinker, BEG, 2001

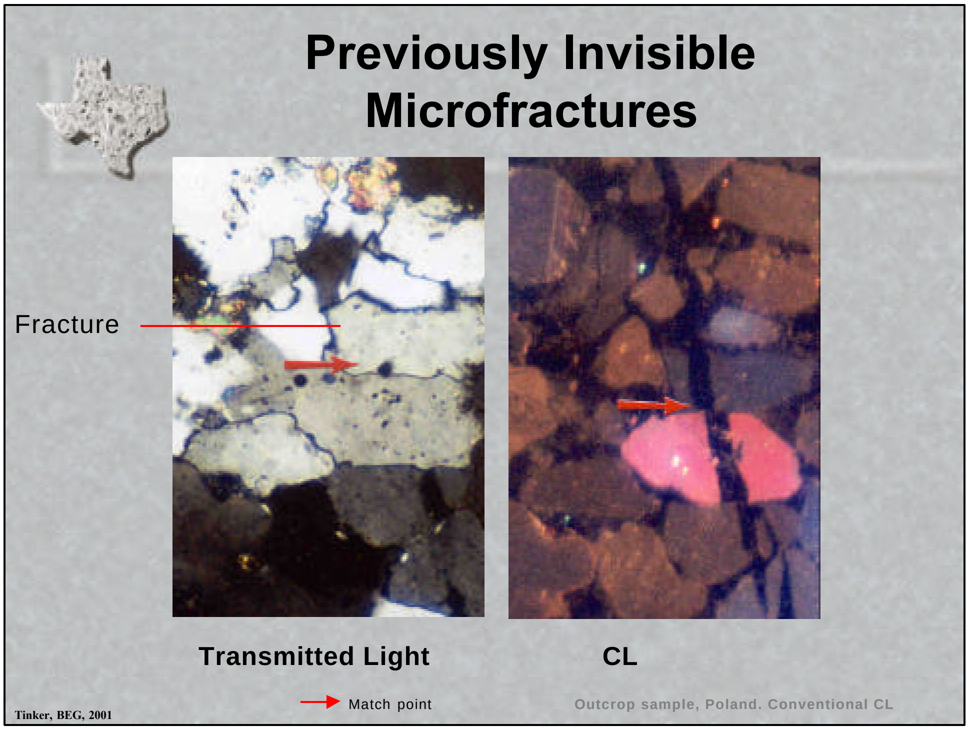

Rock Physics
BEG Austin Core Warehouse

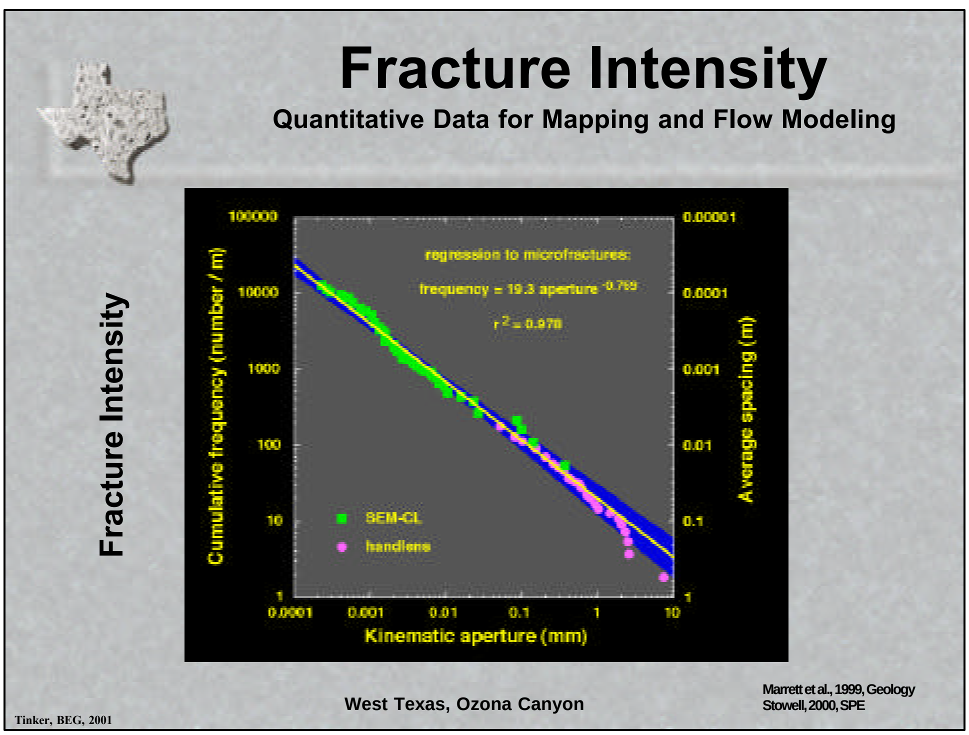


Fractures
10m
F1
F2
100 microns
Frontier Sandstone, Wyoming
Plan View Fracture Traces
Air Photograph
Weber Sandstone
Plan View Fracture Traces
CL
Tinker, BEG, 2001



Fracture Strike Mapping
Microfractures Predict Large Fractures
Microfractures
Depth -9781 ft
n = 97
N
Mean = 80°
Macrofractures
10 wells
n = 51
N
Mean = 82°
Fracture Strike
East Texas, Travis Peak Formation
Laubach et al, 2000, The Leading Edge
Laubach, 1997, AAPG Bulletin
Tinker, BEG, 2001


Previously Invisible Microfractures
Fracture
Transmitted Light
CL
Match point
Outcrop sample, Poland. Conventional CL
Tinker, BEG, 2001

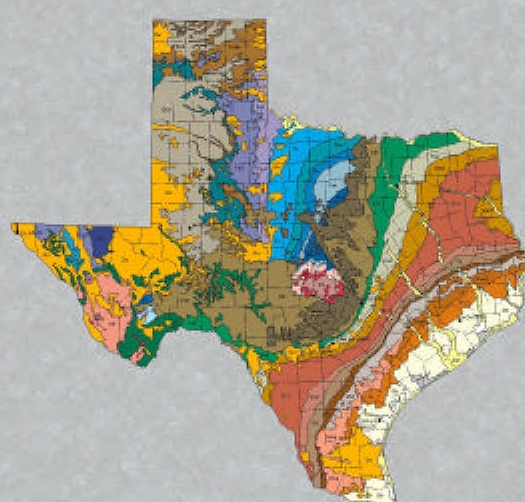

Fracture Intensity
Quantitative Data for Mapping and Flow Modeling
Fracture Intensity
regression to microfractures:
frequency = 19.3 aperture -0.769
r2 = 0.978
Cumulative frequency (number / m)
Average spacing (m)
Kinematic aperture (mm)
SEM-CL
handlens
West Texas, Ozona Canyon
Marrett et al., 1999, Geology
Stowell, 2000, SPE
Tinker, BEG, 2001

Additional Long-Term Research

- High level basin and play analysis
  - For improved access decisions
  - For improved E & P
- 3-D diagenetic modeling
- Visualization to achieve integration
- CO2 sequestration to improve oil recovery
- Advanced technology transfer

Tinker, BEG, 2001

Let's Get After It!



III. Work-Group Products

Following the plenary session, the participants worked in three breakout groups corresponding to Prime Program areas. The three groups working in parallel identified:

- Key barriers and issues to meeting the goals of PRIME,
- R&D opportunities to overcome the barriers, and
- Action plans identifying objectives, products, needed resources, and collaboration opportunities for priority R&D topics.

Figure 1 provides an overview of the work group results. The detailed results are presented as follows:

A. Enhanced Oil Recovery
B. Reservoir Characterization—Advanced Diagnostics and Imaging Systems
C. Drilling, Completion, and Stimulation.

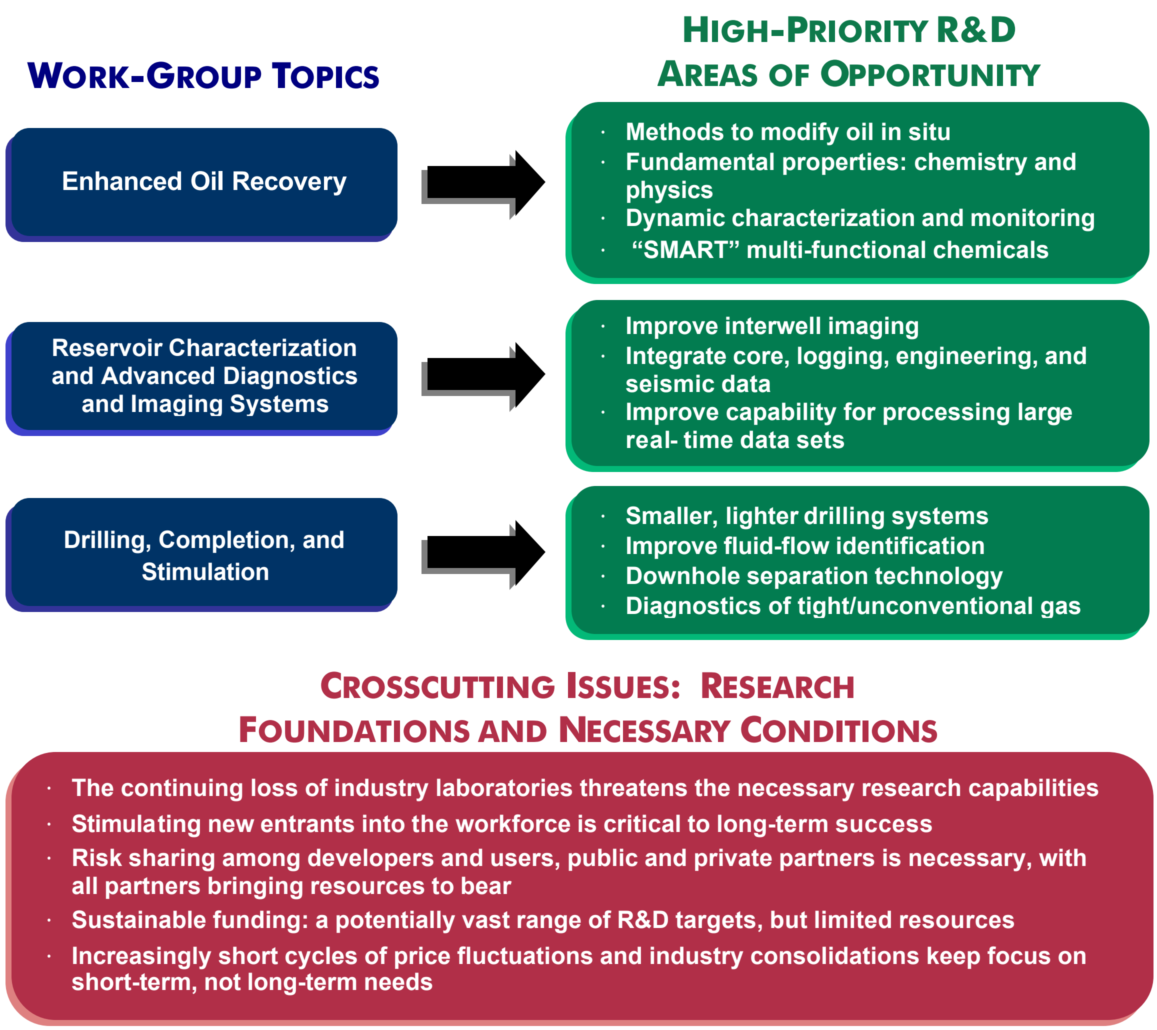


Figure 1. Overview of Workshop Results

A. ENHANCED OIL RECOVERY

Summary

The group was asked to identify barriers and opportunities in the area of oil recovery technology. General themes of the barriers included:

1) **High Cost of Existing Technologies**. There are many effective enhanced oil recovery technologies that currently cost too much.

2) **Lack of Significant Research Spending.** With the exception of one or two major oil companies, DOE remains as the only other current source of research funding.

3) **Lack of engineering professionals entering the field.**

Participants: Enhanced Oil Recovery

NAME	ORGANIZATION
Dave Borns	Sandia National Laboratories
Jill Buckley	PRRC, New Mexico Tech
Norman Goldstein	Lawrence Berkely National Laboratory
Robert F. Heming*	ChevronTexaco, Houston
Daulat D. Mamora	Texas A&M University
James Marsh	RIO Technical Services Inc.
Charles L. McCormick	University of Southern Mississippi
Randy Peden	Texas Energy Systems Corporation
Gary A. Pope	University of Texas
Eric Potter	Bureau of Economic Geology, UT
P. "Som" Somasundaraw	University of Kansas
Paul Willhite	University of Kansas
Mary Jane Wilson	WZI Inc.
Dennis Wimer	University of Alaska Fairbanks

*Report-out presenter

CHAIRPERSON: Jerry Casteel, DOE/NETL/NPTO

FACILITATOR: Phil DiPietro, Energetics, Incorporated

Barriers

The group felt that the United States' ability to perform effective R&D in this area is impaired by the closing of most of the research laboratories and field research activities that had been privately supported by the large integrated oil and gas companies, and that few students have been entering the field due to the paucity of job opportunities and because of the less-than-favorable student perception of the future of the domestic oil and gas industry. Currently, most of the research capabilities reside within the DOE Laboratories, private research laboratories and academia. There was also concern that possible future removal of exemptions under RCRA for drilling activities could inhibit the deployment of certain advanced EOR technologies.

R&D Opportunities

In the research opportunities discussion, the group emphasized the need to concentrate on fundamentals, such as the basic physics and chemistry of geofluids and injectates in porous and fractured media. Fundamental research into wettability, mobility, viscosity, and surface chemistry/interactions could produce the kind of new approaches and insights that are needed. The area with the highest number of votes was the development of chemical EOR methods. Two top-priority chemical approaches were to develop 1) methods to modify the viscosity of oil in situ and increase its mobility and 2) smart multi-functional EOR chemicals. Another suggested approach is to move toward dynamic reservoir characterization during EOR processes. A high-priority approach under the area of thermal EOR was to create steam additives to enhance production from heavy and light reservoirs.

Action Plans

During the action plan discussion, the group members suggested that the DOE engage in a process to craft an effective call-for-proposals. A general approach recommended would be to define end point performance metrics and allow the competitive process to bring forth ideas from the private sector, the DOE laboratories, and academia. In general, the group questioned whether the funding levels were adequate, considering the importance of the issue. Given the limited budgets and the need for multidisciplinary teams, innovative approaches to collaboration will be needed to achieve success.

The detailed results are presented in Exhibits 1.1, 1.2, and 1.3.

Enhanced Oil Recovery
Exhibit 1.1 What are the Barriers?
(categorized after workshop)

Cost Factors	Environmental Factors	Research Infrastructure	Technological Barriers	Communications and Technology Transfer
• Cost of EOR solutions, $4/bbl versus $10/bbl • Lack of combination techniques, e.g., surfactant/ microbial • Thermal EOR economically marginal/poor (generally) • Mobilization of residual oil is not cost-effective • Better low-cost surfactants from suppliers based on needs of EOR for small companies • Reduce cost of chemicals • Cost of technology versus the price of oil.	• Environmental impacts • Inadequate environmental and economic solutions to waste streams from production • Remote site and cold weather issues • Fear of using in-situ combustion as an EOR method	• Energy research is too fragmented • Attracting smart, creative people to work in EOR • Continuity of research (funding, people, equipment)	• Lost chemicals, where did they go? • Industry too "discipline" focused – breakthroughs lie in the white space • Lack of multi-scale understanding of dynamic reservoir behavior • Real-time monitoring for better modeling • Produce heavy oil with gas cap and bottom water • Fundamentals of interactions with oil • Increase volume sweep of EOR process • Technical barriers (oil related, formation-related, process-related) • No techniques to monitor surfactant orientation on surface to affect wettability • More reliable predictions of EOR performance under uncertainty conditions of realistic cases	• Technology transfer to industry, actually implement • Lack of communication networks or forums for producers • Public perception

Enhanced Oil Recovery
Exhibit 1.2 What are the Research Opportunities?

Recreate National Capability	Chemical EOR	Focus on the Basics	Thermal EOR	Other	Novel EOR (mechanical, electrical)	Monitoring and Dynamic Stimulation	Enhance Cross-Fertilization
• EOR virtual research center ✪✪✪✪✪✪ • Consolidate & maintain laboratories' capability ✪ • Fellowship and equipment program in the area of oil recovery • Education materials (books, teaching module)	• Develop methods to modify the oil in-situ – upgrade to increase $/bbl, min poll. – bio-surfactant – in-situ microbial catalysis, nanoscience ✪✪✪✪✪✪✪✪✪ • Smart, multi-functional chemicals – New synthetic techniques to control chemical Architecture – Smart, environmentally sound fluids EOR – Fluids responsive to reservoir conditions ✪✪✪✪✪✪✪ • EOR for carbonates that are not CO2 miscible targets (CO2 foam) ✪✪ • Develop low-cost surfactant systems for a wide range of reservoir conditions ✪ • Learn interactions of microbes with surfactant, polymer ✪ • Eff. Chem. Techniques for in situ, real-time monitoring & manipulating chem. Nanostructure on solids (orient, aggr.) • EOR chemicals for naturally fractured reservoirs ✪ • New approaches for mobility control – CO_2 flooding ✪	• Fundamental physics and chemical properties ✪✪✪✪✪✪✪ ✪ • Up-scaling of lab fluid-rock interactions to reservoir scale ✪ • Find T and brine tolerant effective microbes • Understand controls on sweep efficiency and develop methodologies to increase	• Steam additives to enhance production from heavy and light reservoirs ✪✪✪✪✪ ✪✪ • Higher capacity downhole steam generators to minimize heat loss, deeper injectors ✪✪	• North Slope. Gas-to-liquids CO2 and heat source for EOR • Develop capability to assess fate and transport of EOR chemicals – incorporate into design	• Alternative energy systems. Lower cost and multiple uses ✪✪✪✪ • Rock wettability control for oil release and flow ✪✪ • Combined techniques (e.g., microbial / surface biosurfactant) ✪ • Seismic stimulation	• Move to dynamic reservoir characterization develop capability for monitoring sweep & recovery ✪✪✪✪✪✪✪✪ – Integrate reservoir characterization and production response – Integrate reservoir models and reservoir monitoring – Instrumented oil fields (permanent sensors, inversion options, micro sensors • Smart simulators ✪✪ – Coupled fluid mechanical, and chemical simulation of reservoirs	• Improve tech transfer of advanced power systems (DER) & efficient separations from environmental waste mgmt program to improve economics for EOR ✪ • Merge DOE oil and gas efforts • Promote active, collaborative interaction between research groups • DOE participation in SPE forums where appropriate

✪ = Vote for priority topic

Enhanced Oil Recovery
Exhibit 1.3 Action Plan: The Path Forward

R&D Item	Products			Collaborations	Schedule
Develop methods to modify the oil in-situ to increase oil recovery (reduce viscosity, build pressure)	DOE get to the point where they can ask the right questions Example questions: • What do we need to understand viscosity/wettability? • Is it technically feasible to effect wettability away from the wellbore? • Why didn't it work before? Possible steps DOE holds meetings at universities and other centers to gain insights Bring together group of experts to delve into the science	DOE to write a call for proposals Define modify Define evaluation criteria based on performance endpoint Let competitive process work Utilize phased approach to R&D management	List of ideas presented by the group: Advanced demulsifying agents Wettability alterations Acoustic methods Advanced thermal Microbial Combined heat and chemical	Create ways to get people to collaborate w/out moving to same local Need a champion Collaboration at different levels Need a critical mass Lead Org will be the one with dedicated and capable people	Getting info could take a year
Fundamental physics and chemical properties	Priority areas proposed by the group: Wettability Viscosity control Nanostructure of interfaces Mobility control Petrochemical and petrophysical properties underlying mobility			Universities and the national labs lead	
Move to dynamic reservoir monitoring to control and optimize EOR processes	Capability to convert data to valuable decisions in production time Include rock in iterative program Capability to monitor slug properties			Need adequate program budget so that move to applications stage does not halt other R&D	

B. RESERVOIR CHARACTERIZATION–ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS (ADIS)

The group was comfortable with the targets for resource characterization and advanced diagnostics and imagining systems: fundamental research, 5-10 year time frame, research partnerships, and high-risk aspects for entirely new systems. The emphasis on resource characterization, pore to core, basinal analysis, and logging real time versus seismic was not a problem. All agreed that long-term R&D would require long-term funding commitments up front.

There were several reoccurring themes expressed by the most of the group. One was the inadequacy of current business models to make decisions given the range of data that are available. Another was the need to relax constraints on outcrop data versus well core data to expand the range of data settings. The ability to use an existing well for observations and experimentation is very cheap compared to drilling a new well and should be pursued.

Participants: Reservoir Characterization—Advanced Diagnostics and Imaging Systems (ADIS)

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Tim Bird	Landmark Graphics Corporation
Tom Collins	Oklahoma State University
Chris Corcoran	Shell
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Mark Houston	Northrop Grumman
Neil Hurley	Colorado School of Mines
Jerry Jensen	Texas A&M University
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David Lancaster	Schlumberger
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CHAIRPERSON: Bob Lemmon, DOE/NETL/NPTO

FACILITATOR: Kevin Moore, Energetics, Incorporated

Barriers and Issues

Feedback from the group was easily categorized under two major headings:

1) **Technology.** The technology barrier was then divided into three subheadings: data, integration and links, and models. Although there was no voting prioritization, one can summarize the issues as one of data compilation, integration, and sharing among competing and governmental entities.

2) **Process.** Process wise, effective partnerships are needed for data release and technology commercialization.

R&D Opportunities

The R&D opportunities used the same topic headers from barriers, and added another category. The top vote getter was the opportunity to improve inter-well imaging using logs, seismic, and outcrops. Correspondingly, integrating outcrop, core, log, engineering, and seismic data into better flow simulation models was the next important priority. Also related is the third top vote getter to develop capabilities and work flows for handling large data real time streams. All of these opportunities plus three others were carried over to the action analysis. There was not enough time to analyze a process opportunity.

Action Plans

The group produced lists of activities for each of the top 6 priority opportunities, along with capability requirements and timing schedules. However, funding requirements were too elusive to ascertain. Instead the group used a dotting process of five dots, with each representing 20 percent of a budget. The group then applied the dots among the top 6 priority actions to give relative cost shares. Results indicated that the top two and last priority are relatively twice as costly as the priorities three through five.

The detailed results are shown in Exhibit 2.1, 2.2, and 2.3.

Reservoir Characterization—ADIS
Exhibit 2.1 What are the Barriers?

TECHNOLOGY BARRIERS			PROCESS BARRIERS
Data	**Integration and Links**	**Models**	
• Characterization is *not* (more than) geophysics • Lack of information between logs and seismic • "Real-Time" data processing from instrumented oil fields • Data quality—data screening needed, e.g., core analysis • Basic rock mechanics understanding • Need for hi-res reservoir scale measurements away from the borehole • Detection and identification of shales • Digital capture of legacy/historic data, e.g., core stores	• Need to link outcrop ILRIS to 3D seismic (hi-resolution) • Knowledge management– previous data can be used with proper archive? • Data mining tech forecasting modeling competition intelligence • Lack of good large complete rock properties data bases • Utilization of infrastructure in old oil fields • Data integration requires quantification of uncertainty of data and modeling • Integration between seismic/wellbore measurements • Lack of tie between what we can measure and what we need	• Inability to quantify uncertainty in product • Techniques for visualizing uncertainty and inconsistencies in 3D/4D earth model at all scales • Common-earth model needed – seismic-to-simulation • Robust, repeatable stratigraphic frameworks • Using outcrop descriptions—integrating into reservoir models (more easily)—object orientation • Petroleum play-based studies to identify reservoirs to study • Lack of outcrop-based 3D models in various environments to help EOR and drilling decisions • Poor coupling between "geostatistics" and geology • Lack of time methods to evaluate events • Need better simulation modeling and data • Inadequate fluid dynamics	• Need an R&D formula between government, oil companies and service companies, e.g., IP • Partnership for data release – Majors – Independents – Research • No effective partnership between research groups and service companies to take technology to market • Who will do all this work? Older workforce, short job cycles • Property rights in the U.S. – Access to data • Business models/cases to support more costly hi-res characterization – Seismic – Geologic – Other • Cost-to-benefit ratio of resource characterization needs to be better documented, proven • Long term project management • Inertia among operators may require field demonstration • Methods of choosing research favors grant writers • Long time goals but lack of long-term funding • Short term funding cycles for long term research • Operators are looking for *low cost* solutions • The inefficiency of our technology transfer is a major barrier • Price uncertainty stifles research initiatives

Reservoir Characterization—ADIS
Exhibit 2.2 What are the R&D Opportunities?

Data	Integration	Models	Process	Others
• Build rock properties data base K, K_R, Cap pressure, ϕ, . . . – Standardization meta-data base ✪✪✪✪✪ • Quantify uncertainty of data ✪✪ • Improve inter-well imaging using logs, seismic, outcrops – Technology to look deep into reservoirs from boreholes ✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • Capabilities/workflows for handling large data real time streams in geologic/reservoir models – Techniques to utilize permanent sensor data in reservoir management – Smart techniques to QC and clean streaming real time data ✪✪✪✪✪✪✪✪✪ • Demonstration project for 3-component passive monitor in active reservoir – 1 year data ✪✪ • Develop logging and "VSP" technology in horizontal and deviated wells ✪✪ • Tool/sensors for very slim holes 2½ -3 inches	• Link computational fluid and rock dynamics across disciplinary boundaries ✪✪✪✪ • Integrate outcrop, core, log, engineering and seismic data into better flow simulations (models) – Rapid workflow environment -- Pore core, log, outcrop, seismic, simulation – 3D behind outcrop seismic ground penetrating radar (GPR) – Geologic object modeling (incorporating outcrop "ground truth") ✪✪✪✪✪✪✪✪✪✪✪✪ • Better integration between subsurface reservoir modeling/ visualization and surface facilities modeling/ visualization	• Develop technology to understand fractured reservoir (timing) ✪✪✪✪✪ • Better sampling models to give efficient data collection. What is implementation? How many measurements do we need? • Methods to leverage distributed, parallel simulator engines for EOR modeling • New generation regional basin/play models driven by reservoir-scale data ✪✪✪✪ • Develop techniques for visualization uncertainty of data objects in 3D and 4D reservoir models – Develop methods for quantifying uncertainty in predictions of production – Simulation validation ≠ history matching ✪✪✪✪✪✪✪✪ • Link seismic and EM with fractures and permeability ✪✪✪✪✪	• Change tax-law to allow favorable donation of data e.g., "rock-properties" • Demonstrate the value of converted shear wave seismic to operators ✪✪ • Use unconventional borehole geometries (e.g., multilaterals) to connect compartments, separate oil/gas/water downhole • Invest in an infrastructure to make research and industry partnership work more effectively ✪✪✪✪✪ • Measure research quality, e.g., peer review ✪	• Develop common-earth model, including scale-up and visualization ✪✪✪✪✪ • Advances in seismic and EM technologies to improve resolution (smaller scales) ✪✪✪✪✪✪✪✪ • Improvement in production logging ✪ • Shear zone flow properties and time dependence ✪

✪ = Vote for priority topic

Reservoir Characterization—ADIS
Exhibit 2.3 What are the Actions to Take Advantage of R&D Opportunities?

R&D Opportunity with Details	Actions, Products, Deliverables	Capabilities Expertise	Lead Roles Collaborations	Schedule $ Dollars
ACTION ITEM #1 • Improve inter-well imaging using logs, seismic, outcrops – Technology to look deep into reservoirs from boreholes – Cross well seismic and EM vs. single well imaging – New source physics – Measurements related to flow – How deep is deep? – Deviated and vertical boreholes	• New generation logging hardware • Software analysis methods • Field demonstration • Intelligence from system • Whatever the environment	• Very good engineering and math and physics • Numerical modelers	• Service companies and national laboratories • Academia for modeling and processing	• Proof of principle near term 3 years • Field demonstration >5-6 years • Relative cost share–19 votes
ACTION ITEM #2 • Integrate outcrop, core, log, engineering, and seismic data into better flow simulations (models) – Rapid work flow environmental – Pore, core, log, outcrop, seismic, simulation	• Tools integration • Uncertainty evaluation • 3D behind outcrop seismic and GPR • Geologic object modeling (incorporating outcrop "ground truth") • Laser scanning of outcrops ILRIS tool • Identify genetic data types, digital outcrop imaging, compile dimensional data on objects (petrophysical significance) • History- match retaining plausible geology • Dealing with data at different scales	• Physics, geology, geostatistics • Reservoir engineering, signal processing, inverse theory	• Academia, graduate students • Oil companies then service companies	• Proof of concept and scope <2 years • Populate data base 5-7 years • Relative cost share–18 votes
ACTION ITEM #3 • Techniques to utilize permanent sensor data in reservoir management – Smart techniques to QC and clean streamline real time data – Capabilities/workflows for handling large real time data streams in geologic/reservoir models	• Data networkings wideband data management • Properly engineered sensors-reliability • Install, manage, interpret • Smart systems • Field demonstration • Demonstration in a low-risk environment (i.e., monitoring well)	• Engineering, information technology, electrical engineering, and geophysics • Data integration	• Service and oil companies • National labs and universities	• Initial investment very high • Being done today case by case single techniques • 5 years production environment instrumented reservoir • Relative cost share–12 votes

Reservoir Characterization—ADIS

Exhibit 2.3 What are the Actions to Take Advantage of R&D Opportunities? *(continued)*

R&D Opportunity with Details	Actions, Products, Deliverables	Capabilities Expertise	Lead Roles Collaborations	Schedule $ Dollars
ACTION ITEM #4 • Develop techniques for visualizing uncertainty of data objects in 3D and 4D reservoir models – Develop methods for quantifying uncertainty in predictions of production – Simulation validation≠ history matching	• Dramatically improve visualization interactive capability • Identification of key uncertainties tool • Flexibility to swap models	• Strong math, physics, and geostatistics	• Academia for uncertainty • Service company for visualization • Connections to military and medical	• Not sure, probable leap frog • Relative cost share–10 votes
ACTION ITEM #5 • Advances in seismic and EM technologies to improve resolution (smaller scales)	• Simulate interest workshop plus web community • Recommendations plan product – Measuring experiment – Employ deep source and cost effective recovery	• Information theory • Hardware and engineering • Rock physicists • Astronomers and submariners • Wave propagation and imaging • Interpreters • Mathematician, physicist, geophysicist (exploration & theoretical)	• Coordinate with Society of Exploration Geophysicists (SEG)	• Summer workshops with SEG • As soon as possible with SEG September meeting • Relative cost share–8 votes
ACTION ITEM #6 • Develop technology to understand fractured reservoir (timing) – Link seismic/EM with fractures and permeability – Diagenetic modeling – Role of fractures in fluid flow and other data	• Applications to tight gas and EOR • Comprehensive field experiment • 9C seismic and multicomponent EM • Theoretical prediction from rock mechanics, etc. • Fine scale geochemical sensing	• Geochemists, diagenesis, rock mechanics, and engineering	• Academic and national labs • Service and oil companies	• Very long term • Relative cost share–19 votes

C. DRILLING, COMPLETION, AND STIMULATION

The group charge was to identify barriers and opportunities to achieving the objectives of the PRIME Program and to define action plans for high-priority R&D opportunities. The general parameters of the PRIME Program are:

- Fundamental applied research,
- 5-10+ years for research and development products,
- Breakthrough technologies:
  - Entirely new approaches and systems
  - Radical changes to existing approaches and systems,
- Collaboration among industry, universities, national labs, and others,
- $4 million in FY 2002 appropriation as seed money, and
- Minimum non-DOE 20% cost sharing.

Participants: Drilling, Completion, and Stimulation

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Arnis Judzis*	TerraTek
Ali Kadaster	Anadarko
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Bruce Storm	Halliburton
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CHAIRPERSON: Rhonda Lindsey, DOE/NETL/NPTO

FACILITATOR: Jim Carey, Energetics, Incorporated

Given the comparatively modest amount of funding available in FY 2002, there was considerable discussion about bounding the group's effort to a manageable set of targets. In response, NPTO managers discussed the general framework for all NPTO activity, including the PRIME Program. NPTO drivers are based on attaining and maintaining public benefits. This includes enhancing domestic oil/gas reserve development and resource production, maintaining effective stewardship of public lands, reducing well and infrastructure abandonment, providing R&D products that can aid independents and small-scale operators, and other domestic energy security actions.

Barriers

The predominant barriers identified were not strictly technology based, but rather focused on necessary conditions under which R&D could thrive. For example:

- **Human resource availability:** there is a troubling combination of a declining number of U.S. citizens entering the field and existing technical capabilities leaving the field through attrition and retirement. How/why would the "best and brightest" be attracted to the field of oil and gas technology?
- **Federal policy and vision:** there is presently no broad recognition of the increasing importance of energy security based on oil and gas resources.
- **Long-term risk aversion:** the industry as a whole is focused on short-term goals. Corporate mergers and consolidations, the increasing frequency and of amplitude of oil and gas price

swings, and lower-risk international opportunities all contribute to a shift away from higher-risk, longer-term R&D for domestic resources.

- **R&D dollars:** the likely need is far greater than the current program scope. Significant, sustainable funding will be needed to achieve program objectives, with contributions from a range of collaboration partners necessary to attain a critical funding level.

R&D Opportunities

The opportunities that were identified are focused in three main technology areas: the processing of drilling fluids in an environmentally friendly manner; monitoring and diagnostics to improve information quality and associated quality assurance and quality control; and materials, components, and subsystems for advanced drilling, completion and stimulation systems. In addition, a major non-technical opportunity was identified in the improvement and focus of DOE systems to address industry-specific needs of the oil and gas industry. After brainstorming the R&D opportunities, the work group members voted for high-priority items. In several areas, similar items receiving votes were combined before selecting the set for action plans. For example, votes for QC/analysis and diagnostics of fracturing were combined with ones for tight/unconventional gas. This became one of the items selected for action plans. Five opportunities were selected.

Action Plans

Based on voting for high-priority opportunities, the five items selected for action plans are:

- Smaller, lighter drilling systems,
- Fluid/flow identification,
- Downhole separation technology,
- Diagnostics of fracturing of tight/unconventional gas formations, and
- DOE "project nursery" to identify and high-risk R&D to be performed without co-funding.

For these items, the group identified R&D products and capabilities, collaboration and partnership needs, schedule, and dollars.

The complete work group results are presented in Exhibits 3.1, 3.2, and 3.3.

DRILLING, COMPLETION, AND STIMULATION
Exhibit 3.1 What are the Barriers to Success?

Human/Research Resources	Policy and Vision	Risk and Risk Aversion	Dollars and Sense	Technology Systems	Management of Innovation	Environment and Land Access	Image and PR
• In ten years there will be an 80% reduction of U.S. citizens' based oil technology and expertise. We will be importing. • Loss of industry R&D capability; mergers reduce possible number of collaborators • People – Age – Training/ education – Availability • Lack of inter-discipline cross-fertilization of technology ("not invented here syndrome") • Capturing technical skills being lost, e.g., smart systems to recognize impending problems • Weakness of technology base in industry – deconstruction of research departments	• Need moonshots. Lack of consistent and realistic, practical vision or challenge . . . (leadership and long term) • Clearly defined goals are needed • Lack of incentives for change (taxes, new regulations) • Alignment of regulatory agencies to *fast track*: Evaluation and deployment (permitting) of new technology • There is a looming energy crisis that general public does not recognize. Recent events demonstrate level of comfort we assume even though signs of terrorism, for example, are all around.	• Industry inability to assume risk (short term focus) • Absence of long term commitments – industry, government • Commercial implementation slow • Technology transfer (competitive industry) • Government support of risk-taking in new technology implementation – tax incentives • Short-term performance metrics by industry, not drive long-term • Major oil companies risk $400 mm to $2B or more per company annually for worldwide exploration. That investment will focus on lowest risk, highest potential regardless of where in the world it is. Comparatively, for example, Gulf of Mexico deep water is very high risk.	• Key factors – Who pays? Who plays? – Converting investment to competitive advantage – Time horizon to achieve return on investment – Tax incentives? • Lack of sustainable R&D funding from government and industry • Upstream R&D $ limited (industry) • Budget for new technology demonstrations should be 100 times larger than current DOE budgets focused here. • Budget availability to meet potential DOE award requirements • Oil/gas price fluctuations hinder long term R&D by operators	• Safe, lower cost underbalanced drilling systems • Materials – new or better properties, e.g., lighter, CRA, temperature, pressure • The drilling manager, particularly offshore: – technology management for the user • Drilling, comp. stim. viewed as a *cost* (savings) not as a *value added*	• Government partnerships big bucks $ • Improving linkage between development, application, and commercialization • Management of innovation in industry, large and small companies • Remove barriers to industry collaborating with DOE • Entry barriers to ideas, methods, products from other industries • Market access for small innovators • Integration of "New" with "Existing"; overall system perspective needed • Lack of integrated system solution approach for breakthrough (optimization) (need people to understand the system)	• Prospective areas closed to drilling; necessity/reward for new technology • Environmental impact – Footprint – size, weight – Fate and effects – predicting/ forecasting • Environmental – disposal, reuse, sustainable • Access without disturbing environment • Treatment and disposal of wastes (mud and cuttings) – Mud-less and cuttings-less • Drilling - Laser Technology?	• Image – Negative public reaction – Industry viewed as low tech • Public education of need for production and acceptance of some impact/ risk • Public resistance • Political resistance • Decline of industry image-difficulty in attracting best minds • Centralization of industry around Houston reduces presence and clout in Washington • U.S. political climate for government participation in O&G research has been bad for last 25 years. This needs to improve to support U.S. based research cooperation

DRILLING, COMPLETION, AND STIMULATION
Exhibit 3.2 What are the R&D Opportunities to Overcome the Barriers?

High-Value Targets	Federal/DOE Procurement/Program/ Project/Management	Fluids/Fluid Processing (Environmentally Driven . . .)	Monitoring and Diagnostics	DCS Systems and Components
• Technology and operations support for Native American lands ✪ • Deep plays to increase reserves • Tight, unconventional gas; QA/QC to increase productivity ✪✪✪✪✪	• Leverage U.S. DOE budget by coordinating efforts with West European Energy research programs' limited budgets – Norway DEMO 2000, – EU Energy Research – Belgium • Opportunity for DOE to play more proactive role in encouraging collaboration? – Graduated cost share – Incentives for joining collaborations – Formation of centers • Identify industry liaison focal points in DOE/FE • Government support of risk-taking on new technology implementation – tax incentives? ✪ • (PSA) Production Sharing Agreement contacts, initiated by U.S. government to "hire" oil companies to develop U.S. fields where supply is more important than cost • Promote DOE R&D successes ✪✪✪ • New approach to investment of taxpayer $ to stimulate field demonstrations in deep water requiring drilling of new wells, government participation in dry hole cost percent to reduce risk. In concert with this build in payback of investment to U.S. Treasury like JIP's do. ✪ • Fund R&D long term: development through testing so as to make technology commercially viable • DOE to form JIP that is tasked with review of award process with the goal of achieving "purpose built" contracts for oil and gas industry rather than one size fits all contracts • R&D targeted to remove current political/environmental barriers – government buy in to modify regulations and requirements ✪✪ • DOE project nursery ✪✪✪✪✪ • Reduce Risk: DOE purchase program: capital items used to demonstrate breakthrough technology that meet high breakthrough. DOE standards, for example potential for increase of U.S. based recovery greater than bill or barrels of oil ✪ • Government/DOE support of universities generating E&P researchers ✪✪	• Flow and fluid identification in horizontal wells and multi-laterals; smart pipe/sensors ✪✪✪✪✪✪ • Enhanced methods to separate produced water downhole • Supercritical fluid processing of non-aqueous fluid cuttings • Technology to flow problem fluids from wellhead to plant • Flow assurance/ performance ✪✪✪ • Highly improved water-based drilling fluids for offshore and onshore – Environmentally friendly – Low torque – Borehole stabilizing – Good cleaning, etc. ✪✪✪ • Remediation of brine contaminated soils – improved stewardship • Effective/efficient downhole separation technology ✪✪✪✪✪✪	• Improved cementing – Lower cost – More reliable – Fault tolerant – QC cementing and diagnostics ✪✪✪✪ • Smart well, smart field, sensor and completions • Automation, sensing and smart systems ✪✪ • Field/well/reservoir surveillance data/ control/measurement integrated tool ✪ • Instrumentation for real time monitoring of flow performance, corrosion, scaly deposits, downhole separators: use technology from NASA, national laboratories, and other industries. ✪ • Low cost diagnostics for integrity of completions • Downhole linear accelerator (gamma ray source) for wireline and land tool strings – Elimination of (Cs137) • Data gathering: faster, more reliable, storage	• Fluidless drilling ✪✪ • Drilling fluids testing and analysis: rigsite, automated, remedial ✪✪✪ • Novel drilling miniaturization and weight minimization • Smaller, lighter, more mobile drilling systems – Deepen present offshore – Frontier areas (e.g., Rockies) – Reduce Operation and MOB costs ✪✪✪✪ • Low-cost system for rotary directional drilling ✪✪✪✪ • Robotic drilling/mining/ tunneling system in shallow reservoirs • Casing repair with minimally reduced ID • Grassroots re-design of drilling systems for: – Land/sensitive ecology areas – Land – Deep/hot/high pressure – Example: NASA Mars mission • Light weight/low cost materials to minimize tonnage in well construction • Low cost, high strength expandable casing systems, e.g., composites, roll down or spray in place • Outflow: rod pump, A.L., ESP • Effective conversion of mud to cement for – Zonal isolation – Disposal – Other uses • Formation/permeability damage ✪ • Formation/permeability/ wellbore stability; muds, stress analysis, sealants ✪✪✪ • Novel zonal isolation

✪ = Vote for priority topic

DRILLING, COMPLETION, AND STIMULATION
Exhibit 3.3 Action Plans: The Path Forward

High-Priority Topic	Products	Capabilities	Collaboration and Partnerships	Schedule	Dollars
#1 • Smaller, lighter, more mobile drilling systems – Deepen present offshore – Frontier areas (e.g., Rockies) – Reduce Operation and MOB costs • Low-cost systems for rotary directional drilling ✪✪✪✪✪✪✪✪	• System study and definition of proposed specification • Designs and prototypes of components including – Pipe and Pipe handling – Power system – Fluids system (if applicable) – Delivery (mobilization) – Methodology (monobores, instrumentation and control, advanced automation • Low cost rotary directional drilling • Surface and subsurface intelligent	• Applicability to wide variety of surface and subsurface environments • Environmentally friendly, including footprint, fluids, safety, etc. • Significantly lower cost than current technology	• JIP's: producers, support industry, academia – Space technologists, military contractors with technology to adapt/adopt to oilfield tech. – JIP's with DOE participation – Staged participation of DOE as project progresses – International collaboration or cooperation	• 4-6 mo – system study • 6-8 mo – preliminary system configuration and design • 18-24 mo. - design and build prototype and shop test components • Year 4 - assemble and test at control test site • Year 5 - Precommercial test • Year 6 - forward – commercialization • Milestones at each level	• Gradually increasing total estimated DOE $12-15 million over 5 years (total project estimate ~$40 million • Staged • Feasibility 100% DOE • Preliminary eng. 80% DOE • Technology development 50-80% DOE • Field demonstration 50% DOE
#2 • Flow and fluid identification in horizontal wells and multi-laterals; smart pipe/sensors ✪✪✪✪✪✪	• Sensors • Electronics for remote ops. • Telemetry • Data management at surface • Data interpretation • Decision process • Implementation process	• Materials (ceramics) • Drilling and product management and expertise • High pressure and temperature • Non-intrusive	• Operator/Service Company/ Technology Developer joint effort with DOE coordination	• Define scope – 1-1 ½ years • Sensor design and field test – 3-5 years • Implementation – 5-10 years	• $7-10 million
#3 • Effective/efficient downhole separation technology ✪✪✪✪✪✪	• Technique for identifying high-permeability zone behind casing • Efficient separator • Reliable pump	• Separation (oil/gas/water/ solids) • Pumping • Diagnostics	• Operator • Service Provider • Equipment Provider	• 1-5 years	• $3-5 million

High-Priority Topic	Products	Capabilities	Collaboration and Partnerships	Schedule	Dollars
#4 • QC/analysis and diagnostics of fracturing for tight/ unconventional gas ✪✪✪✪✪	• Tools and techniques — Preparation of job and execution for increased production — More unconventional wells for reserves (tight sands, shales, etc.)	• Analysis of free job data — Definition of free geometry — Optimize flow • Reserves estimation	• Operator/Service Company/ Technology Developer joint effort	• Now to 10 years	• $10 million
#5 • Project nursery by DOE — High risk, no co-funding — Sensitivity analysis — Not renewable! ✪✪✪✪✪	• Market needs • Orphan assessment • Survey; non-petroleum for ideas • Advertising/cooperate with group • Concepts for proofs later • Review board • Future directions • Sensitivities analysis	• Think tanks • Industry, University, National laboratories • DOE Coordination – in-house	• Reviews: Who decides	• Initial screen: 6 months – year • Next step - 2-3 years	• $1-2 million/year

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