2007 Plan for the NETL Complementary Research and Development Program

Complementary to the Consortium R&D Program Implemented Under the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program Established under the

Energy Policy Act of 2005, Subtitle J, Section 999

August 2007

Complementary R&D Plan

This R&D plan describes research to be carried out by NETL that will be complementary to the R&D administered by the Consortium. This complementary program will have four principal areas:

- Drilling Under Extreme Conditions
- Environmental Impacts of Oil and Natural Gas Development
- Enhanced and Unconventional Oil Recovery
- Resource Assessment

In addition, there will be a fifth area of activity (see Section 4, Planning and Analysis Support) where work will be done to identify and quantify the benefits that are expected to accrue as a result of the entire Section 999 Program, and to perform analyses in support of program planning.

Implementation of this plan relies upon existing NETL capabilities but also requires the building of new research competencies at the Morgantown, Pittsburgh and Albany facilities. These efforts will require active participation by the NETL-University Research Initiative, a partnership established between NETL and select universities as well as other industry and national lab partners to further expand DOE's research capabilities and available knowledge base. NETL's Office of Research and Development (ORD) will undergo peer reviews to generate evaluations of its R&D projects. The work described in sections 3.1 through 3.4 describes the initial complementary research program focus. Out-year R&D could be adjusted by comments taken from the peer review process.

3.1 Center for Drilling Under Extreme Conditions

The Center for Drilling Under Extreme Conditions (CDUEC) will improve the economic viability of drilling for and producing from domestic deep (greater than 15,000 ft TVD) and ultra-deep (greater than 25,000 ft TVD) oil and natural gas resources, benefiting the public by increasing the domestic supply of oil and gas. The research will be performed in unique, world-class facilities where researchers will conduct leading-edge fundamental research related to drilling under extreme conditions.

A. Motivation for Study of Drilling Under Extreme Conditions

The potential for domestic oil and gas production from deep and ultra-deep resources is considerable. There are an estimated 114-132 trillion cubic feet (TCF) of technically recoverable natural gas resource onshore and 55 TCF offshore trapped in reservoirs below 15,000 feet. Additionally, deep wells are often very large producers relative to their shallow counterparts. However, producing these resources often means drilling under extreme conditions, especially with respect to High Pressure and High Temperature (HPHT).

From an economic perspective, the drilling rate of penetration (ROP) is the single most important factor in determining the cost of drilling a well. Some reports applicable to deep

drilling in the U.S. Gulf Coast state that: "over 50% of rig time is spent drilling the last 10% of the hole." In a cost benchmarking report prepared for DOE, the drilling/tripping cost category was found to average 50 percent of the total cost of deep wells. Improving the rate of penetration in the deepest segments of deep well drilling through technological advancements is a major motivation for this area.

Without technological advances, the cost of recovering deep resources will remain high. Thus, free market forces dictate that energy prices be sustained at high levels for the private sector to have incentive to develop these costly, deep resources. However, new technology and fundamental understanding of drilling under extreme conditions could reshape the economics of deep resource recovery.

B. Strategy

NETL's strategy is to make key contributions in the area of drilling under extreme HPHT conditions in 5 major subject areas: 1) Drill bit-rock-fluid fundamentals, 2) numerical model development for rock mechanics systems, 3) development of novel drilling fluids, 4) development of sensors and electronics, and 5) materials development to provide new alloys having superior performance with respect to corrosion and erosion. Each of the five subject areas listed above are expanded upon here.

Drill bit-rock-fluid fundamentals – NETL is uniquely positioned to study HPHT drilling via physical simulation under carefully controlled laboratory conditions using the Ultra-deep single cutter Drilling Simulator (UDS). The UDS will be a one-of-a-kind research facility capable of recreating bottom-hole drilling environments of ultra-deep wells. The UDS capability includes operation at pressures up to 30,000 psi (2,068 bar) simultaneous with temperature up to 481 °F (250 °C). NETL's UDS is also unique in that it can operate with "real" drilling fluids, rather than simple fluids like water or air. This is an especially relevant distinction in that previous DOE-funded studies demonstrate that rate-of-penetration performance is several multiples higher for "clear base fluids", as compared to their corresponding drilling fluid. Visualization of physical experimentation is made possible by a sophisticated X-Ray video system that takes images of cutting at down-hole conditions, which includes cutter and rock immersed in an optically opaque drilling fluid.

NETL will carry out its strategy in the UDS initially by testing benchmark rock cores that match the physical properties of rock commonly encountered in basins of interest. Initial research will concentrate on benchmark rock cores of Crab Orchard sandstone, Carthage marble, and Mancos shale which provide analogs to rock encountered in the Arbuckle and Tuscaloosa deep gas plays. Shown below are specific examples of how NETL plans to execute the strategy described here:

1) PDC cutter studies on each rock benchmark. Parametric studies that vary drilling fluid weight (i.e. dissolved solids concentration) and type (examples of various drilling fluids include water-base mud, oil-base mud, and cesium formate mud).
2) Studies that seek out optimal placement and characteristics of drilling fluid around the cutter-rock interface. This involves parametric studies that vary pressure,

temperature, and classical dimensionless quantities known in the field of Fluid Mechanics (e.g. Reynolds Number, etc.).

3) Parametric studies that quantify the effects of weight-on-bit and contact angle during the rock cutting process for various systems.
4) Fundamental investigations that seek out physical evidence of drilling mechanisms and conclusions about the importance of each of these. Such drilling mechanisms may include any of the following:
    a) The hypothesized formation of a filter cake on the rock surface between cutter passes, and any effect it has on reducing friction, impeding fluid flow into pores, etc.
    b) The transfer of fluids between rock and wellbore during cutting, and any effect that this transfer has on ROP.
    c) The role of volume changing events in the rock phase and how/when this is advantageous or detrimental to rock cutting.
    d) The importance of particle size distribution with respect to dissolved solids in the drilling fluid. Emphasis will be placed on quantifying the possible advantages of nanofluid use in drilling fluids.

Numerical model development (rock mechanics) – Concurrent with physical simulation in the UDS, NETL is embarking upon numerical model development. These models seek to better explain and predict rock response to various drilling modes, including rock strain during cutting, formation of shear bands, and influence of fluids in rock pores. These activities ideally complement the physical simulation occurring in the UDS, as model validation becomes possible.

Novel drilling fluids – NETL's pioneering work in nanofluids opens pathways into novel drilling fluid development. Researchers will strive to make drilling fluid advances by establishing a new class of nanoparticle-based drilling fluid and/or by establishing nanoparticle additives to conventional fluids. These advances will potentially increase ROP of deep drilling systems. Concurrently with the Center for Environmental Impacts of Oil and Natural Gas Development (see Section 3.2), researchers will also investigate modified formulations of drilling muds to reduce the impact of drilling in environmentally sensitive areas.

High temperature sensors and electronics – NETL will also leverage its experience in high temperature sensor development to develop sensors and electronics capable of down-hole operation in HPHT wells. Specifically, NETL researchers will concentrate on Silicon Carbide technology that promises sustained operation at temperatures as high as 662 °F (350 °C). This area will leverage the 20+ years of NETL experience in advanced combustion where NETL researchers have developed and patented sensors and controls for operation at temperatures up to 2500 degrees °F (1371 °C).

Materials development – NETL will also use its expertise in materials and metallurgy to gauge performance of materials exposed to extreme HPHT, corrosive/erosive environments associated with deep and ultra-deep resources. NETL will apply its substantial expertise in material processing to deliver advanced alloys having superior

performance in high temperature and sour (high hydrogen sulfide content) applications.

C. Goals/Objectives

Near Term (by end FY 2008)

1) Make operational NETL's UDS, having capabilities described above in the strategy statement.
2) Conduct initial numerical simulations using NETL-developed Dynamic One-Dimensional Shear models to predict shear localization in rock formations as a result of various drilling activity and investigate material properties encountered in ultra-deep formations.
3) Characterize nanofluids created via laser ablation (a novel technique pioneered at NETL) and determine the potential of developing a new class of drilling fluids via Nanofluid technology.
4) Conduct initial research involving the development and testing of novel electronics and sensors for use in HPHT environments such as:
    a) SiC-based high-voltage and high current metal-oxide-semiconductor field-effect transistors (MOSFETs) and bipolar junction transistors (BJTs), which will be essential for motor drives and controls operating as high as 662 °F (350 °C)
    b) SiC-based devices for logic and analog circuits to process signals from high-temperature sensors (described below) and to subsequently communicate measured reading with the surface
    c) High-temperature instruments, such as accelerometers, magnetometers and gamma ray detectors. Research in the near term will concentrate on wide band gap semiconductors, interfaced with sensor circuits containing SiC devices, and
    d) Ohmic and Schottky contacts that do not degrade at elevated temperatures.
5) Identify performance shortfalls in currently-available tubular materials in sour environments at moderately high temperatures and pressures. This assessment will include the High Interstitially Strengthened Steel (HISS) alloys currently being developed at NETL. Specifically, the assessment will include identification of performance gaps with respect to: 1) stress-corrosion of tubular materials, and 2) wear-corrosion of tubular materials. If the HISS alloy performs well, then this assessment will help provide confirmation of the potential of HISS alloys for deep well drilling applications and the benchmark testing against commercially available products will provide a quantifiable measure of value.

Intermediate Term (by end FY 2012)

1) Publish the results of 8 parametric studies conducted in the UDS that identify possible opportunities for improvements in Rate of Penetration applicable to deep and ultra deep oil and gas drilling.
2) Continue research in high temperature electronics as described in the near term section. The following milestones are expected during the intermediate term:
    a) Test SiC-MOSFET and SiC-BJT for high-current operations at 350 °C.
    b) Develop and test SiC electronics interface and aluminum nitride (AlN) accelerometer for deep submergence operation at 350 °C.

c) Develop and test SiC electronics for wireless communication at 350 °C.

3) With an effort commensurate with the conclusions reached in the near term materials performance assessment, develop proof-of-concepts for new materials that can fill identified HPHT performance gaps.
4) Work with industry to identify technology gaps, leading to additional goals for the 2012 – 2017 time frame.

Long Term (through fiscal year 2017)

1) NETL will work with industry to accelerate the deployment of technologies developed during the Intermediate Term.
2) With near and intermediate term conclusions from Resource Assessment activities (see Section 3.4) known, identify new opportunities to exploit the large potential of ultra-deep resources in place. NETL will capitalize on these opportunities by using the UDS to study new but appropriate benchmark rocks via a research regimen similar to the UDS work detailed under the Intermediate Term.

D. Anticipated Results

Through use of NETL's unique UDS, numerous research activities will be reported in open scientific literature for use by industry and academic stakeholders in advancing technology. Disseminating information in this manner, and possibly collaborating with private sector entities via cooperative research and development agreements (CRADAs) will result in superior commercial products for drilling under extreme conditions.

By performing validation studies of existing and new numerical models, numerical simulation techniques will be advanced to the stage of reliably predicting drilling mechanisms under extreme conditions such that commercial advanced drilling products can easily be developed in the private sector.

Research findings will enable commercial drilling products exhibiting a 10x improvement in Rate of Penetration (ROP) over what is currently commercial when drilling very hard rock under ultra deep HPHT conditions. This will be accomplished by coupling knowledge gained from study of drilling processes, rock mechanics, drilling fluids, and simulation techniques. This may also involve a combination of disseminating information via publicly available literature and partnering with commercial entities via CRADAs or similar agreements.

Instruments and electronics that can operate in HPHT wells will be made available to the industry. This will be accomplished through publication of studies on novel electronics and sensors and through partnering with commercial entities via CRADAs or similar agreements.

Advanced materials will be made available to industry for drilling and/or operating wells in HPHT and/or sour reservoirs. These advanced materials will have superior performance with respect to corrosion resistance and usable lifetime.

E. Anticipated Impact

As a result of NETL's work under EPAct Section 999, it is anticipated that:

- The commercially realized ROP for ultra-deep hard rock will improve by a factor of 10 from current levels encountered in the deepest portions of HPHT wells. Specific to this most economically challenging portion of HPHT drilling, this translates to an ROP increase from a typical 3 ft/hr to about 30 ft/hr, having a transformational impact on the economics of deep drilling. This will allow for the economical production of deep and ultra-deep resources that were previously uneconomical.
- Down-hole electronics and instruments will become a commercial reality for high temperature / high pressure wells.
- Superior metallurgy will be available for tubulars in HPHT and sour environments. This will have positive impacts with respect to economics of deep resource recovery and potential environmental threats resulting from early component failures.

3.2 Center for Environmental Impacts of Oil and Gas Development

The Center for Environmental Impacts (CEI) will provide unbiased scientific information and analysis on the environmental impacts of oil and natural gas development, and develop and evaluate new technology or strategies to effectively deal with any negative environmental impacts. It will quantify the benefits of new technologies by comparing them to existing practices.

A. Motivation for Research on the Environmental Impacts of Oil and Natural Gas Development

Environmental concerns are among the most pressing issues limiting U.S. oil and natural gas production, causing significant delays and financial burdens to large and small operators. Environmental protection concerns also limit access to extensive portions of domestic oil and gas resources. Responsible management of the nation's valuable oil and gas resources requires that these environmental concerns be grounded in sound and objective science and, where feasible, mitigated through advanced technology solutions. Environmental studies conducted or funded by either industry or environmental groups can be viewed as biased; NETL is uniquely positioned to provide objective, credible science and technology solutions that both protect the environment and reduce costs for industry. Some of the most important issues are highlighted here.

- Produced water management is the single biggest cost for on-shore domestic producers. While much of this water is re-injected for pressure maintenance, a significant volume must be disposed of through on-site injection, treated and discharged, or transported to a commercial treatment facility.
- Disposal of produced water from coal bed natural gas (CBNG) is limiting a critical supply of natural gas needed to meet U.S. demand. Produced water issues have essentially stopped CBNG development in Montana and have crippled the pace of development in Wyoming. CBNG produced water concerns differ from other produced waters in that the water is potable or near potable when produced, but

mineral interactions from surface disposal can damage soils or cause ground water contamination when the water dissolves additional salt from the soil.

- More than 138 tcf of technically recoverable natural gas underlies on-shore Federal lands. Approximately one third of this resource is effectively off-limits because of environmental stipulations. While these stipulations are intended to protect the environment, many were developed without adequate scientific research.
- Air quality is another issue limiting oil and gas development. In order to comply with Clean Air Act requirements, State and Federal regulators have either restricted development or have imposed costly emission control requirements. Estimates of air quality impacts are generally based on models that treat all oil and gas development in a state as a single point source. This gives a very different impact than would result from modeling the many small, widely dispersed sources that actually exist.
- Access to CO_2 for enhanced oil recovery (EOR) is limited by economics and by pipeline location. At the same time, greenhouse gas emissions (both CO_2 and CH_4) from oil and gas production activities are a developing concern. Recent research indicates that it could be possible to conduct EOR using CO_2 captured directly from the atmosphere if the capture technology could be made more economical.
- Oil shale resources in the Green River Basin exceed 2 trillion bbls, the single largest liquid fuels resource in the world. With oil prices high, technologies exist to make economic recovery of this resource a reality. However, because these resources are mostly on Federal lands, many environmental concerns will have to be addressed before large scale production will be allowed to proceed. Chief among these are the issues of water availability and quality for maintaining a large-scale (>1 million bbls/day) oil shale industry.

B. Strategy

DOE/NETL's strategy is to resolve regulatory issues and environmental barriers to oil and gas production by 1) developing environmentally benign technologies for managing produced water, 2) anticipating environmental barriers to future sources of oil (oil shale) and proactively identifying/developing extraction methods that minimize water use and environmental impact, 3) developing more realistic models of air emissions from E&P activities that are based on actual measurements from widely dispersed sources, and 4) implementing research to better understand ecosystems impacted by E&P activities and their vulnerabilities.

Managing produced water – Industry, regulators, and environmental interest groups concur that issues with the treatment, disposal, or beneficial use of produced water are currently the primary barriers to oil and gas production. CEI has prioritized the following research activities to mitigate produced water issues. Specifically, the CEI will:

- Catalogue existing technology and solutions for treating produced waters.

- Evaluate subsurface drip irrigation (SDI) as a beneficial use for produced water. The study will determine the long-term effect of SDI on crop yield, soil permeability, shallow hydrology, and salt mobilization.

- Test helicopter electromagnetic induction surveys as a rapid means to determine the soil salinity of large areas. The quality of produced water that can be discharged to ephemeral or intermittent streams is based on estimates of soil salinity according to Wyoming's Agricultural Use Protection Policy (Chapter 1, Section 20). A faster, less expensive method for determining soil salinity would expedite discharges of produced water.

- Conduct channel morphology studies to determine the maximum rate that produced water can be discharged to a drainage system before significant erosion or flooding occurs. Currently, produced water discharge limits are conservative; better knowledge of channel flow capacity may permit greater amounts of produced water to be discharged safely.

- Initiate studies to determine the fate of salt deposits and high TDS aquifers when produced water is discharged into overlying dry stream systems or infiltration pits. The quality of infiltrating produced water is expected to be degraded by contact with salt deposits; infiltrating produced water probably will dilute and laterally displace high-TDS water in shallow aquifers. Previous NETL work has shown that salt deposits and shallow, high-TDS aquifers can be mapped using helicopter electromagnetic induction surveys. Such areas can be avoided if this study shows that the infiltration of produced waters has a deleterious effect on underlying Class 1 aquifers or nearby surface streams.

- Identify and exploit opportunities to use passive treatment technologies as pretreatments for the membrane treatment of produced water or as a low-cost means of removing BTEX compounds in legacy oil fields. Only limited options exist for the treatment of high sodium produced waters and there is little likelihood that significantly better technologies will be developed. Further, the two most effective current treatments (reverse osmosis or electrodialysis) require pretreatment to prevent irreversible fouling of expensive membranes. Low-cost, passive pretreatment technologies will be developed that will increase the service life of membranes and, thereby, lower the overall cost of produced water treatment.

- Identify geologic formations in oil and gas producing areas that are suitable for the injection of concentrated brines from the reverse osmosis or electrodialysis treatment of produced water.

Identifying/developing oil shale extraction methods that minimize water use and environmental impact – CEI will conduct research to determine the environmental impact of proposed oil shale extraction technologies. Because oil shale deposits are located in arid-semiarid regions where water resources are limited, water use and the potential contamination of water resources by oil shale extraction will be of paramount concern. CEI will estimate water use for each proposed oil shale extraction technology and evaluate methods to prevent contamination of regional surface and groundwater supplies. Specific to this subset of NETL's strategy, CEI will:

- Work with oil shale developers, other federal agencies, and the states to estimate the water consumption of present and emerging technologies and identify potential sources of air and water pollutants.

- Evaluate the efficacy of applying commercially available pollution control technology developed for other industries to oil shale operations. Currently, no installation and testing of this equipment on full-scale oil shale plants have taken place. Today's commercial water treatment technologies cannot be simply applied at full scale at an oil shale plant, but first must be successfully demonstrated at a smaller scale to evaluate the technology and minimize investment risk.

- Develop environmental strategies that protect atmospheric and groundwater resources at in-situ retort sites. Although surface and in-situ retort pilots of the 1970-80's complied with existing environmental law, today's environmental regulations are more restrictive. Greater gas and water treatment capabilities will be required today and in the future. Further, water flushing of underground residual spent shale retorts was used previously to reduce toxic and other contaminants to safe levels. However, more that 10 years were required to flush and cool the spent retort and surrounding rock. The effectiveness of water flushing for preventing groundwater contamination at in-situ oil shale retorts will be re-evaluated and alternative strategies identified.

Developing models of air emissions from E&P activities – CEI will develop more relevant models for air emissions from E&P activities than those currently used by EPA and state air quality regulators. Air emissions will be modeled as discrete sources and will be validated by monitoring of actual sources from conventional oil and gas operations, coalbed natural gas operations, and enhanced oil recovery operations. Emission monitoring will be conducted at different altitudes using sensors and sample collectors on unmanned helicopters or attached to tether lines from balloons. These data will be used to construct 3-D models of contaminant plumes downwind from E&P activities and identify areas of potential impact.

Improve understanding of the impact of E&P activities on sensitive ecosystems -- The U.S. Forest Service has requested that DOE/NETL conduct surveys to determine the effect that access roads for E&P activities may have on nearby ecosystems. Although the Forest Service request was specific to E&P road construction in eastern forests, ecological impact surveys will be expanded to cover the construction of well pads, pipelines, and electrical utilities in all areas where E&P activities are occurring. These studies will also include the impact that drilling operations may have on raptors, sage grouse, and other wildlife species.

Improve understanding of existing regulatory issues -- Catalogue (identify, compile, and compare) regulatory barriers/issues/best practices (Federal, state, or local) relating to unconventional gas development. Existing and completed studies will be incorporated as a basis for continuing, expanded work by NETL's CEI.

The CEI will work with existing organizations and regulatory agencies to ensure that the results of this work are widely known and implemented in a way that both improves the

environment and increases access to resources. Geospatial data from CEI will be continuously updated and provided to the public via interactive web sites.

C. Goals and Objectives

Near Term (by end FY 2008)

1. Assess and prioritize the barriers identified in previous NETL and industry work to determine the areas that offer the most likely chance for increased production in the near term. This will include, among others, areas such as sub-surface irrigation of CBNG produced water and expediting produced water discharge permits using provisions of Wyoming's Agricultural Use Protection Policy (Section 20).
2. Initiate a coordinated interdisciplinary and multi-organizational study to scientifically assess produced water, its environmental impact, various treatment and disposal options, and the potential for beneficial use. Experimental wetland treatment systems will be assessed, including field-based evaluation of water quality changes over time.
3. Initiate research on the mobilization of salts within a drainage system as CBNG produced water is transported down-gradient. Determine the subsurface connectivity between shallow groundwater aquifers and the surface water system. Evaluate remote sensing technologies such as airborne electromagnetic induction surveys for the extensive mapping of soil salinity of large areas.
4. Investigate the application of light detection and ranging (LIDAR) technology in measuring channel geometry for estimating the amount of water that can be discharged into ephemeral drainages before significant erosion or flooding problems occur.
5. Identify information gaps necessary to assess the impact of air emissions from E&P activities and conduct assessment studies needed to develop models of the impacts of E&P on local and regional ambient air quality. If required, conduct targeted on-site measurements of emissions from E&P activities that may impact the environment.
6. Initiate a coordinated multidisciplinary study of the ecological impact of contemporary and historical O&G activities (well pads, road construction) in a designated watershed on federal land within the Appalachian basin, in cooperation with the U.S. Forest Service and U.S. Bureau of Land Management. Also, reassess available data on the effects of oil and gas activity on nesting raptors, and on sage grouse habitat.
7. Initiate a collaborative Federal and industrial research effort to provide reasonable estimates for water consumption associated with producing oil from shale at various rates and various extraction technologies, and to address how this will impact present and future water demands within the region.
8. Establish procedures for data management and the dissemination of spatial information using modern geographic information system (GIS) technology that meet standards established by the Federal Geographic Data Committee. The GIS spatial database will incorporate collected and available data and demonstrate its utility in the management of contemporary O&G activities.

Intermediate Term (by end of FY 2012)

1. Publish an evaluation of produced water management strategies that addresses cost versus effectiveness.

2. Publish new models for airborne contaminant plumes from oil and gas development activities, using field data to calibrate the models.
3. Complete analysis of airborne surveys over CBNG produced water management areas in the Powder River basin and data interpretations. Incorporate airborne interpretations into GIS models to identify optimal produced water disposal locations. Make this information immediately available to regulators and industry to expedite the issuance of produced water discharge permits.
4. Suggest surveillance plans to protect communities near enhanced oil recovery (EOR) operations or gas storage fields based on measuring, monitoring, and verification (MMV) technologies developed as part of NETL's geological CO_2 sequestration research, and develop recommendations for mitigating gas migration.
5. Refine an upper and lower limit to the potential quantity and quality of water required from available regional water sources (including local rivers, produced waters, mine discharges, and wastewater) to support an oil shale industry at various levels of production, incorporating research being conducted by the Center for Enhanced and Unconventional Oil Recovery.
6. Complete studies in a research watershed on Federal land and fully assess the utility of the spatial database and modeling to predict and minimize the environmental impact of O&G activities. Identify and report innovative technologies/practices for study and implementation to alleviate identified environmental impacts. Initiate parallel watershed assessments in multiple environments representative of major O&G development regions of the U.S.

Long Term (through FY 2017)

1. Propose a data collection, processing, and model construction methodology for produced water disposal management as part of technology transfer. All computational programs developed will be given to industry for their own use.
2. Complete four major watershed assessments and fully transfer data to industry and public.
3. Demonstrate and document the minimization of ecosystem and wildlife habitat degradation associated with O&G activities due to the implementation of NETL-developed modeling programs and research.
4. Complete technology transfer of all CEI research.

D. Anticipated Results

By building on its excellent working relationship with industry and other government agencies and its growing expertise in this technical area, ORD's CEI will:

- Publish evaluation of subsurface drip irrigation systems as a water management alternative for produced water disposal in the Powder River Basin. Positive results from this study will allow Wyoming DEQ to issue produced water discharge permits that are currently on hold.
- Publish comparison of airborne soil conductivity mapping to conventional ground-based soil conductivity surveys. Time and cost efficient salinity mapping using

helicopter electromagnetic induction will expedite permits to discharge produced water into intermittent or ephemeral streams.

- Publish results of study of innovative treatment options and the relative cost effectiveness of the technologies available to treat brine and oil contaminated waters.
- Interpretations from helicopter electromagnetic induction and surveys will be incorporated into GIS models that can be used to identify optimal produced water disposal locations. Results of airborne surveys will be provided to the public as GIS-based mapping products via GIS server technology, and will include decision support models that will enable industry and states to better manage CBNG produced water.
- Determine if and to what extent oil shale development might be limited based on water availability and other factors, and refine this as additional technology is developed by the Center for Enhanced and Unconventional Oil Recovery (CEUOR) to enhance kerogen production and reduce water requirements.
- Publish results of source – receptor modeling studies of the airborne impacts of small scale oil and gas development. Determine the nature, scope and variability of the impacts for different E&P activities, geographic sites, and meteorological conditions. Determine common characteristics that can be addressed in a consistent manner for multiple locations, and those characteristics that are site and operation specific, requiring a customized approach.

E. Anticipated Impact

Through the interdisciplinary and multi-organizational study of produced waters, the economic burden on small operators for the treatment and disposal of these waters should be significantly reduced, consequently stimulating oil and gas production, while environmental protection will improve. The most promising technologies for safe, effective, economical treatment and beneficial use of produced waters will be identified.

The impact of small–scale E&P activities on local and regional air quality will be established through air quality studies and source–receptor modeling to reduce the regulatory compliance economic burden on operators. The CEI will establish what air pollution controls, if any, are required by small producers to comply with requirements of the air quality State Implementation Plans.

Water and other environmental challenges facing oil shale development will be collaboratively and proactively assessed and dealt with so that industry will have viable technical options available to address potential environmental problems prior to development. This work will allow the environmental framework that will allow oil shale development to proceed in a manner that protects the environment.

GIS will be used to disseminate information via WEB portals for public and private applications; decision support models will be developed to support data analysis and the development of risk assessment tools.

3.3 Center for Enhanced and Unconventional Oil Recovery

CEUOR will focus on the mission of developing advanced technologies that will move the status of known but unrecoverable oil resources to technologically and economically producible resources.

A. Motivation for Research on Enhanced and Unconventional Oil Recovery

Conventional primary and secondary recovery operations often leave two thirds of the oil in the reservoir. In the U.S., an estimated 400 billion barrels of the discovered oil resource remains unrecovered. Historically, U.S. industry tertiary or enhanced recovery practice has been to inject steam, carbon dioxide (CO_2), or surfactants into reservoirs to move residual oil to production wells. Often these "floods" have been undertaken without detailed knowledge of the localized geology, which can often be very complex, or without economical means to monitor or map the fluid movement continuously over time. The missing information includes data related to depositional environment, fluid saturations, and the degree to which the pockets of residual oil or gas remaining in the reservoir are connected to one another.

U.S. EOR practices are widely applied but steam and CO_2 miscible flooding account for most of the incremental production (80%) and technological advances in these processes could have widespread impact. For example, CO_2 miscible EOR recovers only 10-15 % of the remaining oil due to limited reservoir contact by the injected CO_2. With the advent of carbon capture technology, millions of tons of CO_2 may be available in parts of the country where CO_2-EOR has been non-existent due to the regional unavailability of carbon dioxide. Improvements in CO_2 miscible EOR technology to reduce the cost or improve the recovery efficiency could revitalize many of these depleted oil fields.

Unconventional oil resources that exist in oil shale in the U.S. contain an estimated 1.2 trillion barrels of oil equivalent in Colorado, Utah and Wyoming. The best existing technologies for producing oil shale have yet to be tested beyond the pilot scale. The lessons learned and the technologies developed from these past efforts remain available and provide the technical basis needed to advance oil shale commercialization efforts.
The resource has been characterized in great detail over the last twenty five years, but current research needs to be concentrated on a number of key barriers; reducing the cost and improving the efficiency of oil shale recovery, reducing water requirements, and mitigating potential environmental damage due to development.

B. Strategy

NETL's strategy is to make contributions to the development of domestic oil reserves by addressing seven petroleum industry needs identified in past workshops: 1) creation of a high quality digital database of reservoir characterization data that can be utilized in the development of EOR, oil shale and tar sand resources; 2) completion of basin characterization models that will evaluate the entire stratigraphic column as a resource for both production of oil and water and treat these as potential products for future use, 3) development of better model algorithms, 4) development of new additives and catalysts that can aid in the recovery of shale oil and tar sands, with an emphasis on reducing the energy required for in-situ processes, 5) development of new uses for the spent shale byproduct of surface oil shale

processing, 6) development of more efficient, cost effective, high resolution, disposable downhole sensors that can transmit data to the surface regarding the dynamic reservoir environment, and 7) development of materials and techniques that will enable economic CO_2 and thermal flooding to be applied in a larger number of mature fields.

Data Management – NETL will create a high quality database of reservoir and reserve characterization information for application to basin modeling. There is an industry identified requirement to provide more detailed information to the petroleum industry on the reservoir characteristics of oil in place (OIP) and oil processing methods for shale and tar sands to make them an economic energy resource for the future. The majority of the historic project reports contain data that can be used to develop plans for enhanced production methodology and create new processing technology to reduce requirements for water and energy requirements to produce them.

Basin and Reservoir Models – Develop basin characterization models that will evaluate the entire stratigraphic column for production of both oil and water and treat both as potential resources. The management of fluids over an entire geologic column will be considered and products from the processing may be disposed of in the same formations. The results will lead to more economic production, reduction in waste disposal and optimal utilization of water during development.

Model Algorithms – The petroleum industry will require more powerful computer capabilities to process the large amounts of data that can be collected with the development of higher resolution instrumentation. The prediction is that new databases and analytical software will exceed the industry's current maximum teraflop processing capabilities. New algorithms to reduce the data through statistical processing may be one method of reducing the load.

Additives and Catalysts for Oil Shale Production – Large volumes of water and a large amount of energy will be required for the extraction of oil from the shale formations. Chemical additives and catalysts will be studied in order to provide lower cost and lower temperature alternatives to current high water requirements and energy for extracting the oil. It is anticipated that the results will also lower the production of CO_2, in the case of oil shale, and improve total recovery of the high temperature carbon trapped in the shale.

Spent Shale By-Product Testing – NETL will design experiments to test the products created during extraction and processing and create new uses that will reduce the amount of spent shale and sand that would otherwise result in unwanted disposal costs. Overall, the reduction in material handling costs will allow for a cleaner, more cost effective method of producing oil shale.

Sensor Development – NETL will pursue technology developments related to acoustic and seismic sensors and will develop a basic nanotechnology program to create sensors capable of providing real-time information on conditions within the reservoir that can help operators adjust their EOR strategies to improve resource recovery. NETL will also evaluate the current state of technologies to improve well bore sensors for both static and dynamic reservoir conditions.

Enabling Technologies for CO_2 and Thermal EOR – NETL will pursue technology developments to enable wider application of CO_2 and thermal EOR. This will include assessments of the impact of using low-quality CO_2 captured from emission streams on the efficiency of oil recovery, developing low cost alternative materials that will enable pipeline transporation of H_2S-contaminated CO_2, development of conformance control materials for improving the sweep of CO_2 floods in heterogeneous reservoirs, and potentially, developing ways to reduce the Minimum Miscibility Pressure of CO_2 such that miscible flooding can be achieved in shallow reservoirs. NETL will also take a science-based approach toward new and novel thermal practices that will allow adaptation of current heavy oil recovery technology to deeper and more geologically complex reservoirs.

C. Goals and Objectives

Near Term (by end FY 2008)

1) Create reservoir characterization data archives from historic NETL EOR, tar sand and oil shale project results. The data will be improved with continued analyses of samples from ongoing projects with industry and partnerships with other government agencies. Laboratory analyses of fluids and formation interactions with carbon dioxide will provide improved input to the reservoir modeling effort and aid in the design of methods unique to each reservoir depositional environment.
2) Assess the current economic viability of various technology scenarios for oil shale development including surface mining, deep mining, in-situ, and surface retorts. Use this analysis, along with concurrent analysis of existing and new approaches to oil shale development, to identify technology gaps in unconventional shale and tar sand production. Identify potential solutions to the problems of high water requirements and waste products from the processing scheme.

Intermediate Term (by end of 2012)

1) Through experiments aimed at understanding the mobility of CO_2 within rocks, develop new techniques for improving the mobility control of CO_2 floods. The long-term goal will be to improve recoveries of oil from CO_2-EOR by 100-200% over the next two decades.
2) Assess the impact of using low-quality CO_2 on the efficiency of oil recovery.
3) Complete an assessment of alternatives for achieving miscibility in CO_2 floods in shallow reservoirs.
4) Test oil shale processing by-products and develop a slate of potential commercial uses. Assess the economic impact of these uses on oil shale development economics and outline barriers to commercial acceptance.
5) Investigate new and novel thermal practices that will allow adaptation of current heavy oil recovery technology to deeper and more geologically complex reservoirs.

Long Term (through fiscal year 2017)

1) Support and accelerate the development of nano-sensors capable of providing real-time information of conditions within the reservoir at a low cost.
2) Develop and test low cost alternative pipeline materials to enable the use of H_2S-contaminated CO_2 in EOR projects on a cost-effective basis.
3) Develop new and better algorithims that can significantly reduce the processing requirements for reservoir simulators.

4) Develop basin characterization models that will evaluate the entire stratigraphic column for production of both oil and water and treat both as potential resources.
5) Develop and test new catalyst that will reduce the temperature of or increase the reaction rate for in-situ pyrolysis of oil shale.

D. Anticipated Results

The CEUOR will produce detailed reports on the research topics listed above and work to disseminate the results to those sectors of the industry that can best utilize them. CEUOR will collaborate with outreach organizations to enhance the utilization and effectiveness of the technologies developed.

Key results anticipated from this effort include:

- The assessment and identification of the critical technology gaps that hinder the development of an economically and environmentally sustainable oil shale industry.
- Products that provide industry with valuable data and insights that can help to lower the cost and improve the efficiency of EOR and unconventional oil recovery.
- Production and delivery of timely reports that respond to the needs of the domestic industrial sectors involved in EOR and unconventional oil production.

E. Anticipated Impact

The products to be developed by CEUOR will enhance the domestic oil industry's ability to produce remaining U.S. conventional oil resources and yet-to-be-developed unconventional oil resources in a cost effective and environmentally benign manner. These products will accelerate and broaden the application of EOR using captured CO_2, an outcome that will both add to domestic oil production and help to create a market mechanism for capturing and sequestering CO_2. Advances in this area alone could result in the production of 100 billion barrels of domestic oil.

In addition, unconventional oil from oil shale and tar sands have between 700 and 1200 billion barrels of potential that await the development of technologies to overcome shale oil extraction and processing and water requirement issues. CEUOR products will enhance the ability of U.S. companies to cost-effectively translate this potential into reserves in an environmentally acceptable manner.

3.4 Center for Resource Assessment

The Center for Resource Assessment (CRA) will provide characterizations of emerging, underutilized, or poorly understood oil and natural gas resource elements, and use these assessments to investigate the potential impacts of technology advances on these resources. CRA will largely focus on natural gas resources but has the potential for coordination with Section 3.3 on oil related assessment needs. Products from CRA will serve both as inputs to analyses of the potential benefit of various alternative technology pathways, and as contributions to industry and the larger research community's need for objective, detailed descriptions of resource characteristics and volumes.

A. Motivation for Resource and Technology Assessments

The domestic gas resource base is extremely large and many of these resources have never been fully characterized by either the public or private sectors. Significant resources of unconventional gas locked up in (mainly) tight gas sands, shales, and coalbed methane exist throughout the Rocky Mountains, Texas, Oklahoma and the Appalachian basin. Independent operators who predominate in exploration and development in the lower 48 states drill 90 percent of the wells and produce 82 percent of the natural gas and 68 percent of the oil. These operators do not have the staff or budget to conduct detailed assessments of the large resource base to prioritize E&P activities. Past DOE-funded assessments conducted by the United States Geological Survey made industry aware of the full potential of unconventional resources and spurred E&P activities in these overlooked plays.

To date, thousands of copies of CDs from previously completed resource assessments conducted by NETL have been ordered and distributed to researchers and industry. The reports, interpretations, and digital datasets in these assessments have contributed to technology advances and increased industry exploration/development activities domestically.

Most resource assessments are designed to quantify either 1) the bulk gas-in-place with no regard for recoverability, or 2) the recoverable resource present under an assumed set of conditions. Assessments conducted by CRA will differ fundamentally from those conducted by other organizations. NETL's work will produce datasets from which recoverable resources can be reasonably appraised under a wide variety of as-yet-undefined future conditions – enabling modeling and analyses of the potential benefit of various alternative technology pathways.

B. Strategy

NETL will use a log-based, gas-in-place approach to provide an unprecedented level of geographic and stratigraphic detail. Detailed dissaggregation of the resource into thousands of uniquely characterized segments that reflect the natural variety in key geologic and engineering parameters is achieved through the analysis of hundreds of well log suites, well production histories, and other pertinent information. Ultimately, these assessments will aim to understand the nature of the existing resource that lies outside the limits of current economic recoverability. This understanding will enable NETL to identify priority basins and plays for further analysis of the potential role of technology advances in generating significant expansions in resource recoverability.

Specifically, this effort will focus on and include:

- *Resource Characterizations* – Conduct detailed regional geologic analyses (including detailed geologic mapping, interpretation of depositional systems and resultant reservoir trends and geometries, and well-log analysis to determine the aerial variations in critical reservoir parameters) of targeted resource elements in mature basins such as the Appalachian. The work will quantify the nature and volume of emerging, overlooked, or underutilized resources, and will present these data through

high-quality regional geologic maps, cross-sections, and databases. In addition, assemble existing studies of offshore resources and determine an estimate of the resources available in offshore areas, including areas currently not open for access.

- *Technology Assessments* –Analyze the results of these resource characterizations to identify opportunities where technological advances could unlock currently untapped resources, and refine the ability to quantify the impact of potential technological advances on resource recoverability.
- *Technology Transfer* – Work with organizations such as the Petroleum Technology Transfer Council (PTTC), the Stripper Well Consortium (SWC), and the Small Producers Program with RPSEA to realize the development or adoption of the most promising technologies in areas currently being developed by small independent oil and gas companies. NETL will evaluate alternatives for developing a repository of all of the information developed under the Consortion and NETL Complementary R&D Programs, as well as other ongoing DOE oil and gas programs, including the option of a Knowledge Management Database.

C. Goals & Objectives

Near Term (by end FY 2008)

1) Assess and identify the most-promising resource elements for characterization within the Appalachian and/or other mature basins. These plays will be those for which there is determined to be significant resources in-place that are poorly characterized or beyond the margins of economic recoverability.
2) Design and initiate a research effort in geologically-based resource assessments targeting the key plays identified above. Collect the available well data and construct a regional network of cross-sections to delineate the area and stratigraphic extent of the identified plays.
3) Work with regional entities, such as the PTTC and SWC, to report on new/innovative technology usage in selected basins (e.g., Appalachian) that encourages faster/broader adoption of potentially high impact advanced technologies.
4) Investigate and enhance modeling capability that enables measurement of the potential impact of technology advances in mature basins.

Intermediate Term (by end 2012)

1) Deliver an initial resource characterization product for selected high-potential plays in the Appalachian basin (by 2010). This product will include a full suite of maps, cross-sections, digitized well logs and reservoir data spreadsheets with accompanying report on methodology to be published on CD in the manner similar to previous NETL assessments. Reports will also be prepared for publication in professional journals.
2) Identify and deliver (by 2012) a second set of assessments on plays yet to-be-determined.
3) Provide an assessment of historical technology utilization in mature basins to determine the potential impacts of federal efforts to accelerate technology utilization.
4) Initiate additional assessments as needed, and have several assessment studies on high priority basins underway in parallel.

Long Term (through fiscal year 2017)

1) Complete four major resource assessment efforts and fully transfer that data to industry and the public.
2) Document instances in which advanced technology utilization in mature basins has been accelerated through the analyses conducted at NETL.

D. Anticipated Results

CRA will produce detailed geologic, geophysical, and reservoir/production engineering analyses to assess the potentially large volumes of available, but currently untapped, oil and natural gas resources. Similar to the results from past NETL assessments, these data will be of great value to the industry, and will also enable NETL to model the impact of technology on resource recovery, particularly emerging and/or unconventional resources. CRA will collaborate with organizations such as the PTTC, as well as regional organizations such as the Penn State SWC, to enhance the utilization and effectiveness of the most promising technologies identified.

Near term results anticipated from this effort include:

- The assessment and identification of the most-promising resource elements for characterization within the Appalachian and/or other mature basins.
- Establishment of a fully staffed research effort in geologically-based resource assessment targeting key unconventional natural gas resources as identified in preceding assessment, described above.
- Deliver an initial resource characterization product for those high-potential plays selected above, Appalachian basin, etc.
- Completion of an assessment of historical technology utilization in the Appalachian Basin and any other target areas selected.
- Production and delivery of reports and products to Industry that respond to the needs of the industry in matching technology to the geological system for the Appalachian Basin and any other assessment areas selected for this initial study.

E. Anticipated Impact

CRA will quantify the nature and volume of emerging, overlooked, or underutilized resources, and generate geological and engineering datasets of unprecedented detail. As a result, these datasets allow modelers, as well as E&P entities, to identify priority basins and plays in which advanced technologies may significantly increase domestic resource recoverability.

Future assessments and studies have the potential for the greatest impact in areas of emerging or highly unconventional resources. In areas, such as the Appalachian basin, where industry activity is limited to small independent operators, integrated regional assessments can help identify and/or expedite exploration and technological breakthroughs. Finally, NETL's resource assessment/modeling efforts may lead to the identification of R&D synergies with other key NETL programs, such as the environmental impacts and CO_2 sequestration.

4. Planning and Analysis Support

The Office of Systems, Analyses and Planning (OSAP) performs studies that are focused at the analysis of complex, large systems and of interactions among those systems. These studies are completed using well-established methods and computational tools. The analyses are performed by federal staff and through joint activities with other organizations, DOE laboratories, and support contractors. Taken as a whole, these system studies provide input to decisions on issues such as national plans and programs; resource use, and environmental and energy security policies, research and development; and deployment of energy technologies.

OSAP has structured teams to accomplish these efforts. In brief, these teams are described as follows:

- **Systems** - Perform studies primarily focused on production and processing of fossil fuels and energy and fuel system synthesis and design.
- **Benefits** - Perform both prospective and retrospective benefits studies in support of fossil energy R&D program areas.
- **Trends and Forecasts** - Collect data and perform assessments that relate to energy production and use, and develop scenarios for technology planning activities.

4.1 Strategy

In order to ensure the most prudent use of EPAct Section 999 funds, a robust, accurate, impartial and transparent analysis of program benefits must be undertaken. Beyond benefits determination, *smartly* focused studies must be completed in order to guide R&D efforts to areas that will yield the most value.

4.2 Goals

The goals of this program element are as follows:

1. Develop rational and objective benefit and impact analysis measures for the EPAct Section 999 R&D program expenditure of public funds
    i. Estimate increases in royalty collections due to the R&D program[1]
    ii. Estimate increases in domestic production and economic gain, and reductions in environmental impacts associated with widespread deployment of EPAct Section 999 technologies and processes

[1] *From the provision:* (5) ESTIMATES OF INCREASED ROYALTY RECEIPTS.—The Secretary, in consultation with the Secretary of the Interior, shall provide an annual report to Congress with the President's budget on the estimated cumulative increase in Federal royalty receipts (if any) resulting from the implementation of this subtitle. The initial report under this paragraph shall be submitted in the first President's budget following the completion of the first annual plan required under this subsection.

2. Complete strategic oil- and natural gas-related analyses in the context of EPAct Section 999 which will optimally guide future research and support the development of national policy and initiatives.

4.3 Approach

OSAP will be the coordinator for benefit and impact studies for implementation of Section 999. OSAP will collaborate with the RPSEA benefits and impacts teams which will allow for effective information exchange and a coherent systems study approach. Section 2.5 of this document provides detail on the type of benefits assessment effort that is envisioned.

OSAP anticipates designing and completing federal lands-focused analyses for unconventional gas, unconventional petroleum, ultra-deep water, and offshore applications. In addition, oil and natural gas policy type studies and forecasts which tie to federal lands issues, royalty collections, and environmental impacts, (e.g., produced water) will also be included in the OSAP portfolio.

These advanced studies will generally include impact and benefit analysis examining increased reserves, increased oil and gas production, increased federal and state tax revenues, increased oil and gas royalties, job creations, co-benefits, and reduction in the costs of supplying energy services. In addition, microeconomic studies may be completed that examine the impact of Section 999 in making available economic resources that can be allocated to other goods and services.

OSAP's may utilize national models such as the National Energy Modeling System (NEMS) modified for oil and gas royalties, and advanced economic models such as the All Modular Industry Growth Assessment (AMIGA) model. As appropriate, these and other models may be used by OSAP to develop work products fully responsive to the requirements of EPAct Section 999.

4.4 Implementation Plan

Short Term (to be completed by 2008)

Complete by 12/07

- Develop baseline royalty collections metric and develop a report template/methodology for future Reports to Congress
    - Enhance collaborative relationship with the Department of Interior
    - Further develop *partnership* with RPSEA
    - For the initial report, no increase in royalties will be reported since [RPSEA] awards are expected to be made during the 4th quarter of CY2007. However, a baseline will be reported along with a conceptual framework of the planned *accounting* methodology.

- Collaborate with NETL SCNGO and RPSEA to ensure adequate data collection efforts are included in consortium awards and that these data are conveyed to OSAP on a mutually agreed upon schedule so that specific benefits can be determined, e.g., increases in formation/play recovery.

- Design an analysis that will determine the value of domestically produced natural gas and/or crude oil, and/or other petroleum resources.

- Initiate an industry data/statistics collection and analysis effort (*environmental scan*) to support updates to the annual management plan and the research that results from that plan.

Complete by 12/08

- Collaboratively with DOI, finalize the methodology for estimating increases in royalty collections based on EPAct Section 999 expenditures and complete a merit review of the methodology.
    - Ensure RPSEA is a partner
    - Implement the methodology
    - Develop and submit increases in royalty collections report [to Congress]

- Complete an assessment that will determine the value of domestically produced natural gas and/or crude oil, and/or other petroleum resources, and subject the analysis to merit review.
    - Publish results of the analysis

- Design and fully test a *framework* for archiving, manipulating and analyzing RPSEA project data for benefits calculation.
    - Initiate population of the database as data availability allows.

- Collect and analyze data (and report out) on trends, etc. to support updates to the annual management plan and to supplement and guide RPSEA's subsequent round of awards.

Intermediate Term (to be completed by 2012)
Complete by 12/09

- Analyze RPSEA year-1 R&D awards data.
    - In partnership with RPSEA, determine the improvements in productivity, efficiency, etc.
    - Develop report on project benefits

- Develop and submit increases in royalty collections report.

- Collect and analyze data (and report out) on trends, etc. to support updates to the annual management plan and to supplement and guide RPSEA's subsequent round of awards.

- Develop and complete a strategic analysis of domestic oil and/or natural gas production in the context of water resources, greenhouse gas emissions/sequestration, and/or *sustainability*.

Complete by 12/10, 12/11, and 12/12

- To be defined in the next update of this management plan.

Acronyms

AMIGA	All Modular Industry Growth Assessment
BOD	Board of Directors
CBNG	coal bed natural gas
CDUEC	Center for Drilling Under Extreme Conditions
CEI	Center for Environmental Impacts
CEUOR	Center for Enhanced and Unconventional Oil Recovery
DOE	Department of Energy
E&P	Exploration and Production
EAG	Environmental Advisory Group
EIA	Energy Information Administration
EOR	enhanced oil recovery
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
GIS	geographic information system
GTI	Gas Technology Institute
HPHT	high pressure and high temperature
LIDAR	light detection and ranging
MMS	Minerals Management Service
MMV	measuring, monitoring, and verification
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NMT	New Mexico Tech University
NPC	National Petroleum Council
O&G	oil & gas
OCI	Organizational Conflict of Interest Plan
OCS	Outer Continental Shelf
ORD	Office of Research and Development
OSAP	Office of Systems, Analysis and Planning
PAC	Program Advisory Committee
PTTC	Petroleum Technology Transfer Council
RAG	Research Advisory Group
RFP	Request for Proposal
ROP	rate of penetration
RPSEA	Research Partnership to Secure Energy for America
S1	Solicitation 1 of 3 planned for Ultra-Deepwater
S2	Solicitation 2 of 3 planned for Ultra-Deepwater
S3	Solicitation 3 of 3 planned for Ultra-Deepwater
SAC	Strategic Advisory Committee
SAIC	Science Applications Internationational Corporation
SCNGO	Strategic Center for Natural Gas and Oil
SDI	subsurface drip irrigation
SWC	Stripper Well Consortium
TAC	Technical Advisory Committee
TCF	trillion cubic feet
TVD	total volume daily
UDS	Ultra-deep single cutter Drilling Simulator
UDW	Ultra-Deepwater