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PROCEEDINGS OF DEPARTMENT OF ENERGY/OFFICE OF THE ENVIRONMENT WORKSHOP ON ENHANCED OIL RECOVERY: PROBLEMS, SCENARIOS, RISKS

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INTRODUCTION

A DOE/EV-sponsored workshop on enhanced oil recovery (EOR) was held at Montana State University, Bozeman, during August 24-27, 1980. The thirty participants represented industry, private consulting companies, academia, national laboratories, environmental organizations, and personnel from DOE and other government agencies. The purpose of the workshop was to discuss the validity of scenarios for increased EOR production; to identify specific environmental, health, and safety issues related to EOR; and to identify quantitative methods for assessments of impacts. Workshop deliberations will be used by national laboratory scientists in their DOE-sponsored evaluation of the environmental, health, and safety (EH&S) aspects of increased EOR production.

In addition, the workshop attempted to clarify the distinction between environmental, health, and safety issues that are substantive, and those considered important simply because the validity of their previous documentation has not been challenged. Several sensitive areas were considered such as release of proprietary information, peer review of published reports, and unofficial comments by individuals concerning the viewpoints of several agencies and oil companies. To encourage free and open exchange of information, formal presentations were held to a minimum, no quotes were attributed to specific individuals, and proceedings were not recorded.

Information provided at registration included an agenda (Appendix A); biographical sketches of workshop participants (Appendix B); background lists of potential EOR environmental and health issues (Appendix C); and estimates of EOR production (i.e., scenarios) by the DOE/Energy Information Administration (EIA), the oil industry, and several national laboratory researchers (Appendix D).

Questionnaires were periodically distributed to help participants focus on specific issues such as production scenarios, environmental impacts, and quantitative assessment methodologies. Harbridge House, Inc., a private consulting organization, was hired to prepare and administer the questionnaires, and to analyze the results (Appendix E).

The conference was attended by five oil company representatives and 25 other professionals drawn from ranks of government and academia. Although the workshop was originally designed to focus specifically upon EOR, the participants reached several conclusions that relate to other DOE technology assessments, and which may also provide guidance to national laboratory researchers interested in EH&S aspects of several new technologies. This report summarizes important conclusions reached at the workshop, most of which represent a consensus among participants.

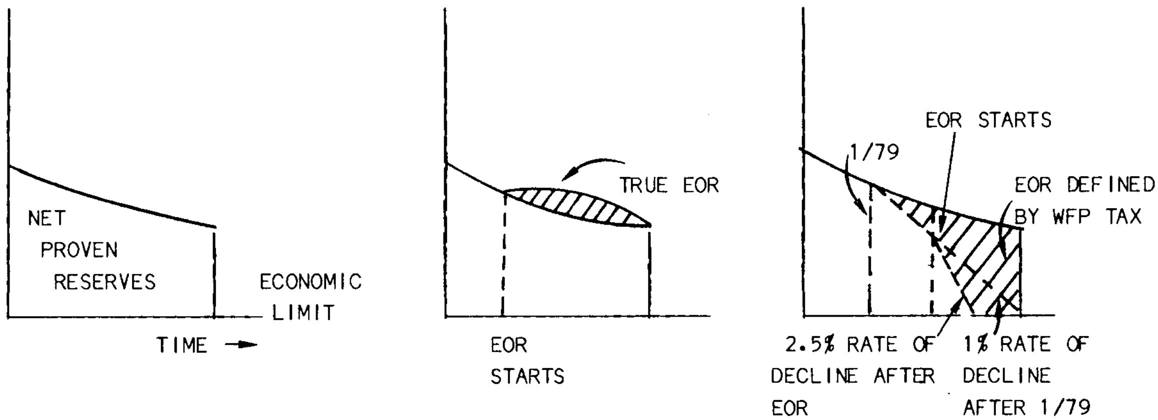
The agenda opened with a session on estimates of EOR production in the year 2000. This was to provide all workshop participants with 1) an understanding of the future potential of EOR and 2) a background for discussions of environmental, health and safety issues, as well as discussions of constraints which may limit EOR production. The following session focused specifically on EH&S, and included environmentalists and private consultants. To complete the formal discussions of the first day, a session was devoted to technical and regulatory constraints. Industrial, environmental, and governmental perspectives on relevant issues were offered by selected panelists.

Opportunities were provided for informal discussions during several luncheons and evening activities. The structured portion of the workshop continued on the second day, with participants grouped into two concurrent sessions. The first continued discussions of production scenarios, models used to predict future EOR production levels, technological breakthroughs, regulations, environmental control technologies, offshore EOR, and Alaskan EOR. The second group concentrated on technological, conservation, and safety aspects of EOR, on methods for quantifying environmental impacts, on regulatory processes, and on other EH&S considerations. All participants worked together on the third day to discuss their findings and conclusions.

EOR IN THE YEAR 2000: PRODUCTION ESTIMATES AND REGULATORY CONSTRAINTS

PRODUCTION AND THE WINDFALL PROFITS TAX

Expectations for EOR production were discussed in the context of federal programs to stimulate oil production, and in terms of production scenarios formulated by both industry and government. A representative from a major oil company provided an industrial perspective of future EOR production.[1] Figure 1A shows a theoretical natural decline curve of daily oil production at a given field as a function of time, starting from initial production. The shaded area in Figure 1B represents the theoretical additional oil produced as a result of applying some specific EOR process. This additional amount of



A. B. C.

Figure 1. Theoretical production decline curve. Incremental EOR production is shown as well as a normal decline. Tax rate decline is applied to production decline curve resulting from EOR. [True EOR should only be net gain over the proven reserves, while EOR defined by the Windfall Profits Tax (WFPT) includes entire production beyond the 2.5% decline curve.]

recovered oil is termed "true EOR" and is the net gain in production and reserves because of the application of a specific EOR technology. A complication arises because of the Windfall Profits Tax (WFPT), which interposes on the production curve several predefined rates of production decline above which daily oil production is officially termed "EOR" (see Figure 1C). The reason for this is to provide a basis for reducing the effect of the WFPT on the application of an EOR process.

The Windfall Profit Tax legislates an arbitrary statutory tax decline rate of 1% per month, starting January 1, 1979, for determining the tax rates which will be applied to oil produced after the beginning of the EOR process. With the beginning of an EOR process, the tax decline rate becomes 2-1/2% per month. Any oil produced after the start of the EOR process which exceeds the 1 to 2-1/2% curve is taxed at a lower Windfall Profit Tax rate.

Referring now to the production decline curve of Figure 2, point A represents the introduction of a specific EOR technique. Point B is the instant in time at which all oil is taxed at the lowest Windfall Profit Tax rate. Point C represents the normal decline of production over time until the economic limit of production is reached. The area bounded by the curve DOE represents the incremental oil production resulting from application of an EOR process.

The area bounded by the points ABCEOD is all taxed at the lowest Windfall Profit Tax rate. The so-called incentive provided by the tax is the oil production bounded by points ABCD which has the same tax treatment as oil obtained by application of an EOR process.

The distinction between DOE (i.e., new EOR) and ABCEOD (legally defined EOR) may make investment in EOR projects economically attractive to the oil companies, because the tax rate on EOR production is only 30% compared to 70% on primary production. However, this can actually work against the perfection of EOR technology, because the actual effectiveness of the process is not as important, in a legal sense, as the economics of the EOR technique. It is often in a company's interest to apply an inexpensive, less risky, and perhaps less effective technique, which will nevertheless qualify the reservoir for the reduced tax rate. More expensive and risky (but more effective) techniques may go untested.[2]

Industry representatives repeatedly voiced the opinion that the WFPT has hurt overall U.S. oil production and was therefore adversely affecting some

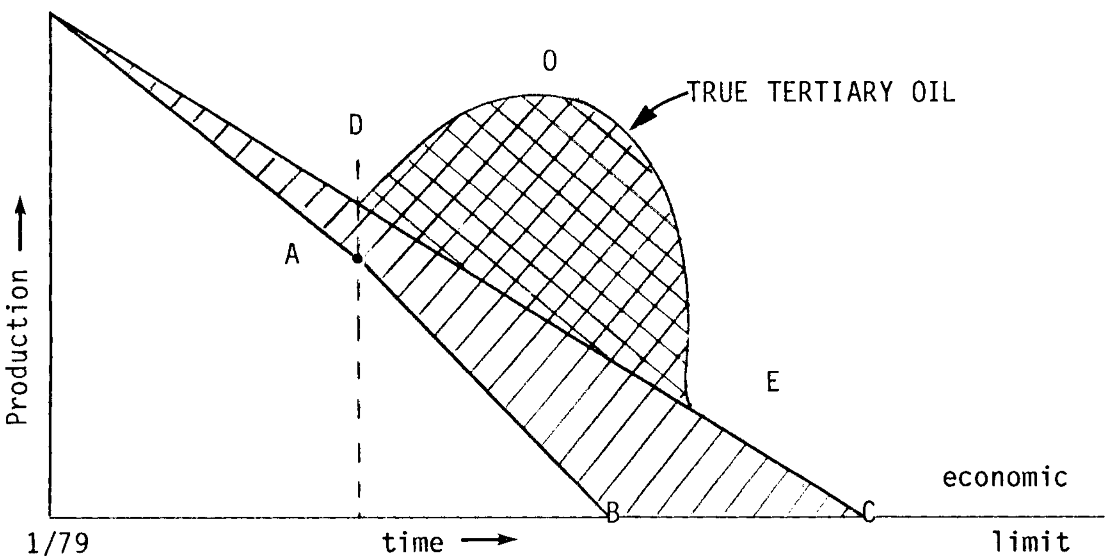


Figure 2. Theoretical Production Decline Curve (refer to text for explanations of shaded areas).

EOR processes as well. Interestingly, a number of the government representatives seemed to agree with this point. "WFPT/EOR" could theoretically lead to very little gain in proven reserves and, perhaps, could negatively affect future recovery as producers rush to apply the least costly and often the least effective technology.

Existing Production Estimates and Scenarios

The distinctions in perception of tertiary oil by industry and government are particularly important for EOR production scenarios. For several years the DOE/Energy Information Administration (EIA) has been developing scenarios for future EOR production based on a methodology that purports to screen each field for the most promising recovery technology (Appendix D1). As presented by an EIA spokesperson, the most recent application of EIA screening techniques predicted 1,230,000 barrels of oil per day from EOR by 1995, down 400,000 bbl/day from the preceding year's predictions. Other DOE speakers estimated that from 1 to 3 million barrels of oil per day could be obtained solely from the 160 fields now defined as EOR projects. The total EOR production base was considered to be 20 to 50 billion barrels.

It was indicated that downhole steam generation, steam and additives, oil mining, and added production from tar sands could increase production somewhat, perhaps by 20%, but that the biggest unknowns were the Alaskan Prudhoe Bay field, OCS (outer continental shelf), and other offshore oil. None of these considerations were factored into the EIA scenarios. It was indicated that an average-sized project, such as M-1 in Illinois, producing 1800 bbl/day on 400 acres would have to be replicated 800 times to attain the production level often predicted for U.S. EOR in the 1990s.

Discussions of a best estimate for future EOR production continued throughout the workshop proceedings. As with all rapidly developing technologies, estimates of future production are difficult to establish. The figure from the recent survey published in the Oil and Gas Journal (March 31, 1980) is often quoted as the accepted one for present EOR production, although the 385,000 bbl/day given as total U.S. production was not agreed upon unanimously by the participants.

Critiques of Estimates and Scenarios

EIA scenarios included high, intermediate, and low estimates for each of the years 1985, 1990, and 1995. These estimates were based on a model which included no offshore EOR production and no consideration of technologies such as gravity drainage or downhole steam generation. Models used to estimate EOR production were criticized for the following reasons:

- Long lead times for new projects not adequately incorporated.
- Questionable criteria used to screen fields for EOR production technologies.
- Neglect of the sequential application of different technologies applied to a given field.
- Neglect of offshore production (especially Prudhoe Bay and California).
- A primary emphasis on low temperature/low salinity fields (representing only 15% of target oil), whereas high temperature/high salinity fields represent 50% of target oil.

  Several suggestions were offered to improve these models, including:

  - use of screening criteria involving several variables
  - use of a composite index to assess the viability of a technology in a given field
  - inclusion of processes that use nitrogen or flue gases in place of CO_2; oxygen instead of air for in situ combustion; downhole steam generators; etc.
  - inclusion of offshore fields
  - application of several recovery techniques to any given field
  - consideration of large numbers of smaller fields.

Screening Criteria

A more detailed, field-by-field projection was offered by a researcher from Pacific Northwest Laboratory.* This information, shown in Appendix D2, was prepared for use by national laboratory personnel in their health and environmental assessment of EOR. The projections went relatively unchallenged, and it was decided that, with minor corrections, this production scenario could form the basis of EH&S assessments by researchers.

Caveats were offered on the subject of screening criteria in production scenarios, a particularly difficult issue for industry representatives. They recognized that screening criteria are necessary for assessing the applicabil-

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*Operated by Battelle Memorial Institute for the U.S. Department of Energy.

ity of EOR technologies to specific reservoirs for regulatory and government-support purposes. However, they issued several warnings. First, although they are often treated as such, criteria are not absolutes and should therefore be viewed as one set of many possible decision aids. Second, such criteria are often applied indiscriminately from reservoir to reservoir, despite the fact that they are not always appropriate. Third, and most important, not enough is known about all reservoirs and all EOR technologies to support the establishment of immutable screening criteria.

Industry representatives recommended that, in setting criteria, government analysts should follow industry practice: i.e., they should specify "preferred criteria" and state (and observe) limitations and assumptions. Specific criteria, which have been established to aid in computer oriented searches of candidate fields, are frequently ignored in actual practice. (For example, evidence of a good waterflood can overshadow all other criteria in selecting a reservoir for a micellar-polymer flood.)

Factors for Production Rates

Further discussions of future production took place in a special session on the second day of the conference. It was thought that production of enhanced oil would increase to between 900,000 and 1,200,000 bbl/day by the year 2000. Actual production could differ from these projected figures for several reasons. For example, offshore production, Prudhoe Bay production, mining oil sands, and technological innovations such as downhole steam generators and better mobility control could increase production substantially. On the other hand, rising costs of items such as chemical and environmental control technologies are making EOR more expensive and hence may reduce future production below the projected figures.

DOE cost-sharing programs were welcomed by most representatives of industry, who indicated a need for such alliances in the future. Since the lead time for EOR projects is from 4 to 10 years, long-term stable government policy on EOR is critical to their development. Industry representatives also suggested that additional tax incentives for high cost and high risk processes, such as micellar-polymer and CO_2 flooding, would help to attract more capital investment to EOR projects; for example, they implied that expensive EOR technologies requiring micellar polymers would have been cost competitive had it not been for the increased burden posed by the windfall profits tax.

Although there are large oil reserves that can be recovered by tertiary methods, several participants lacked optimism for the future of EOR. They based this on several factors: the impacts of the windfall profits tax; the lack of provision for any optimism in the Energy Information Administration's forecasting procedure, which is an economic model; and the lack of consistent federal policies [especially supportive policies (in the aforementioned context)] on EOR. Because of these shortcomings, the oil industry often decides in favor of exploration for new oil rather than EOR. Several oil company participants mentioned that exploration has historically been substantially more cost efficient than EOR. Moreover, if new oil is discovered, there is typically a better up-front payoff, while some EOR processes require heavy, up-front investment and yield slow rates of return.

Oil industry representatives opined that overly restrictive regulations were responsible for their lack of confidence in the future of EOR. They felt that there is often a lack of consistency between federal, state and local regulations, resulting in time-consuming and costly attempts at compliance. Thus, they anticipate that increased EOR will occur very slowly, despite the existence of enormous reserves of oil amenable to tertiary processes.

ENVIRONMENTAL, HEALTH, AND SAFETY IMPACTS

Panelists discussed several environmental assessments by private consultants and others for both DOE and EPA, and concluded that these assessments were inadequate in breadth and detail. For example, details of a specific technology would be useful when applied to a specific field, but such details were usually missing. On the other hand, the wide-ranging comparisons of different EOR technologies could be usefully applied to production scenarios, but these, too, were lacking.

Several participants expressed the belief that EOR is environmentally benign compared to other fossil energy technologies. For example, they felt that mitigation strategies using available control technologies could alleviate environmental impacts in most EOR applications. Proposed federal and state underground injection control regulations would mitigate aquifer contamination due to oil or brines without seriously affecting future production.

Air emissions from California's heavy oil fields requiring steam injection were possible exceptions; strict state regulations on thermal EOR may affect future increases in production. These regulations will require stack scrubbers which produce solid wastes, disposal of which is also controlled by regulations from these same agencies. EOR production could be affected; in California, for example, air emission standards may require new steamflood projects to obtain offsets. (In some cases few such offsets are possible.) California also has strict regulations for the certification of solid waste disposal sites, which may also affect EOR production.

Further discussions of environmental, health, and safety (EH&S) considerations led to several important conclusions:

1. It is essential to distinguish issues which are specific to EOR. Evaluations of EH&S impacts should consider that most EOR techniques are applied to already existing oil field production facilities. For example, opening up wilderness areas in the overthrust belt of the Western U.S. should not be linked to EOR, but rather to primary and secondary production. The lack of geological information to adequately describe reservoirs is a problem endemic to oil exploration and production, not necessarily specific to EOR. The same may be said for knowledge of brine compositions and the location of abandoned wells. On the other hand, concerns which are specific to EOR include polymer and surfactant compositions and behaviors, mobility control, separation of produced fluids, air pollution, the characterization and disposal of solid wastes, and groundwater contamination from well casing failures and improperly plugged wells.
2. Previous EH&S assessments suffered because they emphasized issues of lesser importance. The overthrust belt is one such example. The important environmental concerns, according to a broad consensus, are:
   - aquifer contamination due to casing failures and improperly plugged wells,
   - competition for water in water-short areas,

- regional air pollution,
- solid waste disposal,
- wilderness degradation specifically due to incremental increases in petroleum production, and
- occupational safety and health concerns. In this context,

a list of EOR chemicals for safety considerations would include about a dozen compounds, rather than the hundreds so frequently mentioned.

An example of a 'lesser issue' was the continued mention in several assessments of toluene as a potentially dangerous pollutant specifically associated with EOR activities. Several years ago toluene was listed as a dangerous pollutant in an EPA-sponsored report on EOR, and since that time this designation has been carried forward in succeeding reports unchallenged: in fact, toluene is not used exclusively in EOR projects, nor is such exclusive use contemplated for the future. Toluene, like a number of other chemicals,* is simply used for well bore cleaning in general oil field operations.

This type of misunderstanding illustrates two important points. First, it serves as an example of the confusion in people's minds over what is an EOR-specific issue. (For example, chemicals used for well cleaning should not be considered as liabilities specifically associated with EOR.) Second, inaccurate information is often incestuously perpetuated in the literature because of inclusion in earlier assessments which, though based upon best information available at the time, are no longer valid. These were the points that the workshop participants attempted to resolve by an overview of environmental aspects of EOR technologies.

3. Particularly vexing is the lack of adequate EOR data, both technical and environmental, which are regularly updated and easily accessible. This is evident from several EPA- and DOE-sponsored assessments of EOR, all of which relied upon the same data which had not been reviewed for some time. This insidious aspect of

*Toluene is now being evaluated as to carcinogenicity in the Carcinogenic Testing Program of the National Toxicological Program, sponsored by the National Institute of Health (Institute for Environmental Sciences), Rockville, Maryland.

current technology assessments, i.e., a small, aging data base used repeatedly by a variety of analysts, hinders the development of EOR. Furthermore, comprehensive collection of field data is a fundamental requirement. Without improved knowledge, decisions on EOR, particularly policy decisions, will be open to serious question.

4. Oil industry representatives expressed perception of an apparent lack of understanding (primarily on the part of government officials) of important environmental issues related to EOR. It was said at the workshop that this lack of understanding is most apparent in regulatory programs. For example, the environmental control problems of tertiary oil recovery were said to be similar to those for primary and secondary recovery. However, industry claims that government does not seem to realize this, and that special regulations and controls are imposed on EOR that are simply not necessary.

   Irrespective of the validity of this claim, one serious result is that the permitting process for EOR projects is unnecessarily impeded. A case was offered as an example of lack of regulatory understanding: viz., the State of California classifies sludges from scrubbers appended to steam generator as hazardous wastes, requiring special handling and several disposal sites. It was suggested that a better approach would be to define classes of hazardous wastes, each having a different degree of potential impact, each requiring different types of disposal sites.

   Another problem has been the preparation of generic environmental impact statements (EISs) for the EOR technologies. Some workshop participants concluded that, for most of the technologies, such EISs are of little value and are misused. Therefore, these participants felt that generic EISs should be discarded and field-specific EISs prepared instead, where they are needed.[3]

Geology and Water Supply[4]

There was a consensus that geological problems mentioned in previous assessments (such as fracturing, or inducing earthquakes) were unimportant. Another consensus was that water availability, often considered a major potential constraint to EOR, was not an overriding problem, except for specific sites. On a wider, regional scale, the consensus was that sufficient water existed and that allocation, not availability, is the central issue. It was noted that at least one Oklahoma EOR project may be delayed because of the large quantities of water required for the specific process being considered. The proposed site is an area where fresh groundwater is used for farmland irrigation. The farming community fears that the EOR project might significally reduce the reserves of the freshwater aquifer. There are also situations where water availability can have an environmental impact. An example is the Powder River Basin where a decline of 300 to 500 feet of pressure in hydraulic head has been observed, caused by a combination of activities, including EOR.

In some areas of the West, the allocation of even small amounts of water can have unexpected consequences. Allocators and planners should look at the entire spectrum of usage. For example, if one were to allocate water to an oil project from a given source, the entire usage of that resource should be examined; that is, how much will the nearby farms and cities require, what is the rate of recharge, how much is required by other users, etc. Any EIS for tertiary oil recovery should address overall energy development programs as well as the <u>entire</u> water usage spectrum.

GROUNDWATER CONTAMINATION[5]

Possible groundwater contamination should be put into the proper perspective: primary and secondary production may already have led to groundwater degradation, particularly from casing failures, abandoned or improperly plugged wells, the disposal of produced waters, and spills of the myriad of chemicals used during normal operations. Industry is vitally concerned with the loss of expensive EOR chemicals during injection, most of which are also subject to some degree of degradation from physical, chemical, and bacterial processes. Some important questions which do require better understanding are: what EOR-specific chemicals are hazardous or toxic, what are their potentials for degradation, what are the properties of the degradation products, and what mechanisms may lead to groundwater contamination specifically due to EOR production. It was indicated that most EOR injection pressures are low enough that hydraulic fracturing should not occur.

This is even true for CO_2 flooding which uses higher injection pressures than other processes.

Recent EPA regulations concerning underground injection (i.e., Underground Injection Control--UIC) were considered to be adequate in reducing the incidence of well failures. The UIC program establishes guidelines for the testing and monitoring of all new wells drilled. The possibility of leakage from older wells, in most fields reopened for EOR, was not considered to be a serious technical problem: the need for high pressures and tight reservoir seals should force producers to carefully examine their fields for abandoned wells, which should then be properly sealed. In actual practice, however, it may sometimes be impossible to locate all improperly abandoned wells. If such wells are found, UIC may require the producer to have them redrilled and satisfactorily replugged if possible. UIC will thus constitute a capital risk for the industry. If such wells are discovered in an EOR project and if they cannot be satisfactorily redrilled and replugged, the project will have to be abandoned. It was noted that changes in injection patterns might be an alternative procedure if leaks cannot be properly repaired. Water wells would then be carefully monitored especially around "leakers" to avoid vertical movement of fluids. An industry participant noted that about half the oil produced in the U.S. comes from waterflooding and that leaky wells are common to such operations.

Enforcement of UIC for disposal of produced waters is very important. Waters from EOR projects should be similar in quality to those currently being disposed of during waterflooding operations with the addition of small amounts of EOR-specific chemicals.

Air Pollution

It was concluded that air pollution would be an issue of major concern primarily in California. Industry representatives and government officials familiar with California expressed concern over the question of both sulfur and nitrogen oxides produced during the combustion process that provides the steam for thermal EOR projects. The best current technology can remove up to 95% of the sulfur compounds, but only 30% of the nitrogen oxides. With increased EOR activity, the levels of pollution would rapidly reach their legislated maxima, leaving the industry with no choice but to curtail production unless offsets were found.

One speaker during the "Associated Environmental Issues" session suggested that the key pollutant for air control technologies ought to be NO_X, not SO_X, and that prevention of significant deterioration represented a "Catch-22" situation. There seem to be few offsets available in locales such as Kern County. Therefore, both the California legislature and the Congress may have to consider more latitude in definitions of Clean Air Act standards. The problems currently confronting the users of steamflooding in California were singled out for separate mention because of the vast quantities of oil that could be produced in California if these problems were satisfactorily resolved. Another workshop participant estimated that California could produce 2 million bbl/day of tertiary oil by the year 2000 and possibly before 1990 "if all barriers were removed." By comparison, the DOE/EIA estimates a maximum national total of 1.26 million bbl/day through all EOR techniques in 1995.

The use of stack scrubbers holds promise of removing atmospheric environmental contamination. Unfortunately, these control devices produce sludges which must be disposed of; an air quality problem is thus transformed into one of solid waste disposal. This may represent another obstacle to EOR, because of the possibility of EOR-related solid wastes containing hazardous and/or toxic substances.

Returning to the California experience, the air-to-solid waste problem leads to another regulatory quandry brought about by California's classification of scrubber sludges as hazardous wastes.* These wastes must meet strict disposal requirements and be disposed of in specially designated, tightly managed sites. Such sites have become very scarce in California. Moreover, California appears to be the only jurisdiction that considers these scrubber sludges as hazardous at this time, for reasons unclear to industry representatives and others, but illustrative to them of government's lack of understanding of environmental issues. While no participant expected all regulations to be removed, the magnitude of this problem and the need for its resolution are clear. A sentiment was expressed for the need to distinguish between degrees of danger for hazardous waste disposal. Another aspect of the problem are the "offsets" allowed for new sources of air emissions. New

*Congressional action since the workshop has resulted in the suspension of EPA regulations on scrubber sludges pending a two-year study.

models are important because of the diminishing air pollution offsets available to industry from other emission sources.

It was generally agreed that air pollution would not be an important environmental constraint for increased EOR applications outside of the state of California. Air pollution would decrease considerably should the downhole steam generator prove trustworthy, because most of the pollutant gases are trapped and contained in the well when this method is used.

Air pollutants are somewhat related to other EOR technologies as well. For example, the micellar polymer and improved waterflooding (caustic and polymer) technologies may contribute emissions from evaporation of improperly handled volatile chemicals such as alcohols, ethers, and other hydrocarbons, as well as fugitive emissions. This is apparently a very minor concern, however.

CO_2 and fireflooding technologies may also have air quality problems, primarily resulting from the use of diesel engines. For a sour reservoir, such as commonly found in Texas there are H_2S-handling and emission problems, but these are similar to those encountered in a primary or secondary operation.

Management of Hazardous Chemicals and Wastes

Several participants expressed the opinion that the current practice of simply labeling chemical substances as either "safe" or "hazardous" should be modified. Chemicals should be put into several different categories depending on how hazardous they are. Thus more disposal sites, each capable of safely storing wastes representing various degrees of hazard or toxicity, would become available. This would also prevent scrubber sludges due to steamflooding from being put in the same category with polychlorinated biphenyls (PCBs), as they are now in California.

Spills represent handling problems. Because the handling of chemicals used in micellar-polymer flooding can be complex, spill-contingency plans on such projects may require re-evaluation and revision.

Surface Impacts

Potential impacts to land were generally of minor concern with the exception of land use. Marginal lands are often classified "agricultural" and the impacts thus appear to be larger than they really are. The small extent to which EOR actually requires the use of superior lands determines the magnitude of this problem.

Difficulties exist in relation to dredge and fill operations in wetlands or in the tundra on the North Slope of Alaska. These operations are very disruptive to the local ecosystems. Increased activities in old abandoned fields may cause runoff problems, especially in the Rocky Mountain region. Furthermore, reclamation of old lands must be done carefully. Most large-scale surface impacts are of short duration (3 to 6 months); smaller areas are sometimes affected for longer periods.

Occupational Health and Safety

Some EOR chemicals are hazardous and may require special handling and disposal techniques. The oil industry is addressing this problem, which relates primarily to technology transfer because the chemical industry is experienced in handling such chemicals as polyacrylamides, polysaccharides, and microemulsions. For example, chemical producers have stringent requirements for the safe handling and storing of polyacrylamides. Petroleum sulfonates have been used for many years as a component of dormant sprays.

It was noted that employee unions are quite interested in worker safety and that the DOE Safety Analysis Review System (SARS) Program requires analysis of each DOE-sponsored project. (This is already being done at the Bartlesville Energy Technology Center for EOR projects.)

New problems may arise in the transportation of chemicals in Alaska and offshore because of sensitive environments. The potential harm from releases may be many times greater than for an equivalent onshore release in the lower 48 states.

SPECIAL TECHNICAL AND LEGAL CONSIDERATIONS

Offshore Production

Unlike its onshore equivalent, an offshore well cannot be easily reopened once abandoned, and there is a greater incentive for beginning EOR processes immediately after primary and/or secondary production. Offshore EOR poses several issues not considered before. Offshore wells have much greater spacings than onshore wells and are usually plugged when their production falls below threshold levels above those of their onshore counterparts. Once this happens it is not easy to recomplete a well and put it into tertiary production (as at onshore sites). Furthermore, platform space is limited and usually precludes onsite production, mixing, and storage of chemicals. Space for steam generators is also quite limited; CO_2 projects would require long underwater pipelines from CO_2 production sites to platforms offshore.

Regulatory Constraints

Regulatory considerations were identified as an important class of constraints to EOR production. Although there was no consensus about regulations being too restrictive, it was generally agreed that it took too long to obtain many local, state, and federal permits. One viewpoint held that the regulatory situation has spawned odd strategies such as the sale of air pollution offsets, a response to ill-conceived regulations that involved severe penalties. There were serious doubts about the value of programmatic environmental impact statements in terms of time, effort, and costs. It was felt that generic issues common to EOR should be included in programmatic environmental impact statements, while specific problems encountered with specific technologies at individual fields are more appropriately left for the permitting process.

States typically do an inadequate job of enforcement primarily because of a lack of manpower and budgetary restrictions. Some state agencies are aware of violations but can do nothing about them (e.g., in the case of well logs showing gross problems, such as a poor cement bond that is never squeezed and relogged). It was felt that the industry should do a better job of complying with existing regulation. However, it was generally recognized that there is not enough manpower at both the state and the federal levels to enforce existing regulations.

Government tax policy drew the greatest amount of criticism. It has already been explained that the advantage of EOR in the Windfall Profits Tax might work toward the damping of research on new EOR methods. This is especially true in areas of the nation where EOR accounts for a low percentage of total production. Even in an area such as California, where EOR is already a significant factor in total oil recovery, tax policy might be a disincentive.

Government policies to promote EOR were in general well received, although the industry representatives felt that such programs should not have time constraints, as they presently do. Industry representatives suggested that the federal government should give tax write-offs for long term EOR development to ease the heavy financial front-end loading of these projects.

Environmental regulations predictably drew criticism from the industry, with a surprising amount of concurrence on the part of the government analysts. An interesting example of what the industry considered to be overzealous regulation was the definition of Best Available Control Technology (BACT). As environmental regulations call for the installation of BACT, the definition of what is BACT becomes important. Industry participants bemoaned the fact that many of their research discoveries in the area of environmental control were immediately labeled BACT, despite the fact that such technologies were still in the R&D stage. This has the effect of holding back the exchange of information in this important field, as companies prefer to perfect their processes before they make them public.

On the subject of delays, one federal government representative in the workshop stated that it is conceivable that a permit application received by EPA, complete and fully supported with background information and data, could take up to 18 months to be processed, especially if it is contested. He also said that a state receiving the same application could declare "primacy" for the project and get the permit issued within 60 days; however, this is unlikely. The real danger, of course, is that the delays are expensive and can cause the applicants to cancel EOR projects, and perhaps turn to other areas instead.

Another problem is manpower shortage. As mentioned previously, the oil companies are having trouble finding enough qualified engineers, technicians and field personnel to work on EOR. This shortage may intensify as increased EOR activity and a parallel increase in government regulation and regulators further depletes the pool of available talent.

The industry participants asked that government policy makers recognize EOR as an evolving technology full of risk and uncertainty for the companies attempting to develop it. Excessive government regulation has the effect of stifling EOR before it has a chance to become established. At present, the potential for increased oil production through new exploration is still economically equal to or better than through EOR. Because these activities must compete within the corporate bureaucracy for funds, it is natural for oil executives to rely upon a familiar activity, especially if EOR is made unattractive through excessive regulation. In this light, the potential for environmental damage associated with the opening up of a new oil field makes any EOR-related problems seem minor in comparison.

Technical Constraints

Workshop participants felt that the availability of chemicals, mentioned repeatedly as a possible deterrent to more widespread EOR activity, would not pose a major problem, since the long lead times required for EOR projects would allow establishment of reliable supplies.

It was stressed that much more testing and modeling is needed. Present reservoir simulations are inadequate, and the mathematical models used to predict flow in these reservoirs are therefore even less reliable, as demonstrated by the frequent failure of laboratory experiments to duplicate field tests.

A number of potential breakthroughs might alter the EOR picture significantly. The downhole steam generator might make steam EOR more acceptable for expansion, especially in California, which presently accounts for the bulk of EOR-produced oil in the U.S. Major stimuli to EOR might come from large-scale implementation of CO_2 and micellar polymer flooding. Research is being directed towards new types of polymers used in micellar flooding. Currently such polymers are highly sensitive to salinity, and are therefore not applicable to reservoirs that contain saline solutions. If saline-tolerant polymers could be perfected, the potential for increased EOR would be vast. It is this potential for such breakthroughs that makes the forecasting of production figures so problematic.

Data Base Development

A discussion was scheduled on the computerized data base compiled by BNL (Appendix E). Most of the primary EOR data were provided by the DOE/Energy Information Administration, to which additional information was appended. The latter included location (latitude/longitude, FIPS code), county, ambient air quality, surface water quality, distribution of several rock and soil types, and county land uses. Some specific comments stated that:

1. Aquifer information should be coded according to how well an aquifer is understood.
2. Residual oil saturations should be carefully checked.
3. County tons/mi^2 of emissions of air pollutants were far less important than attainment vs non-attainment areas.

4. Emission factors from field equipment should be updated from EPA document A.P.-42.
5. Most surface water data were largely irrelevant except for amounts of water available for EOR.
6. 10,000 mg/ℓ TDS was a better criterion for "saline" aquifers than 3000 mg/ℓ.
7. Pollutant levels measured by state agencies were more significant than those given by EPA.
8. Groundwater availability could best be checked from U.S. Geological Survey data.

Special Areas for Potential EOR Activities

It was felt that the promising Overthrust Belt in the Rocky Mountain area might well be the center of environmental debates, but that these would concern the question of introducing exploration and primary production, and not specifically EOR. Prudhoe Bay (Alaska) was mentioned as an obvious candidate for CO_2 flooding, since that gas is a by-product of the present gas production there. Questions of disturbing the delicate tundra environment of the North Slope belong more fittingly in the realms of primary and secondary production than to EOR specifically, although any incremental impact would be important there, too.

CONCLUSIONS*

- The major consensus that emerged from the discussions was that, in environmental terms, EOR is a relatively benign way to increase oil production, except in certain localized areas. (X)
- EOR is a good source of new oil and, from the standpoint of environment, health, and safety, is probably preferable to shale, coal, and other synfuels. Evaluations of environmental impact should be placed in perspective, especially when it is known that alternative sources of oil (such as syncrude or new exploration and drilling) could generate far greater damage.
- Environmental issues which might constrain future EOR production include air quality, solid waste disposal, water availability, and aquifer contamination.
- Important tasks should now be the understanding of local environmental problems and the definition of effective methods to deal with them. Poorly defined conceptions of potential environmental problems can be counterproductive.
- A technically adequate EOR data base should be assembled, regularly updated, and expanded.
- Projections of future EOR production should include both Alaskan and offshore fields.
- Potential increases in EOR production from technological advances should be factored into scenarios, whenever possible.
- DOE technological and environmental assessments should focus on thorough analysis of important issues. Too often, such documents include issues that are irrelevant and detract from the professionalism of the assessment.
- DOE EOR assessments should distinguish between likely and improbable impacts; continued inclusion of "shopping lists" of hazardous substances, most of which are not peculiar to EOR per se, only serve to

*One participant disagreed with the conclusions marked by X and asked that his disagreement be cited accordingly.

raise sham issues. However, special emphasis should be given to hazardous substances widely used in EOR. Assessments should relate to EOR-specific issues, not remotely peripheral ones.

- There is widespread interest by industry and environmentalists in co-operating with DOE analysts in order to ensure technical adequacy of assessments. This interest should be actively encouraged.
- Previous EIA forecasts of EOR production only approximate the limits for (non-Alaskan) onshore operations.
- Rigid screening criteria for EOR technologies are general guidelines, primarily for use in forecast models and in computer searches, but are rarely used in actual site selection.
- The greatest opportunities for increasing EOR by the year 2000 appear to be: downhole steam generation; additives to improve sweep efficiency; Prudhoe Bay EOR; offshore EOR; and tar sands recovery. (X)
- Prime constraints on EOR are political uncertainties and lack of government stability with regard to oil policy and pricing. (X)
- A major impediment to EOR production is the slow response of regulatory agencies, with permits sometimes taking years instead of weeks. (X)

REFERENCES AND COMMENTARIES

Note: The following information was provided by individual participants who reviewed the first draft of the Proceeding.

1. "Some comments regarding the history concerning incentives for enhanced oil recovery might be appropriate. In early 1978 the DOE proposed an incentive for enhanced oil recovery which would provide for free market pricing of any enhanced oil recovery. The Department of Energy wanted to establish a decline curve for continued production and allow incremental production above this decline curve to be priced at the free market price and the remaining production to be sold at controlled prices. This proposal drew a great deal of criticism from the industry because of the difficulty in projecting a decline curve agreeable to any two petroleum engineers. The establishment of an agreed upon decline curve between engineers working for the government and engineers working for an oil company would be almost impossible. Oil companies claimed that they should be allowed to price all production from the property at market price since indeed, enhanced oil recovery processes involve total production from the property, that is, the installment of an enhanced recovery process will have several effects on the normal production decline from a property. Many enhanced recovery processes require closer [well] spacing which in itself would change the production curve and a number of the enhanced oil recovery processes actually realize a decreased injection rate which would tend to decrease the actual annual production rate while increasing total final recovery. For this reason, it is difficult to attribute annual production to continued waterflood or to the enhanced recovery process itself.

   It appears that the U.S. Congress took these arguments into account in establishing the amount of oil to be placed in Tier III category under "Tertiary Oil." The existing law was a compromise between the position originally espoused by the DOE and that proposed by the oil companies. It is a workable compromise. The existing law does tend to provide a mechanism by which to recover some of the heavy front-end capital expenditures before the true tertiary response is observed. This is accomplished by allowing some of the oil, which under continued operations should be taxed at 60 or 70%, to be taxed at a 30% rate."

2. Another participant offered the following qualification: "[The] safeguards within the Windfall Profit Tax Act which require the certifying of the process either by a registered petroleum engineer or a state regulatory agency should work against this type of short-sighted operational decision. The processes which produce the most economic oil will be instigated first and those high cost, high-technological risk processes will be instigated at a more cautious rate. To qualify for the reduced tax rate, these processes must be shown to produce more than the insignificant amount of oil than that which might otherwise be produced by other means."

3. One participant strongly disagreed with this paragraph, for the following reasons:
   1. Under NEPA, an EIS is required only for "major Federal actions significantly affecting the quality of the human environment." The numerous Environmental Assessment [documents] that have been prepared for on-going EOR projects indicate that such projects are not major federal actions. Thus, no EIS is required. Perhaps it should also be noted that the time required for EIA preparation (approximately 3 years to completion) would be prohibitive.
   2. It is doubtful that the federal government will be directly concerned with future EOR projects. Unless the government supports a project with federal monies or has the responsibility for control, the project does not fall under NEPA.
   3. In the event the government should take part in future EOR projects, the Environmental Assessment [document] should suffice. Environmental Impact Statements could be required if the government were to become involved in offshore or, perhaps, Alaskan EOR projects.

4. Recent developments have cast some doubt on the optimism of the workshop with respect to water availability. For example, during the past two months legislation has been introduced in the Oklahoma Congress to prohibit the use of fresh groundwater for EOR by defining such use as waste. Another amendment was introduced which would allow groundwater use for EOR without defining it as waste, but only up to a prescribed limit. These deliberations resulted from a case brought by residents in the Oklahoma Panhandle against an oil company. While the company owned water rights

to 3442 acres of land in the Oklahoma Panhandle, its use of these fresh waters was challenged by a district judge because the waters were held to be limited resources shared by the landowners.

5. New data have recently come to the attention of the senior author of documented cases relating oil production to aquifer contamination. In one Western state, for example, 32 such cases have been discovered since 1958. Fourteen of these (44%) were discovered in the last five years. Of the total, 22 (69%) were attributed to casing and tubing failures, and eight (25%) to cement failures. Half the wells were operated by major oil companies.

Appendix A .... Workshop Agenda

DOE/EV Sponsored
ENHANCED OIL RECOVERY WORKSHOP
Problems, Scenarios and Risks

University Center, Montana State University
Bozeman, Montana
August 24-27, 1980

PROGRAM

Prearrival . . . . .Distribution of resource materials and first questionnaire

Sunday, August 24th . . . . Arrival and Registration at Strand Union (7:30-10:30)
Distribute information packets (including biographies and results of questionnaire)

Monday, August 25th . . . .

9:00 a.m.	Welcome (M. Garrell)
9:05 a.m.	Role of EV/DOE (G. Rotariu)
9:15 a.m.	Purpose and Objectives of Workshop
9:30 a.m.	Introduction of Participants (approx. two minutes per person; 35 people)
10:30 a.m.	Coffee Break
10:45 a.m.	"E.O.R. in the Year 2000" (Speakers) Fred Poettmann (Marathon), Dave Pomphrey (DOE/RA), Phil Shambaugh (EIA), Bob Anderson (DOE/FE)
12:00 NOON	LUNCHEON
1:30 p.m.	"E.O.R. - Associated Environmental Issues" (Panel) Stan Zwicker (Union), Gary Peterson (DOE-SF), Henry Walter (DOE/EV), Janet Cole (EEA), Jeff Mahan (BAH)
3:00 p.m.	Coffee Break
3:30 p.m.	"Constraints to E.O.R." (Panel) Harry Chang (CITIES), Dan Luecke (EDF), Paul Osborne (EPA), Ken Tolmachoff (DOE/IRD)
6:00 p.m.	Cocktails and Dinner at University Museum

NOTE: from time-to-time, questionnaires will be distributed in an effort to lead the group to better quantitative estimates of the consequences of expanded E.O.R. production.

(continued)

Tuesday, August 26th	9:00 a.m.	Organization
	9:10 a.m.	Discussion of previous day's results (this includes results of various questionnaires and discussion of consensus)
	9:30 a.m.	E.O.R. Production Scenarios
	10:00 a.m. to 4:00 p.m.	(includes 2 coffee breaks and lunch) <u>Group 1</u> - Technologies (J. Sathaye, chmn.) This group will focus on technologies and their relation to scenarios for E.O.R. production. Included will be discussions on technological breakthroughs, regulations, environmental control technologies, offshore E.O.R., Alaskan E.O.R., future world E.O.R. <u>Group 2</u> - Issues and Impacts (F. Riedel, chmn.) This group will discuss legal, technological, conservation, and safety aspects of E.O.R., quantifying of environmental problems, revised scenarios, environmental assessments by technology, well failures, aquifer contamination, water availability, air quality degradation, accidents, and E.O.R. extension to new areas.
	4:00 p.m.	Summaries by Group Leaders Discussion of common issues
	7:30 p.m.	Off-campus event (barbecue)
Wednesday, August 27th. . . .	9:00 a.m.	Organization and discussion of previous day's findings, including questionnaires
	9:30 a.m.	Common Issues in discussion groups and their applications to scenarios: Any issues not discussed Relation of E.O.R. to other fossil technologies, consensus (coffee break included)
	12:00 NOON	Closing remarks

Appendix B1 .... List of Attendees

DOE/EV WORKSHOP ON
ENHANCED OIL RECOVERY

ATTENDEES LIST

Bob Anderson	M.S. D-107 GTN, U.S. DOE Germantown, MD 20545	301-353-2746
George R. Bierman	Science Applications, Inc 1710 Goodridge Drive Mclean, VA 22102	703-821-4586
Harry L. Chang	Cities Service Company Box 50408 Tulsa, OK 74136	918-561-4718
Janet Cole	1111 N. 19th Street Energy & Environmental Analysis, Inc. Arlington, VA 22209	703-528-1900
Anny B. Coury	U.S.G.S., Mail Stop 971 Denver Federal Center Denver, CO 80225	303-234-3435
Jeffrey I. Daniels	Environmental Sciences Division L-453 Lawrence Livermore Laboratory PO Box 5507 Livermore, CA 94550	415-422-0910 (FTS) 532-0910
Bob Froning	Amoco Production Company Box 591 Tulsa, OK 74102	918-660-3151
Martin Garrell	Building 475, BNL Upton, NY 11973	516-345-2045 (FTS) 666-2045
Ed Kaplan	Building 475, BNL Upton, NY 11973	516-345-2007 (FTS) 666-2007
Ronald F. Kendall	BETC - P.O. Box 1398 Bartlesville, OK	918-336-2400 (FTS) 735-4343
George Kinsel	U.S.G.S. - Box 590 Thermopolis, WY 82443	307-864-2156
Daniel Luecke	EDF 1659 Pennsylvania Street Denver, CO 80203	303-831-7559
Jeffrey Mahan	4550 Montgomery Avenue, Suite 1000 N Booz, Allen & Hamilton Bethesda, MD 20014	301-951-2026

Rosa Meehan	U.S. Fish & Wildlife Service Box 20, Federal Building 101 12th Avenue Fairbanks, AK 99701	907-456-6071
Matthew Milukas	Lawrence Berkeley Laboratory Room 3125, Bldg 90 U.C. Berkeley, CA 94720	415-486-4701 (FTS) 451-4701
Joe A. Moreland	USGS, Drawer 10076 301 S. Park Helena, MT 59601	406-449-5263 (FTS) 585-5263
Paul S. Osborne	U.S.E P.A. 1860 Lincoln Street Denver, CO	303-837-2731
Gary Peterson	DOE - 1333 Broadway Oakland, CA 94612	415-273-7951 (FTS) 536-7951
Fred H. Poettmann	Marathon Oil Company P.O. Box 269 Littleton, CO 80160	303-794-2601
David Pumphrey	Office of Oil & Natural Gas Resource Applications/DOE (M.S.3344) 12th & Pennsylvania Avenue, N.W. Washington, D.C. 20461	202-633-8383
E. Fred Riedel	Battelle Pacific Northwest Laboratories Richland, WA 99352	509-376-3585 (FTS) 444-3585
George J. Rotariu	EV-22; Mail E-201 U.S. DOE - Washington, D.C. 20545	301-353-5865 (FTS) 233-5865
W. M. Sackinger	NOAA/OCSEAP Arctic Project Office 611 Elvey Building University of Alaska, Fairbanks, Alaska 99701	907-479-7371 or 907-479-6808
Jayant Sathaye	Lawrence Berkeley Laboratory Room 3120/90 Berkeley, CA 94720	415-486-6294 (FTS) 451-6294
Phil Shambaugh	DOE - EI 522, Mail Stop 4530 12th & Penn N.W. Washington, D.C. 20461	202-633-8547
Bertram S. Shelby	Cities Service Company Box 300 Tulsa, OK 74102	918-561-3149

Peter A. Thomas	Harbridge House, Inc. Suite 305 - 2101 L. Street, NW Washington, D.C.	202-223-4990
I. Tolmachoff, Jr.	DOE/IRD, Room 3120, Federal Building 12th & Pa. Avenue, N.E. Washington, D.C. 20461	202-633-9619
Henry F. Walter	Environmental and Safety Engineering Div EV-132 - Mail Room D-201 U.S. DO Energy Washington, D.C. 20545	301-353-5510 (FTS)233-5510
Stan Zwicker	Union Oil Company of California 461 S. Boylston, Los Angeles, CA 90017	213-977-7787

Appendix B2 .... Biographical Sketches of Participants

Bob Anderson is the Program Manager of heavy oil and tar sands for the Fossil Energy Branch of the Department of Energy. In this position, he oversees and manages the Fossil Energy Research and Development Program in heavy oil and tar sands. Prior to his work at DOE, Mr. Anderson was an energy consultant with Booz-Allen, working in the areas of enhanced oil recovery and coal technologies. Mr. Anderson was also a process engineer in the petrochemical area for Continental Oil. He received a B.S. degree in Chemical Engineering from the University of Maryland, and an M.B.A. degree from the George Washington University.

George R. Bierman is a registered professional mechanical engineer with over 25 years of experience. His principal areas of experience are in transportation, regulatory issues analysis, environmental analysis and facilities and equipment engineering. With Science Applications, Inc. (SAI) for the past seven years, he has worked as a consultant to many Federal Government agencies. His projects include development of multi-year program plans and R&D project evaluation methods for the Bureau of Mines; support to the Department of Energy (DOE) in the conduct of technology assessments for oil shale, enhanced oil recovery and unconventional gas recovery; work for DOE/Morgantown in the flue gas cleanup/hot gas cleanup program, including market penetration analysis for selected processes; assistance to EPA in the development of noise abatement regulations; and commodity transportation analysis for the Federal Railroad Administration. He has also designed numerous plant facilities, including a fuels and lubricants research laboratory, and an aerospace environmental research laboratory, both for the Air Force. Mr. Bierman is presently Manager of the Systems Engineering Division of SAI's Energy Utilization Group.

Harry Chang is the manager of the entire enhanced recovery research effort of Cities Service Company. His prior experience with Mobil Oil involved the areas of chemical flooding and enhanced recovery. Dr. Chang received a B.S. degree in Chemical Engineering from Tunghai University, Taiwan and a Ph.D. degree in Chemical Engineering from Rice University.

Janet Cole is Project Manager at Energy and Environmental Analysis in Arlington, Virginia. She was responsible for the Draft Environmental Impact Statement for the USDOE EOR Program as well as site-specific Environmental Assessment for three DOE cost shared EOR projects. She has analyzed the effects of environmental regulation on EOR, NO_x control for California steam generators, and the adequacy of air quality monitoring for EOR in California. She has a B.A. in Government from Cornell as well as a Masters Degree in Urban and Regional Planning from George Washington University.

Anny B. Coury is a geologist with the Branch of Oil and Gas Resources of the U.S. Geological Survey. After spending 18 years doing exploration and exploitation work for several oil companies, she joined the USGS in Washington, D.C. almost 10 years ago. For the past several years, she has been involved in resource appraisal - the estimation of undiscovered petroleum and natural gas.

Jeffrey I. Daniels is in the Environmental Sciences Division, Lawrence Livermore National Laboratory. He is currently involved in analysis and assessment of in situ oil shale atmospheric emissions and a technology assessment of tar sands recovery practices, and is interested in acquiring the quantitative data and information concerning environmental impacts from operation of EOR facilities.

H. Robert Froning is currently Research Director for Recovery Methods at the Amoco Production Company in Tulsa. For the past 20 years he has conducted studies in recovery methods, including wettability alteration, inferfacial tension and caustic flooding, micellar flooding, polymer flooding, and miscible type oil recovery processes. He finished a B.S. in Chemistry at Ottawa University in 1943 and completed his Ph.D. in Physical Chemistry at Indiana University in 1949. He is a member of the Society of Petroleum Engineers, American Chemical Society and Board of Trustees of Ottawa University.

Martin H. Garrell is an Associate Professor at Adelphi University in the Department of Physics and Energy Studies. He is currently on leave at Brookhaven National Laboratory in the Department of Energy and Environment, working for Dr. Peter Meier. His current research includes energy studies and environmental problem solving, and his past experience is in the following fields: water quality management, fisheries research, experimental high energy physics, and nuclear physics. He completed his A.B. in Physics at Princeton University in 1960 and finished his Ph.D. in Physics at the University of Illinois (Urbana) in 1966. He is a member of the American Physical Society, Sigma Xi, and the Association of Environmental Professionals.

Ed Kaplan is a scientist with the Division of Regional Studies, National Center for the Analysis of Energy Systems at Brookhaven National Laboratory. He is responsible for the development and implementation of programs to study impacts to water systems from energy activities. This includes aspects of both water quality and quantity, coastal zone management issues, and relationships between water, energy and economic development. Dr. Kaplan received his Ph.D. in water resources systems engineering from the University of Pennsylvania and has been at BNL since 1976. Prior to this he worked at Argonne National Laboratory and with the General Electric Company. He also teaches part time at SUNY/Stony Brook in the graduate environmental engineering program.

Ron Kendall is a physical science analyst with the Bartlesville Energy Technology Center. He jointed BETC in 1957 and was active in the instrumental fields of mass and infrared spectrometry and chromatographic techniques. Later on, he was assigned to BETC's Petroleum Production Branch where he became interested in environmental research and concerns associated with enhanced oil recovery processes. In 1979, he joined the Center's Planning and Environmental Coordination Branch to further pursue work in the areas of environment, safety and health as they related to fossil energy technology development.

George Kinsel is District Engineer at the USGS Branch in Thermopolis, Wyoming. He has worked for the Conservation Division of the USGS for the past 21 years after employment by Imperial Oil, Ltd., the Texas Company, and Schlumberger Surveying, Inc. He graduated from the Colorado School of Mines in 1955 with a degree in Petroleum Engineering and attended Carnegie Tech for one year in Industrial Administration.

Daniel F. Luecke is an environmental engineer with the Environmental Defense Fund in Denver. His training is hydraulics, hydrology, economics, statistics, and mathematical modeling, and for the past 10 years he has worked on the quantitative analysis of project, program and public policy issues, associated natural resource development, water pollution control, hazardous waste management, and energy conservation. His most recent work prior to joining EDF involved the management of studies of the economic impacts of water pollution control regulations on several major U.S. industries. He is currently the staff scientist in the Denver office of EDF with responsibility for water and energy issues. His education includes a B.S. and M.S. at Notre Dame University in 1961 and 1965, respectively, and a Ph.D. at Harvard University in 1971.

Jeffrey S. Mahan, a senior consultant with the Energy and Environment Division of Booz, Allen and Hamilton has been actively involved in the environmental analysis of developing energy technologies. In particular, he has focused on the water resources implications of enhanced oil recovery (EOR), unconventional natural gas recovery (UGR) and shale resource development. His experience includes a study of monitoring requirements for EOR and UGR for DOE, as well as other environmental planning documents in support of DOE technology programs. Mr. Mahan has also worked, under contract with the U.S. EPA, in assessing the impacts of Underground Injection Control (UIC) Regulations on secondary and tertiary oil recovery. His responsibilities included assessing the technical and institutional feasibility of the "area of review" process and the potential costs of associated corrective actions. Mr. Mahan holds a Masters of Engineering degree in Systems Engineering from the University of Virginia.

Rosa Meehan is a biologist with the U.S. Fish and Wildlife Service, where she is involved in review of permit applications for Alaskan North Slope Oil Development. This work has involved review of environmental impacts of the Prudhoe Bay Waterflood project as well as other oil development-related activities. She received a Bachelors degree in Biology from the University of California at Santa Cruz and a Masters in Biology from the University of Alaska in Fairbanks.

Matt Milukas is a research assistant in the Energy and Environment Division of Lawrence Berkeley Laboratory, working in the area of enhanced oil recovery. His professional interest is in energy policy and he will begin work shortly involving energy conservation in Kenya.

Mr. Milukas is working toward a Ph.D. degree in Geography at the University of California at Berkeley, and has a Bachelors degree in Chemical Engineering from the Pratt Institute and a Masters degree in Geography also from U.C. Berkeley.

Joe A. Moreland is Supervisory Hydrologist and Chief of Hydrologic Investigations and Reports Section for the Montana District of the Water Resources Division, U.S. Geological Survey. He has had 15 years of experience in ground water investigations, including saltwater intrusion, artificial recharge, waste disposal, ground water modeling, ground water quality, and program management.

Paul Osborne is a ground water hydrologist with the Drinking Water Branch of the Environmental Protection Agency in Denver. His role there involves providing technical assistance to the regional office and Headquarters in the areas of underground injection controls and ground water, and aiding in development of a national ground water strategy. Prior to his work at EPA, Mr. Osborne served as a ground water hydrologist with the Arizona Water Commission where he was involved in the adequacy of ground water supply for general use. He received his M.S. degree in Hydrology from the University of Arizona.

Gary Peterson works in the Fossil Energy Division, Department of Energy, San Francisco where he acts as program coordinator in the area of enhanced oil recovery. The Fossil Energy Division also has the lead role in heavy oil recovery methods. Mr. Peterson is a member of the Society of Petroleum Engineers and serves as Program Chairman for the Golden Gate Section. He is primarily concerned with environmental and other regulatory actions which may affect heavy oil production. Mr. Peterson received a B.S. degree in Chemical Engineering from the University of Minnesota.

Fred H. Poettmann is Manager of the Commercial Development Department for Marathon Oil Company in Littleton, Colorado. Aside from administrative responsibilities, his primary technical activity with Marathon has been in EOR, both micellar polymer flooding and in-situ combustion. Prior to his joining Marathon, he worked for the Phillips Petroleum Company in Bartlesville in the field of production research. He obtained his B.S. in Chemical Engineering from Case Institute in 1942 and his Ph.D. in Chemical Engineering from the University of Michigan in 1946. He is a member of the U.S. National Academy of Engineering.

David Pumphrey is an industry economist for the Enhanced Oil Recovery Group, Office of Oil and Natural Gas in the Resource Applications branch of the Department of Energy. His work involves the development and implementation of industrialization activities, enhanced oil recovery and tar sands techniques. He was formerly with the Federal Energy Administration, where he worked on projects involving the Alaskan natural gas pipeline. Mr. Pumphrey also worked for the Bureau of Land

Management's Outer Continental Shelf Leasing Program where he was involved with analyses of the socioeconomic impacts of outer continental shelf development. He received a B.A. degree in Economics from Duke University and a Masters degree from George Mason University.

Fred Riedel is a senior research scientist at Battelle's Pacific Northwest Laboratory currently specializing in systems safey and environmental impacts analysis. He is the program manager of the enhanced gas recovery and enhanced oil recovery programs. He received his Ph.D. degree in Chemical Physics from Washington State University.

George J. Rotariu is the Project Manager for Enhanced Oil Recovery in the Department of Energy's Office of Environment. His work currently involves aiding in the preparation and evaluation of environmental policies relating to the fossil area, including enhanced oil recovery. At DOE, Dr. Rotariu has served as project manager overseeing the preparation of Environmental Development Plans (EDPs), Environmental Readiness Document (ERDs), and other assessments involving the EOR area. He is a physical chemist with experience in universities, industry, and government. Dr. Rotariu holds Masters and Ph.D. degrees in Physical Chemistry from the University of Chicago and the University of Illinois, respectively. He is a member of American Society for Testing and Materials (Committees D.16 and D.19), Sigma Xi, the American Chemical Society, the American Nuclear Society, and is a Fellow of the American Institute of Chemists.

William Sackinger is an Associate Professor of Electrical Engineering at the University of Alaska; he is also associated with the Geophysical Institute. Dr. Sackinger has served as a visiting professor at the Institute of Offshore Engineering, Heriot--Watt, Edinburgh, Scotland and for the Faculty of Engineering and Applied Science, Memorial University, St. Johns, Newfoundland. He was also Associate Dean for Engineering Research, School of Engineering, University of Alaska. At the Geophysical Institute, Dr. Sackinger served as coordinator for the Outer Continental Shelf Program. He received a B.S. degree in Physics from Notre Dame University and Masters and Ph.D. degrees in Electrical Engineering from Cornell University.

Jayant Sathaye is a staff scientist at the Lawrence Berkeley Laboratory. Most of his professional experience has been at LBL where he has been involved with energy analyses, environmental impacts, integrated energy systems and technology assessments. Dr. Sathaye received a Ph.D. degree in Environmental Resources Engineering from the University of California.

Phil Shambaugh is an Operations Research Analyst in the Energy Information Administration branch of the Department of Energy, working in the area of oil and gas supply. He is also in charge of the enhanced oil recovery model for EIA. He received a Bachelors degree in Engineering and a Masters degree from Johns Hopkins University.

Bertram S. Shelby is the Special Projects Coordinator for Enhanced Oil Recovery with Cities Service Company. He is presently involved in the planning and administration of incentive funding of EOR projects; in economic evaluation of EOR projects in the U.S., Canada and South America; and in environmental studies and administration of environmental regulations by state and federal agencies. Mr. Shelby has had more than 25 years experience in exploration and production, holds a B.S. in Geology from the University of Oklahoma, and has completed advanced studies at the University of Texas and at Tulsa University.

Peter Thomas is a consultant with Harbridge House, Inc., in Washington, D.C. His work is primarily in the areas of energy, environment and natural resources, with concentration on the interactions of the three disciplines and the resulting impacts on public policy and legal/regulatory systems. He holds a B.S. degree in Biology from Hobart College, an M.S. degree in Civil Engineering and a J.D. degree from the State University of New York at Buffalo, and an M.A. degree in International Law from the Fletcher School of Law and Diplomacy.

Ken Tolmachoff is currently Director of the Industrial Research Division of the U.S. Department of Energy. He heads an interdisciplinary team, whose task is to determine trends in domestic oil production and refining. For seven years he was a market analyst for the strategic stockpile, where he initiated and implemented production plans for the acquisition, transportation, storage, and disposal of over ninety materials, including asbestos, lead, beryllium, and mercury. He holds a B.A. from Bellarmine College and a Ph.D. from the University of Virginia, along with a J.D. degree from Georgetown University.

Henry F. Walter is in the U.S. Department of Energy, Office of Environment, Environmental and Safety Engineering Division, Environmental Control Technology Branch. The branch has an overview role and assesses the adequacy of current technology to control the emission of various pollutants. Where the controls are deemed inadequate or nonexistent, it supports preliminary evaluation of innovative concepts to meet control needs. With respect to enhanced oil recovery technology, branch projects include evaluation of membrane technology to clean up micellar polymer coproduced waters, assessment of control needs for heavy oil production in California, and control adequacy for process waters coproduced by in situ steam recovery of tar sand bitumen. Walter is also the Office of Environment R&D Coordinator for Petroleum, in which role he provides the initial point of contact for the Office of Fossil Energy with the Office of Environment in matters dealing with R&D in petroleum; he is a member of the Tar Sand Program Management Team, which currently is conducting an in situ steam recovery experiment at Vernal, Utah, through the Laramie Energy Technology Center. Prior to joining the Federal Government in 1975, he worked in the optics industry and the steel industry, taught undergraduate level chemistry and mathematics courses, and consulted in statistics and programming for a timesharing computer services company.

Stanley L. Zwicker is Manager of Environmental Programs for the Union Oil Company of California. Mr. Zwicker has corporate-wide responsibility for environmental matters relating to energy resources and minerals exploration, development, and production, including: oil, gas, uranium, shale oil, geothermal, molybdenum, rare earths, and other minerals. Since joining Union Oil in 1977 as Senior Environmental Engineer in the Corporate Environmental Sciences Department, he has been responsible for helping formulate the Company's approach to environmental legislation and regulations which affect the Company's operations. Prior to joining Union Oil, he was employed by Memorex Corporation in Santa Clara, California, where he set up their corporate program for environmental control and energy conservation. He also served with the U.S. Environmental Protection Agency's San Francisco Regional Office where he was responsible for the early development and implementation of the "offset" policy as a part of the New Source Review permit program under the Clean Air Act. Mr. Zwicker holds a B.S. in Engineering from U.C.L.A. and is a graduate of the USC Graduate School of Public Administration's Environmental Management Institute.

Appendix C .... Handout: Potential Critical Problems for Increased EOR

Critical Current EOR Problems

Regulations

- Impact of California SO_x and Ozone rules on steamflooding.
- Impact of RCRA on disposal of drilling muds and brines.

Risk

- Risk of groundwater contamination from oilfied waters or injected chemical slugs.
- Failure of abandoned wells in EOR fields.
- Fugitive air emissions.

Resource Constraints

- Supplies of polysaccharides and polyacrylamides.
- Availability of water for injection or steam.
- Technological constraints on surfactant recovery and emulsion breaking.
- Refining capacity for EOR heavy and dirty oils.

- Potential for contamination of groundwaters by the chemicals used for chemical flooding; impacts if a failure event occurs.
- Safe transportation and handling of the EOR crude oil product of chemical flooding, between wellhead and refinery.
- Worker safety and health hazards posed by the chemicals used in flooding, both at the wells and when the crude oil product is put into refining processes.
- It is not yet technically possible to determine how much oil remains in a partially depleted reservoir (i.e., a reservoir that is a candidate for EOR).
- Heavy oil resources have been insufficiently explored and characterized (i.e., it has been found "accidentally" during searches for light oils).

- Great uncertainty exists in estimating EOR process performance and costs, except for well-tested thermal technologies (i.e., steam drive and in-situ combustion).

General Problems

- Good Reservoir Description.
- Lack of Good Mobility Control Method.
- Good Mathematical Models.

Chemical Flooding

- Lack of full understanding of the process mechanisms.
- High chemical costs and chemical losses.
- High risk involved.
- Further technology advancement is necessary.

Miscible Flooding (CO_2)

- Limited capability in the description of the displacement process phase behavior, multicomponent thermodynamics, various displacement mechanisms (multiple contact miscibility, low interfacial tensions, etc).
- Lack of good mobility control method--premature CO_2 breakthrough.
- Limited CO_2 supply and high transportation cost.

Thermal Recovery Methods

- Only limited to shallow sandstone reservoirs.
- Poor vertical sweep--premature heat front breakthrough and bypass of oil.
- Problem related to heat loss in the case of steam drive.

- Uncertainty regarding fate of micellar polymer materials in underground environment over time.

- Uncertainty regarding potential for contamination of groundwater by chemical or brine injection.

- Uncertainty over effect of CO_2 and micellar polymer injection in offshore environment.

- Availability of adequate NO_x controls to permit increased EOR in California.

- Effectiveness of RCRA, UIC Program, and TSCA in managing potential environmental impacts from EOR.

- Quantitative data concerning direct and indirect liquid, solid, and gaseous process emissions.

- Ground water contamination and air pollution potentials.

- Subsidence problems.

- Environmental control technologies for expanded EOR and their efficiencies.

- By-products after application of emission control technologies (e.g., SO_2 scrubber waste).

- Waste disposal and classification (e.g., RCRA-hazardous).

- Water requirements/recycling capability.

- Worker safety and health concerns.

- Auto ignition of resource possibilities.

- A major problem in micellar polymer is the loss of integrity of the injected chemical. Sulfated and to a lesser degree sulfonated alcohols which are effective in the laboratory for displacement of oil under high salinity and calcium environments are not thermally stable. Also polymers not only may suffer thermal degradation, but also chemical and microbiological. In addition, polymers do not enter all pores entered by the micellar fluid, thus, true mobility control may not be achieved.

- Miscible gas flooding including CO_2 flooding generally depends upon gas water injection to achieve mobility control. Two problems are apparent: (1) gravity segregation of the gas and water occurs in thick pays resulting in poor sweep, and (2) flood rates may be significantly reduced below water flood rates hurting the economics of the project.

- How extensively is each of the several Enhanced Recovery methods likely to be used in future years? Will thermal methods be found applicable to other than the present heavy California and similar crudes? Will miscible floods (CO_2 and perhaps nitrogen) be found applicable to heavier crudes and thus compete with thermal methods?

- How much otherwise unrecoverable crude can we realistically expect the various Enhanced Recovery methods to produce? In the national energy picture is EOR the most promising way to help "buy time" with additional liquid hydrocarbon fuels until renewable energy resources can make a significant impact? Is it more promising than the expensive—and so far largely unproductive—OCS development? Should consideration of potential controls be affected by a National need for maximum EOR?

- Is there evidence that current practices involve significant industrial (personnel) hazards?

- Are any present or potential EOR chemicals in fact significantly hazardous to workers? If so, are present State and OSHA regulations inadequate for worker protection?

- How do we evaluate the potential public or ecological hazard of injecting polymers or surfactants into oil-bearing formations to displace oil already there?

- Given the strict present-day requiremtns for oil well completions, protection of known aquifers from crude or drilling fluid contamination, and thorough "plugging" of a well before abandonment, where is the specific threat of injected chemicals?

Important environmental consequences associated with enhanced oil recovery include air pollution, surface and ground water contamination, and, in some instances, water supply problems and solid waste disposal difficulties. The following table summarizes, by recovery method, the potential effects and their causes.

PROCESS	PROBLEM	CAUSES
Thermal Methods		
-Steam Displacement	Air Quality	SOx and particulates from steam generators. Hydrocarbons from producing wells and other field sources.
	Water Quality	Spills, leaks of chemical foaming agents (if used).
	Water Supplies	Process water demand.
-*In-Situ* Combustion	Air Quality	Hydrocarbons and CO from producing wells.
	Water Quality	Spills, leaks of low pH water with heavy metals.
Chemical Methods		
-Micellar-Polymer Flooding	Water Quality	Spills, reservoir and well leaks, disposal of chemically-loaded brines.
	Air Quality	On-site manufacturing of chemicals.
	Solid Wastes	On-site manufacturing of chemicals.
	Water Supplies	Process water demand.
Carbon Dioxide Methods	Air Quality	Fugitive emissions of H_2S combined with CO_2.
	Water Quality	Low pH water with H_2S. Spills, leaks.

For EOR to be developed in an environmentally acceptable manner appropriate monitoring, protection measures, and reclamation strategies must be an integral part of initial project development.

Industry rate of return requirements are high for EOR projects due to the perceived riskiness of these projects. The risks are both technical and institutional and include:

- Uncertainty in reservoir performance under stimulation, e.g., micellar-polymer slug propagation.

- Questionable competency of older U.S. oil fields which represent a significant percentage of EOR targets. Past well development and poor abandonment or completion procedures may result in impractical remedial action requirements and in high field development costs.

- Industry uncertainty of the implications of current and future environmental regulations, e.g., UIC, RCRA.

<u>Source of water required for various EOR production scenarios</u>

- Quantification of water requirements.

- Resolution of conflicts with other water uses in the arid west.

- Monitoring withdrawals and water level declines if ground water extraction were used.

<u>Ground water contamination resulting from EOR</u>

- Migration of fluids from EOR operation into aquifers containing useable water.

- Interaquifer leakage through improperly installed injection or recovery wells.

- Leakage of fluids through damaged well casing into freshwater aquifers.

- Disposal of waste fluids generated through EOR techniques.

- The "Windfall Profits Tax" will hurt EOR. Not just the tax itself, but the tax incentive as set-up will encourage the application or motions of going through an EOR process to take advantage of the lower tax on EOR and the artificial 2 1/2 percent decline on field production per month. In particular, it will affect the more sophisticated, front loaded processes such as microemulsion-polymer flooding insitu combustion.

- Compliance with government regulations.
- Trained technical manpower constraint to rapid development.
- Ability to describe reservoirs.
- Ability to determine residual oil saturation.
- Availability of chemicals.
- Separation of produced fluids.
- Use of and disposal of produced waters.

- Capitalization of EOR projects which are contingent upon techniques that have not been commercially proven entails acceptance of high risk.
- The uncertainty associated with future modification of federal regulations that impact the oil industry or EOR specifically adds enormous risk to EOR projects. As a consequence, EOR investments become less desirable.
- Concerning environmental problems, the impact upon aquifers may require elaborate scrutiny. Chemicals injected by an EOR method may degenerate slowly. They could migrate into aquifers. Construction and maintenance of long distance pipelines for transporting gaseous substances for EOR projects may entail adverse environmental impacts. Air pollution associated with thermal EOR project may entail substantial difficulties.

<u>Supply</u>

<u>Surface Water</u>

- Present water rights picture.
- Availability for EOR?
- Feasibility of use (delivery)?

<u>Ground Water</u>

- Identification of aquifers?

- Occurence & distribution of aquifers?
- Hydrologic characteristics of aquifers?
- Availability for EOR?
- Feasibility of use (production)?

Impact of EOR

Surface Water

- Baseline data?
- Effects on stream flow?
- Effects on stream quality?

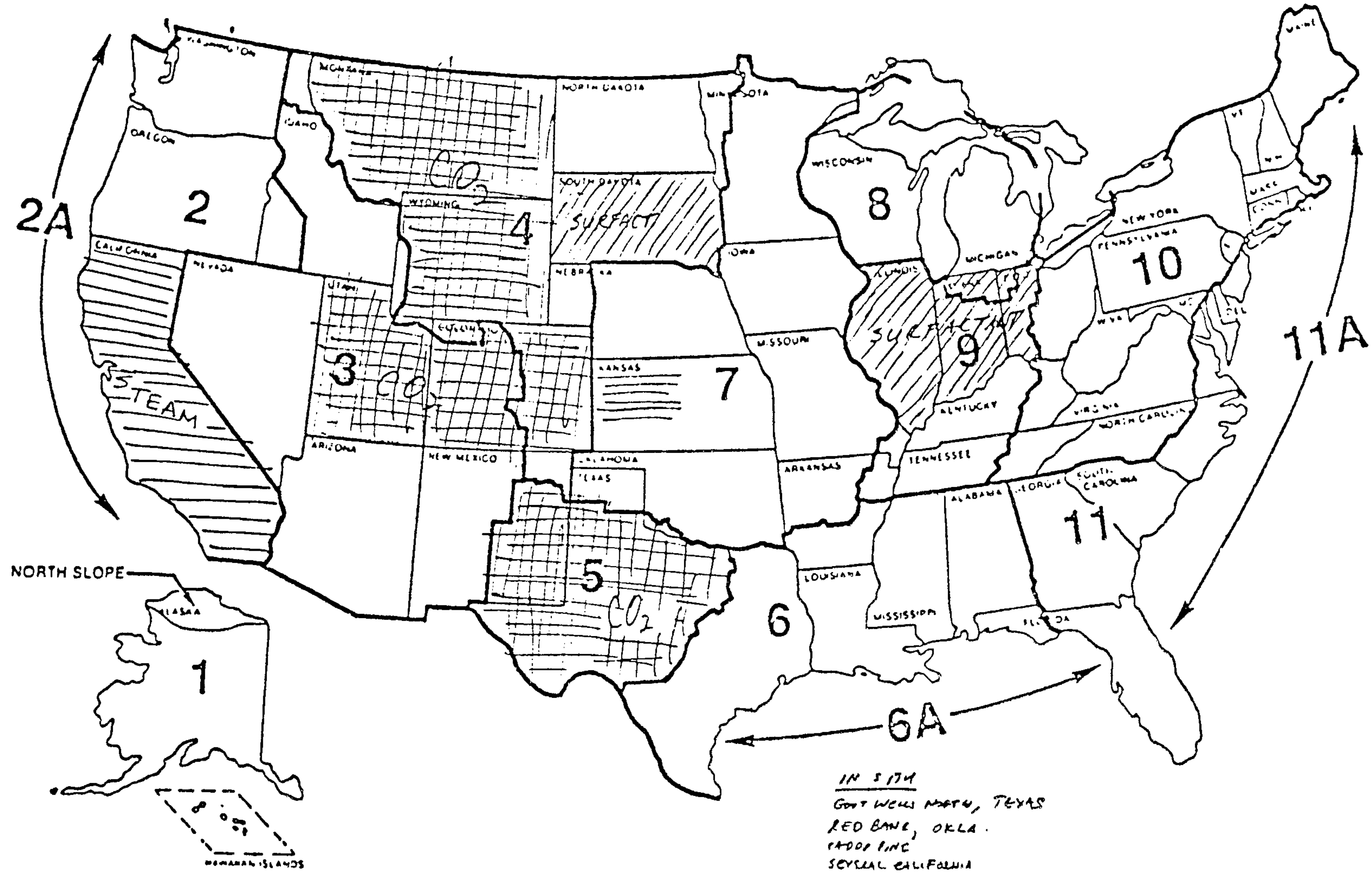
Ground Water

- Baseline data?
- Effects on regional water levels?
- Effects on ground water quantity?
- Effects on ground water quality?

- Regional water availability, e.g. in Rocky Moutain States
- Individual reservoir uncertainties for EOR potential production.
- Cost and availability of CO_2 and chemicals for micellar-polymer flooding.
- Accidential contamination of aquifers through faulty brine injection and through fractures.
- PSD requirements for air quality in certain areas, e.g. California.
- Integrity of old producers and injectors (wells) within areas of review around new injection wells.
- Handling of certain chemicals in accidental spills.

Appendix D1 .... Handout: EIA Production Scenarios for EOR

Regional Selections For DOE/EIA Model,
1979 A.R.C.



Regional Boundaries: Region 1 – Alaska and Hawaii, except North Slope. Region 2 – Pacific Coast States. Region 2A – Pacific Ocean, except Alaska. Region 3 – Western Rocky Mountains; Region 4 – Eastern Rocky Mountains; Region 5 – West Texas and Eastern New Mexico; Region 6 – Western Gulf Basin, Region 6A – Gulf of Mexico, Region 7 – Midcontinent, Region 8 – Michigan Basin, Region 9 – Eastern Interior; Region 10 – Appalachians, Region 11 – Atlantic Coast; Region 11A – Atlantic Ocean.

Source: NPC, *Future Petroleum Provinces of the United States* (July 1970) – with slight modification.

Figure 1 Petroleum Provinces of the United States.

Table 4.21 Projections of Petroleum and Coal Liquids Production: History and Projections for Three Base Scenarios, 1965–1995
(Million Barrels per Day)

	History[a]			Projections								
	1965	1973	1978	1985			1990			1995		
				Low	Mid	High	Low	Mid	High	Low	Mid	High
World Oil Price (1979 dollars per barrel)	6.00	6.50	15.50	27.00	32.00	39.00	27.00	37.00	44.00	27.00	41.00	56.00
Conventional Crude Oil Production[b]												
Lower-48 States Onshore												
From Proved Reserves	7.14	7.56	6.20	2.39	2.40	2.40	1.23	1.24	1.24	0.66	0.67	0.67
From Indicated Reserves	NA	NA	NA	0.88	0.88	0.88	0.88	0.88	0.88	0.75	0.75	0.75
From New Discoveries	NA	NA	NA	1.51	1.55	1.62	1.98	2.23	2.35	2.07	2.53	2.69
Subtotal	7.14	7.56	6.20	4.78	4.83	4.90	4.09	4.34	4.46	3.49	3.95	4.11
Lower-48 States Offshore (Includes South Alaska)												
From Proved Reserves	0.66	1.64	1.15	0.47	0.47	0.47	0.25	0.25	0.25	0.14	0.14	0.14
From Indicated Reserves	NA	NA	NA	0.28	0.28	0.28	0.22	0.22	0.22	0.17	0.17	0.17
From New Discoveries	NA	NA	NA	0.22	0.22	0.23	0.64	0.66	0.68	0.86	0.94	0.97
Subtotal	0.66	1.64	1.15	0.97	0.97	0.97	1.11	1.13	1.15	1.17	1.25	1.28
Total, Lower-48	7.80	9.20	7.38	5.75	5.80	5.87	5.20	5.47	5.61	4.66	5.20	5.39
North Alaska												
From Proved Reserves	0	0	1.09	1.50	1.50	1.50	0.92	0.92	0.92	0.41	0.41	0.41
From Reserve Additions	NA	NA	NA	0.05	0.05	0.05	0.51	0.58	0.61	1.05	1.29	1.42
Subtotal	0	0	1.09	1.55	1.55	1.55	1.44	1.51	1.53	1.46	1.70	1.83
Enhanced Oil Recovery[c]												
Steam Drive	—	—	0.15	0.50	0.53	0.53	0.81	0.88	0.88	0.63	0.71	0.73
Gas Flooding	—	—	0.11	0.14	0.14	0.14	0.31	0.32	0.32	0.31	0.35	0.36
Other	—	—	0.01	0.05	0.05	0.06	0.14	0.14	0.14	0.17	0.17	0.17
Subtotal			0.27	0.69	0.72	0.73	1.26	1.34	1.34	1.11	1.23	1.26
Total, Conventional Sources	7.80	9.20	8.71	7.99	8.07	8.15	7.90	8.32	8.48	7.23	8.13	8.48
Unconventional Crude Oil Production												
Shale Oil and Tar Sands	0	0	0	0	0.01	0.05	0	0.25	0.40	0	0.40	0.80
Coal Liquids	NA	NA	NA	0	0	0.03	0	0	0.03	0	0.23	0.26
Natural Gas Liquids Production	1.21	1.74	1.57	1.11	1.11	1.11	0.94	0.99	1.00	0.80	0.89	0.90
Total Petroleum and Coal Liquids Production	9.01	10.95	10.27	9.10	9.19	9.34	8.84	9.56	9.91	8.03	9.65	10.44

[a]Source for historical data is Volume 2 of the EIA *Annual Report to Congress*, 1979.
[b]Includes lease condensate.
[c]1978 Estimate from *Oil and Gas Journal*, March 27, 1978. The published estimate includes an additional .10 million barrels per day produced by Steam Soaking which is included in conventional oil production.

Notes: — indicates not available.
NA indicates not applicable.

Enhanced Oil Recovery

Enhanced oil recovery (EOR) techniques comprise three general categories:

- Thermal recovery, in which heat is applied to make the oil flow more easily
- Gas flooding, in which fluids are injected into the formation to dissolve the oil and form a liquid that flows more easily
- Chemical flooding, in which chemicals are injected into the formation to affect the interaction between the oil and its surroundings, allowing the oil to flow more easily.

Oil recovered using steam drive (a thermal technique) from shallow, heavy oil reservoirs in California contributes the bulk of EOR production through 1995. Production from these fields peaks around 1990 and then declines.

The use of gas flooding increases in importance and contributes 28 percent of EOR production in 1995, partially offsetting the decline in steam drive. The remaining production through 1995 comes from in-situ combustion, a thermal technique, and chemical flooding techniques, which include flooding with surfactant polymers and polymer-augmented waterflooding.

The actual timing of production from EOR is very uncertain. Delays in initiating projects will have a major impact on the schedule of production, because of the long leadtimes necessary for the study and development of EOR projects. Difficulties in meeting air quality standards for thermal projects and in developing adequate supplies of carbon dioxide for gas flooding are two areas that could potentially delay initiation of EOR projects and, consequently, production from these techniques through 1995.

Table 1: Criteria for the Application of Selected Enhanced Oil Recovery Methods

Screening Parameters	Steam Drive	In Situ Combustion	CO2 Miscible	Surfactant/ Polymer	Polymer Waterflood
Viscosity - CP at Reservoir Condition	NC	NC	< 15	< 20	< 200
Gravity - Degree API	> 10 < 25	10 - 45	> 25	NC	NC
Fraction of Oil Remaining In Area to be Flooded (Before EOR) - % PV	> 40	> 40	> 20	> 25	> 30
Oil Concentration - B/AF	> 500	> 400	NC	NC	NC
Porosity X Oil Saturation	>.065	>.050	NC	NC	NC
Depth - Feet	<2500	> 500	> 3000	10-8500	10-8500
Temperature - Degree F	NC	NC	NC	< 200	< 200
Original Bottom Hole Pressure - PSI	NC	NC	> 1500	NC	NC
Net Pay Thickness - Feet	> 20	> 10	NC	NC	NC
Permeability - MD	NC	NC	NC	> 20	> 20
Transmissibility (Perm. * Thick / Visc)	> 100	> 20	NC	NC	NC
Salinity - PPM	NC	NC	NC	< 150000	NC
Hardness - PPM Calcium Magnesium	NC	NC	NC	< 1000	NC
Fractures	NC	None to Low	None to Low	None to Low	NC
Lithology	Sandstone Only	Sandstone Only	NC	Sandstone Only	Sandstone Only

NC = Not critical.

Appendix D2 .... Handout: PNL Production Scenarios for EOR

ENHANCED OIL RECOVERY IN THE YEAR 2000

The main source of Enhanced Oil Recovery (EOR) in the year 2000 as seen in Table 1 will be the steamflooding of California heavy oil reservoirs. The bulk of these large reserviors should yield 575,000 BOPD. Inherent in this value is the tacit assumption that there are no refinery or regulatory constraints imposed.

The second major source of EOR as seen in Table 2 will be the miscible gas flooding of West Texas reservoirs. These reservoirs should yield at least 235,000 BOPD. The primary assumption here is that there will be a large source of CO_2 readily available for this flooding.

Other minor sources of petroleum will yield from 100,000 to 250,000 BOPD. Each of these reservoirs is deemed to be capable of producing at a rate of less than 5,000 BOPD. This other oil will use all the EOR methods. This oil will come from the states of Arkansas, California, Colorado, Kansas, Illinois, Montana, Nebraska, New Mexico, Oklahoma, Pennsylvania, Utah and Wyoming. A few likely fields are shown in Table 3.

TABLE NO. 1. PRINCIPAL CALIFORNIA FIELDS FOR STEAM FLOODING

Field Name	Production - BOPD
Belridge South	45,000
Cat Canyon	10,000
Coalinga	10,000
Cymric	10,000
Kern Front	10,000
Kern River	100,000
Lost Hills	10,000
McKittrick	10,000
Midway Sunset	75,000
Oxnard	50,000
San Ardo	45,000
Santa Maria Valley	100,000
Wilmington	100,000

Fields <5000 BOPD neglected (~50% of this type)

TABLE NO. 2. PRINCIPAL TEXAS FIELDS FOR CO_2 FLOODING

Field Name	Production - BOPD
Fairway	5,000
Hawkins	45,000
Kelly-Snyder	50,000
Levelland	17,500
North Crowden	17,500
Salt Creek	5,000
Slaughter	35,000
Wasson	60,000

TABLE NO. 3. PROBABLE RESERVOIRS FOR OTHER EOR (<5000 BOPD)

Field	State
Micellar Polymer	
Wilmington	California
Salem	Illinois
Louden	Illinois
Robinson	Illinois
Madison	Kansas
El Dorado	Kansas
Bell Creek	Montana
Sloss	Nebraska
Sho-Vel-Tum	Oklahoma
Bradford	Pennsylvania
Bid Muddy	Wyoming
Salt Creek	Wyoming
Torchlight	Wyoming
Caustic	
Smackover	Arkansas
Orcutt	California
Huntington Beach	California
Wilmington	California
Fannett	Texas
N. Ward Estes	Texas
Toborg	Texas
Van	Texas
Bison Basin	Wyoming
Polymer	
Smackover	Arkansas
Buena Vista	California
Coalinga	California

TABLE 3/p.2

	Field	State
CO_2 Miscible		
	Huntington Beach	California
	Bay St. Elaine	Louisiana
	Weeks Island	Louisiana
	Tinsley	Missippi
	Malijamar	New Mexico
	Glenn Pool	Oklahoma
	Kurten	Texas
	North McElroy	Texas
	OSR Halliday	Texas
Steam/Combustion		
	Bradley Canyon	California
	Guadalupe	California
	Round Mountain	California
	Bellevue (c)	Louisiana
	White Castle	Louisiana
	Hospah South	New Mexico
	Holt (c)	Texas
	Sour Lake	Texas
	Winkleman Dome	Wyoming
Other		
	Jay-Little Escambia Creek N_2	Florida/Alabama

Appendix E .... Results of Questionnaires Administered at Workshop

RESULTS OF QUESTIONNAIRES

ADMINISTERED AT THE

EOR WORKSHOP

Prepared by

Harbridge House, Inc.

Washington, D.C.

RESULTS OF THE QUESTIONNAIRES ADMINISTERED AT THE EOR WORKSHOP

Introduction

A total of four questionnaires were prepared for the workshop, with the first being sent to participants several weeks beforehand and the remaining three passed out as follows:

Questionnaire II on Monday morning (8/25)
Questionnaire III on Monday afternoon (8/25)
Questionnaire IV on Wednesday morning (8/27)

The questions in Questionnaire I were formulated by the steering committee, based on a broad range of areas of interest. Questionnaires II and III were developed by the committee as the results of prior responses became known. Specifically, when issues were felt to be incompletely addressed, or when responses pointed up new and interesting avenues of inquiry, new questions were tailored to elicit more exact information. When, on the other hand, consensus was achieved on an issue, questions were dropped from subsequent questionnaires. Finally, Questionnaire IV was created based on the submittals of the participants who had been asked to identify areas of interest which they felt needed further study.

A total of 28 participants submitted at least one questionnaire. Most of them responded to all four, although few completed each instrument in total. This was expected because their areas of expertise varied and they were told that a blank was more desirable than unfounded guesswork for our purposes.

On this compilation of responses, 27 of the 28 have been grouped in four basic categories which could possibly show a bias or specific viewpoint; one respondent could not be identified. The groups are:

- Government (12 respondents)
- Oil/Energy Companies (or "industry") (5 respondents)
- Consultants (4 respondents)
- Labs, Universities, Public Interest Groups (or "labs etc.") (6 respondents)

Where consensus is not apparent, or where the nature of the question necessitates it, responses are analyzed with respondents backgrounds in mind.

Finally, within each of these background categories, the participants indicated primary and secondary types of work they do. Specifically, Planning and Management is the primary function of five, and a secondary function of four. Thirteen are principally involved in Research, and four are secondarily thus employed. One person is principally (and two secondarily) concerned with Development and one is primarily active in Production Operations (and one is secondarily so involved). Finally, seven are primarily involved with Environmental Safety and Health Compliance; four have this as a secondary function.

WHAT IS CURRENT U.S. OIL PRODUCTION?

It was agreed that the figure is no higher than the 9×10^6 bbls/day offered in the questionnaire. Almost 48 percent (10 of 21) of the respondents felt that this figure is correct and the remainder indicated a slightly lower figure, generally in the $8.6 - 8.75 \times 10^6$ range. Those showing a lower amount were representative of all backgrounds.

WHAT IS CURRENT EOR - RELATED PRODUCTION?

The figure of 400,000 bbls/day is substantially correct according to the group. This was indicated by 76 percent (16 of 21) respondents. Interestingly, of the five not so agreeing, four were from labs etc. and their answers were not too far off (373K;385K;387K; and 300-400,000.

WHICH EOR TECHNOLOGY WILL BE PRODUCING THE MOST OIL IN THE YEAR 2000?

The list of EOR technologies is offered here, with 1. being the most productive and 5. the least:

1. Steam
2. Carbon dioxide (CO_2)
3. Improved water flood (IWF)
4. Micellar polymer flood (MPF)
5. In-Site Combustion

There was no linkage detectable between respondent backgrounds and these answers. Results were computed from rank orderings and tabulated twice, once by number of votes for each place, and once by weighted ranking; both methods showed very similar results. It should be noted that IWF and MPF scored closely, but the former appeared to be of a higher rank (more productive).

WHAT ARE THE VARIABLES WHICH INFLUENCE CURRENT PREDICTIVE CAPABILITIES IN THIS AREA?

When one goes into more detail regarding predictions of future EOR production, issues become much more complicated. For instance, the questionnaires cited Energy Information Administration Projections for EOR production of 690,000 - 730,000 bbls/day for 1985 and 1.26 - 1.34 million bbls/day for 1990. The respondents felt that these numbers charted the upper limits of the ranges.

Specifically, nine respondents thought they were correct, eight thought them too high and two thought them too low. The "better" numbers offered by the "too high" people are in the area of 400-600,000 bbls/day (1985) and 600,000 - 1 million bbls/day (1990).

An interesting breakdown occurs here vis-a-vis respondent backgrounds. The government participants were evenly split (four-to-four) between correct and too high. However, industry representatives believed the figures to be correct (three versus one too high) and the lab etc. people thought them too high (three versus one correct and one too low). One consultant said correct and one said too low.

Several suggestions were offered concerning ways in which EIA can fine tune or correct its predictive methodology:

- Set out an array of forecasts with assumptions
- Use industry numbers
- Estimate longer times for project development
- Allow for opportunities to shift EOR technologies in fields
- Use better data
- Include effects of Federal research
- Maintain close industry contacts
- Include political scenarios (e.g. tax incentives, cost sharing)
- Accommodate reservoir heterogeneity
- Account for various regulations
- Study reservoir by reservoir

On the whole it was agreed that current predictive models are less than perfect due to the impacts of various constraints and incentives. Taking the case of the EIA as an example again, the range of impediments preventing attainment of predictions includes the following:

- Technological constraints
- Low current production
- Environmental restrictions
- Facility deployment time
- Lack of strong industry commitment
- Economics (e.g. cost; poor profit margins)
- High risks
- Manpower shortages
- Site unsuitability

Among these impediments, those of a regulatory nature are felt to be important in accurate predictions. There are problems, however, and 88 percent (14 of 16) of the respondents believe that current predictive models do not fully reflect regulatory constraints.

HOW DO EOR TECHNOLOGIES COMPARE IN COST?

The most economical EOR technology in use in the year 2000, according to the group, will be improved water flood, followed by (in increasing cost) fire, steam, CO_2 and micellar polymer flood. Based on a sample of rank orderings, a double tabulation shows strong agreement that IWF is the least costly and even stronger consensus that MPF is far and away the most expensive. While steam and fire are close, the latter seems to be more economical.

Representative cost elements include: CO_2: pipelines, CO_2 supply; Steam: steam generation (especially fuel); In-Situ: air compression, surface equipment, exhaust control, monitoring.

There is no notable split by respondent background in this assessment.

WHAT ARE THE ENVIRONMENTAL HARMS INHERENT IN EOR OPERATIONS?

The EOR technology with the greatest potential for environmental harm is felt to be micellar polymer flood. Following this, in order of decreasing harmfulness, are steam, fire, IWF and CO_2. This determination is based on a two-tiered analysis of rank orderings by the respondents, based on number of votes per position as well as a weighted valuation. However, it must be noted that MPF and steam are closely ranked for most harmful. In this case, lab etc. respondents favored MPF and other groups tended to choose steam for the number one position.

The specific environmental effects of the various technologies which were named appear to be quite uniform among all respondents, namely:

- Steam - air pollution; some brine problems
- MPF - water pollution
- CO_2 - air and water pollution; worker safety
- In-Situ - air pollution; some water pollution
- Water flood - water pollution
- Caustic - water pollution; worker safety

Looking at thermal EOR processes, scrubber wastes emerge as a moderate and localized problem. Seventy-seven percent (17 of 22) called it moderate (two said severe and three said insignificant), and 91 percent (20 of 22) called it local.

Finally, the group was split about the question of whether EOR chemicals pose a safety problem for workers, with nine saying yes and ten saying no (and one yes/no). However, when the narratives included are factored in, it appears that the no's are assuming proper care and handling in many cases, thus giving rise to the assumption that the chemicals could be, but aren't always, a hazard. Industry people tended to answer no on this, lab etc. people yes, and government people were split both ways.

HOW FEASIBLE IS EOR PRODUCTION AND WHY?

EOR feasibility is shaped by a number of factors, such as incentives, constraints, and process - specific factors, like needs for breakthrough (e.g. technological).

Looking first at the last of these, respondents offered steam, MPF and CO_2 as the three EOR technologies which now appear the most likely to achieve a significant technological breakthrough in the next twenty years. No order among the three emerged. The specific breakthroughs for each are:

- Steam - Downhole steam generation; improved sweep efficiency; mobility control; increased depth capacity
- MPF - Better chemicals (cheaper, more stable); mobility control; loss control
- CO_2 - Mobility control

Overall, micellar polymer flood was held to be the technology in greatest need of support to ensure its viability. This support could take many forms, for instance:

- More demonstration efforts
- R & D funding
- Financial incentives
- Chemical development
- Predictive tools to ensure better reservoir knowledge
- Long term economic and regulatory commitments from the government
- Tax reduction or writeoffs; removal of EOR from the excess profits tax

On the specific question of whether current Federal financial incentives are a sufficient tool for stimulating EOR research and production, no consensus was reached. However, a well distributed majority (11 of 18, or 61 percent) believed that they aren't.

On an issue of incentives which are less formally tied to government activity, the participants were asked whether there would be an increase in support of EOR if that oil were more widely valued in terms of a given percentage of the price of foreign oil. Ninety percent (18 of 20) respondents believed there would be.

On the other side of the equation determining feasibility of EOR are the constraints to its use. The range of these constraints identified by the respondents is quite large, and includes the following often-recurring illustrations:

- Steam – Air pollution; depth limitations
- MPF – Costs; water pollution; limited applicability
- CO_2 – CO_2 availability; air and water pollution; process performance
- In-Situ – Costs; air and water pollution; technological problems
- Water flood – Water availability; process performance; pollution
- Caustic – Cost; pollution; process performance; limited applicability

Looking at one specific, non-regulatory constraint--rising fuel costs and competing users for EOR processes--the group was asked about the potential for large scale process changes, such as fuel conversion. Ten respondents thought costs will prompt changes and eight felt they wouldn't. Differing responses by background did not emerge here.

An important regulatory constraint to EOR which was an element of these questionnaires is the Underground Injection Control (UIC) program. The respondents were evenly split as to whether the UIC regulations have taken adequate account of EOR problems, the count being eight yes and eight no.

Among the most important EOR - related portions of the UIC regulations are the following:

- Well completion integrity
- Fluid migration
- Abandoned wells (e.g. plugging, reabandoment)
- TDS limits
- Monitoring
- Area of review
- Non site-specificity of the regulations
- Recognition of separate categories of oil production

Just over half of the respondents (8 of 15) felt that UIC would not be an impediment to EOR. Impediments were seen as possible in several contents:

- EOR in old fields could require reabandonment
- Industry refusal to perform ground water protection activities
- Toxic chemical uses
- Locating and plugging old wells
- General cost - increasing activities

It is interesting to note that all the lab etc. respondents felt that UIC would not be an impediment, while other groups were evenly split between yes and no.

Another issue in a regulatory context involves the question of whether the regulations of different states lead to different conclusions regarding the use or usefulness of various EOR technologies. Fifty-nine percent (10 of 17) felt that this is true. In this breakdown the lab etc. respondents tended to vote yes, while the industry and government participants voted no.

WHAT IS THE ROLE OF THE WINDFALL PROFITS TAX IN EOR?

When asked the impact of the tax on EOR production, ten respondents felt the tax is restrictive (six "moderately" and four "very"), while ten thought it was stimulating (eight "moderately" and two "very"); two saw no impact. The lab etc. and industry people tended to be rather evenly divided as to whether the tax is stimulating or restrictive, while most government people saw it as a stimulant and consultants as a restriction.

On the question of what percentage of oil remained in a field following an EOR operation because of the current tax, half the respondents (7 of 14) said more than 20 percent, three said 10-20 percent, three said 5-10, percent and one said less than 5 percent.

Two-thirds of the respondents (10 of 15) thought the tax's negative impacts on EOR occur in the long term and three-quarters (9 of 12) believed the positive impacts come in the short term. On this question, the lab etc. and consultant groups were divided in their opinions, but the government and industry participants stood solid with the majority.

As for comments and suggestions about the windfall profits tax, they most frequent called for its elemination.

WHAT DOES THE EOR DECISIONMAKING PROCESS LOOK LIKE?

The majority (13 of 22) felt that traditional internal corporate processes are the primary shaper of EOR development. The free market and technological/physical factors were noted by a significant minority, and Federal/state orders by one. No one thought a national energy plan was the principal factor.

The respondents also ranked the following factors in order of descending importance in corporate decisionmaking:

1. Maximized per barrel revenue
2. Maximized oil production
3. Minimized corporate tax liability
4. Maximized positive public relations
5. Maximized compliance with governmental regulations
6. Minimized negative environmental impact

In answering both these questions, the respondents showed no noticeable grouping by background.

Ninety percent (18 of 20) of the participants felt that there should be a forum where industry, regulatory agencies, scientists/ engineers, and affected parties could develop monitoring programs.

WHAT ARE SOME WEAKNESSES OF THE EOR EDP?

Among the comments on the EDP which the respondents offered were the following:

- It is too broad.
- It includes too many non-issues, and amounts to a laundry list.
- There is too much reliance on old documents and too little new information.
- There is too much effort expended in "covering flanks."
- It is too qualitative.
- It is too vague.
- It should clarify the impacts of regulations.

WHAT ARE SOME GEOGRAPHIC CONSIDERATIONS RELATING TO EOR?

There was broad agreement about the areas in which certain categories of EOR technologies will find heavy use. These are:

Thermal:	Extremely heavy use in California, and use in Texas, Louisiana, Oklahoma, Utah, Wyoming, and the Gulf of Mexico.
Chemical:	Use in California, Illinois, the Dakotas, Wyoming, Montana, Pennsylvania, Indiana, Ohio, and the Gulf of Mexico.
Gas:	Same as chemical.

Operations in Alaska will be strongly affected by considerations such as: harm to fragile environments; logistical/transport problems; costs; water availability; severe climate (e.g., freezing); waste disposal; and seawater intrusion.

Similarly offshore operations were felt to be subject to problems due to: lack of platform space; logistics and transportation; costs; pressure on the tube; heat loss; excessive well spacings; and fresh water availability. Improved water flood, CO_2, thermal, polymer flood and caustic/chemical technologies were all offered as likely candidates for offshore operations, with CO_2 achieving the strongest response and IWF the next strongest. The time frame noted ranged from "immediate" through the year 2000, although direct correlations with a given technology are difficult.

Operations in estuarine or wetland areas are a combination of onshore and offshore processes, and embody many of the problems of each. Some additional, somewhat unique factors are also present, such as tidal fluctuations and coastal zone management requirements.

The overthrust belt per se poses few unique problems for EOR, but account must be taken of earthquakes, groundwater protection, fracturing, and heat/fluid losses. Additionally, in view of the large portion of wilderness lands in the overthrust belt, care must be taken to guarantee its integrity.

HOW SHOULD GOVERNMENT OVERSIGHT OF EOR BE STRUCTURED?

Most of the respondents (11 of 21) believed that responsibility for monitoring the environmental, OSHA and other impacts of EOR should be shared at all levels of government, while four of twenty-one believed it to be a state/ local concern and five thought it should be a joint state/local and industry effort. One respondent felt it was the role of industry alone. In this issue there was little evidence of choices based on respondent background.

Fifty-seven percent (13 of 23) of the group thought that governmental monitoring of aquifers and/or injected substances is a worthwhile activity, while ten disagreed. Those in the minority generally felt that this is an industry concern, while those favoring monitoring relied on traditional bases of government oversight. For example:

- Toxic and hazardous material identification and control.
- Groundwater pollution prevention.
- Technical knowledge to provide accuracy and credence to regulations and control.

Thirteen of 21 respondents believed it was infeasible for the Federal Government to become fully aware of site specificity of processes or process components for preparation of documents such as EDPs. When asked in a slightly different way, the result was even more dramatic. Thus, over 91 percent (19 of 21) thought that Federal oversight programs should look at generic questions, while permit programs should be site specific. Similarly, when asked if both oversight and permit programs should be site specific, there were 17 responses in the negative and none in support.

An example of governmental oversight concerns reporting requirements. Here 45 percent (10 of 22) of the respondents believed the problem of non-record abandoned wells is a serious one and 11 of 22 thought it moderate. Only one person noted it as a non-problem.

MISCELLANEOUS ISSUES

Most respondents (10 of 17) felt confusion based on improper terminology is a moderate problem, although three felt it to be severe and four thought it was a non-problem. Examples of problems are prevalent in the area of water flood, well cleaning/treatment, huff and puff, analyses which lump various EOR processes (and thereby generalize impacts), and drafting of regulations in the absence of technical knowledge.

The role of EOR-produced oil in U.S. national security is an important one. This was stated by 11 of 21 respondents, and six others called the importance critical. Four felt its importance is measured in more general equations. There was little correlation between respondent background and response on this question.

The future of EOR use in other countries is unclear as far as universality, but operations will be large scale. Of 19 respondents, seven felt the operations to be universal and large scale, two said universal and small scale, six said scattered and large scale, and four noted scattered and small scale. The specific locations mentioned tended generally to be those where oil production is now well established.

The issues and impacts in enhanced gas recovery are not the same as those in enhanced oil recovery. Twelve out of eighteen thought this is true for a variety of reasons.

Risk assessment data, event scenarios, and similar information held by industry are obtainable according to 12 of 17 respondents. In general the most often suggested approaches involved direct request or cooperation with those regulatory agencies which have that information.

The degree to which we are neglecting important components of production scenarios by concentrating on big fields is unclear. The responses of the participants ranged across the spectrum from zero to a great degree.

APPENDIX

Questionnaire 1

Questionnaire 2

Questionnaire 3

Questionnaire 4

EOR Questionnaire I

PLEASE RETURN THIS QUESTIONNAIRE NO LATER THAN AUGUST 15

1. Name: ______________________________

2. Affiliation: (Check one)
   - Government ☐
   - Oil/energy company ☐
   - University ☐
   - Consultant ☐
   - Other __________ ☐

3. Functional area: (If you check more than one please rank by relative importance)
   - Planning/management ☐
   - Regulation development ☐
   - Research ☐
   - Development ☐
   - Production/operation ☐
   - Environmental, safety and health compliance ☐
   - Public affairs ☐

4. The conventionally accepted estimate of current U.S. oil production is 9×10^6 bbls/day. (Choose one)
   - ☐ This is correct.
   - ☐ A better estimate is: ______________

5. The conventionally accepted estimate of current production attributable to EOR is 400,000 bbls/day. (Choose one)
   - ☐ This is correct.
   - ☐ A better estimate is: ______________

6. Please rank the EOR technologies which will be producing the most oil in the U.S. in the year 2000. (1 is most productive and 6 is least)
   - ___ Fire
   - ___ Steam
   - ___ Improved water flood
   - ___ Micellar polymer flood
   - ___ CO_2
   - ___ Other ____________

7. Please rank the EOR technologies as to which will be the least costly to operate in the year 2000. (1 is least costly and 6 is most costly)
   - ___ Fire
   - ___ Steam
   - ___ Improved water flood
   - ___ Micellar polymer flood
   - ___ CO_2
   - ___ Other ____________

8. Which EOR technologies have the greatest potential for technological breakthroughs in the next 20 years?

1. ______________
2. ______________
3. ______________

9 Which EOR technology currently is most in need of economic, technical or regulatory support to ensure its viability? ______________

10. Please rank the EOR technologies in terms of their potential for causing overall environmental harm. (1 is most harmful and 6 is least)

___ Fire
___ Steam
___ Improved water flood
___ Mycellar polymer flood
___ CO_2
___ Other ____________

11. For each of the following EOR technologies, please rank the inherent environmental issues . This ranking should concern impacts caused by use of the technology, i.e. magnitude of damage, reversability, availability of controls, geographic extent and other cumulative factors.(1 is the issue with the greatest negative impact, and 4 the least.)

Steam soak/steam drive
1. ______________
2. ______________
3. ______________
4. ______________

Mycellar polymer flood
1. ______________
2. ______________
3. ______________
4. ______________

CO_2
1. ______________
2. ______________
3. ______________
4. ______________

Fire
1. ______________
2. ______________
3. ______________
4. ______________

Water flood
1. ______________
2. ______________
3. ______________
4. ______________

Caustic
1. ______________
2. ______________
3. ______________
4. ______________

12. For each of the following EOR technologies, please rank the four most critical constraints to its use during the next 10 years. (1 is the most restrictive constraint and 4 the least)

Steam soak/steam drive
1. ____
2. ____
3. ____
4. ____

Mycellar polymer flood
1. ____
2. ____
3. ____
4. ____

CO_2
1. ____
2. ____
3. ____
4. ____

Fire
1. ____
2. ____
3. ____
4. ____

Water flood
1. ____
2. ____
3. ____
4. ____

Caustic
1. ____
2. ____
3. ____
4. ____

13. Please elaborate on any of your answers or add relevant comments:

____

____

____

____

____

____

THIS QUESTIONNAIRE MUST BE RETURNED TO:

Peter A. Thomas
Harbridge House, Inc.
2101 L Street N.W.
Washington, D.C. 20037

ON OR BEFORE AUGUST 15

DOE/EV WORKSHOP ON ENHANCED
OIL RECOVERY

QUESTIONNAIRE II
8/25 Morning

1. Name: ______________________________

2. For the technologies of steam, fire, and CO_2, please rank them by increasing cost (i.e. 1 is cheapest) in the year 2000, state which element/component of the technology will be the most costly, and whether the cost of that element/component is now rising, falling or remaining the same.

Technology	Most Costly Element	Current Trend
1)		
2)		
3)		

3. Please name and/or describe the most significant technological breakthrough which awaits the following:

Steam: ______________________________

Micellar Polymer Flood: ______________________________

CO_2: ______________________________

4. What sort of assistance (in the nature of, for example, technology, regulation or financing) is needed for micellar polymer flood? Please be as specific as possible.

____

____

____

____

____

5. For each of the following techologies, please list three geographic regions where it will be heavily used in the next 20 years:

Thermal (e.g. steam, fire)

1. ____________________

2. ____________________

3. ____________________

Chemical (e.g. IWF, MPF, caustic)

1. ____________________

2. ____________________

3. ____________________

Gas (e.g. CO_2, HC, N_2)

1. ____________________

2. ____________________

3. ____________________

6. See following page

6. For each of the following technologies, please list the geographic regions where its use will be curtailed by one or more constraints. Please name the constraints in each category.

CONSTRAINTS

		Region of Curtailed Use	EOR Technology	Physical/Geological	Regulatory	Economic	Environ[illegible]
Thermal (e.g. steam, fire)	1						
	2						
	3						
Chemical (e.g. IWF, MPF, Caustic)	1						
	2						
	3						
Gas (e.g. CO_2, HC, N_2)	1						
	2						
	3						

7. Name three problems in EOR which are unique to <u>Alaskan</u> operations.

1) ______________________________

2) ______________________________

3) ______________________________

8. Name three problems in EOR which are unique to <u>offshore</u> operations.

1) ______________________________

2) ______________________________

3) ______________________________

9. Can any EOR technology effectively operate in a wetland or estuarine environment:

Yes ___ Which one(s)? ______________________________

No ___ ______________________________

____

10. What unique problems are faced in wetlands and estuaries?

1) ______________________________

2) ______________________________

3) ______________________________

11. Will proximity to the overthrust belt pose any severe problems for EOR operations?

Yes ___ If yes, please describe: ______________________________

No ___ ______________________________

____

____

DOE/EV WORKSHOP ON ENHANCED
OIL RECOVERY

QUESTIONNAIRE III
8/25 Afternoon

1. The impact of the "windfall profits tax" on EOR production is:

   very stimulating ___
   moderately stimulating ___
   has no impact ___
   moderately restrictive ___
   very restrictive ___

2. Scrubber wastes from thermal EOR processes presents a:
   severe ___
   moderate ___
   insignificant ___
   environmental problem, which has a localized ___ / national ___ scope.

3. Will increasing costs of and competing demand for traditional fuels for EOR processes (e.g. oil for steam operation) prompt large scale process changes, such as fuel conversions?
   yes ___
   no ___
   If yes, please give examples and cost figures ______________________

   ____

   ____

4. Recent EIA projections show 1985 EOR production ranging from 690,000 - 730,000 bbl/day and 1990 production ranging from 1.26 - 1.34 million bbl/day. Both sets of figures are gross (i.e. process fuel needs are not accounted for).
   These numbers are: correct ___
   too high ___
   too low ___

   A better range is: ______________ bbl/day (1985)

   ______________ bbl/day (1990)

5. If you have shown a different range, please describe the most immutable impediments to the attainment of the EIA numbers.

   1) ______________________

   2) ______________________

   3) ______________________

5 (continued)
What suggestions would you make to EIA to fine tune or correct its predictive methodology?

____

____

____

6. Do any current production predictive models fully reflect regulatory constraints?

yes ___ If yes, which one(s)? ____________
no ___

____

____

7. Current Federal financial incentives are a:
sufficient ___
insufficient ___ tool for stimulating EOR research and production. What would the best possible incentive program for the next ten years look like?

____

____

____

8. One has to admit that day to day EOR decisions are, in the final analysis, made by corporate executives who are affected by a range of factors. Please rank these factors in terms of real-life importance to these executives. Here 1 is the most important decision making factor and 6 is the least:

_____ Maximixed oil production
_____ Minimized negative environmental impact
_____ Maximized per barrel revenue
_____ Minimized corporate tax liability
_____ Maximized positive public relations
_____ Maximized compliance with governmental regulations

9. EOR development is principally shaped (i.e. forced) by (choose one):

Traditional internal corporate processes _____
Federal/state fiat or order _____
The free market _____
Technological/physical factors _____
National energy planning _____

10. Have the new Underground Injection Control (UIC) regulations taken adequate account of EOR problems?

    yes ___
    no ___

11. What are the most significant EOR-related portions of the UIC regulations? Please describe:

    ____
    ____
    ____
    ____

12. Over the next ten years, will UIC be an impediment to EOR production?

    yes ___
    no ___

    Please comment, vis-a-vis specific EOR technologies and UIC restrictions.

    ____
    ____
    ____
    ____

13. Please list the weaknesses of the EOR EDP and discuss a solution to each one you named.

    ____
    ____
    ____
    ____
    ____
    ____
    ____

14. Current confusion or misunderstanding based on improper terminology (e.g. calling well treatment or stimulation EOR processes) is a

severe ____
moderate ____ problem.
non ____

Please name some marked examples.

1) ____________________

2) ____________________

3) ____________________

15. Please name and describe (including location/availability) key mass balance studies in EOR.

1) ____________________

2) ____________________

3) ____________________

16. Is governmental monitoring of aquifers and/or injected substances a worthwhile endeavor?

yes ___ Why? ____________________
no ___

____

____

17. Would it be technically or economically feasible for the Federal government to become fully aware of site specificity of processes or process components (e.g. need for given chemicals) for preparation of documents such as EDPs.

yes ___
no ___

18. Should permit programs be site oriented and oversight programs look at generic elements?

yes ___
no ___

Should both be site specific?

yes ___
no ___

18 (continued)

Both generic?

yes ___
no ___

19. The issue of non-record abandoned wells is a:

significant ___
moderate ___ problem.
non ___

DOE/EV WORKSHOP ON
ENHANCED OIL RECOVERY

QUESTIONNAIRE IV
8/27 Morning

1) What is the degree of importance of EOR produced oil in U.S. national security?

Critical factor ____
Important factor ____
Included in more general equations ___
Plays no role ____

2) If EOR oil were more widely valued in terms of a given percentage of the price of foreign oil, would there be a marked increase in support for EOR activities?

Yes ____
No ____

3) What is the future of EOR use in other countries?

Universal/large scale ____
Universal/small scale ____ Where? ____________________
Scattered/large scale ____
Scattered/small scale ____ ____________________
No foreseeable use ____
____

4) Are issues and impacts in enhanced gas recovery the same as those for EOR?

Yes ____ Comments? ____________________
No ____
____
____

5) Please estimate the time needed to bring a new EOR project on-line, including the steps indicated below. Note the type of EOR technology you are thinking of and special considerations (e.g. permitting in a State like California, logistics in Alaska).

Regulatory (permitting) ____________

Litigation ____________

Equipment deployment ____________

Manpower deployment ____________

Financing ____________

Other (________) ____________

Total ____________

5 (continued)

Special Considerations: ______________________

____

____

6) Should the responsibility for monitoring the impacts of EOR (occupational health and safety, environmental or other) be the responsibility of:

State/local government ____
Federal government ____
Industry ____
All ____

7) Should there be a forum where industry, regulatory agencies, scientists/engineers and affected parties could develop monitoring programs?

Yes ____
No ____

Comments: ______________________

____

____

8) What is the capital cost of a scrubber for a 25 million Btu/hr. steam generator used at a California EOR well?

$______________________

9) Is a package-type, coal-fired fluidized bed boiler applicable as a steam generator in the California fields (assuming that limestone will be the sorbent in the bed)?

Yes ____
No ____

If no, why not? ______________________

____

____

10) How could the windfall profits tax be revised to encourage commercialization of improved EOR technologies?

____

____

____

11) Do the regulations of different states lead to different conclusions regarding the use/usefulness of various EOR technologies?

Yes ____ What are some examples? ______________

No ____

____

____

12) What mechanisms exist to address the cumulative impacts of several EOR projects in a given basin (and who will address them)?

____

____

13) Will EISs be required to consider slurry pipelines, synfuel production, strip mining, etc., in conjunction with a given EOR plan?

Yes ____

No ____

Will these be a separate undertaking (I.e. not part of the EOR planning process)?

Yes ____

No ____

14) At what per barrel price would the mining of shallow fields become feasible today?

$ ______________

What technological improvements are necessary to allow shallow field mining at current oil prices?

____

____

Oil mining in the year 2000 will be:

Much greater than ____

Slightly greater than ____ today.

the same as ____

less than ____

15) What EOR method will most likely be used offshore and when might this occur?

____

16) Do EOR chemicals represent a significant safety problem for workers?

Yes ____ Please describe: ______________________________
No ____

____

____

17) The windfall profits tax has been mentioned repeatedly as a very important cost of doing business in the oil industry. Approximately what percentage of the oil remaining in a field following an EOR operation is there because of the tax (as it is presently structured)?

Less than 5% _____
5-10% _____
10-20% _____
More than 20% _____

18) The most negative EOR production impact of the windfall profits tax is in the:

Long term _____
Short term _____

The most positive EOR production impact of the windfall profits tax is in the:

Long term _____
Short term _____

19) Are there any EOR production methods which haven't been covered here and will be of major importance in the next 20 years?

Yes ____ What are they? ______________________________
No ____

____

____

20) Is there any way to obtain risk assessment data, event scenarios and similar information held by the industry?

Yes ____ Where (or why not)?
No ____

____

____

____

21) In what degree are we neglecting important components of production scenarios by concentrating on big fields?

---

22) What suggestions do you have as to how the results and lessons of this workshop can provide the maximum benefit for all concerned (<u>especially</u> those individuals and agencies who were not present).
