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9300 Lee Highway, Fairfax, Va. 22031-1207 Phone: 703 934-3000 Fax: 703 691-3349 Telex: 440126 ICF UI

July 26, 1991

MEMORANDUM**TO:** Bob Folstein
Bill Hochheiser
John Pyrdol**FROM:** Brian Wood

AC01-88FE61679

SUBJECT: Evaluation of the Crude Oil Policy Model (COPM) and Recommended Modifications

In response to your request, we have undertaken an evaluation of the COPM and the assumptions driving the estimates of future crude oil production and abandonments attributable to an accelerated federal oil R&D program which were cited in the National Energy Strategy. This evaluation focuses on the logic and inputs to the model itself, and their impact on the NES estimates. A plan for making the recommended enhancements is also discussed. Our analysis of the estimates of the Base Case, Advanced Oil Recovery (AOR) Case, the resulting increment, and cases representing the existing and projected Oil Research Program, disaggregated by geographic region and resource category as requested by Bob Folstein, will be presented separately.

A parallel effort is also now in progress to make a number of model enhancements that will facilitate the analysis of RCRA impacts. This effort is scheduled to be completed for the Office of Planning and Environment in mid-August. A description of these enhancements is also included in our plan for correcting and enhancing the COPM.

Evaluation of COPM Inputs and Results

The critique of the NES estimates and underlying assumptions is the first extensive review that has been authorized, although the model was developed nearly a year ago and the results have been extensively quoted. Our evaluation has focused on the resource categories affected by the AOR case: the EOR, UMO, and EOR+UMO resource categories. Our observations and recommended enhancements are in five areas: extrapolation assumptions, input values, reserves development, abandonment/redevelopment of abandoned resources, and resource disaggregation. While a number of the recommended modifications have offsetting effects, the net impact is likely to reduce the previous estimates of the impact of accelerated RD&D by as much as 20%-40%.

Extrapolation Assumptions

TORIS estimates of EOR and ASR recovery potential were extrapolated to the entire U.S. resource for use in the COPM. Extrapolations were based on OOIP according to the reservoir

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coverage in the TORIS data base used in making the recovery estimates. The following observations are relevant:

- Previously abandoned reservoirs. In general, extrapolations are made to the entire U.S. OOIP. However, at least 40% of the U.S. resource has already been plugged and abandoned. EOR and ASR development would require redrilling wells, which would not be economic until prices rise considerably. The estimates thus overstate recovery potential substantially. This may be corrected by reducing the extrapolation factors in proportion to the amount of abandonment and shifting that amount of resource to become an initial value of abandoned potential, which can later be redeveloped. To make this adjustment, we recommend that the ROIP in abandoned TORIS reservoirs be determined by state and extrapolated to total state ROIP to estimate the current abandonment level.
- Uniform extrapolation of all EOR categories. Some resource categories are represented more completely in the TORIS data base than others, but for simplicity the COPM extrapolates all EOR categories at the same rate (1.66). However, TORIS coverage of heavy oil reservoirs (53% of lower-48 OOIP) is less extensive than of light oil reservoirs (71% of lower-48 OOIP), so thermal EOR categories are understated and non-thermal EOR categories are overstated by the application of uniform extrapolation factors. Differentiating light oil from heavy oil extrapolation factors would be a simple enhancement. More fine-tuned extrapolations for each category could be accomplished through a state-by-state assessment of TORIS reservoir coverage and a new TORIS run in which reservoirs are not permitted to switch processes as prices and the technology level change.
- Extrapolation of UMO categories. All UMO categories are extrapolated by a factor of 3.69, based on TORIS results for the three states. More representative TORIS results for ASR potential (covering 23 states) will be available in the new RCRA runs from TORIS to permit more accurate projections at a smaller extrapolation factor.
- Extrapolation of UMO+EOR categories. The extrapolation factors in this group vary by price increment and technology level, because they represent weighted average extrapolations for EOR and UMO alone based on their relative potential at each increment. At present, TORIS does not model potential synergies from combined process applications (i.e., expanding the EOR target by doing ASR first). Until this is implemented in TORIS, it may be more clear to analysts examining COPM estimates if these UMO+EOR results are reallocated to the respective UMO and EOR categories, eliminating the UMO+EOR categories.
- EOR and ASR in Alaska. EOR and ASR potential in Alaska is extrapolated by OOIP from TORIS analysis of lower-48 reservoirs, though the characteristics are quite different. Alaska light oil potential for miscible and chemical EOR is projected on the basis that Alaska reservoirs represent 8% of U.S. OOIP for light oil. The thermal EOR estimates also included extrapolation to Alaska (25% of U.S. OOIP), although there are no Alaska heavy oil reservoirs in the data base. The trend does not therefore represent any analysis of expectations for the development of the West Sak field (ARCO projects production from West Sak using hot water injection rather than steam). We recommend that Alaska be left out of the extrapolation, and that both light oil and heavy oil advanced recovery potential be based on the estimates of

Alaska producers such as ARCO. Better TORIS representation of Alaska reservoirs and process modeling must wait for a later date.

- EOR and ASR in the lower-48 offshore regions. The lower-48 offshore also represents about 8% of U.S. light oil OOIP, and the extrapolation is made on this basis. At present, TORIS includes only a few offshore reservoirs in state waters, and none in federal waters. The models do not reflect any costs or other characteristics that would be unique to EOR and ASR applications in offshore reservoirs, and therefore the extrapolated estimates are suspect. We recommend that the offshore region be removed from the extrapolation. EOR and ASR potential should be estimated at zero until a data base and TORIS modeling capability are developed.
- EOR and ASR in Appalachia. By implication, the extrapolation procedure assumes that advanced extraction techniques will have similar results in Appalachian reservoirs as in other lower-48 regions. This is unlikely, but enhancement of the TORIS data base to include Appalachian reservoirs will take considerable time (a feasibility study is now in progress under the Multi-State Analysis). We recommend comparing TORIS coverage to OOIP on a state-by-state basis to evaluate the extent of extrapolation in this region and consider whether the estimates should be adjusted.
- Small vs. large reservoirs. Also by implication, the extrapolation procedure generally assumes that advanced extraction techniques will have similar results in small or even large, complex reservoirs as in those large, well-behaved reservoirs that were selected to be included in the TORIS data base. No analysis has been conducted to establish whether this is a valid assumption or to develop an acceptable adjustment.

Input Values

This critique permitted the identification of some data entry errors in the COPM input tables and presents an opportunity to reconsider certain assumptions made in the original modeling effort.

- Offshore inferred reserves. The value for lower-48 offshore inferred reserves was entered incorrectly in the COPM input table. As a result, this resource category was overstated by about 30% in the model's output. This error is easily corrected.
- Reconciliation of TORIS output to COPM input. The translation from TORIS to the COPM input tables was done by manual data entry and only one minor error was identified. An automated data entry procedure has been considered as one of the enhancements under the RCRA analysis, but is most likely beyond the scope of the current funded task. Many of the TORIS assignments for recovery potential at specific prices required adjustment to accommodate differences in the modeling approach between TORIS and the COPM. TORIS selects the most economic technology process for each reservoir in each run, permitting reservoirs to switch processes as oil prices or technology level change. This presents problems for the COPM, because process switching implies movement of reserves between resource categories, whereas there is no inter-category communication within the Dynamo structure. This problem appears almost exclusively under the advanced technology case.

For the NES estimates, the COPM inputs were adjusted to minimize any net discrepancy between TORIS and COPM on an aggregate basis across all categories at each price level. Generally, adjustments were necessary to increase the input reserves potential for new miscible EOR, and new surfactant EOR potential reserves were reduced to compensate. Some adjustments were necessary in other categories, but to a lesser degree. This problem can be alleviated by minimizing the process switching in TORIS runs. Our recommendation is to prevent price-induced process switching and permit limited switching when advanced technology becomes available, as indicated below:

Proposed TORIS Process Selection Rules					
TORIS Assignments for Implemented Technology	TORIS Assignments for Advanced Technology				
	Miscible	Surfactant	Alkaline	In Situ	Steam
Miscible	Miscible	—	—	—	—
Surfactant	Miscible	Surfactant	—	—	—
Alkaline	Miscible	Surfactant	Alkaline	—	—
In Situ	—	—	—	In Situ	Steam
Steam	—	—	—	—	Steam

These process selection rules will be incorporated in the TORIS runs to be conducted for the RCRA policy analysis.

- Lack of class-specific data in the COPM inputs. The original structure of the COPM categorizes the oil resource by recovery process and to some extent geographic region. This approach is not very amenable to analyses of the geologic class-oriented structure of the oil research program. Approximations can be made to phase in technology availability according to a schedule of class-specific RD&D, but this approximation process and the disaggregation approach would not be as efficient as it would be if the COPM were further disaggregated into class-specific resource categories. This would require a relatively extensive effort and is beyond the scope of the RCRA analysis schedule.
- 3-states basis for UMO category inputs. The recent upgrade of the TORIS reservoir data base permits a more accurate projection of U.S. recovery potential using ASR methods. The TORIS runs conducted for the RCRA policy analysis will include this upgrade.
- Double-counting between inferred reserves and infill drilling resource categories. We are currently studying this issue to determine the necessary adjustment. The USGS reserves growth factor for determining inferred reserves (used to develop the COPM initial resource amount) includes (1) revisions and net adjustments to proved reserves,

(2) extensions, and (3) discoveries of new reservoirs in known fields. Our hypothesis is that revisions and net adjustments constitute the overlap with TORIS estimates of infill drilling potential. We recommend that the COPM inferred reserves inputs be reduced by the sum of estimated ASR potential at implemented technology, at \$20/bbl, and the expansion of proved EOR reserves.

Representation of Reserves Development

Once reserves become economic, the COPM permits their development at a uniform rate over a predetermined period, which is specific to each resource category. The development periods were determined to approximate the projected production rates of the NPC's 1984 EOR study, and are indicated below. For example, if the model projected that 400 MMB of surfactant EOR reserves become economic in a given year, then it would permit 10 MMB of reserve additions each year for the next 40 years.

COPM Resource Development Assumptions (in years)			
Resource Category	Test Time Delay	Reserves Development Period	Production Period for Booked Reserves
Ongoing Miscible EOR	0	13	11.5
New W. Texas Misc. EOR	2	28	11.5
New non-W. Texas Misc. EOR	2	28	11.5
New Surfactant EOR	1	40	18
New Alkaline EOR	1	40	18
Ongoing Thermal EOR	0	15	13
New Steam EOR	4	13	13
New In Situ EOR	4	13	13
Infill Drilling	0	10	10
Infill + Polymer	1	10	10
Infill + Profile Mod.	1	10	10
UMO+W. Texas Misc. EOR	2	28	11.5
UMO+non-W. Tex Misc EOR	2	28	11.5
UMO+Surfactant EOR	1	18	18
UMO+Alkaline EOR	1	18	18
UMO+Steam EOR	4	13	13
UMO+In Situ EOR	4	13	13

This uniform development approach is somewhat simplistic, producing abrupt changes in reserves activity and production for any given category, though these changes had been expected to become more smooth in the aggregate of all categories. Dynamo delay functions can be used to

better model the expected development and production profile in each resource category. In revising the modeling approach to resource development, the following issues should be considered:

- Phased applicability of R&D advances. Whereas the AOR case assumed that all technology advances become available in a given year, a class-differentiated RD&D program phases in technology developments over time. This can be modeled by the amount of reserves represented by each class, differentiated by resource category and technology level. This can be implemented in Dynamo using a table function using the results of the TORIS runs for the RCRA analysis that also incorporate the proposed process switching rules.
- Testing delay. The current model assumes a delay between reserves availability and the time development begins to allow testing, setup, and permit acquisition. The test time varies depending on the resource category, but a modeling glitch does not currently permit this delay to function properly. This is being corrected.
- Diffusion of new technologies in the industry. The penetration of new technology processes (i.e., results of technology transfer) for both implemented and advanced technology levels depends on a number of factors. The literature on commercialization of technology innovations does not support the reserves development profile as modeled, but indicates an inverse exponential function that is dependent on factors such as the relative profitability of the innovation compared to other opportunities, capital requirements, industry-specific characteristics for innovation, and the initial level of industry penetration. We are exploring possible mechanisms to represent this process and include it in the Dynamo model.
- Treatment of implemented vs. advanced technology levels. At present, all assumptions regarding the test time delay, reserves development period, and production period are identical for both technology levels, at all prices, and under both the Base Case and AOR Case, in any given resource category. It may be appropriate to use more aggressive assumptions in some cases.
- Internal adjustments to the reserves development rate. A glitch in the modeling logic resets the reserves development rate from its input value if the cash flow module delays the onset of development. This issue arises during sensitivity runs when parameters such as discount rate and environmental costs are adjusted and affect cash flow-driven development decisions, delaying development. This is being corrected.

Representation of Abandonments and Redevelopment of Abandoned Reserves

A number of issues should be considered in modeling abandonments and the redevelopment of abandoned reserves. Some of these are errors in the modeling logic, but others concern assumptions that deserve some reevaluation.

- Uniform application of abandonment rates. At present, all EOR, UMO, and EOR+UMO categories are abandoned at the same rate, 2% per year of potential reserves, until reserves become economic and the technology becomes available (Exception: in the AOR case, potential reserves are abandoned at 1.5% per year).

A state-by-state analysis of abandonment trends, such as in the DOE abandonment report, would permit category-specific abandonment rates.

- No abandonment of economic, technically recoverable reserves. No abandonment is assumed to occur once reserves are both economic and the technology is available. This is valid in the sense that operators are likely to delay abandonment when a profitable technology is available. However, there are limits to such delays. Several resource categories have reserve development periods of 20-40 years, and uneconomic fields are unlikely to be kept active this long. It would not be difficult to change the model logic to permit abandonment of such reserves, but at a lower rate.
- Abandonment rates are unaffected by oil price. While the abandonment rate may remain relatively constant under constant prices, it seems less plausible that a high rate would persist under rapidly rising prices as in the NES price track.
- Redevelopment of abandoned reserves. Abandoned reserves are allowed to be redeveloped once prices are \$13/bbl higher than the value of the original price increment. There are three issues worth considering with respect to this approach:
 - If the extrapolation factors are reduced as proposed to account for previously abandoned reservoirs, this resource represents an initial level of abandonments. A portion of this resource ought to be made available for redevelopment once prices have increased sufficiently.
 - About 70% of all EOR and ASR potential reserves abandoned during the 1990's are projected to be redeveloped and produced under NES prices in the Base Case. This may be an aggressive assumption. It suggests that the abandonment phenomenon delays production by ten years or so, with less net loss of potential than many would imagine. It may be more appropriate to assume that only a portion of abandoned reserves are likely to be redeveloped.
 - As with the development of other reserves, abandoned resources are modeled to become available in a lump sum and would be better modeled as a more gradual addition to reserves.
- Modeling of the redevelopment process. This is not yet working properly in the model. At present, annual abandonments increase as portions of the abandoned resource become available for development--the resource is being abandoned a second time before it is redeveloped. The influx of previously abandoned resources also resets the development function, delaying the development of any existing balance of economic resource. Solutions to these modeling problems are being developed.

Resource Disaggregation

The COPM is currently disaggregated by price interval (9 increments from \$12-60/bbl), technology level (2 cases), and technology process/region (8 EOR, 3 UMO, 6 UMO+EOR, 3 conventional proved, 3 conventional inferred, 11 undiscovered L-48 onshore, 22 undiscovered L-48 offshore, 7 undiscovered Alaska). Of the advanced extraction categories, only miscible EOR has

geographic differentiation (West Texas vs. all other). Several DOE offices have expressed interest in further disaggregation. The extent of disaggregation must be balanced with its effect on the time needed to run the model.

- Geologic class disaggregation. Analysis of R&D program policies would be facilitated if the COPM could readily provide results by geologic class, perhaps by as many as 10-15 classes. At present, this can be done manually on a very approximate basis from the model output. Many classes are nearly single-process and are correlated with the existing technology categories. Others present a greater challenge. This enhancement would be very useful but requires time to develop a methodology.
- Geographic disaggregation. Projected impacts by state and larger geographic regions would also be useful. Geographic disaggregation in the COPM is currently very explicit for undiscovered resources, but not for advanced recovery processes. TORIS permits disaggregation by state so data development is not the issue, whereas significant expansion of the number of resource categories in the COPM will increase the model's run time in proportion.

Other Model Enhancements

The following enhancements to the COPM have been proposed for the RCRA analysis, some of which are already in progress:

- Improve input/output procedures. More streamlined model routines for writing reports and reading input tables will reduce the run time.
- Functionalize some input tables. The model now has a separate input table for each price increment and technology level. Run time may be reduced substantially by expressing the input parameters as price-stepped table functions within the model, reducing the I/O iterations.
- Modularize the model. Analyses frequently focus on a limited number of resource categories, but the model now requires all categories to be run at once. Run time would be reduced for many analyses by permitting the user to specify a subset of the entire category list to be run.
- Improve cash flow routines. Several of the operations required in the cash flow analysis pose problems in the Dynamo language. The cash flow modules may be more accurate and easier to manipulate analytically if it is made external to the COPM in another language, such as FORTRAN.
- Automate the data input process from TORIS and REPCO. The input tables are now generated manually from TORIS and REPCO outputs. This process would be made more efficient and error-free by permitting data input directly from the TORIS and REPCO systems. However, this is beyond the scope of the RCRA analysis because it is unlikely to be implemented by mid-August.
- Documentation and delivery of the model to DOE. This is the ultimate goal, to provide DOE analysts with a versatile, user friendly, and analytically more robust

policy tool. However, this effort has not been authorized under the current RCRA analysis task.

Plan for COPM Modifications

The recommended changes are summarized below to indicate the time needed and resources that would be required (e.g., new TORIS runs). They are listed in our recommended order of priority.

Plan for COPM Modifications	
Prioritized Schedule of Recommended Modifications	TORIS Interaction
Enhancements Possible by mid-August Data input corrections Extrapolation corrections: <ul style="list-style-type: none"> - previously abandoned reservoirs - light vs. heavy oil - UMO categories - UMO+ EOR categories - Alaska EOR and ASR Corrections to the model logic (e.g., development delay, redevelopment logic) Phasing of resource development Refine TORIS/COPM reconciliation by limiting process switching Cash flow module improvements Input/Output enhancements Functional representation of input tables Modularization of the model	None Use Abandonment study None New input from RCRA runs New input from RCRA runs None None None New input from RCRA runs None None None None
Enhancements possible later in 1991 Automated data entry process Category-specific abandonment rates Geologic class disaggregation Further geographic disaggregation Process-specific extrapolation factors Documentation of the model	Some interaction Disaggregate existing runs Disaggregate existing runs Disaggregate existing runs Disaggregate existing runs None
Enhancements possible beyond 1991 Develop offshore models for EOR and ASR Develop Alaska models for EOR and ASR Develop Appalachia models for EOR and ASR	TORIS enhancement req'd TORIS enhancement req'd TORIS enhancement req'd

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