BREAKOUT SESSION ON

IMPACT OF ALTERNATIVE FEEDSTOCKS

ON THE

REFINERY OF THE FUTURE

Facilitators: **Douglas Rundell**
(Amoco Oil)

Linda Schilling
(DOE/OIT)

SUMMATION OF THE DISCUSSIONS/DELIBERATIONS OF THE BREAKOUT SESSION BY THE FACILITATORS

The participants in the session were encouraged to take a "broad" view of the key questions posed - namely, can or will the refinery of the future make use of a broad range of feedstock materials; also, can or will it supply a broad range of feedstocks for other industries? A brief summary of the issues raised and discussed is outlined below.

Policy Issues Raised

- Should DOE provide technology/process demos for energy security?
- How do you effectively communicate risks and trade-offs about feedstocks?
- Infrastructure for recycled oil and plastics - San Jose example
- Impact of imported gasoline on prices
- Role of agriculture
- Can always buy crude but not product
- Excess heavy crude refinery capacity exists

Technology Issues (Needs)

Consensus existed on this need for R&D in the following areas:

- Pretreatment of feedstocks
- Crude upgrading at the wellhead
  - sulfur removal
- Water recycling
- More uses for coke

Mixed views evolved on:

- Hydrogen generation and use (management)
- Recovery of organics from low-quality dilute streams
- What is meant by flexibility?
- Who should pay for flexibility?
- Markets for sulfur
- Chemicalization of the industry

QUESTIONS, COMMENTS, AND ISSUES RAISED BY PARTICIPANTS DURING THE BREAKOUT SESSION

- EIA data show that the quality of crude has been decreasing, increasing with sulfur and asphaltene content
- The quality of crude processed in the U.S. may be dictated by the price spread between heavier and lighter crude
- The apparent decline in U.S. crude quality may be a self-fulfilling prophecy because of the large number of refineries that have been built with heavy crude processing capacity. Because such a capability represents a substantial investment, the refiners are searching for and buying heavier crudes to utilize their investment. Thus crude quality is not necessarily decreasing; it reflects a response to earlier capital decisions
- The trend in crude API gravity and sulfur in Europe is not the same as in the U.S. There, the quality of crude is improving. Light crudes are readily available at competitive prices. The North Sea is producing far more oil than previously estimated
- Increased heavy crude use in the U.S. is the result of demand-pull rather than supply-push
- The decline in sweet crude refinery capacity, which has been precipitous over the past decade, is the result of a conscious decision made by refiners who were responding to the threat of a cut-off of the higher grade middle-eastern crude and/or an insufficiency of North Sea crude, and/or increases in Alaskan crude oil supplies
- The concern that refineries may decline because of the possibility of product importation needs to be tempered by the consideration that it is always possible to buy crude but not always possible to buy product on the open market (e.g., gasoline or partially refined feedstocks)
- The Japanese and other countries in the Far East are installing new refining capacities to process heavy crude. The decision to do so is based on the price differential between heavy and light crude
- The use and/or disposal of petroleum coke can be expected to become an escalating problem as heavier crudes are used. It is not clear that the present outlet market (the Mediterranean area) for coke will continue to exist. Development of alternative environmentally sound

uses for coke - e.g., chemical feedstock, power generation, etc. needs to be pursued

- Crude oil will probably not be the only feedstock for the ROF. We need feedstock flexibility. Alternative feedstocks could include recycling other materials, e.g., plastics, agriculturally generated materials, recycled oil, etc.
- There is little support for or interest in long-term alternative feedstocks
- It is not clear how the individual refiner should derive the true cost of using alternative feedstocks. How do you factor in true costs and markets for these alternatives?
- What is the real cost of crude in the U.S. when all costs are considered? The 30/BBL crude of today has an actual cost of $60 - 100/BBL when you take into account the defense expenditures to protect our Middle Eastern allies and their crude. If you account for the full cost, then the economics of recycling and alternatives are self-evident.
- The Federal Government is pushing the use of compressed natural gas (CNG) and liquid natural gas (LNG) as environmentally clean transportation fuels. If this takes off, the demand for crude oil could fall dramatically
- Far Eastern countries are ordering equipment (technologies) for their new refineries that will allow them to process sour heavy crudes and residua because they want equipment that will meet U.S. environmental requirements and they recognize that their own politicians and public pressure will require similar safeguards in the future
- Why not use natural gas as a feedstock, since there could be environmental benefits (methane is excluded from proscribed VOCs)? The reason is that it does not appear to make a whole lot of sense economically
- Assuming practical solutions to technical problems can be found, why isn't biomass being seriously considered as a potential future feedstock? The answer is that there will be enough crude available worldwide for the foreseeable future (even if crude supplies dry up in the U.S.) and because the U.S. is simply not pushing renewables very strongly

- It may be possible to use petroleum coke to make methanol or syngas, even though it is a nonuniform product and its ash has a high metal content; the issue is not whether this technology exists but is it economical?
- Current refining capacity is almost fully utilized (at the 90-92% level). Without increased capacity future needs will not be easily met
- Shouldn't we pursue development of technology to preprocess crude to remove the sulfur?
- A major R&D effort on preconditioning of feedstocks looks like a plausible area for a cooperative effort
- People don't want to be bothered with recycling used oil; collection, transportation, and sorting adversely impacts cost and quality of the recycled oil
- Flexibility to use different feedstocks in the refinery is highly desirable; the cheapest raw materials should be processed to produce the desired products
- What is the cost of and is feedstock flexibility needed in the U.S.?
- What are the long-term implications if coke is banned?
- Japan learned in Desert Storm that if you have money you can always import crude, but not product
- The oil (availability) question is becoming more and more unpredictable
- Transportation fuels are becoming chemicals; as an example, about 15% of future gasoline supplies will be composed of non-fuel-derived compounds (chemicals) such as MTBE. Most MTBE is or will be in the near future made by non-refinery suppliers. This trend if it persists could strongly affect the structure of the transportation fuel supply business
- There is money to be made in a niche market, making products from noncrude feedstocks
- The U.S. will always be a major importer of raw materials; therefore it needs flexibility in use of feedstocks
- There are two groups of refiners, those that upgraded for processing heavy crude and those that did not. A higher price-spread will open up

- The marginal imports drive the price of the products - if environmental costs in the U.S. rise, U.S. imports will increase
- Should DOE build a demonstration plant with flexibility in feedstocks?
- Cheaper and new ways of making hydrogen needs to be developed; also, preprocessing crude to remove the metals will also lower demand for hydrogen
- What is precompetitive and what is preprocessing seems OK
- If the government doesn't regard the industry as strategic, the industry will die

SUMMARY OF REMARKS

BY

PLENARY SESSION CHAIRMAN

ON

VISION OF THE REFINERY OF THE FUTURE (ROF)

In summary, the consensus from the four break-out sessions was that the ROF Vision as presented provides a plausible outlook for future development of the domestic refining industry. Not surprisingly, a number of areas were identified for which there are wide differences of opinion. These included:

- The level of petroleum imports, with some expectations that imports will be higher than those presented.

- Trends in the average quality of crude oil. The Vision presented a continued, though slowing, decline in crude oil gravity and sulfur. The opinion was given that the decline in quality will not be as severe.

- The outlook for demand for residual fuel. The Vision presented a flat demand (no change in absolute terms), whereas a number of attendees expect continued loss of markets for residual fuel.

Finally, an opinion was given that the Vision does not take into account the potential for quantum changes in the use of petroleum, such as complete elimination of gasoline as an automotive fuel. While it was acknowledged that such changes are possible, the consensus of the audience was that the Vision of incremental change was the most plausible.

EPA-AMOCO YORK TOWN PROJECT:

LESSONS LEARNED & FUTURE STEPS

Presenters: **Ronald Schmitt**
(AMOCO)

Steve Harper
(EPA)

AMOCO/EPA YORKTOWN PROJECT PRESENTATION BY RONALD SCHMITT, AMOCO

This conference is exploring ways to map the strategy of the refinery of the future, as well as set the goals for the future of the refining industry. I am excited to be part of this program because as individual companies, and together as an industry, we need to be able to achieve our national environmental protection goals while sustaining a strong industry and a healthy economy. And we need to work together to develop the tools to set priorities and implement effective solutions to tomorrow's environmental challenges.

All of us want to breathe clean air, drink clean water, and enjoy our rich lands. Certainly industry and government share these goals, but we are often at odds over ways of reaching them. Recently, the Amoco Corporation had the privilege to work with the United States Environmental Protection Agency on a pollution prevention project which we believe can serve as a model for setting priorities in achieving cleaner production at industrial facilities. We believe that this unprecedented project marks a new approach to achieving the goals of improved air, land, and water quality. Before describing the project and its findings, let me provide you with some background to show why the project was initiated.

Amoco Oil Company operates five refineries in the United States, which process nearly a million barrels of crude oil a day, providing gasoline and other fuels, lube oils, and other refined products. Although Amoco refines and distributes products only in the U.S., Amoco Oil Company's survival depends on its ability to compete in the global market, so it is keenly committed to ensuring that environmental benefits can be achieved in the U.S. without placing it at a disadvantage to those operating in other countries.

Following the first Earth Day celebration at the beginning of the 1970s, the United States began passing legislation that set a number of environmental goals for the nation's air and water, and to require proper waste disposal. During the 1980s, with heightened concern over environmental progress, the U.S. Congress began passing a series of more complex and prescriptive statutes. These statutes spelled out in detail how the Environmental Protection Agency should develop and enforce regulations.

As environmental regulations have grown in complexity, compliance costs have skyrocketed. The concern, however, is not the amount spent. Rather, the question is whether we are achieving genuine environmental improvements for the outlays. And are we doing the things we should be doing to protect the environment? Have we set the right priorities, and are we following them?

From the viewpoints of both government and industry, it seemed there had to be a better approach to achieve the goal both sides wanted: a cleaner environment. Faced with those challenges and frustrations, Amoco and EPA in late 1989 began talking about the possibility of cooperating in a pollution prevention project.

Such an unprecedented project had many risks, such as whether the project results would be worth the cost, the risk of discovering an inadvertent violation of an environmental regulation, and the fear of EPA appearing too close to a company that it regulates. But the project also had many benefits. For example, each side would have the opportunity to become better educated about the problems of its counterpart. At the same time, working side by side would give participants a chance to build better relationships that might lead to improved drafting and administering of regulations.

More concretely, the Yorktown Project provided for an overall instead of piecemeal examination of pollution prevention. In place of individual examinations of water, air, or land emissions, investigators would conduct an integrated review to discover what interaction takes place between these media, and whether our programs were focusing on the highest priority issues. This integrated review had the potential of pointing out opportunities for improving the methods employed to *prevent pollution*—or identify those areas requiring additional research. Lastly, the project would be carried out in an actual, operating industrial facility—providing a unique opportunity to generate new ideas for improving our environment. Never before had regulators and the regulated been given a real-life facility to work in side by side.

Acknowledging the risks and anticipating the benefits, Amoco and EPA decided to go forward. There were no guarantees or promises exchanged on the use of information, such as immunity for violations discovered. Instead, both parties agreed to get involved on a simple verbal agreement. Mutual trust was no small part of this project. Both parties were working with previous adversaries, and the success of the project depended on each side placing their trust in the other.

Amoco's Yorktown, Virginia, oil refinery was chosen as the site for study. The facility, located on 1,400 acres along the York River near Chesapeake Bay, is capable of processing 53,000 barrels of oil per day into gasoline, heating oil, and other products. The size and product mix are representative of the petroleum industry. Yet the Yorktown Refinery was small enough to permit a thorough study within the two-year period planned for the project. Also, its proximity to Washington, D.C. and its location in an environmentally sensitive area made the refinery a logical choice. During the course of the project, over 100 EPA and Commonwealth of Virginia regulatory professionals visited the refinery.

Over 200 people from various organizations, including Amoco, EPA, Commonwealth of Virginia, and many others, contributed to the Project. This slide gives you an idea of the many levels of expertise at Amoco that were involved in the project. An Amoco/EPA Workgroup was formed to provide project oversight.

The Project Workgroup developed a simple set of goals. They agreed that the project should:

- Determine the types, amounts, and sources of emissions that the refinery releases to the air, land, and water.
- Develop options to reduce these releases. Determine the benefits, impacts, and costs of different options, and select the most cost-effective option for improving environmental quality.
- Identify factors that encourage or discourage pollution-prevention initiatives.
- Increase participants' knowledge of refinery and regulatory systems.

A special feature of the Yorktown Project was its use of outside experts who could provide peer review. The EPA chose Resources For the Future to select the people to serve on the committee. These 12 experts represented many disciplines and were associated with government agencies, private consulting firms, and universities. They analyzed the approach, methods, and findings and provided independent, informed opinions on the validity of each step in the project.

At the outset of the project, it was quickly realized that, despite all the monitoring the refinery does for compliance with operating and discharge permits, the type of information needed for this type of evaluation was not available. Therefore, an extensive data gathering program was initiated, collecting about 1,000 air, water, groundwater, and soil samples. Most of these were air samples, as airborne releases account for nearly 90 percent of the refinery's emissions. Besides analyzing the makeup of these samples, the project team attempted to associate each sample with a source in the refinery. The nature of refinery operations, as well as the complexity of processing equipment, made this task difficult. Special monitoring methods were used, and some new techniques were developed. A flux chamber was used to quantify emissions from the oil-water separator.

Well, what did the data show? Analysis of the emission data showed that, of the material that was released, most—some 88 percent—was released in the air. Hydrocarbon vapors made up more than half, with nitrogen, sulfur, and carbon monoxide comprising the second large category. Smaller amounts of material were released to land and a very small amount to water. One of the findings of the project was the high quality of water around the refinery.

The data were examined at a workshop attended by about 120 people from Amoco, EPA, and outside organizations. The workshop participants identified some fifty emission-reduction options. Twelve of the options were selected as most promising and then further evaluated. The study showed that Source Reduction options are more cost-effective than treatment but do not necessarily pay for themselves. The average break-even cost of the Source Reduction projects was $2.50 per gallon, while the refinery receives an average of 75 cents per gallon for its gasoline product.

The projects were evaluated for such features as risk reduction potential, technical merit, cost, construction safety, and operability, and then ranked according to weights assigned to these characteristics by individual groups. It was interesting to note that both Amoco and the EPA, using different weights for ranking criteria, chose the same option as best one in reducing emissions.

While a comprehensive risk assessment for the entire facility was outside the scope of the project, one of the goals of the Project Workgroup was to rank the projects in terms of their risk reduction effectiveness. Further, the Peer Review Committee believed that the projects should be ranked solely on the basis of risk reduction—or cost-effective risk reduction. Since previous studies showed ecological effects from the refinery were insignificant, the study focused on risk to human health. Exposure to benzene was selected as a surrogate for risk. The project emission data were combined with a year's worth of meteorological data and modeled to obtain average annual concentrations of benzene around the facility. Isopleths of benzene concentrations for baseline conditions were compared to those for each of the projects if implemented.

The project team identified a set of options that could prevent or capture almost 6,900 tons of emissions a year for a cost of about $510 per ton. These options included the installation of controls to reduce emissions from barge-loading operations. At Yorktown, over 80 percent of the gasoline and other products leave the refinery by barge. Capturing these emissions was found to be the single most *effective* measure, although *not the lowest in cost..*

Also effective, but less costly, were three other suggestions:

1) installation of improved seals on certain storage tanks,

2) instituting a leak detection and repair program to reduce small leaks around valves and flanges, and

3) the upgrading of emergency venting equipment called blowdown stacks to reduce hydrocarbon losses to the air.

This plot of benzene emission patterns at Yorktown illustrates how local weather patterns distribute emissions at this location. By adopting the recommended options developed from the study, emissions could be reduced by the amount shown between the line marked existing emissions and the line labeled emissions after controls. The cost of this significant improvement would be a capital investment of about $10 million, or about $510 per ton.

However, the Yorktown Refinery faces some mandated requirements, such as the modification of its sewer system. The cost of these required modifications is four times greater than the recommended options, or an estimated capital cost of $41.3 million. This plot shows the minor emissions improvement that will be gained as a result of upgrading the sewer system. The narrow band between the line marked existing emissions and the line labeled emissions after controls demonstrates the shortcomings of imposing industry-wide measures without taking into account how effective they will be at a particular facility.

In the case of Yorktown, mandated requirements for all sources, including the sewer system, will reduce emissions at a cost of $2,400 per ton, while optional alternatives could achieve virtually the same emission reductions at a cost of about $500 a ton.

In addition to fairly specific pollution-control options, the project identified several broad policy recommendations aimed at achieving an improved environment. Because mandatory compliance deadlines are short, the current system is directed at short-term fixes, sacrificing more effective, if *less immediate* solutions. Most programs require compliance within six months to three years. However, the design, engineering, and construction times for many environmental improvement projects may take much longer than the compliance deadlines. In addition, there are often delays associated with difficulties in interpreting regulations, understanding design criteria, obtaining construction permits, or developing unfamiliar technologies. In light of these facts, the Yorktown Project team recommended that legislators and regulators adopt more realistic time frames to encourage long-term solutions.

Since the initiation of environmental legislation in the early 1970s, regulations have maintained a narrow focus on single issues. This piecemeal approach lacks an overall goal that might be achieved through a variety of programs. Better coordination among numerous environmental requirements could help industry develop broader management initiatives to meet the overall objectives. In response to these findings, another recommendation calls for the introduction of incentives to conduct facility-wide assessments and emission-reduction strategies.

The Yorktown Study revealed that some regulations are misdirected, imposing controls on sources that are no more than minor sources of pollution. Ineffective regulations arise from a lack of sound, reliable data that accurately identify the type, amount, and source of emissions. That data base is a necessity for cost-effective pollution control. The Yorktown Project team recommended that additional research be undertaken to develop improved techniques for data collection, analysis, and management.

The Yorktown Project is the first joint effort between government and industry to study pollution-control opportunities at an operating refinery. Many benefits flowed from the project, including greater appreciation on both sides for the problems of the other. With a spirit of open-mindedness and cooperation, a better knowledge of environmental problems and more innovative, cost-effective solutions can be developed. A fourth recommendation of the project is to encourage additional partnerships between the public and private sectors.

The Yorktown Project was designed to look at refinery emissions, develop options to reduce those emissions, and analyze the regulatory system for incentives and barriers to implementation. The study identifies some new and effective pollution prevention ideas. At the conclusion of the sudy, however, no mechanism existed to implement any of the preferred options in lieu of those required by law.

Some of the projects identified in the study have been engineered and installed, some at little cost and others at high cost. The upgrades to the sewer system and wastewater treatment plant to reduce benzene emissions have been completed. This project involved the construction of a new sewer for process waste water, built completely above-ground, and the replacement of the oil/water separator and floatation system with an above-ground closed unit. The project was installed at a capital cost of $29 million dollars, significantly less than the $41 million estimate, but still an enormous investment which achieves little environmental protection.

On the other hand, the project which offered the most risk reduction potential—controlling emissions during barge loading—is still on hold. The capital funds commitment remains in the current investment plan, but the engineering awaits the issuance of the regulations that address this emission source. The refinery cannot afford to risk implementing a system to control the emissions which may not comply with a future technology or performance standard.

The Yorktown experience demonstrates the opportunities and pitfalls that can occur when government and industry work together. The opportunities are significant. The pitfalls are worth overcoming. All organizations—EPA, the Commonwealth of Virginia, and Amoco—sought to develop and test innovative approaches to reduce releases to the environment. In general, we found that opportunities exist at this facility.

Given the large potential for achieving better environmental benefits more cost-effectively, we believe that additional demonstration projects need to be undertaken to develop more innovative and more cost-effective approaches to environmental protection. These projects can be a proving ground for new systems of decision making which can help set priorities for our national and local pollution prevention programs.

And just as importantly, these systems will help unleash the creativity of individuals in industry, government, academia and the public to jointly address the common goals of protecting the environment and achieving sustainable development.

SUMMARY OF AMOCO-YORKTOWN PROJECT EXPERIENCE PRESENTATION BY STEVE HARPER, EPA

The Yorktown project is seen as a model for the future and a valuable partnership project.

Lessons learned by EPA:

1. Learned about refineries and compliance requirements
2. Need to increase ability to bring in flexibility in regulations
3. Cost savings of environmental compliance requirements can be achieved by using a multi-media process
4. Development of site-specific data is expensive
5. Command and control regulations precluded innovative cost-saving technology

Hoped-for follow up:

- Improvements in the way regulations are developed by EPA
- Critical mass of data gathered to convince people to change

Traditional EPA way of command and control - extremely effective and overall not anti-competitive. Environmental costs generally are a small cost of doing business; however, refining, the most regulated industry, is the exception.

Administrator Browner's goal - to find easier, cheaper ways of achieving environmental aims. Economic incentives and flexibility are necessary prerequisites.

An example of new approaches at EPA is:

- Green sectors program
  - industry works with both regulators and environmentalists
  - looks at industries as a whole, not in segments
  - coordinates different media compliance requirements
  - sector program
  - cross agency teams - environmental management teams

Refining may be one of the industries put in the program - the EPA air office is interested in doing this.

Six areas of concern to EPA which evolved from this program are:

- retrospective review of existing regs and how to improve them
- improve new yegs by evaluating cross media impacts
- simplify reporting
- improve enforcement and compliance assistance
- permit streamlining with the states
- improve technology and innovative approaches

- Another example is the council on sustainable development
  - improve environmental and economic decision making
  - refining is represented
  - series of demonstration projects based on the Amoco project

There is interest on the Hill in allowing companies to implement the outcome of such studies. What are the barriers to implementing these studies? There are both legislative and regulatory barriers - more flexibility is needed.

QUESTIONS, ANSWERS, COMMENTS

Question:	A recent article about the Amoco Mandan refinery in Hydrocarbon Processing indicated that the cost of benzine reduction was much less than at Yorktown. Why?
Amoco reply:	Better data was gathered. There was less emissions than overtly thought. An innovative approach was used at Mandan that could not be used at Yorktown.
Question:	You indicated 2mm were spent and 20mm would have been saved if there was flexibility in the regulations. Is site-specific risk assessment the way to go?
Amoco reply:	Site-specific risk assessment is the way to go if there was flexibility in this regulation.
EPA reply:	The study produced data that could be used in part for site specific risk assessment. When, where, and how this can be done will be looked at in the sectors program.
Question:	Will review of retrospective regs look at site specific risk assessment?
EPA reply:	Probably will. Its time has come. The issue is - will it fly?
Question:	Was the most cost-effective method considered?
Amoco reply:	Because of time, there was no way to factor it into the benzine waste NESHAPs regs.
EPA reply:	The history of the rule is not ideal. It was litigation driven. The revision has additional levels of flexibility. The industry must talk to EPA.

ADDITIONAL BACKGROUND INFORMATION ON THE AMOCO-EPA YORKTOWN EXPERIENCE IS PROVIDED IN THE ATTACHED NEWSPAPER ARTICLE TAKEN FROM THE WALL STREET JOURNAL, 03/29/93

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Clearing the Air

What Really Pollutes? Study of a Refinery Proves an Eye-Opener

An EPA-Amoco Test Finds That Costly Rules Focus On Wrong Part of Plant

One Gigantic Culture Clash

By CALEB SOLOMON
Staff Reporter of THE WALL STREET JOURNAL

Nowhere has animosity between regulator and regulated been more acrid than in environmentalism and pollution control. But now, some signs of change and pragmatism are in the air.

"The adversarial relationship that now exists ignores the real complexities of environmental and business problems," said Carol Browner, head of the Environmental Protection Agency, at her confirmation hearings. Last week, she told the auto industry she favors flexibility in meeting clean-air goals.

As it happens, the EPA itself has been involved in a far-reaching experiment in finding new approaches to pollution control, one that has involved nothing less than a full-bore study of how best to regulate an oil refinery.

The study, launched four years ago as an unprecedented joint venture between the EPA and Amoco Corp., tested the goodwill of both sides. Enormous obstacles of mistrust had to be surmounted, as the two sides found that, in jargon and analysis, they literally didn't speak the same language. The study was almost doomed midway through when the EPA slapped a stern penalty on Amoco in an unrelated matter.

Less for More

Yet the project finally was completed—with startling conclusions. Among them: The refinery could achieve greater pollution reduction for about $11 million than it is getting for a $41 million expenditure required by current EPA regulations.

Equally unsettling: While that $41 million was spent to trap air pollution from the refinery's waste-water system, no controls at all were required—or yet exist—on a part of the plant that the study showed to emit five times as much pollution. It could be dealt with for a mere $6 million.

Why such miscalculations? Because, it turns out, nobody had ever actually tested to see how much air pollution the refinery was emitting, or where the pollution was coming from.

The Clinton-administration EPA is just beginning to consider the refinery study, known as the Yorktown Project, which is now winding up with a multivolume report that will call for such changes as tailoring a solution to each industrial facility. But Ms. Browner indicates she is sympathetic to many of its ideas. "If we were starting out today to develop an environmental program with all the knowledge we have today, we'd probably do it quite differently," she says in an interview. "What I'm absolutely committed to is making sure we can do the job we need to do in the least costly, most expeditious manner."

Serendipity Aloft

The spark for the rare EPA-industry joint study was a chance meeting of old acquaintances aboard a 1989 Chicago-to-Washington flight.

Debora Sparks grabbed the open seat next to James Lounsbury. They had been part of a Washington crowd that used to gather after work in the 1970s at bars along Pennsylvania Avenue. After some catching up, they began talking about their work: pollution, energy, regulation.

Though both had worked in the energy industry in the old days, now much had changed. Mr. Lounsbury was at the EPA. Ms. Sparks worked for Amoco.


Debora Sparks

They talked about the complaints of each side about pollution control, and how despite all the cost and effort much pollution went uncontrolled. The tenor of the in-flight conversation, recalls Mr. Lounsbury, was, "If we could be king and queen for a day, wouldn't it be nice if we could restructure the world of environmental analysis." They wondered if something might come of a joint look by regulator and regulatee at a particular pollution site.

When the plane landed, the two returned to their offices full of enthusiasm but unsure how to channel it. To Mr. Lounsbury at the EPA, the notion of working with an oil company was dangerous heresy. But he knew a midlevel regulator whose job was to look at new ways to regulate, and who had mulled the idea of a joint venture with an energy company. Mr. Lounsbury said he had a candidate.

As for Ms. Sparks of Amoco, "there was some part of me that worried about coming across as a flake." But she gently suggested an EPA joint venture.

"It was a hard sell in Amoco," recalls the company's vice president for environmental affairs, Walter Quanstrom. "Lots of people thought that opening the gates was stupid," because the regulators would crawl around a plant and find problems. Yet within a few days, he told Ms. Sparks to begin developing a project to take a deep look, jointly with the EPA, at the pollution output and possible preventive measures at one of Amoco's facilities.

Soon, Ms. Sparks, Mr. Lounsbury and the midlevel EPA official Mr. Lounsbury had in mind, a quiet man named Mahesh Podar, began meeting at EPA offices and a Hardee's restaurant. They were stiff encounters in which "we sometimes used words that didn't mean the same thing," Ms. Sparks says. For Amoco, "risk" was a term of economics, dealing with issues like "efficiency and results," she says. To the EPA, she says, it was a four-letter word that meant political peril or health risk.

Mr. Lounsbury set some ground rules: At no point could a study recommend changing laws, altering permits at the industry plant that was studied, or overlooking any violations.

Amoco offered its Yorktown, Va., oil refinery. Soon, teams from Amoco and the EPA came together for their first formal meeting at Amoco's Washington office.

"The first three or four meetings," says Howard Klee, named to head the project for Amoco, "were what I envision the Vietnam peace talks were like when they fought over the shape of the table."

Neutral Corners

Amoco executives, the men among them wearing blue or gray suits and crisp white shirts, voiced concerns about being fined for violations the regulators might stumble over. EPA types, in less formal attire, retorted that "EPA is not in a position to offer the company a shield," said Mr. Podar, whom the EPA had named to head the project from its end.

Pleasantries were few. "The meeting would end and we'd go off to our respective corners," says Ms. Sparks.

One day, Amoco brought sandwiches and chips for the group, a small offering. Regulators each dropped a few dollars in an envelope and passed it across the table. They would not be bought.

The first barrier to overcome was language. Amoco executives kept referring to RVs, Amoco-ese for relief valves. An EPA staffer thought they meant recreational vehicles. The industry types also spoke of "pigging out the line." It turned out to mean cleaning a pipeline by pushing a scrubber called a pig through it.

Amoco was equally stumped by EPA jargon like "red border review." It meant the final review of an EPA rule before it was published in the federal register.

A Real Issue

After a series of these painful meetings, the group arrived, with some relief, at a genuine regulatory problem: They realized they didn't know precisely how to measure emissions from the refinery.

Surprisingly, this was new ground for both. The EPA, even though air-pollution-control is a central mission, doesn't often measure emissions from industrial plants. It enforces regulations spelling out what equipment a plant must have, with the belief that this will keep pollution low. It may check that a certain type of smokestack is a certain height, for instance, or whether a water filter is in place. But these rules are often based on old or over-generalized information, and rarely allow for adjustment to individual cases.

Regulators from each of the pollution-control divisions – air, water and solid waste – visit plants every few years with long checklists. Too many missed checks may result in an order to modify the plant or in a fine. But to what extent the rules are actually reducing pollution at a given site – and whether they are doing so in the most proficient or efficient way – are normally not at issue.

Nor does the regulated industrial company generally measure actual pollution. It, too, focuses on the rules it must meet.

If the project was going to learn anything at all about the efficiency of current pollution-control efforts, it would have to devise ways to measure the pollutants given off by the refinery as a whole – fumes, fluids and solid wastes. Only then could it consider the best ways to keep them out of the air and water and soil.

Separate Fiefs

The Amoco executives were surprised to learn that the EPA officials regulating each of those three kinds of pollution seldom spoke to one another. They operated from separate offices, enforcing separate pollution laws and maintaining their own regulatory staffs.

It was for that reason that the EPA oversaw its end of the study from its policy office in Washington, away from turf-conscious division regulators. J. Clarence Davies, who headed the policy office, says that some within EPA were strongly opposed to the joint project with Amoco. "I suspect," he says, "that half the people in the EPA water or air office, the people doing the regulating, think they're the good guys going after the bad guys."

To measure air pollution, Amoco designed testing methods with the help of its regulatory colleagues. But the methods needed approval by the EPA's air pollution office in North Carolina. After several trips and many calls to the office in the spring of 1990, Amoco's Mr. Klee still didn't have what he felt was a definitive response. Finally, Mr. Podar, reading EPA tea leaves, said that the air office's neutral stance meant it had no objections.

It was a risky supposition. But it allowed work to continue.

Howard Klee

So the group began measuring pollution. Forty wells were drilled to test the water all about the grounds, a few miles from where British troops surrendered in the last major battle of the Revolutionary War.

When winds prevented using a crane to put a test device atop a 130-foot smokestack, they built $5,000 of scaffolding around the stack, drilled a hole in the side and inserted a sampling probe. The data proved ambiguous, and they had to do it again months later, scaffolding and all.

Yorktown's main pollution problem is benzene, a carcinogenic byproduct of oil refining. For years, benzene-tainted waste water ran into pipes that led to an open-air treatment facility. Though laws passed in 1977 said substances like benzene needed to be controlled, it wasn't until 1990 that the EPA, which slowed its rule-writing during the Reagan years, finally drafted specific rules to contain benzene.

Based on them, Amoco in 1990 began building a $41 million enclosed canal and water treatment system that would capture the benzene vapors. Other oil refineries also had to build one.

But the Yorktown Project's extensive testing revealed that the EPA's basic assumptions in requiring such a system – assumptions based largely on a 1959 study of benzene emissions from pools of dirty water known as "separators" – were wrong for this refinery. Fumes and evaporation of benzene from the plant's dirty water was, in fact, 20 times less than the 1959 study predicted it would be.

The real benzene problem was at the loading docks, where fuel is pumped onto barges. Fumes released here carry 1.6 million pounds of pollutants into the atmosphere a year, the study found. The EPA rules didn't address loading docks.

Indicting Evidence

"It was like 'My God, a blind person could see this,'" says Amoco's Ms. Sparks, recalling when she first heard about the data. "This is what we believed in our hearts but never had the data to demonstrate."

In a way, it was also what some EPA people were secretly hoping for: evidence indicting the current rigid structure of checklists and often-outdated assumptions. "We didn't know as much as we thought we knew about what is being released to the environment," says the EPA's Mr. Podar.

Madeline Grulich, a Virginia environmental official who worked with the project, says, "Those were astonishing conclusions that the waste water was not the problem and that the loading dock was. At the time, loading docks weren't something regulators were even looking at."

By early 1991, the work group was ready for a show, and 120 people from the EPA and Amoco gathered at the Williamsburg Inn in Virginia. But a small problem arose. EPA's per diem expense limit was short of what a room costs at the sumptuous colonial inn. "In an aberrant moment," says Amoco's Mr. Klee, "I decided why don't we have EPA people and Amoco people share rooms."

Strange as the idea seemed to some, it helped to thaw the cold war. Deborah Hanlon of the EPA says her Amoco roomie turned out to be "a real blast." One night, Ms. Hanlon rounded up 10 Amoco and EPA people to go dancing at a country and western bar. "What was so exciting was not just the camaraderie," she says, "but it was like we were all on the same team."

At one workshop during the conference, people had to think about being a vegetable, then tell the group what vegetable they would be. One Amoco executive was a carrot, because most of him was underground and he revealed little.

By the final night, Mr. Klee says, the EPA attitude seemed to be, "Gee, you don't all have horns." The Amoco consensus? "Wow, not everybody at EPA was walking around with a pair of handcuffs."

Sudden Setback

But shortly after the conference came an episode that shook Amoco's faith.

The EPA, describing a "nationwide crackdown to enforce lead laws . . . with particular emphasis on high blood levels in children," hit Amoco's Yorktown refinery with a $5.5 million fine. Virtually everyone from the oil company working on the joint project – and a few people from the EPA contingent – thought it was retribution for getting too cozy.

Gordon Binder, who was chief of staff to then-EPA Administrator William Reilly, doubts that Amoco was targeted. But "it raised a very real dilemma," he says. "When you're working with industry cooperatively, shouldn't you reward good behavior? At the same time, you've got your established procedures."

In any event, the carefully nurtured trust had been shattered. With the project in jeopardy, Mr. Reilly picked up the phone and, in a move with virtually no precedent in environmental regulation, called Amoco's chairman, H. Laurance Fuller in Chicago. Recusing himself from any further dealings on the lead fine, Mr. Reilly said he was sorry Amoco hadn't received any warning and hoped it wouldn't pull out of the Yorktown Project.

Although the call patched up a lot, "there was awkwardness in the air" at the work group's next meeting, Ms. Sparks says. "It was a little like finding your spouse cheated on you, and it takes time to get over it." But Amoco people, seeing that their EPA counterparts were also troubled by the fine, grudgingly moved ahead with work on the common goal of seeking a way to cut the loading-dock benzene releases the study had uncovered. And in September 1991, the team finally began writing the Yorktown Project's report.

Air Attack

Then, EPA's North Carolina air office—the one that didn't give a definite answer when asked to rule on the appropriateness of the test method—weighed in.

"They tried to submarine the whole thing," says a senior EPA official. "It was ludicrous that a minute before midnight they complained about technical problems they could have addressed" more than a year before when Mr. Klee had pressed them to approve the testing procedures.

The air office now said that the testing methods were improper, and that the conclusions drawn from that data were too broad.

The EPA's Mr. Podar, who says his Buddhist beliefs don't allow him to get angry, says simply: "The air objections unfortunately came later than I would have liked."

Mahesh Podar

The EPA's acting assistant administrator for the air office, Michael Shapiro, contends the tardiness wasn't sinister but merely bureaucratic, reflecting the EPA's difficulty coordinating its various offices. In any case, senior EPA officials arrived to arbitrate. After difficult negotiations, they ruled that the air office's objections didn't change the fundamental findings but only modified them in some instances, and the project should proceed.

Even with that, there was frustration at Amoco. Armed with study data showing the waste-water plant's benzene emissions were only a tiny fraction of what the EPA had assumed them to be, the company petitioned in early 1992 for an exemption to rules requiring it to complete its massive sewer system. EPA said no — there was no procedure to waive existing environmental laws and regulations, even if they were contradicted by an EPA-sanctioned study.

Prescribed Remedy

As for the loading area that the study had fingered as a worse culprit, the group decided that controlling its benzene fumes would take a special two-nozzle hose. The second nozzle would suck in escaping fumes, and pipes would carry them away. Cost of the system: about $6 million.

The group also agreed the refinery could stand about $5 million of other modifications, like new smokestacks, extra tank seals and cooling equipment for open-air sludge ponds. One Yorktown sludge pond, the study showed, emitted twice as much hydrocarbons as the EPA's rules assumed. The low-cost solution: lowering the pond's temperatures.

Late last year, Amoco completed its high-tech water-treatment system. Building that costly facility (something many other refineries have had to do over the past two years) brings Yorktown current with environmental laws. The plant now controls the modest output of benzene fumes from its waste water.

Five times that much benzene still rises from the refinery's docks. "It's not required to be controlled, so it's not," says Chris Klasing, an Amoco manager.

EPA officials concede the point. The Yorktown study points to "potential opportunities" for better, cheaper pollution control, says the agency's Mr. Podar, but "we must confirm them before we make national policy." EPA officials say new regulations to control benzene at loading docks should be drafted by the mid-1990s.

Winding Down

The final Yorktown report is nearing completion. The volumes done so far make the basic argument that each plant is different, and each requires unique pollution solutions. They say only exhaustive testing at each plant will accurately tell what needs to be cleaned up.

Short of rewriting laws like the Clean Air Act, there is little hope for immediate, far-reaching change — such as setting a benzene maximum and letting a plant meet the goal any way it wishes. If Yorktown cuts pollution at its loading dock or the EPA requires it to do so, that doesn't mean the agency would let Yorktown out of any requirements at its waste-water plant, even if they were based on faulty assumptions. Says Mr. Davies: "You invest so much in terms of time, money and political chits in arriving at one of these regulatory decisions that to go back and change it is something nobody wants to do."

Still, there are signs that EPA regulation is evolving. The air, water and solid-waste offices talk more to each other, as Yorktown's report recommends. And EPA Administrator Browner says, "The idea that one solution works in every situation is something we've probably passed beyond, and we need to recognize that. We need to become more flexible."

As the rare industry-agency joint venture winds down, many of its participants have moved on. Amoco's Howard Klee and Debora Sparks both have new assignments, as do the EPA's Jim Lounsbury and Mahesh Podar. Summing up his experience, Mr. Podar says, "Some of my colleagues may not agree, but Yorktown shows that EPA and industry can work together. You *can* find more effective ways to meet environmental objectives."

Ms. Sparks, whose spotting of Mr. Lounsbury aboard the 1989 flight led to the project, even feels a certain ennui, as if a precious union has ended. "You know," she says, quietly, "I should call Mahesh and Jim. I haven't even wished them a happy New Year."

PLENARY SESSION

ON

R&D NEEDS/OPPORTUNITIES

Session Chairman: **"Fritz" Dawson**
(California Synfuels)

CHARGE TO FACILITATORS OF BREAKOUT SESSIONS ON R&D NEEDS/OPPORTUNITIES

We in the refining industry have been approached by the Department of Energy with some legitimate inquiries:

- Left to ourselves, will we adequately fund our own research needs?
- Do we want the federal government in our business?
- If so, how deeply do we want them involved?
- If support is desired at this stage, should this be a "one-shot deal" or is there a need for an ongoing program? And if so, what kind?

This morning we heard a consensus of much careful thought as to the status of the refining industry, and what we might expect during the next couple of decades or so. An initial version of this vision of the refinery of the future has been the subject of discussion and criticism throughout the past year in meetings DOE held with a number of industry companies to solicit industry views and comments. The process started at the MPRA meeting in San Antonio last year. Meetings were held individually with a number of executives and managers in the refining and research segments of our industry (some of you are here today). These discussions prompted DOE to pursue more detailed meetings with a broader segment of the industry. Today, finally, the entire industry has an opportunity to express its views in the workshop breakout sessions today and tomorrow.

Up to now, there has been general support among the executives consulted that some type of cooperative, cost-shared program of research and development activities would be worthwhile, if it could be made available, and assuming a suitable organizational structure. There, however, has not been a clear consensus as to the scope to R&D activities which should be considered, nor the extent to which this program should properly be carried.

This meeting may be different from most MPRA meetings you have been to. This will not be the typical MPRA program, where you listen to papers, nor the typical panel discussion, all the Q&A sessions or maintenance panels.

In this meeting, DOE seeks your individual and collective expression of views/opinions/recommendations. The program being discussed here will happen if we in the industry are prepared to say that we want and need such a program, and here's what it ought to look like. Today is your opportunity to express your views.

I am not advising you that we should or should not support collaborative research with the federal government. I only wish to convey that your attitude this afternoon and the actions you recommend will likely determine what happens, if anything.

Objectives

This afternoon you will split up into smaller groups to discuss a proposed collaborative program in detail. These are to be action sessions. You will be asked to express your views and recommendations as to what specific R&D activities if any you want your government to help support, the type of support it should provide, and what you want it not to do. You are also asked to offer your best judgments as to priorities - that is, which areas are most important and which can be done later, and which can be skipped altogether. Based upon the views expressed, DOE will attempt to structure a program which meets the needs you specify.

We will examine specific R&D projects which are described in the Draft R&D Plan that was prepared by ANL and described by M. Petrick this morning. As he indicated, the plan was discussed with company representatives during the past year and was modified to incorporate their views. We want your views as to whether these are appropriate areas for study. We also want your ideas as to other subjects which ought to be included in the ROF program.

We want you to define specific critical program elements desired and associated research objectives. What categories of R&D are especially of interest, and what specific R& D activities are of interest in each category?

We will attempt to determine if a consensus appears to exist as to the relative priorities of the various specific projects. Tell us whether you think a given program should be high, medium, or low priority, or whether there is no interest. In discussing priorities you should also attempt to identify the criteria you feel are important for setting priorities such as: benefit to a broad spectrum of industry; greater resulting benefits; ability to meet a reasonable schedule; lower technical risk; and lower research costs. You may wish to consider using a scoring system to help you prioritize; a suggested sample will be provided you. As you know from your agenda, we will have four breakout sessions. These are: Environmental R&D, Process Development, Enabling Technology, and Fundamental Science/Basic Research.

Dr. Arnold Schaffer, Phillips Petroleum, will lead the Environmental session. Bill Hillier of M.W. Kellogg will preside over the Enabling Technology group, Ronnie Jackson will head up the Process Development session, and Art Suchanek from Criterion Catalyst will lead the discussions on Fundamental Science and Basic Research; you will have ~2 hours to complete these tasks. We will then meet in joint session tomorrow morning for groups' findings and draw conclusions where possible.

Critical Review of the Draft of R&D Plan

Each of you received a copy of the draft Program Plan prepared by Argonne National Laboratory. As Mike Petrick mentioned earlier, the purpose of this draft is to stimulate discussions and generation of ideas and to help identify areas which merit study. You undoubtedly will find research topics with which you will agree and not agree. Our goal is to get solid reactions and identify the good stuff and reject the rest.

Your views, reactions, and conclusions will be factored into the final process that will be pursued by DOE to prepare a Program Plan that would be responsive to the industry's needs.

Our strategy is fairlystraight-forward. We are asked to examine and define the strategic goals of a program, such as Environmental Stewardship, Process Efficiency, Process Flexibility, Yield Improvement, and Feedstock Flexibility. We will use this plan as a starting point for discussions. For example, in the Environmental group, the plan suggests several ideas:

- Scientific and economic evaluation of regulations

- Combustion science
- Health effects studies
- Wastewater treatment
- Wastewater sludges
- Solid waste disposal
- Gaseous emissions, and
- Site remediation

For the benefit of the Environmental group, there is included in your draft plan a listing of pertinent regulatory requirements.

The other groups - the one handling basic science and enabling technology and the process development group will work the same way. Suggested topics are noted.

Starting with these suggestions, we want to critique these subjects, select specific R&D targets, expand the list, and then assess whether the topics belong in a cooperative research program. Then we will seek your thoughts as to the relative priorities of the items noted.

I propose that we use the worksheets which have been prepared for us. Some suggested topics are already listed. We can agree that a topic is relevant and worth pursuing, or we can throw it out. You will also have blank forms for addition of other topics which your group feels merit study.

While we have established breakout sessions with the intent of covering limited, particular areas of study with each group, it is likely that ideas may surface as a matter of course in your discussions which more properly belong in another group. Do not try to send messengers to the other groups - just add the topic to your own list, note the proper forum and make your own observations as to relative importance and priority. We will try to consolidate these suggestions after the several groups wind up.

BREAKOUT SESSION ON

ENVIRONMENTAL R&D NEEDS/OPPORTUNITIES

Facilitator: A.M. "Arnie" Schaffer
(Phillips Petroleum Co.)

SUMMATION OF THE DISCUSSIONS/DELIBERATIONS OF THE BREAKOUT SESSION BY THE FACILITATOR

The session was conducted in the following manner: an agenda was first adopted to organize and facilitate the discussions. The objective was then discussed and adopted. A brainstorming session was then held to allow the participants an opportunity to suggest broad R&D categories that should be discussed. The broad categories were then combined and refined. Within each category, specific R&D needs were identified. Selection criteria were then discussed and adopted for identification, selection, and prioritization of these R&D needs. A voting/selection process was adopted wherein each participant was allowed to select three topics he considered of greatest importance in each broad category.

Agenda

- Objective
- Develop Broad Categories
- R&D Needs - brainstorm
- Develop Selection criteria
- Prioritize R&D in each area

Objective

- Identify what R&D is needed to help industry address and respond to environmental concerns and regulatory mandates in a cost-effective manner.

Major R&D Categories

A brainstormed list of major R&D categories in the environmental area was developed after discussion; the final list was considered to incorporate the major environmental concerns of the industry.

- Air emissions
- Waste water
- Solid waste
- Remediation
- Risk assessment
- Health & safety

- Products
- Basic science/measurements

Criteria for Selection of R&D

A list of R&D needs was developed within each broad category. A method to prioritize these needs was based on using the following selection criteria.

- Need for regulatory acceptance
- Timing
- Industry -wide application
- Few proprietary issues
- Cost
- Type of research
- Skills of DOE
- Importance/significance
- Probability of success (implementation)
- Incorporates public concerns

Major R&D Categories

- Air emissions
- Waste water
- Solid waste
- Remediation
- Risk assessment
- Health & safety
- Products

Using the selection criteria, each individual was allowed to vote for three of the R&D needs in each category. The following received the greatest number of votes:

Air Emissions

- Scientific basis of future requirements
- Modeling
- Risk assessment
- Process for selecting/evaluating MACT

- Gathering emissions data

Waste Water

- Waste water toxicity (definition; determination, rapid screening)
- Purification/separation
- Risk assessment
- Wastewater minimization
  - Zero discharge

Solid Waste

- Recycling/re-use in regulatory framework
- Risk assessment
- Catalyst disposal/handling/regeneration
- Additional listing

Remediation

- Site specific risk assessment
- Site closure issues
- Enhancement of natural biodegradation

Risk Assessment

- Overall process
- Education
- Standardized methods

Products

- Life-cycle analysis of alternative fuels
- Engine combustion technology
- Atmospheric chemistry
- Asphalt product quality

Health & Safety

- Risk assessment
- Measurement technology
- Explosion prevention protection
- Risk Assessment - catastrophic releases

Basic Science/Measurements

- Atmospheric chemistry fundamentals
- Fate of refined product pollutants
- Biodegradation mechanism

QUESTIONS, COMMENTS, AND ISSUES RAISED BY PARTICIPANTS IN THE BREAKOUT SESSION

The deliberations in this session focused on a wide range of research topics and resulted in the selection and prioritization of the research topics outlined above. No attempt was made to record all the comments, questions and issues raised relative to the individual R&D areas. Therefore, the comments, questions and issues presented below are intended to reflect discussions of other topics during the session.

- Is the objective adopted wide enough; what about environmental concerns that affect competitive positions?
- We need to look at the whole picture and not compartmentalize our environmental concerns to air and water. The thrust should be on overall protection of human and nonhuman health
- Where do you draw the envelope? Once you start worrying about everything where do you stop?
- How do you force people to invest in MACT when the technologies will be out of date in a few years and are usually capital-intensive. Refiners will try to stay out because they are concerned about becoming the MACT standard
- There is a need to do risk assessment in advance of and in anticipation of what is likely to evolve in future regulations.
- Environmental R&D should be pursued first because these are less proprietary problems and it directly addresses public concerns
- There are time problems getting something into place as shown by the PERF work. Technical agreement is relatively easy. Working together is more difficult
- How can new money jump-start the program?
- There is a priority need to get risk assessment down cold to evaluate the polution equipment already installed. This would be better than pursuing a better mousetrap
- In developing an industry-DOE collaboration program, one needs to paint as broad a canvas in environmental technology as possible; you may only find a good match in a few areas. Environmental R&D is the only shot for the industry

BREAKOUT SESSION ON

ENABLING TECHNOLOGY DEVELOPMENT

Facilitator: W.J. (Bill) Hillier
(The M.W. Kellogg Company)

SUMMATION OF THE DISCUSSIONS/DELIBERATIONS OF THE BREAKOUT SESSION BY THE FACILITATOR

In addition to identifying and prioritizing R&D areas of interest to the industry, the participants in this session also addressed a number of issues impacting implementation of a (DOE-Industry) collaborative program. The key conclusions, recommendations, and issues raised are as follows:

Current Industry Attitude

- Industry appears to be ready to work with DOE
  - downsizing has occured with lower budgets for research
- Industry is prepared to work together collectively in noncompetitive areas, e.g., environmenta R&D
  - work in such areas viewed as directly helping industry at a time when pressures are intense to make a profit
  - individually industry companies can and are pursuing collaborative R&D with National Labs in competitive areas
- Industry would like to leverage resources
  - labs and industry each have unique people and skills to bring to the table as well as specialized equipment to assist in the development effort
- Mechanism for working together is not clear
  - industry is not sure of the programs and the restrictions that these programs have built into them
- Industry expects National Labs to be competitive
  - if labs are not competitve industry would not be willing to use them
- Industry needs to sell ROF development programs to DOE

Critical Issues

- Control of technology
  - some countries in the world do not value intellectual property and never simply copy (steal) new technology after it is first applied in that country.

- inability to protect trade secrets can result in a decision no to do research

- Fighting patents can be very costly and time consuming
- Control of intellectual property rights
  - DOE needs to help industry
- Use of National Labs
  - some labs are transitioning from military R&D to peace time projects
  - how does industry take advantage of this expertise in the labs
- The model for moving the ROF initiative forward is not clear; some possibilities are as shown:
  - PERF
  - USCAR
  - CRADA
  - Textile program (AMTEX)

Specific Action Items (Recommended)

- National Labs need to market their capabilities, both people and equipment
  - industry is not sure what capabilities exist in the National Labs
- DOE needs to help sort out any intellectual property rights issues
- DOE needs to send industry information on CRADAs
- DOE needs to consider sponsoring a 1/2 day workshop on programs, etc.
  - industry is not knowledgable about ongoing programs not how to access them
- DOE should convene a meeting to decide on mechanisms and major areas of interest

Definition of Enabling Technologies

- Generally precompetitive in nature
  - available industry-wide
- Can be used in a number of processes (technologies)
- Fits in between basic science and process development
- Encompasses (for example):

- catalytic science
- combustion
- separation science
- knowledge-based control system
- process monitoring and analysis

Enabling Technology Development Objectives

An attempt was made to define what was meant by enabling technologies. It was felt that these technologies bridge across many industries and processes and in most cases are not of a competitive nature

- Generally precompetitive in nature
  - available industry wide
- Can be used in a number of processes (technologies)
- Fits in between basic science and process development
- Encompasses (for example):
  - catalytic science
  - combustion
  - separation science
  - knowledge-based control system
  - process monitoring and analysis

Enabling Technology Development Objectives

In order to progress, it is important to develop a more fundamental understanding that can move an idea from the basic science level to the process development level. The fundamental understanding will include some of the practical aspects of the technology.

- Knowledge and data used for development and analysis of novel and advanced processes
- Development of analytical "tools" and data tat would benefit the entire industry

Types/Characteristics of Programs

- Need to prioritize
  - not possible to remain focused when there are too many projects spread over too few people
  - industry would like to participate actively in this process
- Need some early successes
  - success breeds success
- Some programs could be > 10 years

- current focus in industry is short term
- some programs take a long time to mature
- a few long term programs should be included
- longer term programs would probably require more seed money from DOE

- Environmental programs are a logical choice for joint (collective) development
- Energy efficiency R&D
  - improved energy efficiency helps the competitive picture as well as the environmental picture.
- Alternative fuels
  - the national labs could help in the evaluation and development of alternate fuels.
- Raw material pretreatment
  - quality of raw materials is becoming poorer over time
  - sulfur, metas and nitrogen, itc is slowly increasing
  - processes to treat crude at the wellhead could become attractive
- Programs should have clear objectives and deliverables
- Do not include licensed processes
  - strong feeling exists that joint (collective) development projects do not include licensed processes

Programs with High Interest

An attempt was made to develop a list of potential programs that the industry would have an interest in. Many companies in fact are already working in these areas in their own labs.

- Energy efficiency enhancements
- Catalysis
  - high interest exists in catalyst development
  - expectation is that catalyst development will help improve the efficiency of the industry
- Separation sciences
- Knowledged-based control systems, including advanced sensor technology
- Petrochemical reactor modeling
- Materials/reliability
  - improved materials that would allow a process to operate in a new envelope would be helpful especially if the reliability of

the plant is enhanced and this time between turnarounds is increased

- Sulfur chemistry
  - targeted at both the quality of the product as well as emissions from the plant
- coke processing
  - disposition of petroleum coke is a concern

The programs were prioritized by the group. The list would probably be ordered somewhat differently if done by say independent refiners versus major oil companies. Small independent companies do not have the resources to work in certain areas, e.g., catalysts or materials/reliability

Program Priorities	Votes
1. Energy efficiency	9
2. Separation sciences	9
3. Knowledged based control systems	8
4. Coke processing/utilization	7
5. Sulfur chemistry	6
6. Catalysis	3
7. Reactor modeling	1
8. Materials/Reliability	1

Conclusion

1. Industry feels there is a need to meet with DOE to develop a mechanism to work together

2. Programs should focus on noncompetitive areas

QUESTIONS, COMMENTS, AND ISSUES RAISED BY PARTICIPANTS DURING THE BREAKOUT SESSION

- There is a need to protect the benefits of technology development both domestically and internationally. Licensing fees do not cover true costs
- U.S. loses technology in three ways: the world steals the technology; it is kept as a trade secret (and then not used); the decision is made not to pursue technology development since it cannot be protected
- Technology can be patented but it takes a great deal of diligence to protect a patent, at a cost that most companies are unable or unwilling to accept
- Restricting (a collaborative program) to now-competitive areas limits National Labs involvement/contributions
- National Labs can and do work with industry on a single-client basis, and the results are protected in a number of ways, e.g., CRADAs wherever rights are based on cost sharing and decided upfront, work for others wherever 100% funding by industry protects the proprietary rights/data
- National Labs have about 100,000 staff and maintain substantive base load equipment and capabilities
- Industry does not know what the National Labs can do - DOE should act as a centralized contact point for Lab capabilities
- Do Labs have significant capabilities in refining? Can they supplement industry capabilities?
- Labs traditionally have had focus on technology development; they need to get a better understanding of commercial issues
- What is government role when government regulations are shaping the industry? The National Labs should investigate and/or develop the scientific basis for the regulations that are being promulgated
- There seems to be sentiment in the industry to leverage the capabilities of the National Labs
- A mechanism needs to be developed to allow companies to share costs
- A problem with the oil industry is that it has a long history of competitive relations; furthermore, antitrust has limited cooperation
- The oil industry must give DOE a strong message that it wants to have and it needs a collaborative program. Only then can money be

allocated to the refinery industry. Otherwise there will not be any matching funds

- Can a Refinery of the Future Program be defined that can benefit a broad range of companies in the industry? Probably in the following areas: environmental, alternative fuels and feedstocks, and energy management/reduction
- A collaborative program should have a long-term focus, but it needs some early successes
- If DOE's goal is to protect the U.S. refinery industry, maybe a focus on environmental R&D is appropriate since the environmental burden is so high
- Need to develop clear objectives that DOE, Labs and industry can agree on
- The Labs and DOE don't necessarily know what the industry needs; they need help to get objective and priorities
- Processes that are currently licensed are not likely to be candidates for a collaborative program
- Catalysis is an area that is of great interest to the industry; however, it is a highly competitive area and the Labs likely have little to contribute
- Group consensus: there is a need for a joint program with DOE

BREAKOUT SESSION

ON

PROCESS DEVELOPMENT/IMPROVEMENT

Facilitator: Ronnie D. Jackson
(Lion Oil Co.)

SUMMARY OF THE DISCUSSIONS/DELIBERATIONS OF THE BREAKOUT SESSION BY THE FACILITATOR

A broad array of topics were discussed. Strongly divergent views and opinions were expressed by the participants relative to what type of process development and what level of government involvement would be appropriate. Divergent views existed both within industry sectors (e.g., refiners) and between sectors (e.g., process developers vs refiners). Although there was a lack of broad consensus, in virtually all discussions there were a number of topics (process development activity areas) that generated a substantive level of support. These areas are listed below, essentially in order of degree of support. Comments relative to these areas are provided in the following section.

1. DOE-Industry to operate FCC user facility for process and environmental improvement

2. DOE/Nat. Lab/Industry partnership to operate (subcontract) fully integrated refinery for process and environmental improvement

3. Crude oil pretreatment technology

    - Biodesulfurization of crude and resid or feedstocks vs HDS

4. Nonintrusive inspection crossover study and research

5. Equipment reliability and design testing at shut-down military facilities

6. DOE to become clearinghouse for crossover technology, i.e., nuclear, steel

7. Odor and remote sensing devices

8. Evaluate membrane technology for refinery water reuse

9. Improved monitoring and control of processes

10 **PC-based operator training and simulation**

11. **Petroleum coke utilization study**

12. **FCC catalyst disposal and or reuse**

13. **Hydrogen from water**

QUESTIONS, COMMENTS, AND ISSUES RAISED BY PARTICIPANTS DURING BREAKOUT SESSIONS

The diversity and number of comments and opinions offered during the discussion precluded development of a definitive compilation of all the views expressed. An attempt has therefore been made to summarize in concise form the sense of the discussions on each item listed in the previous section, based on the limited notes taken. The comments are presented and correlated numerically with the topics outlined in the previous section.

1. FCC units produce about 1/3 of the total U.S. gasoline. There are a number of problems today even though FCC and catalyst development is the most competitive field in the industry. Emissions of SO_x and NO_x, product quality, yield optimization, particulates problems, and possible future catalyst disposal are examples of areas where further work is required. It was concluded that the DOE, with industry, could operate an FCC unit as a user facility that could be used by any company for process and environmental improvement R&D. The size of the unit that should be considered was not specified.

2. A partnership of DOE/National Labs/Industry could likewise acquire (or subcontract) and operate a 50,000 B/D integrated refinery for further process and environmental development/improvement and technology demonstration. The refinery could be used by the industry to test advanced components and concepts without incurring severe economic penalties.

   This concept had not been raised earlier in the ROF discussions, but relatively little objection was voiced to the idea during the discussions.

3. The activity discussed does not refer to "synfuels" but rather to removal of sulfur, nitrogen, aromatics, etc. The suggestion to pursue biotreatment as the approach generated considerable

interest and support. It was noted that this could be a long-term high-risk activity that individual companies cannot afford; also that Japan had a $\$50x10^6$ program. Both crude oils and residual fractions could be useful feedstocks. This research was cited as an example of an intractable area but one that the industry has no choice but to continue to revisit.

4. On-line inspection of operations was discussed, e.g., flow distribution inside vessels. Techniques developed for military and/or other industries may offer potential for refinery use. The National Laboratories may also have useful experience in these areas. Nondestructive testing of materials is likewise of interest.

5. Greater equipment rehabilitation and improved designs are the key to longer run-times and thus better economic performance. It was suggested that shut-down military facilities might be used to test different approaches, components, etc. to develop enhanced reliability.

6. DOE could serve as a clearinghouse of information relevant to refining, originating within the National Laboratories and in other disciplines and industries. Information developed in the nuclear, steel, and other industries may not be easily located by refiners. Such assistance would not only help the refiners but also enhance technology transfer.

7. Odor detection was raised as an important public relations issue. Equipment which could detect odors, and perhaps locate the source by triangulation, would enable fast corrective response. The discussion moved to other sensing devices and the need for better sensors in general, as a means of better on-line control.

9. Both site boundary and process stream monitoring need improvement. Discussion was generally supportive of work in this area, and no dissenting views emerged.

10. Refiners expect to incur large costs in pursuing Process Safety Management objectives as well as Process Hazard Analysis obligations. Modern PC computers have the capability to support training-emergency response operations, start-ups, shutdowns, etc. A standard format subscribed to and developed with DOE could save much time and expense. No dissenting views surfaced.

Note: The following three areas were considered to be of medium to low priority.

11. Concern was raised as to adequacy of markets for additional petroleum coke. A participant reported that their company's recent study indicated that a market will be available, especially in the Mediterranean cement plants. Further, their study indicated that even at low prices delayed coking remains economically viable. Another view expressed was that the likely area of expansion for coke utilization will be power generation. Additional views were that some exporters report considerable difficulty in moving coke and therefore major concerns exist about future market limitation.

12. Disposal of FCC catalyst is not presently a difficult issue. It was noted that FCC catalyst disposal in Europe is handled by requiring the vendor to take back spent catalyst. Concern was voiced, however, that if controls should be imposed in the U.S. we would wish that prior work had been done.

13. Hydrogen from water is recognized as a very desirable goal, but it is also recognized that much time and money has already been spent by other industries and governments on this problem It is doubtful as to whether the refining industry would be interested in providing financial support for developing speculative systems, e.g., use of large solar collectors.

Other Comments

- Many of the R&D problem areas that are being discussed are considered intractable. The industry has been working in these areas for years, e.g., biodesulfurization of crude petroleum coke utilization, etc. Perhaps DOE should undertake work in these areas.

- Another area where it would be appropriate for DOE to work is in development of concepts and technologies that could subsequently be applied by individual companies. In this case the application of the technology itself is of value, e.g. nonintrusive inspection technology.

- The industry has traditionally been very competitive. Any industry-wide-supported program developed must not intrude on this characterization. Therefore, process development/improvement must focus on noncompetitive areas. The ability of individual companies to compete must be preserved.

- Small groups of companies can and do join together to pursue technology development in order to share costs and risks; they also share in the commercial rewards according to agreements reached among themselves. Such groups can and have worked with individual National Laboratories to order to tap expertise that they do not possess. So it is possible to work on competitive projects wherein the individual companies do share in the costs and risks. The expertise in the National Labs is available to any organization pursuing commercial opportunities.

BREAKOUT SESSION

ON

FUNDAMENTAL SCIENCE/BASIC RESEARCH

Facilitator: Art Suchanek
(Criterion Catalyst Co.)

SUMMARY OF THE DISCUSSIONS/DELIBERATIONS OF THE BREAKOUT SESSION BY THE FACILITATOR

The goal of this session was to attempt to identify areas wherein additional basic research is needed to achieve a more fundamental understanding of critical phenomena, chemistry, etc., that in turn could lead to the development of improved, more efficient processes and technology. The degree of agreement reached between the session participants on particular topics is indicated by (C) general consensus; (M) mixed (split) opinions.

Areas of Opportunity

- Feedstocks
- Processing
- Products

Feedstocks of Interest

- Crudes
- Gas
- Shale
- Coal
- Coke
- Others
    - used oil, recyclables, etc.

Feedstock Research Needs

- First determine what data is available
  - extensive research done by "partners" (refinery companies) and DOE
    - *Will this data be made available and shared?
- Develop plan for further basic research after evaluation and analysis of data

Processing Research Needs

- Chemistry of heavy crudes, resids and other products (C)
  - S,N, Ar, metals, asphaltenes
  - Need to develop better understanding

    *reactions
    *behavior of catalysts
- Whole crude processing (knowing all of above) (C)
  - Wellhead pretreatment/integration
- Process synergies: Can Conditions of One Process Effect Another Process? (M)
  - primary & secondary processes
  - combined processing
- H_2 manufacture/management (Hydrogen will be in short supply) (C)
- Membrane and separation chemistry/materials (C)

- Catalysis/chemistry modeling (C)
- Materials/corrosion

Products Research Needs

- What causes emission problems: All fuels, refiners being told what to make, but not why (C)
  - Compare to natural gas

    *can you alter fuel to get comparable levels?
  - Can refinery be tweaked (to produce cleaner fuels)? Searching by understanding processing synergies
- Effects of oxygenates (on pollutant formation)
  - Can gasoline be changed to maximize positive aspects of oxygenates? No studies are definitive. Cause and efect studies are needed.
- Diesel Fuels - what is the right composition? We need to understand requirements.
  - Control pollutants
  - Combustion characteristics/composition relationships
- Coke, sulfur - profitable uses
- Analytical methodology - DOE ownership
- Fundamental chemistry understanding
- Cradle-to-grave resource recovery (life-cycle analysis)

Bang Statements (Conclusions and Issues)

- Oil is really a bunch of chemicals
- Oil industry and DOE data banks
    - Will they be available?
    - Industrial sponsor?
    - Confidential?
- Crudes, products, environment most likely areas for cooperation
- DOE - takes ownership (lead) of required (development of) analytical techniques
- Chemistry-catalysis-design = cost-effectiveness
    - Multidisciplined approach (needed)

SEARCH FOR SYNERGY!

QUESTIONS, COMMENTS, AND ISSUES RAISED BY PARTICIPANTS DURING THE BREAKOUT SESSION

- You don't have to develop entirely new processes to increase performance, efficiency, etc. Focus on what you have. The existing processes can be altered through developing a better understanding of what is going on. As an example, fundamental data and understanding can lead to an increase of reaction efficiency.

- Linear models used today are OK but they don't tell you how to tweak refinery operations to get better overall performance efficiency etc.

PLENARY SESSION

ON

NATIONAL LABORATORY CAPABILITIES

Session Chairman: **Bill Schertz**
(Argonne National Laboratory)

In response to the Workshop attendees' request, the slides used in the presentation of the Overview of National Laboratory Capabilities are attached. In addition, key comments made by the speaker are provided opposite each slide.

Additional information requested by the workshop attendees is also provided. A compilation of R&D activities currently under way at the National Laboratories that are relevant to the industry's interest and needs was developed and is summarized in Appendix A. For each laboratory the following is provided: 1) a listing of the titles of ongoing CRADAs (Collaborative Research and Development Agreements) and the industrial partner(s); 2) a list of industry-sponsored R&D activities (Non CRADAs), and 3) a list of R&D topics being pursued that are supported by DOE and/or other government agencies. The listings provide an indication of the breadth of R&D activities being pursued in the Labs. An interesting fact that emerged from development of the compilation is the number and value of ongoing industry-supported R&D programs in the nations Labs; also the major fraction of these activities appear to be competitive R&D area. The value of these ongoing programs is ≈ $82,000,000: the industry cost share is roughly one half of this amount. It is apparent that individual companies are accessing and utilizing expertise in the National Laboratories in pursuit of competitive R&D opportunities.

Appendix B is a matrix of National Laboratory capabilities in R&D areas that were described in the draft R&D Plan that was distributed to all workshop participants. The matrix was compiled from data provided by the laboratories. The depth of capability and expertise is identified and defined in the key. As is apparent, the Labs individually and/or cumulatively have strengths in many of the areas of interest to the industry.

The individual Lab symbols used on the matrix are as follows:

ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory

Lab Symbols (cont'd)

NIPER	National Institute of Petroleum & Energy Research
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNL	Pacific Northwest Laboratory
SNL	Sandia National Laboratory

Overview of DOE National Laboratory Capabilities to Assist in Refinery of Future Program

Houston, TX Feb. 14-15

William Schertz

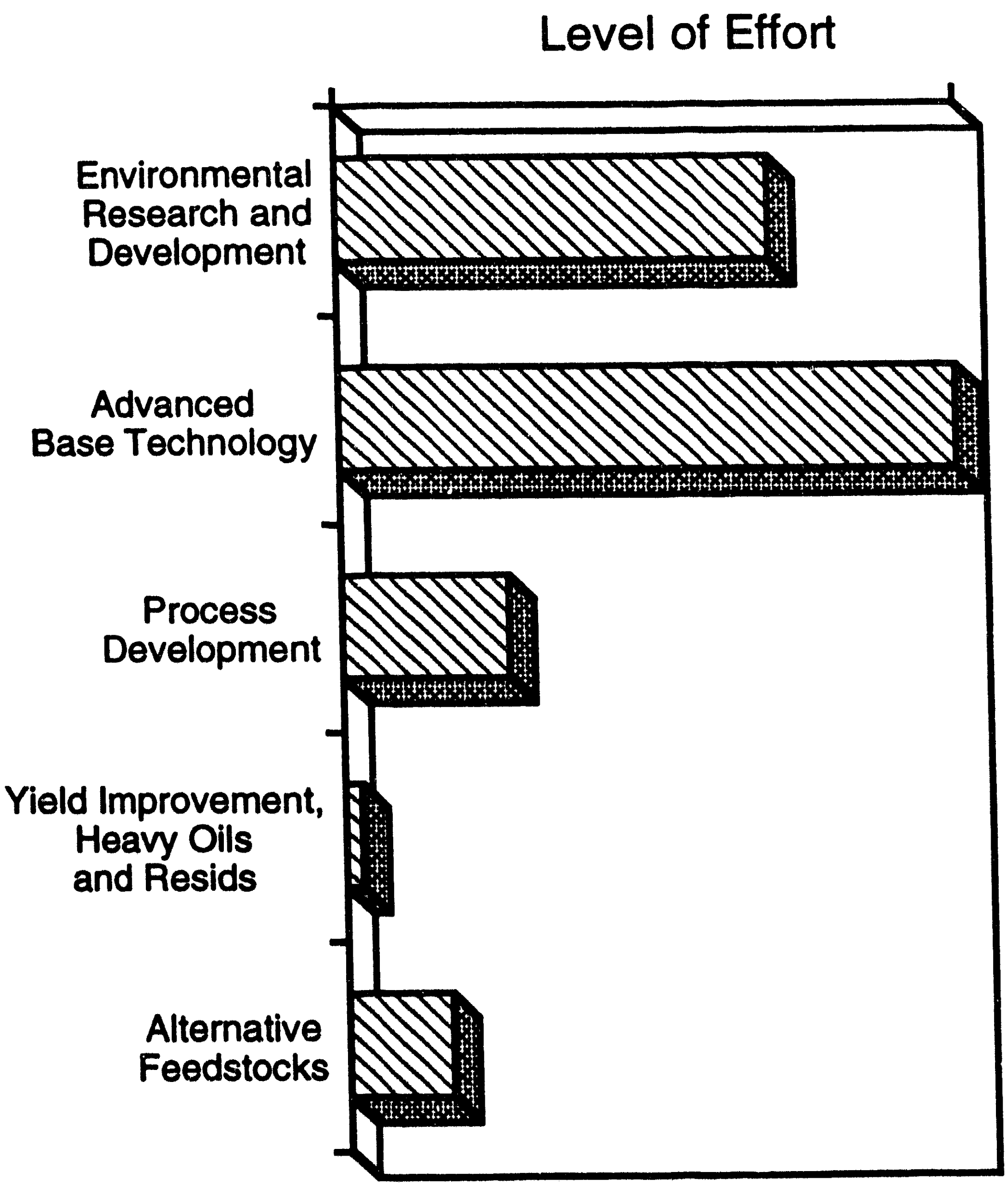
The Department of Energy National Laboratories are a Resource that can be Leveraged by the Oil Refinery Business for:

- Environmental research and development
- Advanced base technologies for process improvement
- Process development
- Yield improvement from heavy oils and crudes
- Alternative feedstocks

The National Laboratories that are operated by the Department of Energy have a number of capabilities that can be a resource that can be leveraged by the Refinery industry. This talk is organized by the 5 topical areas shown on this slide, which were taken from the draft program plan distributed to the participants of the workshop.

The laboratories have considerable expertise in some of the categories, and limited but applicable capabilities in others. This talk will concentrate on those areas of greatest potential contribution.

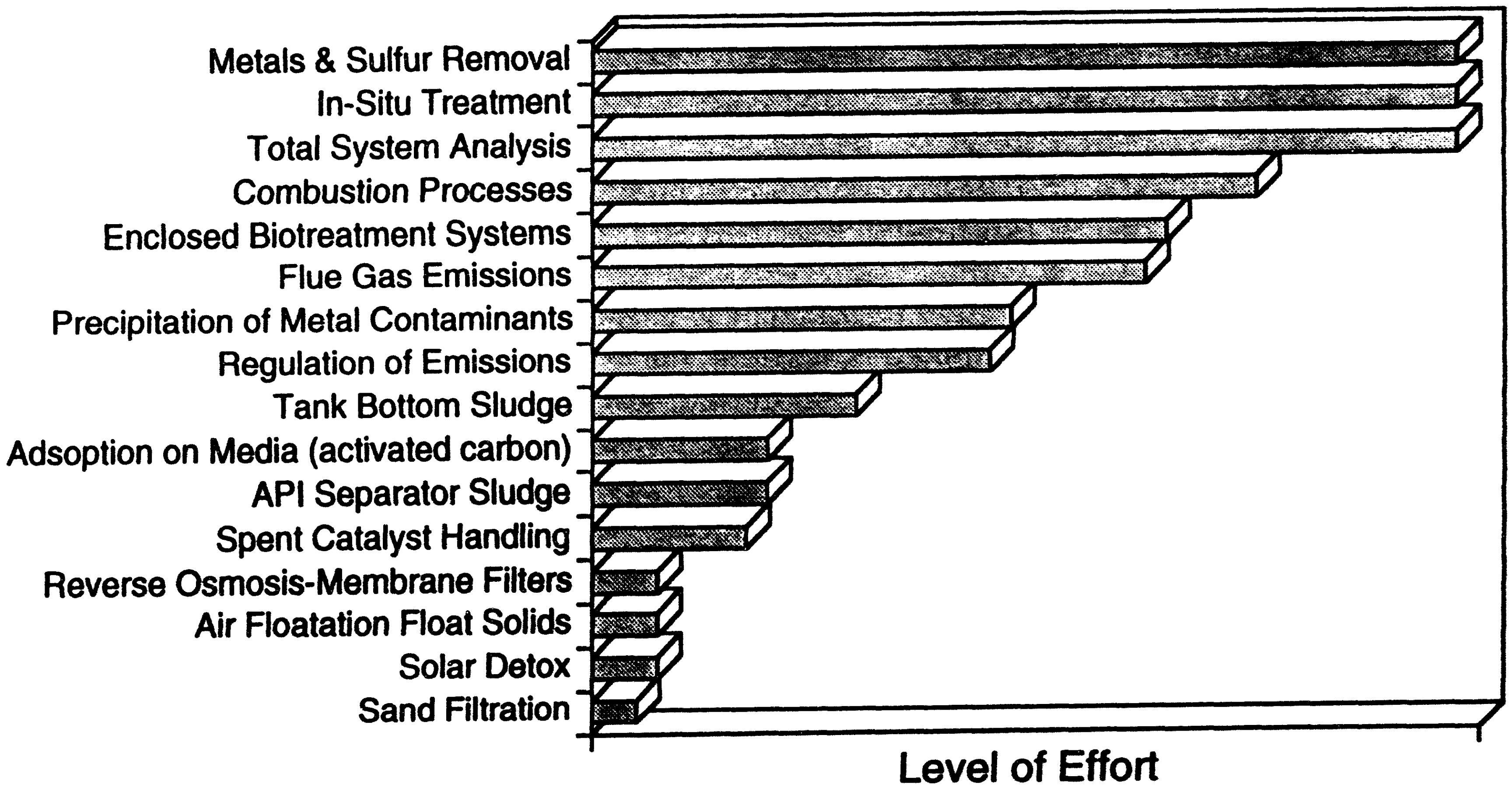
A Survey of Capabilities Shows Areas of Relative Strength in the DOE System



We performed a survey of the laboratories to determine those areas where they could contribute to the goals of the refinery program plan. This chart shows the relative levels of effort that has been expended over the last 5 years in the national laboratory system against the 5 main categories as identified in the program plan. The longest bar (Advanced Base Technology) represents over 2000 man-years of effort in research that is closely related or directly applicable to refinery operations and processes.

The bulk of this presentation will be devoted to the Environmental Research activities, and the Advanced Base Technology category.

Environmental Research and Development for DOE may be Applied to Refinery Problems



DOE has been conducting research in the area of environmental technologies for a number of years. This research was funded to address the problems faced by DOE and its contractors, but much of the R&D can have application to the problems facing oil refineries and other industrial operations.

The longest bars on this chart represent over 200 man-years of effort in this research technology. The categories that are shown are taken from the draft refinery program plan. Clearly the problems of metals and sulfur removal from aqueous streams is faced by many industries, and the solutions for one application may provide technology for another industry.

Due to the limited time for this presentation, only some of the more intense efforts will be described in more detail.

The Laboratories Have Developed Advanced Technologies for Removing Heavy Metals from Aqueous Streams

- Selective complexing agents
- Ion-exchange resins
- Liquid liquid extractions
- Biotreatment for solubilization or fixation of metals

The laboratories have done a considerable amount of work in developing advanced technologies for removing heavy metals from aqueous streams.

These include the development of selective organic complexing agents that can extract specific groups of metal ions from solutions containing common (Na^{+}, Ca^{++}, etc.) positive ions. This allows the stripping of heavy metals from solutions for recovery or disposal. This technology was developed in support of the nuclear fuel reprocessing capability that the laboratories have developed. Companies have been formed to offer the specialized ion selective complexing agents as a commercial product.

Selective ion-exchange materials have been developed. Some employ the complexing agents described above, others have been developed for trapping radioactive isotopes for disposal (see next slide)

Development of organic complexing agents to remove metal ions from solution requires the development of highly efficient liquid - liquid extraction techniques to contact the complexing agents with the aqueous stream, and effect efficient separation of the two phases. Details of some solutions to this problem will be described in this presentation.

Biotreatment processes for the solubilization or fixation of metal species have been developed in the laboratory system to handle effluents from geothermal produced waters and other applications.

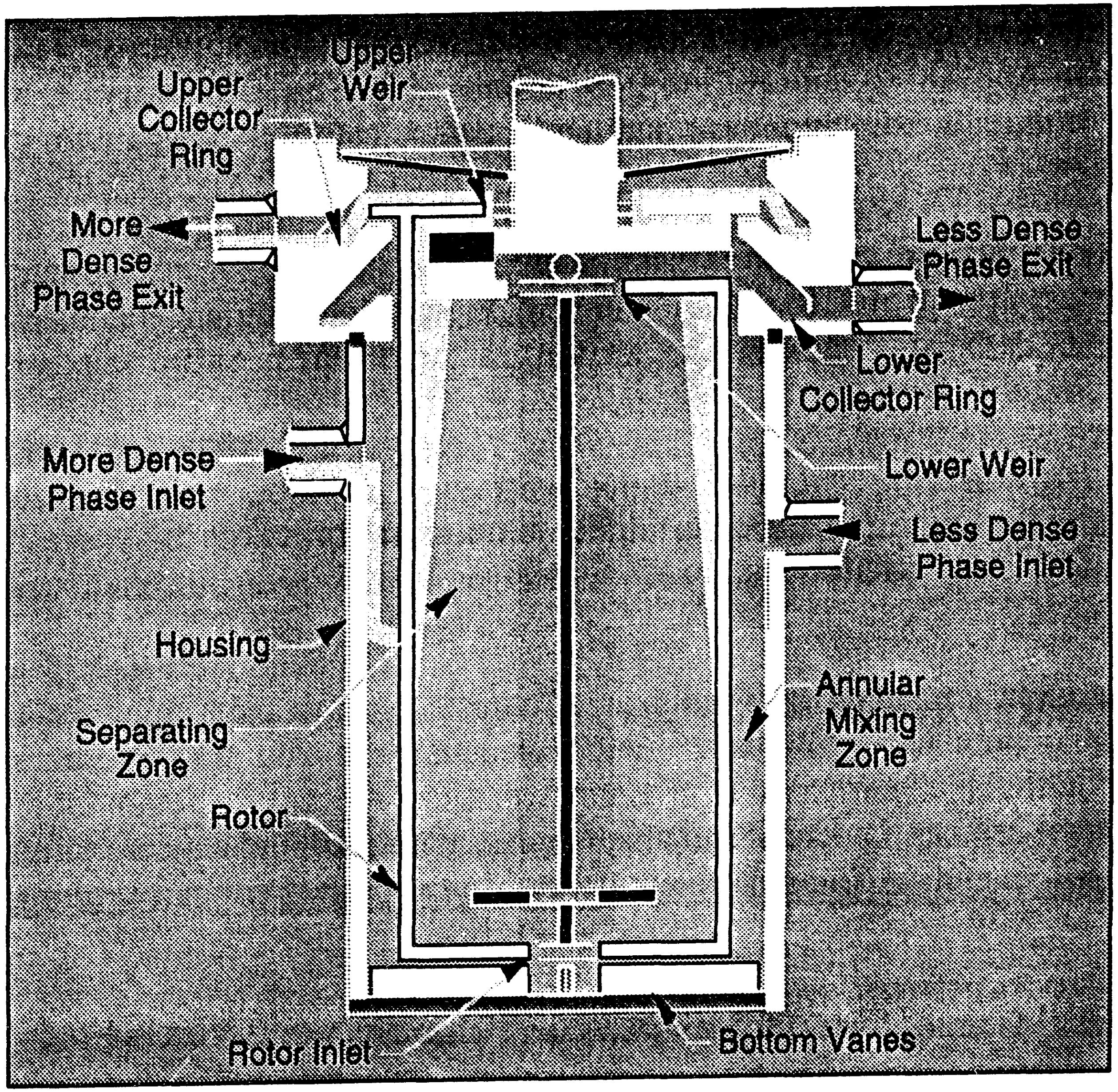
Specialized Ion-Exchange Gel Beads Have Been Developed for Liquid Waste Treatment

Laboratory researchers have developed a new method of liquid waste treatment based on the same principle behind common, in-home water purification systems. Using a process called "internal gelation", researchers have produced inorganic ion exchangers in the form of small, highly stable porous beads that exchange their non-hazardous, positively charged ion of sodium, potassium, or hydrogen for the ions of hazardous materials in solution.

This is a simple, but critical task, allowing for treatment of radioactive solutions at the source. In one step, the process removes more than 95 % of some ions in many cases, producing a liquid with a very low level of contamination. The beads, now loaded with radio nuclides or other waste, are dried at 200 degree Celsius and sealed in canister for disposal. They can be placed in storage, or made into glass through a process called vitrification. Heat treatment significantly reduces the possibility of contaminants leaking from the beads.

The beads have already proven more successful than the usual granulated or powdered ion exchangers in treating many waste streams.

Centrifugal Contactors Provide Rapid and Scalable Liquid-Liquid Extraction as Multi-Stage Units



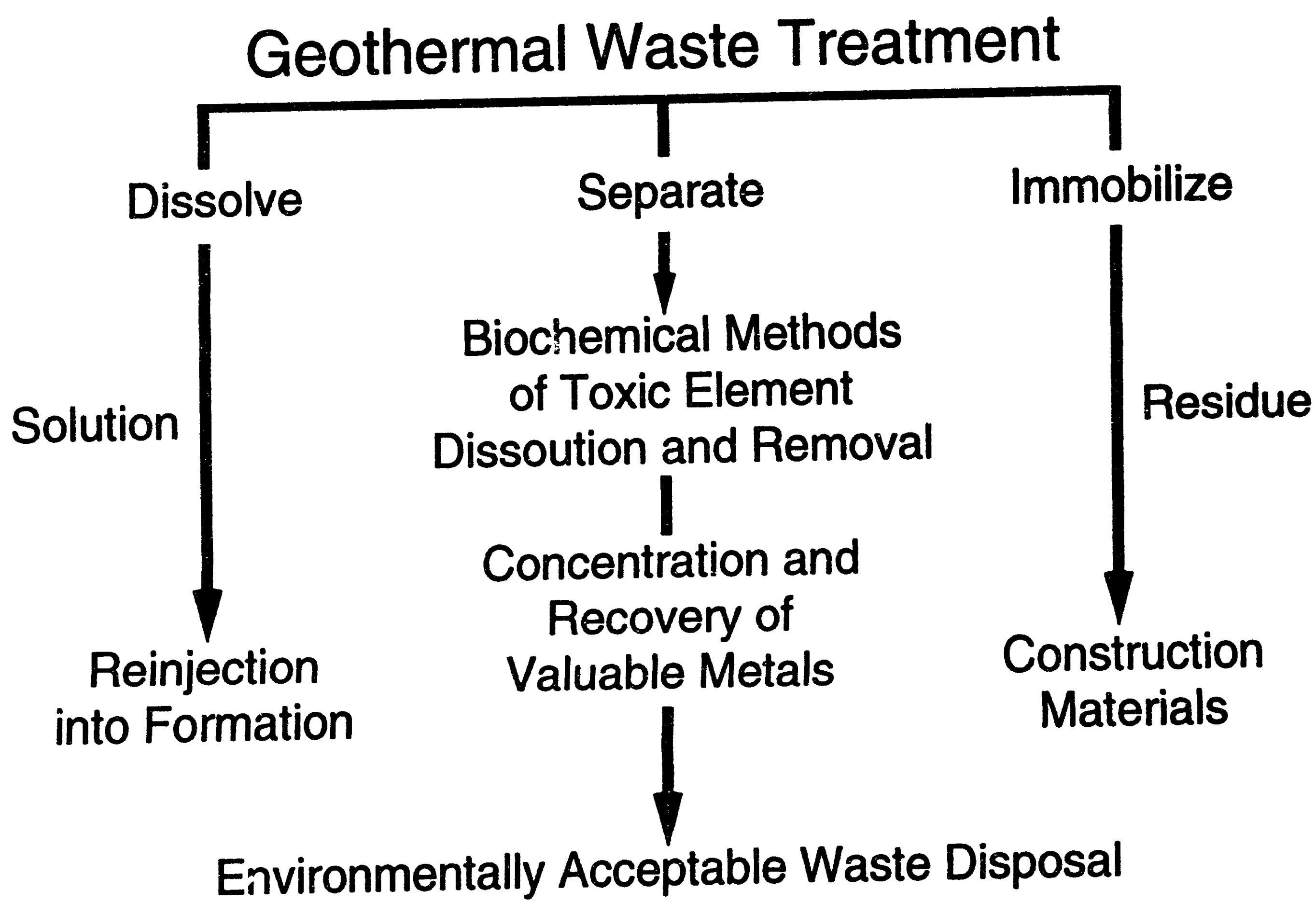
Liquid-liquid extraction is used extensively in the processing of nuclear fuels, with desired components being extracted from an aqueous phase by the use of selective organic complexing agents. To work efficiently, it is necessary to get rapid mixing for good mass transfer between the phases, and to then rapidly separate the phases. It is also desired to have an easy system to have multiple stages for achieving the desired degree of separation.

Centrifugal contactors have been developed to serve this purpose. The aqueous and organic phases are mixed in an annular region between the outer shell and the rapidly rotating inner cylinder. The shear action promotes intimate mixing, and hence, good mass transfer.

The liquid then flows to the inner portion of the cylinder, and is subjected to centrifugal forces that rapidly separate the emulsions back into an aqueous and an organic phase. These devices can be staged easily, to effect the equivalent of a multi-stage separation unit.

The contactors behave as "ideal stages" such that tests done on a laboratory sized unit 2-cm in diameter with a flow rate of 0.07 ml/min can be used to design a process for a 50 cm diameter unit capable of a throughput of 1000 liters/min.

Biotreatment Processes Have Been Developed for the Treatment of Metals in Geothermal Brines



In Geothermal energy systems, hot brines are brought to the surface that may contain up to 350,000 ppm of dissolved solids, and can lead to the generation of geo-thermal solid wastes in power plants. As a result, all of the solid waste produced must be analyzed for regulated metals for regulatory compliance. If found to be hazardous, it must be disposed of offsite in an approved waste management facility. This is increasingly expensive.

This research program, microorganisms have been identified that can interact with toxic metals found in geothermal residual brine sludges and can convert them into soluble species for subsequent reinjection or concentration. As shown in the slide, biochemical processes can dissolve, separate, or immobilize hazardous materials from geothermal wastes, then convert the by-products to useful forms.

The process has been shown to remove 80% of the metals in a 24 hour period, achieving a 60% savings in disposal costs.

The Laboratories Have Developed Innovative Technologies for In-Situ Cleanup of Contaminated Sites

- Rapid characterization of contaminant plumes through instrumentation
- Modeling of contaminant plumes
- In-situ and pumped slurry reactors
- Stripping and contaminant recovery
- Site restoration technologies