For the Instructor: Amoco Case Teaching Note

Purpose

Increasingly, decision-analysis techniques are being applied to decisions outside the traditional engineering and business spheres. These are designed to show students that decision analysis is an effective tool for complex environmental issues.

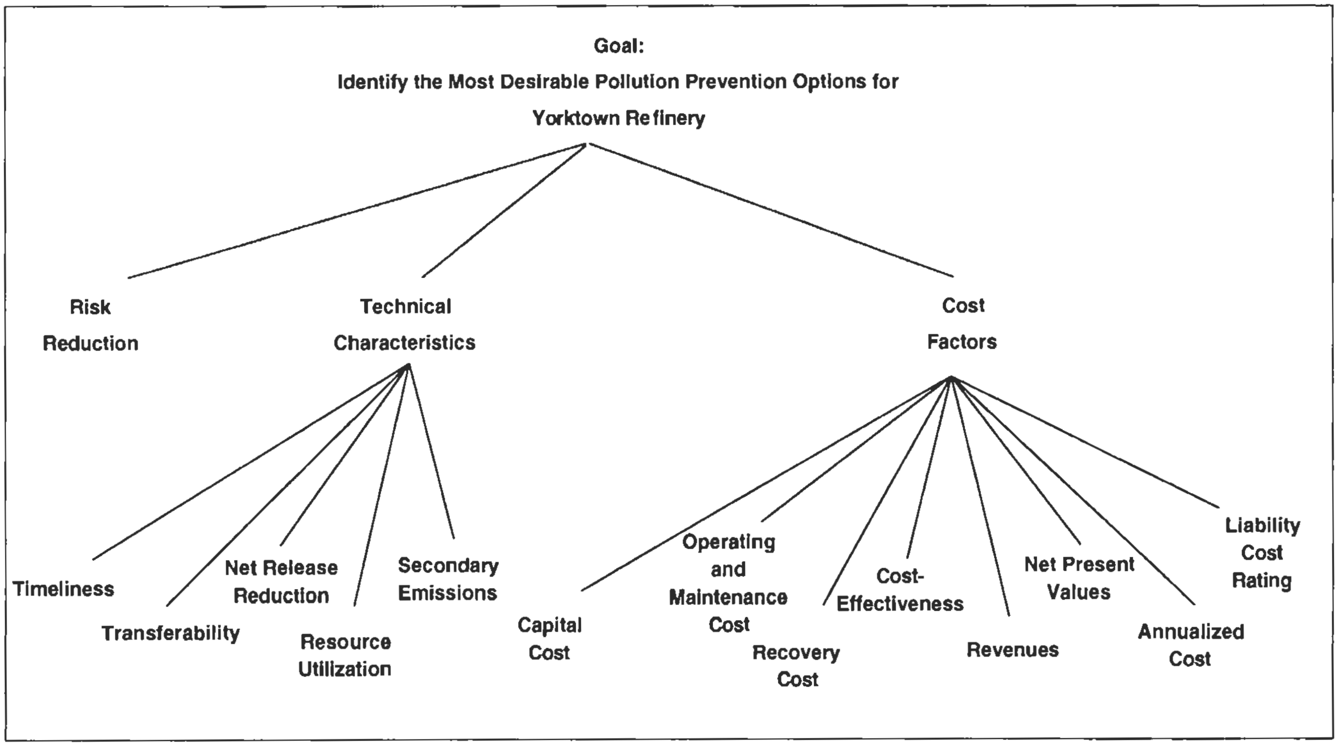
"Amoco and the Environmental Decision Analysis" is composed of two case studies. Case A briefly discusses the Analytical Hierarchy Process and presents criteria and option information on a pollution prevention project at Amoco's Yorktown refinery; included are discussion questions and exercises that allow students to develop a hierarchy and perform AHP computations. Case B investigates Amoco's use of the AHP in a pollution prevention project at its Yorktown refinery.

This material was designed for inclusion in an introductory Decision Analysis or Management Science course; it is appropriate for both MBA and industrial engineering students. It is recommended that you allow 50–80 minutes over two class periods, assigning Case A prior to the first class and Case B prior to the second class. Students should have some familiarity with the Analytical Hierarchy Process before undertaking this assignment.

National Pollution Prevention Center for Higher Education • University of Michigan
Dana Building, 430 East University, Ann Arbor MI 48109-1115
Phone: 313.764.1412 • Fax: 313.674.5841 • E-mail: nppc@umich.edu

Case A Exercise Answers

1. One possible criteria hierarchy:



2. Workshop member #1 developed the following priority weights.

    Risk Reduction: .763
    Cost: .063
    Technical Characteristics: .173

    Workshop member #2 developed the following priority weights.

    Risk Reduction: .111
    Cost: .333
    Technical Characteristics: .561

3. Assuming that students develop the following priority scores (and any weighting is acceptable),

	Risk	Cost	Tech
5c	.333	.204	.140
9	.069	.739	.287
11b	.598	.057	.564

and use the workshop members' priority weights, the following results:

.763 (.333) + .063 (.204) + .173 (.140) = .289
.763 (.069) + .063 (.739) + .173 (.287) = .149
.763 (.598) + .063 (.057) + .173 (.564) = .557

Therefore, choose 11b.

.111 (.333) + .333 (.204) + .561 (.140) = .183
.111 (.069) + .333 (.739) + .561 (.287) = .415
.111 (.598) + .333 (.057) + .561 (.564) = .402

Therefore, choose 9 or 11b.

4. One party viewed the reduction of risk as all-important, almost to the exclusion of the other factors, while the other viewed cost considerations as most important. Yet, even with these seemingly disparate perspectives, given the technical and financial attributes of Option 11b (quarterly LDAR program with a 10,000 ppm hydrocarbon leak level), an agreement can be reached to develop a pollution prevention alternative.

Case Study: Amoco and the Environmental Decision Analysis

The major part of this document is excerpted, with modifications, from the executive summary and project summary of Amoco–U.S. EPA Pollution Prevention Project, Yorktown, Virginia, *by Amoco Corporation and the U.S. Environmental Protection Agency. The Analytical Hierarchy Process subsection is by Leith Harmon, NPPC research assistant. The Case A discussion questions are by Martin Young, assistant professor at the U-M School of Business Administration. Harmon and Young collaborated on the Case A exercises. The NPPC thanks Amoco for granting permission to reproduce the text of this case.*

Introduction

Environmental issues are playing an increasing role in many firms' strategic, tactical, and operational activities. Regulatory pressure and public concern demand that manufacturing process wastes be dealt with effectively. Historically, industry has dealt with pollution using increasingly sophisticated and expensive methods of control, adding an ever-increasing, non-value-added component to a product's cost. In many cases, however, it may be more economical to *prevent* pollution, rather than try to control it after the fact.

To this end, in late 1989, Amoco Corporation and the United States Environmental Protection Agency began a voluntary, joint project to study pollution prevention opportunities at an industrial facility. EPA, Amoco, and Commonwealth of Virginia staff formed the Amoco/EPA Workgroup. This group conducted a multimedia assessment of releases to the environment at Amoco Oil Company's refinery at Yorktown, Virginia, and then developed and evaluated options to reduce those releases. To evaluate these options, the Workgroup used a decision analysis technique called the Analytical Hierarchy Process (AHP).

Case A discusses AHP and presents the Amoco/EPA criteria and options; Case B discusses the results of Amoco/EPA's application of AHP. Much of the work done in assessing releases (defining the Refinery Release Inventory), developing options, and reviewing implementation obstacles and incentives is beyond the scope of this case, and will not be covered as such.

Amoco/EPA Project Background

At the time the Amoco/EPA project began, pollution prevention was a concept predicated on reducing or eliminating releases of materials into the environment rather than managing the releases later. The Workgroup adopted this concept and agreed to consider all potential management opportunities: source reduction, recycling, treatment, and environmentally sound disposal. Since then, Congress (in passing the Pollution Prevention Act of 1990) and other organizations have put greater emphasis on source reduction as the primary, if not exclusive, means to prevent pollution.

A central goal of this project was to identify criteria and develop a ranking system for prioritizing environmental management opportunities that recognized a variety of factors: release reduction, technical feasibility, cost, environmental impact, human health risk, and risk reduction potential. Due to the inherent uncertainties in risk assessments, the project focused on relative changes in risk compared to current levels, rather than establishing absolute risk levels. Because of difficulties in quantifying changes in ecological impact from airborne emissions, changes in relative risk were based primarily on human health effects indicated by changes in exposure to benzene. The risk assessment did not quantitatively analyze volatile organic compounds (VOCs) due to limited information on their health effects. This Project focused on pollution and potential risks posed by normal operation of the Refinery and chronic exposure to its releases into the environment.

Case A: The Analytical Hierarchy Process, Selection Criteria, and Options

The Analytical Hierarchy Process

The Analytical Hierarchy Process addresses the issue of how to structure a complex situation in five steps.

1. Identify the overall goal and the important decision criteria. For the Amoco/EPA Project, the goal was to select the most effective pollution prevention options for the Refinery.
2. Organize the criteria into a hierarchical structure based on the relationships among criteria and the project objective.
3. Establish the relative significance (weight) of each criterion. This usually is accomplished by choosing pairs of criteria on the same hierarchical level and directly comparing them. The decisio-maker (in this case, the Workgroup) establishes the importance of one criteria relative to the other. All possible combinations of unique pairs at each level are compared. AHP then translates the pairwise comparison results into a relative weight for each criterion.
4. Evaluate each option within the context of the proposed hierarchy. Base the overall score for each option on its performance on the criteria in the hierarchy—this establishes a comparative ranking of options among themselves.
5. Adjust and/or revise the hierarchy on the basis of information acquired during the preceding steps in the decision-making process. Using sensitivity analyses, decision-makers can review the overall contributions of specific criteria and judgments to the final decision; how changes in criteria weights affect outcomes; or how changes in the hierarchical structure influence the decision. This review may lead to altered judgments and/or revised hierarchy.

AHP has been used in a variety of complex decisions. Examples include use by the U.S. Department of Energy to prioritize hazardous waste remedial efforts at federal energy facilities, use by the Regional Advisory Committee of the National Health Care Management Center to identify problem areas for research affecting health care in the U. S., and use for setting priorities in development of a transportation system for the Sudan.

The Analytical Hierarchy Process has been found to be a flexible model for solving problems — it allows individuals or groups to shape ideas and define problems by making their own assumptions and deriving the desired solution from them.

The Yorktown Refinery

Exhibit 1 shows a schematic diagram of the Refinery, potential release sources, and a number of pollution prevention options identified in this Project. **Exhibit 2** describes specific options to reduce releases.

Project Definitions

WORKGROUP

Monthly Workgroup meetings provided project oversight, a forum for presentations on different project components, and an opportunity for informally discussing differing viewpoints about environmental management. Although attendance varied, each meeting included representatives from various EPA offices, the Commonwealth of Virginia, and Amoco.

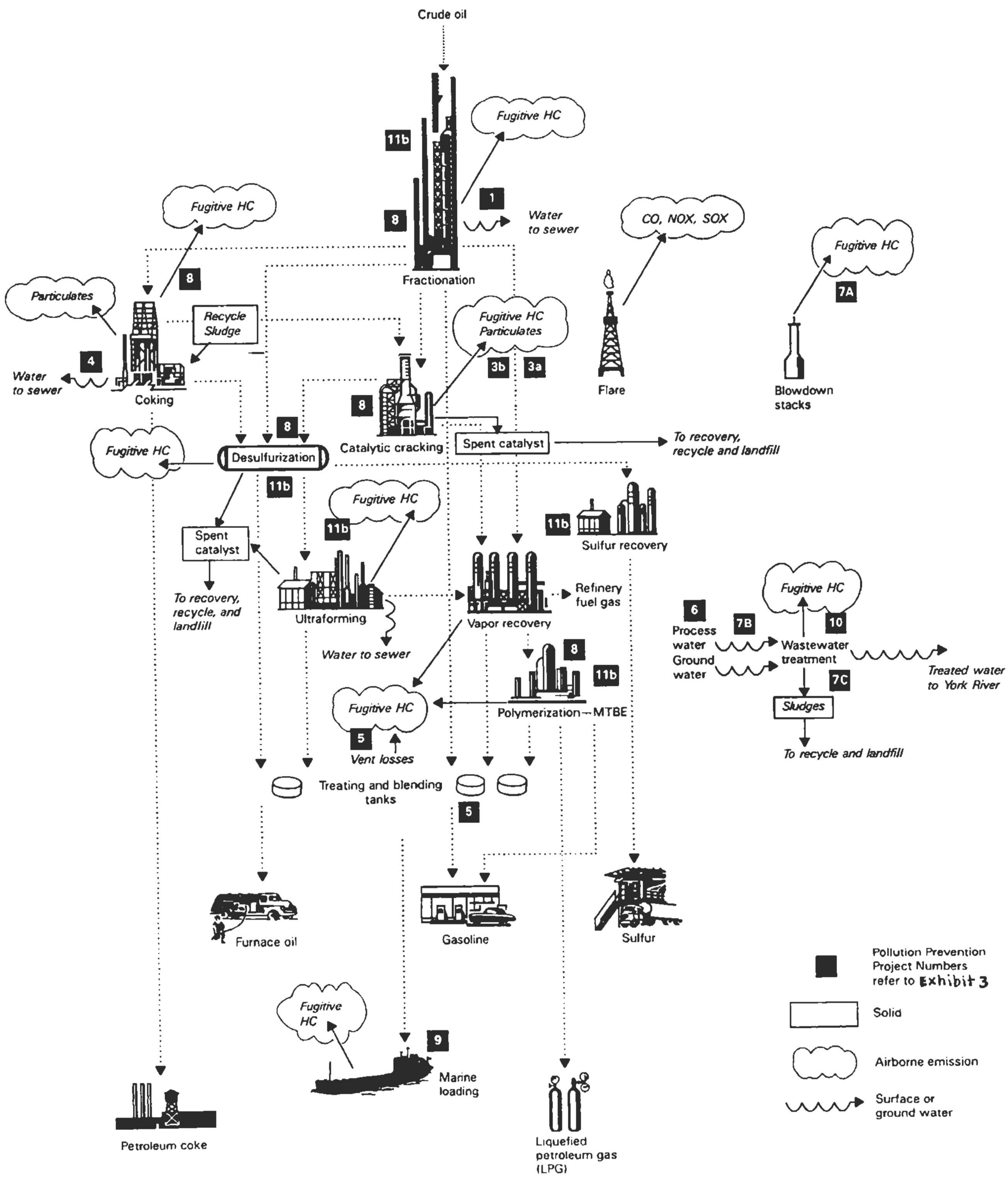
WORKSHOP

In March 1991, more than 120 representatives from EPA, Amoco, the Commonwealth of Virginia, and academic, environmental, and consulting organizations met for a three-day brainstorming Workshop in Williamsburg, Virginia. Workshop sessions included both a structured review of process synthesis techniques and a more free-wheeling discussion of ideas, resulting in suggestions that further refined and directed Project activities. Participants reviewed sampling data and considered ranking criteria, permitting issues, and obstacles and incentives for implementation. They developed a variety of release reduction options and proposed more than 50 concepts for further consideration, covering energy conservation (affecting criteria pollutant releases), volatile hydrocarbon controls, solid waste, groundwater, and surface water streams.

PEER REVIEW

At the Workgroup's request, Resources for the Future organized a group of outside scientific and technical experts. This Peer Review Group provided evaluation and advice on the project workplan, sampling, analytical results, and conclusions. The EPA paid members of this group small honoraria for their participation and reimbursed them for travel expenses to Washington.

EXHIBIT 1: SIMPLIFIED FLOW DIAGRAM OF AMOCO'S YORKTOWN REFINERY



PARTICIPANTS

More than 200 people, 35 organizations, and many disciplines have been involved in this project.

COST

Total cost for this project was approximately $2.3 million. Amoco Oil Company provided 70 percent of the funding and EPA the remainder.

Criteria

The Workshop participants identified and organized the following criteria into an analytical hierarchy:

- **Risk Reduction:** Changes in relative risk were based primarily on human health effects indicated by changes in exposure to benzene.
- **Capital Cost:** Cost estimates with a ±25 percent accuracy were made for these scoping studies. Additional engineering effort would be required to prepare an estimate with the ±10 percent accuracy typically needed for management approval.
- **Operating and Maintenance Cost:** Costs were estimated as a percentage of total capital cost and option complexity. Depending upon the option, this cost varied between three and six percent of total capital. It also includes depreciation, taxes, insurance, and other indirect costs.
- **Recovery Cost:** For liquid hydrocarbons or VOC emissions, the equivalent annual cost was divided by the net release reduction volume to determine an average $/gallon for each option. This number is equivalent to the price which would have to be charged per gallon of recovered material to recover capital, operating, maintenance, and distribution costs.
- **Cost-Effectiveness:** The equivalent annualized cost was divided by the net release reduction to determine a $/ton cost effectiveness for all options.
- **Revenues:** Revenues were estimated for those options where salable materials were recovered. The quantity of recovered material was equivalent to the emissions reduction. All recovered hydrocarbons were valued as gasoline at $0.75/gallon, with an average density of 6.5 lbs/gallon.
- **Net Present Values:** Present value of all cash flow, including initial capital, operating expenses, taxes, depreciation, indirect costs, revenues, etc.
- **Annualized Cost:** These costs were estimated as the sum of annualized capital costs and all variable expenses. Future costs were discounted at 10 percent (or 15 percent) to determine their present value, assuming a option life of 15 years.
- **Liability Cost Rating:** Each option was evaluated qualitatively for its potential to affect future remediation, catastrophic, and product-quality liability concerns.
- **Timeliness:** The number of years needed to complete each option was estimated, subject to current equipment maintenance schedules and operating limitations.
- **Transferability:** Qualitative assessment of the ability to use the option technology within other refineries and other industries was made.
- **Net Release Reduction:** Estimates of emissions reduction (tons/year) vary in accuracy. Additional emissions sampling and more detailed engineering analysis would be needed to improve these estimates. Where possible, generation and transfer of releases in other media were included in estimating the "net" change in release. Within the release reduction criteria, one or more of the pollution prevention modes in the pollution prevention hierarchy was assigned based on review, discussion, and consensus among Workgroup members. These classifications were not obvious in several cases and required extended debate.
- **Resource Utilization:** Qualitative estimates were developed for each option's effect on raw materials and utilities requirements.
- **Effects on Secondary Emissions:** The impacts of each option on other emissions were judged qualitatively. For example, increased power requirements would normally increase emissions in utility systems.

Ranking and prioritizing these options required specific, quantitative (and sometimes qualitative data) about each choice.

EXHIBIT 2: SELECTED POLLUTION PREVENTION PROJECT OPTIONS

The following options were identified for further study as a result of the March 1991 Workshop and subsequent Workgroup meetings.

1. **Reroute Desalter Effluent.** Hot desalter effluent water currently flows into the process water drainage system at Combination unit. This option would install a new line and route this stream directly to the API Separator. This process lowers sewer temperature and oil content. Volatile losses at the API Separator increase slightly.

3a. **Replace FCU Cyclones.** Assess potential for reducing emissions of catalyst fines (PM10) by adding new cyclones in the regenerator.

3b. **Install Electrostatic Precipitator at FCU.** Assess the potential of electrostatic precipitator in reducing catalyst fines (PM10) emissions.

4. **Eliminate Coker Blowdown Pond.** Change operating procedures for coke drum quench and cooldown so that an open pond is no longer needed. This reduces volatile losses from the hot blowdown water.

5a. **Secondary Seals on Gasoline Tanks.** Install secondary rim-mounted seals on tanks containing gasoline.

5b. **Secondary Seals on Gasoline and Distillate Tanks.** Install secondary rim-mounted seals on tanks containing gasoline and distillate material.

5c. **Secondary Seals in <u>all</u> Floating Roof Tanks.** Install secondary rim-mounted seals on all floating roof tanks.

5d. **Option 5c + Internal Floaters Fixed Roof Tanks.** Install secondary rim-mounted seals on floating roof with a primary seal in all fixed roof tanks.

5e. **Option 5d + Secondary Seals on Fixed Roof Tanks.** Install secondary rim-mounted seals on all floating roof tanks and then install a floating roof with a primary and secondary seal on all fixed roof tanks.

6. **Keep Soils out of Sewers.** Use road sweeper to remove dirt from roadways and concrete areas which would otherwise blow or be washed into the drainage system. Develop and install new sewer boxes designed to reduce soil movement into sewer system, particularly from Tankfarm area. Estimate cost for installation on a Refinery-wide basis. Both items reduce soil infiltration, in turn reducing hazardous solid waste generation.

7a. **Convert Blowdown Stacks.** Replace existing atmospheric blowdown stacks with flares. This reduces untreated hydrocarbon losses to the atmosphere but creates criteria pollutants.

7b. **Drainage System Upgrade.** Install above-grade, pressurized sewers, segregating storm water and process water systems.

7c. **Upgrade Process Water Treatment Plant.** Replace API Separator with a covered gravity separator and air floatation system. Capture hydrocarbon vapors from both units.

8. **Modify Sampling Systems.** Install flow-through sampling stations (speed loops) where required on a refinery-wide basis. These replace existing sampling stations and would reduce oil load in the sewer or drained to the deck.

9. **Reduce Barge-Loading Emissions.** Estimate cost to install a marine vapor loss control system. Consider both vapor recovery and destruction in a flare.

10. **Sour Water System Improvements.** Sour water is the most likely source of Refinery odor problems. Follow up on options previously identified by Linnhoff-March engineering to reduce sour water production, and improve sour water stripping.

11. **Institute LDAR Program.** Institute a leak detection and repair (LDAR) program for fugitive emissions from process equipment (valves, flanges, pump seals, etc.). Consider costs and benefits of the following configurations:

    a. Annual LDAR Program with a 10,000 ppm hydrocarbon leak level

    b. Quarterly LDAR Program with a 10,000 ppm hydrocarbon leak level

    c. Quarterly LDAR Program with a 500 ppm hydrocarbon leak level

Options Identification and Analysis

After assembling the Refinery Release Inventory, the Workgroup identified potential process and operating changes that might impact these releases.

To meet option schedule and budget constraints, the Workgroup later selected 12 options for more detailed analysis. The options chosen were felt to: (1) be feasible with current technology, (2) offer significant potential for release reductions, (3) have manageable (or no) impact on worker safety concern, (4) be amenable to more quantitative analysis in the time available, and (5) address concerns in different environmental media.

Preliminary material balances and engineering designs were used to analyze each potential option. Some of this work was completed specifically for this option. Other portions were completed as part of environmental engineering work at Amoco for the Refinery.

Important characteristics of the 12 options, and their alternatives, are summarized in **Exhibit 3**. For three options — 3, 5, and 11 — only one of the several alternatives considered would be implemented.

Two options reduce solid wastes (catalyst fines and listed hazardous wastes), while the remaining 10 focus on air emissions (VOC, HC, H_2S, and NH_3); five employ source reduction to reduce releases. Capital costs range from a low of \$10,000 to a high of \$22,500,000. Annual costs, based on discounting capital, operating, and maintenance costs at a 10-percent discount rate, range from \$30,000 to \$7,400,000.

EXHIBIT 3: IMPORTANT CHARACTERISTICS OF THE 12 OPTIONS AND THEIR ALTERNATIVES

#	Project	Pollu-tant	PP Mode	Rel. red'n. (tons/yr)	Cap. Inv. ($MM)	An. Cost ($MM)	Cost-effect. ($/ton)	Recov. Cost ($/gal)	Benz Expos. Red'n %	Cost-effect. BER $M/% Expos. Red'n	Statu-tory Pro-gram	Exp. Year Compl.	Impl. time (yrs)
1	Reroute desalter effluent	VOC	R	52	1.00	0.33	6,279	21.00	1	329			1–3
3a	Replace FCU cyclones	catalyst fines	R, D	245	8.30	3.03	12,363	-	0				4–7
3b	Install FCU ESP	catalyst fines	D	442	9.10	3.58	8,106	-	0				4–7
4	Eliminate blowdown coker	VOC	SR	130	2.00	0.63	4,862	16.00	2	316	RCRA/ CAA	1994	1–3
5a	Secondary seals on gas tanks	VOC	SR	475	0.26	0.09	190	0.65	18	5	MACT, ozone	1994	>7
5b	Secondary seals on gas & distribution tanks	VOC	SR	482	0.32	0.11	232	0.74	18	6	MACT, ozone	1994	>7
5c	Secondary seals on floating roof tanks	VOC	SR	541	0.45	0.16	287	0.93	18	9	MACT, ozone	1994	>7
5d	5c + fixed roof tank internal floaters	VOC	SR	592	1.83	0.64	1,077	3.51	18	35	MACT, ozone	1994	>7
5e	5d + fixed roof tank secondary seals	VOC	SR	592	2.00	0.70	1,179	3.34	20	35	MACT, ozone	1994	>7
6	Keep soils out of sewers	Listed HW	SR	530	0.34	0.20	383	-	0				4–7
7a	Upgrade blowdown	VOC	T	5,096	5.10	1.63	320	1.04	11	148	BzNE-SHAP	1993	4–7
7b	Upgrade drainage system	VOC	T	113	18.80	5.94	52,809	171.00	5	1,188	ozone	1994	1–3
7c	Upgrade process water treatment	VOC	T	58	22.50	7.40	127,638	415.00	5	1,481	BzNE-SHAP	1993	1–3
8	Modify sampling system	VOC/HC	SR	63	0.08	0.03	429	1.39	0		ozone	1995	4–7
9	Reduce barge loading losses	VOC	R	768	4.70	1.61	2,094	7.00	55	29	BzNE-SHAP	1994	1–3
10	Improve sour water system	H2S, NH3	R,T	18	0.06	0.20	11,056	-	0		ozone		1–3
11a	Annual LDAR (10,000 ppm)	VOC	R, T	320	0.01	0.09	288	0.94	2	46	MACT or HON	1994	<1
11b	Quarterly LDAR (10,000 ppm)	VOC	SR	511	0.01	0.14	270	0.88	3	46	MACT, ozone	1994	<1
11c	Quarterly LDAR (500 ppm)	VOC	SR	706	0.01	0.20	276	0.90	3	46	ozone	1994	<1

D=disposal, R= recycle, SR=source reduction, T=treatment
NESHAP=National Emission Standards for Hazardous Air Pollutants

Case A Exercises

1. Structure the criteria discussed in the case into a . sensible hierarchy.

2. Two workshop members developed pairwise preferences for the following criteria:

Workshop member 1:

Criteria	Risk	Cost	Tech
Risk	1	9	7
Cost	$^1/_9$	1	$^1/_4$
Tech	$^1/_7$	4	1

Workshop member 2:

Criteria	Risk	Cost	Tech
Risk	1	$^1/_7$	$^1/_3$
Cost	7	1	$^1/_4$
Tech	3	4	1

Compute the priority weights for each criterion.

3. Using Options 5c, 9, and 11b from Exhibit 2, and information from Exhibit 3, develop pairwise comparison matrices for the options. Compute the overall scores for each decision alternative (using the workshop members' priority weights).

4. Draw conclusions from the computations.

Case A Discussion Questions

What decision does the AHP analysis suggest?

What are the numbers to which the analysis is most sensitive? (e.g., if the estimate of cost for option 5c is increased by $1,000, does the final conclusion change?)

What do you think are the major criteria and why?

Case B: Results of Applying AHP to the Amoco/EPA Project

Single Criterion Ranking Methods and Results

This section describes the process the Amoco/EPA team used to rank pollution prevention options. Important characteristics of the 12 options, and their alternatives, are summarized in **Exhibit 3**. For three options — 3, 5, and 11 — only one of the several alternatives considered would be implemented.

As mentioned in Case A, two options reduce solid wastes (catalyst fines and listed hazardous wastes), while the remaining 10 focus on air emissions (VOC, HC, H_2S, and NH_3); five employ source reduction to reduce releases. Capital costs range from a low of $10,000 to a high of $22,500,000. Annual costs, based on discounting capital, operating, and maintenance costs at a 10-percent discount rate, range from $30,000 to $7,400,000.

Members of the Peer Review Committee suggested that the options be ranked according to a single criterion, such as risk reduction. In addition to risk reduction, two other single criterion rankings are of interest: total release reduction and cost.

EXPOSURE REDUCTION

Since the risk assessment is still being conducted, a risk proxy of benzene exposure at a nearby residence was used to finish ranking the options. Benzene concentrations calculated at a nearby residence were assumed to reasonably indicate population exposure and the exposure reactions achievable by implementing a particular option. Several rankings were produced using this measure and the option characteristics developed by Amoco engineers (**Exhibit 3**).

The second set of columns in **Exhibit 4** shows the ranks resulting from using benzene exposure reduction as the sole criterion for valuing the options. Reducing barge-loading emissions is the outstanding option using this criterion — no other option comes close. The other ranking values provide insight into which options generally provide greater exposure reduction. For example, all secondary seal alternatives achieve significant exposure reduction, and the blowdown system upgrade also performs effectively in this regard. Four options achieve no benzene exposure reduction because these options deal with release sources that do not emit benzene.

EXHIBIT 4: SINGLE CRITERION RANKINGS BASED ON RELEASE AND EXPOSURE REDUCTION

		Release Reduction	
Rank	#	Project	ton/yr
1	7a	Upgrade blowdown system	5,096
2	9	Reduce barge loading losses	768
3	11c	Quarterly LDAR (500 ppm)	706
4	5e	5d + fixed roof tank sec. seals	592
5	5d	5c + fixed roof tank int. floaters	592
6	5c	Sec. seals on floating roof tanks	541
7	6	Keep soils out of sewers	530
8	11b	Quarterly LDAR (10,000 ppm)	511
9	5b	Sec. seals on gas & dist.tanks	482
10	5a	Sec. seals on gas tanks	475
11	3b	Install FCU ESP	442
12	11a	Annual LDAR (10,000 ppm)	320
13	3a	Replace FCU cyclones	245
14	4	Eliminate blowdown coker pond	130
15	7b	Upgrade drainage system	113
16	8	Modify sampling system	63
17	7c	Upgrade proc. water treatment	58
18	1	Reroute desalter effluent	52
19	10	Improve sour water system	18

		Exposure Reduction	
Rank	#	Project	%
1	9	Reduce barge loading losses	55
2	5e	5d + fixed roof tank sec. seals	20
3	5a	Sec. seals on gas tanks	18
3	5b	Sec. seals on gas & dist.tanks	18
3	5c	Sec. seals on floating roof tanks	18
3	5d	5c + fixed roof tank int. floaters	18
7	7a	Upgrade blowdown system	11
8	7b	Upgrade drainage system	5
8	7c	Upgrade proc. water treatment	5
10	11b	Quarterly LDAR (10,000 ppm)	3
10	11c	Quarterly LDAR (500 ppm)	3
12	4	Eliminate blowdown coker pond	2
12	11a	Annual LDAR (10,000 ppm)	2
14	1	Reroute desalter effluent	1
15	6	Keep soils out of sewers	0
15	8	Modify sampling system	0
15	10	Improve sour water system	0
15	3a	Replace FCU cyclones	0
15	3b	Install FCU ESP	0

The rankings are intended to provide an approximate guide to which options rank near the top with regard to certain criteria and which rank near the bottom. On this basis, the preferred options are those that consistently rank near the top across all criteria felt by the decision-maker to be important. Options that receive comparable scores during the ranking process should be considered equivalent independent of their rank. For example, from an exposure reduction perspective, **Exhibit 4** indicates that (a) controlling barge-loading emissions is the best single action; (b) installing secondary seals and implementing an upgrade of the blowdown stacks also will achieve beneficial exposure reductions; and (c) the remaining options achieve minimal or no reduction in benzene exposure.

RELEASE REDUCTION

The results obtained when pollution prevention options are ranked by extent of release reduction are shown in the first set of columns of **Exhibit 4.** Upgrading the blowdown stacks is a clear winner, reducing releases more than six times as much as the nearest competitor; the remaining options diminish gradually in terms of release reduction. All of the highest ranked release reduction options — blowdown stack upgrade, barge loadings, quarterly LDAR program (500 ppm), and double seals on tanks — also rank at the top in terms of exposure reduction.

COST

It is interesting to compare the exposure reduction and release reduction results with the ranking based on cost, shown in the first set of columns of **Exhibit 5.** In this case, modifying the sampling procedure is the best option, costing three times less than its closest competitor. Comparing this result with the results based on exposure reduction and release reduction, modifying sampling ranked near the bottom with respect to these other criteria. On the other hand, two options ranked highly with regard to exposure reduction and release reduction — (secondary seals and quarterly LDAR 500 ppm) — also rank well with respect to costs. Barge loading and blowdown system upgrade, which rank near the top from the exposure reduction and release reduction respectively, rank near the bottom from the cost perspective. Based on these three single criterion rankings, the secondary seals and quarterly LDAR options look promising, and, if sufficient funding is available, barge loading and the blowdown system upgrade may be promising as well.

EXHIBIT 5: SINGLE-CRITERION RANKINGS BASED ON ANNUALIZED COSTS AND NET ANNUAL CASH FLOW

Annualized Costs				Net Cost			
Rank	#	Project	Annualized cost (in $MM)	Rank	#	Project	Net ann. cash flow (in $/T)
1	8	Modify sampling system	0.03	1	11b	Quarterly LDAR (10,000 ppm)	-4
2	5a	Sec. seals on gas tanks	0.09	2	11a	Annual LDAR (10,000 ppm)	-2
3	11a	Annual LDAR (10,000 ppm)	0.09	3	5a	Sec. seals on gas tanks	-1
4	5b	Sec. seals on gas & dist.tanks	0.11	4	11c	Quarterly LDAR (500 ppm)	-1
5	11b	Quarterly LDAR (10,000 ppm)	0.14	5	8	Modify sampling system	5
6	5c	Sec. seals on floating roof tanks	0.16	6	5b	Sec. seals on gas & dist.tanks	10
7	6	Keep soils out of sewers	0.20	7	6	Keep soils out of sewers	17
8	10	Improve sour water system	0.20	8	5c	Sec. seals on floating roof tanks	30
9	11c	Quarterly LDAR (500 ppm)	0.20	9	10	Improve sour water system	110
10	1	Reroute desalter effluent	0.33	10	1	Reroute desalter effluent	131
11	4	Eliminate blowdown coker pond	0.63	11	5d	5c + fixed roof tank int. floaters	242
12	5d	5c + fixed roof tank int. floaters	0.64	12	4	Eliminate blowdown coker pond	246
13	5e	5d + fixed roof tank sec. seals	0.70	13	5e	5d + fixed roof tank sec. seals	281
14	9	Reduce barge loading losses	1.61	14	9	Reduce barge loading losses	568
15	7a	Upgrade blowdown system	1.63	15	7a	Upgrade blowdown system	734
16	3a	Replace FCU cyclones	3.03	16	3a	Replace FCU cyclones	1,158
17	3b	Install FCU ESP	3.58	17	3b	Install FCU ESP	1,548
18	7b	Upgrade drainage system	5.94	18	7b	Upgrade drainage system	2,467
19	7c	Upgrade process water	7.40	19	7c	Upgrade process water	3,120

Exhibit 5 provides annualized cost and net annual cash flow information for each option. The two numbers differ because the net annual cash flow includes revenue generated through product recovery; the annualized cost values do not.

In viewing these rankings, it is important to remember that the capital cost estimates are within **25 percent**. Thus, values in the table are a best estimate, but have an unstated probable range. For example, the $90,000 annualized cost shown for modifying sampling systems (Option 8) has a range of $73,000 to $107,000. Similarly, the $632,000 annualized cost shown for eliminating the coker blowdown pond (Option 4) is the average of a range between $500,000 and $764,000. While it is possible to rank the options in the order shown, to find a distinction would be difficult, if not foolish, in practice.

Options 10 through 19 are ranked identically in both columns. These options have small or no product recovery revenues. Thus, no differences in ranking would be expected. The same group of options fall in the top half of both lists, although the order does change within each list. This is not unexpected, since a ranking based on the lowest cost would not necessarily coincide with a ranking based on the highest net annual cash flow. Options that generate income (primarily the LDAR programs and adding secondary seals to gasoline tanks) rank near the top of the list on a cash-flow basis. The top seven options that require least annualized cost to implement include modifying sampling systems and adding secondary seals to gasoline tanks (options that are also ranked near the top in the Net Cost column). This indicates that options that minimize annualized costs either generate income or minimize negative net annual cash flow.

Again, this ranking process provides a rough screen on the basis of one criteria, highlighting options that may merit further consideration and more detailed analysis.

OTHER CRITERIA

The decision-maker typically will augment rankings of the type established in this section by considering other criteria that have not been quantitatively evaluated. For example, institutional factors were originally included in the multiple criteria ranking process discussed below. When taking such institutional factors into account, a lower ranked option that significantly improves refinery odor or visibility performance might be elevated in rank if odor or visibility are of significant public concern in the region. Resource constraints are another important consideration. For example, some options may be precluded by their cost, or a group of options in the middle rank may, taken together, achieve better results at lower cost than the top ranked option. Such resource constraints may initially be addressed elsewhere, and a composite option then included in the multiple criteria ranking process as discussed below.

Multiple Criteria Ranking

Conducting a set of single criteria rankings and comparing results, as was done in the preceding section, lets the decision-maker quickly identify the more promising and least promising options. Often this provides sufficient perspective to proceed with in-depth evaluation of the more promising options.

In some cases, however, a more integrated multiple-criteria process is desired to help with selection. For example, the importance attributed to each criterion may be in dispute, and a systematic process may be needed to enable the decision makers to resolve these differences. In such cases, it is helpful to have a conceptual and computational framework for assessing the effect that alternative viewpoints have on the rankings. Usually, some differences can be put aside because they have limited effect on the rankings, and attention can be focused on those differences that do significantly affect the end result.

The Workgroup considered a number of multiple-criteria decision-making techniques for ranking options. The three approaches given greatest attention were: (1) the Analytical Hierarchy Process or AHP (Saaty, 1988 and 1990); (2) the Kepner-Tregoe approach (Kepner and Tregoe, 1979 and 1981), which Amoco has used in reviewing selected corporate decisions; and (3) Computation of Alternative Equivalents (Stokey and Zeckhauser, 1978), which a member of the Peer Review Committee suggested.

Ultimately, the Workgroup selected AHP as the ranking methodology, because it has proven useful in making decisions involving a large number of diverse criteria and options. As its name implies, AHP devotes a great deal of attention to the process by which the decision is made. Since the Amoco/EPA project involved a diversity of viewpoints at the federal, state, and industrial levels, a systematic process was needed for reaching a consensus or for identifying where and to what extent viewpoints differed. AHP provides such a framework:

it proceeds by using group discussion to identify criteria, organize them into a hierarchy that embodies relationships among the criteria, and establish priorities (i.e., criteria weights) with respect to an overall goal.

An initial list of criteria was generated from the project workplan and two brainstorming sessions at the Williamsburg Workshop. The project workplan provided overall perspective for criteria selection. Criteria identified at the Workshop provided a "base" list that was refined at subsequent Workgroup meetings. Initial criteria lists, broad in scope, were made more specific as the Workgroup gained knowledge about the characteristics of the options and the availability of data.

Through a process of elimination and refinement, the following criteria ultimately were selected for ranking options based on quantitative (and sometimes qualitative) assessment of the following characteristics:

Risk
- Relative benzene exposure reduction

Technical Characteristics
- Release reduction (mass)
- Status in pollution prevention management hierarchy (e.g., source reduction versus treatment)
- Transferability of option to other refineries/industries
- Timeliness of option implementation
- Secondary emissions

Cost Factors
- Resource utilization (raw materials and utilities)
- Capital, operating, and maintenance costs
- Effects of option implementation on potential remedial, product, and catastrophic liabilities.

Hierarchy structure was developed in parallel with refining the criteria list. The Workgroup identified relationships among criteria and constructed a hierarchy to represent these relationships. Within the hierarchical structure, each level is influenced only by the next higher level and can influence only the next lower level. The most general criteria contributing to achievement of the overall goal were identified as primary criteria or subgoals; these form the first level of hierarchy under the primary goal. Remaining criteria were grouped within these subgoal areas. Over the course of three iterations, the hierarchy evolved as Workgroup members gained information. **Exhibit 6** presents the hierarchy used to rank options.

To rank options, each criterion on the hierarchy must be assigned a relative weight. Developing weights

EXHIBIT 6: HIERARCHY AND CRITERIA WEIGHTS USED FOR RANKING

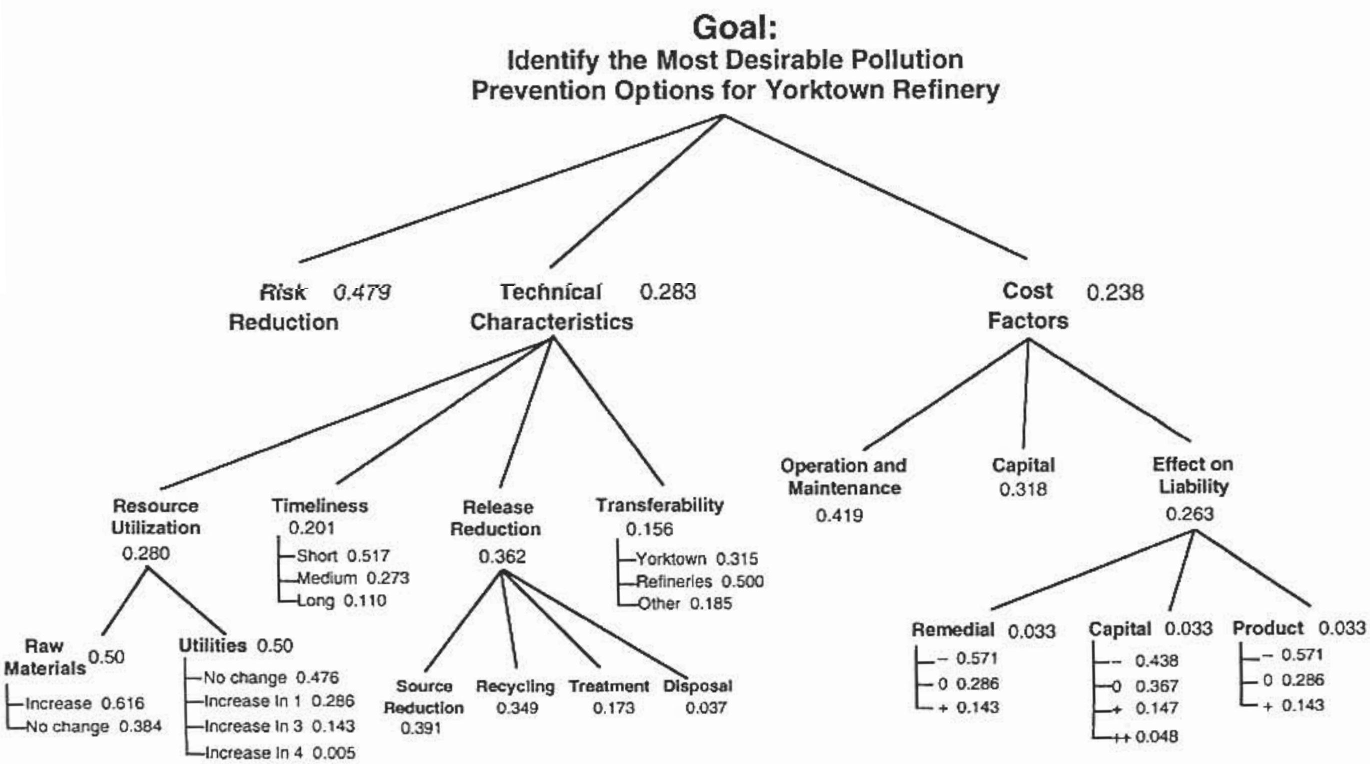
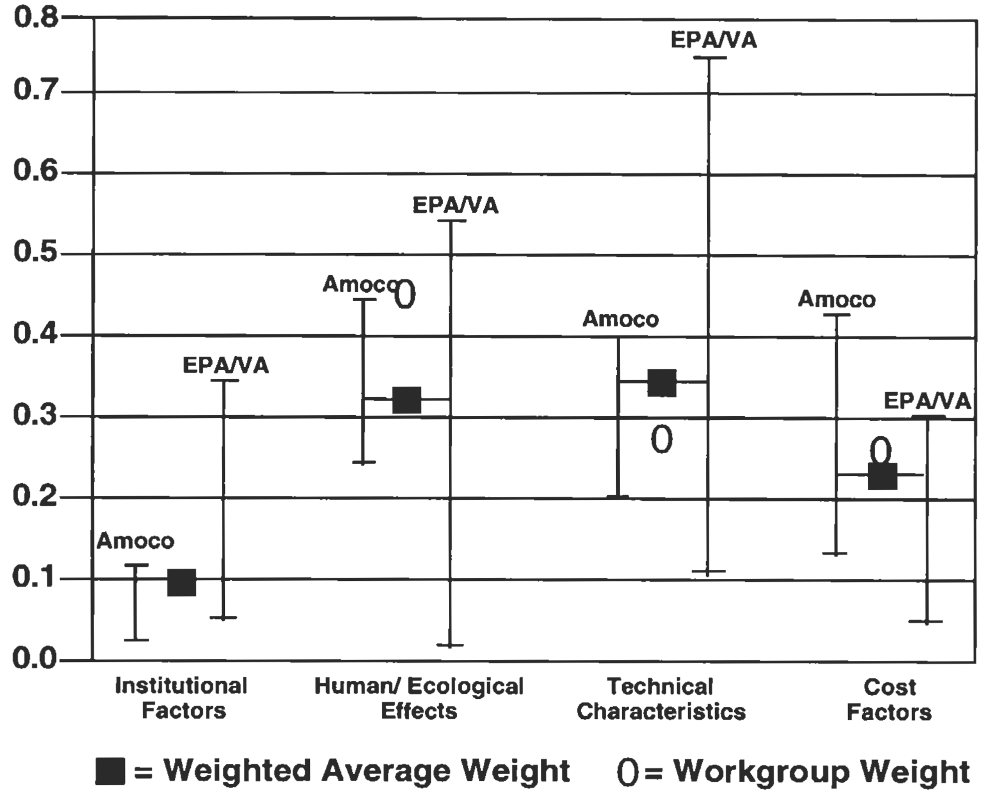


EXHIBIT 7: COMPARISON OF CRITERIA WEIGHTS



involved two steps: completing a survey of pairwise comparisons for each set of criteria, and convening an all-day session to review survey results and revise the criteria weights and hierarchy structure.

It is interesting to compare the weights proposed by the Amoco representatives with those proposed by EPA and state regulatory personnel. In three of four areas, the variability of proposed weights is much greater for the EPA/state personnel than for the Amoco representatives, and the spread of weights proposed by Amoco is nearly entirely encompassed within the spread of weights proposed by EPA and the state. **Exhibit 7** shows the weights proposed by each group and compares the weights obtained via the survey of individual respondents with weights established via extended discussion at a full-day Workgroup meeting, which were the principal weights used in the AHP analysis. The Workgroup placed greater emphasis on human/ ecological (risk) effects, less emphasis on technical characteristics and comparable weight on cost factors. Institutional factors were deleted as a ranking criterion, with the intent that these considerations be addressed external to the completed AHP ranking.

AHP Ranking Results

Exhibit 8 presents the results of the AHP ranking using the Workgroup's hierarchy and criteria weights. There appear to be three distinct groupings of options: most preferred, least preferred and a middle ground where no strong preference exists for one choice over another. Two major factors influenced the overall ranking of options — exposure reduction and cost. Technical characteristics determine the rankings within the mid- and low-performance groups.

The option of reducing barge-loading emissions, which achieves a 55 percent benzene exposure reduction, receives a ranking score more than two times greater than the next best option. The five mid-performance options (double seals, quarterly LDAR, sampling, blowdown system, and annual LDAR) have low to moderate costs and (except for sampling) a positive exposure reduction. The eight projects ranked lowest (drainage upgrade, treatment upgrade, reroute desalter, sour water improvements, soils out of drain, coke blowdown pond, install FCU ESP, and replace FCU cyclones) all have minor or no impact on the benzene exposure to the surrounding human population.

As discussed above, Amoco and EPA personnel proposed somewhat different weights for the AHP ranking criteria. AHP analyses were conducted to compare the results obtained using the criteria weights proposed by EPA and state Workgroup members to those suggested by Amoco. The results are presented in **Exhibit 9.** This analysis suggests how the options might be ranked from an industry outlook as compared with the ranking from a regulator's viewpoint. Despite differences in perspective, the results show that reducing barge-loading emissions is the preferred choice for both groups. In addition, while other options change order, the readjustments are minor. The average weights proposed by each group are shown at the bottom of the exhibit. Workgroup members from Amoco assigned nearly equal weights to all three categories, while EPA/state members assigned the highest weight to risk reduction, next highest weight to technical factors, and the lowest weight to cost.

Project Options and Regulatory Requirements

As indicated in **Exhibit 3,** eight of the 12 project options would, if implemented, contribute to meeting current or anticipated regulatory and statutory program requirements. The characteristics of these eight options are summarized in **Exhibit 10** (listed by compliance year). Legal requirements dictate that these options or equivalent be undertaken at the Refinery. The eight options, at an annual cost of $17,500,000, achieve a release reduction of 7,280 tons per year and a benzene exposure reduction equaling 99 percent of that associated with all 12 options.

For purposes of comparison, analyses were conducted to assess what options might be selected to achieve comparable release and exposure reduction objectives in the absence of the existing regulatory constraints. To avoid double-counting, a specific alternative was arbitrarily selected for those options involving multiple alternatives. The alternatives selected were 3b for FCU fines recovery, 5c for secondary seals, and 11b for LDAR. The goal in this analysis was to attain the desired environmental targets — release reduction or exposure reduction — at a lesser cost.

The 12 options are ranked in **Exhibit 11** with respect to cost-effectiveness of release reduction, expressed in dollars per ton. The results indicate that five options — 11b, 5c, 7a, 6, and 8 — are significantly more cost-effective with regard to release reduction. Taken together, these five options attain a release reduction of 6,741 tons per year at an annual cost of $2,160,000. When compared to the regulatory requirement options, the cost-effectiveness options attain more than 90 percent

EXHIBIT 8: AHP RANKING USING WORKGROUP WEIGHTS

Rank	#	Project	Score
1	9	Reduce barge loading losses	100
2	5a	Sec. seals on gas tanks	43
2	5b	Sec. seals on gas & dist.tanks	43
2	5c	Sec. seals on floating roof tanks	43
2	5e	5d + fixed roof tank sec. seals	43
6	5d	5c + fixed roof tank int. floaters	40
7	7a	Upgrade blowdown system	29
8	11c	Quarterly LDAR (500 ppm)	19
9	11b	Quarterly LDAR (10,000 ppm)	18
10	11a	Annual LDAR (10,000 ppm)	16
11	7b	Upgrade drainage system	13
12	4	Eliminate blowdown coker pond	12
12	7c	Upgrade proc. water treatment	12
14	1	Reroute desalter effluent	11
14	6	Keep soils out of sewers	11
14	8	Modify sampling system	11
17	10	Improve sour water system	10
18	3a	Replace FCU cyclones	5
18	3b	Install FCU ESP	5

EXHIBIT 9: COMPARISON OF AHP RANKING USING WORKGROUP WEIGHTS VS. AMOCO AND EPA WEIGHTS

WORKGROUP WEIGHTS				AMOCO WEIGHTS				EPA WEIGHTS			
Rank	#	Project	Score	Rank	#	Project	Score	Rank	#	Project	Score
1	9	Reduce barge loading losses	100	1	9	Reduce barge loading losses	100	1	9	Reduce barge loading losses	100
2	5a	Sec. seals on gas tanks	43	2	5a	Sec. seals on gas tanks	53	2	5e	5d + fixed roof tank sec. seals	44
2	5b	Sec. seals on gas and dist. tanks	43	2	5b	Sec. seals on gas and dist. tanks	53	2	5a	Sec. seals on gas tanks	43
2	5c	Sec. seals on floating roof tanks	43	2	5c	Sec. seals on floating roof tanks	53	2	5b	Sec. seals on gas and dist. tanks	43
2	5e	5d + fixed roof tank sec. seals	43	5	5e	5d + fixed roof tank sec. seals	49	2	5c	Sec. seals on floating roof tanks	43
6	5d	5c + fixed roof tank internal floaters	40	6	5d	5c + fixed roof tank internal floaters	46	6	5d	5c + fixed roof tank internal floaters	40
7	7a	Upgrade blowdown system	29	7	7a	Upgrade blowdown system	37	7	7a	Upgrade blowdown system	32
8	11c	Quarterly LDAR (500 ppm)	19	8	11c	Quarterly LDAR (500 ppm)	31	8	11c	Quarterly LDAR (500 ppm)	20
9	11b	Quarterly LDAR (10,000 ppm)	18	9	11b	Quarterly LDAR (10,000 ppm)	30	9	11b	Quarterly LDAR (10,000 ppm)	19
10	11a	Annual LDAR (10,000 ppm)	16	10	11a	Annual LDAR (10,000 ppm)	28	10	11a	Annual LDAR (10,000 ppm)	17
11	7b	Upgrade drainage system	13	11	4	Eliminate blowdown coker pond	21	11	7b	Upgrade drainage system	14
12	4	Eliminate blowdown coker pond	12	11	6	Keep soils out of sewers	21	12	4	Eliminate blowdown coker pond	13
12	7c	Upgrade process water treatment	12	11	8	Modify sampling system	21	12	7c	Upgrade process water treatment	13
14	1	Reroute desalter effluent	11	14	1	Reroute desalter effluent	20	14	1	Reroute desalter effluent	12
14	6	Keep soils out of sewers	11	15	10	Improve sour water system	19	14	6	Keep soils out of sewers	12
14	8	Modify sampling system	11	16	7b	Upgrade drainage system	16	14	8	Modify sampling system	11
17	10	Improve sour water system	10	16	7c	Upgrade process water treatment	16	17	10	Improve sour water system	10
18	3a	Replace FCU cyclones	5	18	3a	Replace FCU cyclones	10	18	3a	Replace FCU cyclones	6
18	3b	Install FCU ESP	5	19	3b	Install FCU ESP	9	18	3b	Install FCU ESP	6
CRITERIA WEIGHTS											
Risk reduction			0.479				0.30				0.421
Technical characteristics			0.283				0.376				0.394
Cost factors			0.238				0.324				0.185

of the release reduction at less than 15 percent of the annual cost. Adding Barge Loading Emission Reduction to the five most cost-effective options achieves 103 percent of the required tonnage reduction for just over a quarter of the annual cost.

The cost-effectiveness values in **Exhibit 11** do not include the potential revenue stream that could result from product recovery associated with source reduction and recycling activities. Including potential revenues in calculating a net cost effectiveness, results in the option ranking are shown in **Exhibit 12.** Because the revenue streams are relatively small for most options, the ranking changes very little: the option ranked highest — the Quarterly LDAR Program (Option 11b), which generates a positive cash flow and an estimated 19 percent rate of return —is the same in both tables, as are the options ranked 6 through 12. However, the ranking order for Options 2 through 5 does change somewhat. Installing secondary seals on all floating roof tanks (Option 5c) moves from the second choice to third. Upgrading blowdown stacks (Option 7A moves from third to fifth. Reducing soil intrusion into the sewer system (Option 6) moves from fourth to second.

EXHIBIT 10: REGULATORY REQUIREMENT OPTIONS

#	Project	Material	PP mode	Release reduct. ton/yr	Annual-ized cost $MM	Benzene Expos. Red'n %	Statuatory Program	Expect Compli-ance Year
7a	Blowdown Upgrade	VOC	treatment	5,096	1.63	11	BzNESHAP, non-at.	1993
7c	Treatment Pit Upgrade	VOC	treatment	58	7.40	5	BzNESHAP	1993
4	Elim. coker pond	VOC	s. red'n	130	0.63	2	RCRA/CAA	1994
5c	Sec. seals-all fltRfTk	VOC	s. red'n	541	0.16	18	MACT, Oz non-at.	1994
7b	Drainage Upgrade	VOC	treatment	113	5.94	5	BzNESHAP/stmwtr.	1994
9	Barge Loading	VOC	rec/treat	768	1.61	55	MACT, non-at.	1994
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	511	0.14	3	Oz non-at	1994
8	Modify Sampling	VOC/HC	s. red'n	63	0.03	0	MACTor HON	1995
	Total			**7,280**	**17.54**	**99**		

EXHIBIT 11: COST-EFFECTIVE RELEASE REDUCTION RANKING

#	Project	Material	PP mode	Release reduct. ton/yr	Cum. Rel. Red'n (tons/yr)	Annual-ized Cost $MM	Cum. Ann. Cost $M	Cost effective $/ton
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	511	511	0.14	0.14	270
5c	Sec. seals-all fltRfTk	VOC	s. red'n	541	1,052	0.16	0.3	287
7a	Blowdown Upgrade	VOC	treatment	5,096	6,148	1.63	1.93	320
6	Soils Control	listed HW	s. red'n	530	6,678	0.20	2.13	383
8	Modify Sampling	VOC/HC	s. red'n	63	6,741	0.03	2.16	429
9	Barge Loading	VOC	rec/treat	768	7,509	1.61	3.77	2,094
4	Elim. coker pond	VOC	s. red'n	130	7,639	0.63	4.4	4,862
1	Reroute desalter	VOC	recycle	52	7,691	0.33	4.73	6,279
3b	Install FCU ESP	Cat. fines	disposal	442	8,133	3.58	8.31	8,106
10	Sour water improvement	H2S, NH3	rec/treat	18	8,151	0.20	8.51	11,056
7b	Drainage Upgrade	VOC	treatment	113	8,264	5.94	14.45	52,809
7c	Treatment Pit Upgrade	VOC	treatment	58	8,322	7.40	21.85	127,638
	Total			**8322**		**21.85**		**2626**

A similar analysis is shown for exposure reduction in **Exhibit 13**. In this case, six options — 5c, 9, 11b, 7a, 4, & 1 — are much more cost-effective in terms of benzene exposure reduction, collectively attaining 90 percent benzene exposure reduction at an annualized cost of $4,500,000, which is about one-fifth the annualized cost of the regulatory requirements options.

The regulatory requirements shown in **Exhibit 10** have been or will be developed using administrative procedures. The regulatory development process includes review and comment opportunities for the public and for industry organizations. It is not the intent of the analysis presented here to critically assess all of those regulatory requirements, because the level of evaluative detail here is considerably less. The results presented above merely indicate the possibility that when the collective requirements of the regulations imposed on a given facility are taken into account, granting the industrial organization greater flexibility in how to achieve the designated standards may enable a facility attain standards at a significantly reduced cost.

EXHIBIT 12: COST-EFFECTIVENESS VS. NET CASH FLOW EFFECTIVENESS

		Cost-Effectiveness				Net Cash Flow Effectiveness	
Rank	**#**	**Project**	**$/ton**	**Rank**	**#**	**Project**	**$/ton**
1	11b	Quart LDAR (10,000 ppm)	270	1	11b	Quart LDAR (10,000 ppm)	-8
2	5c	Sec. seals-all fltRfTk	287	2	6	Soils Control	32
3	7a	Blowdown Upgrade	320	3	5c	Sec. seals-all fltRfTk	56
4	6	Soils Control	383	4	8	Modify Sampling	86
5	8	Modify Sampling	429	5	7a	Blowdown Upgrade	144
6	9	Barge Loading	2,094	6	9	Barge Loading	740
7	4	Elim. coker pond	4,862	7	4	Elim. coker pond	1,886
8	1	Reroute desalter	6,279	8	1	Reroute desalter	2,500
9	3b	Install FCU ESP	8,106	9	3b	Install FCU ESP	3,502
10	10	Sour water improvement	11,056	10	10	Sour water improvement	6,114
11	7b	Drainage Upgrade	52,809	11	7b	Drainage Upgrade	21,933
12	7c	Treatment Pit Upgrade	127,638	12	7c	Treatment Pit Upgrade	53,793

EXHIBIT 13: COST-EFFECTIVE BENZENE EXPOSURE REDUCTION RANKING

#	Project	Material	PP mode	Annual-ized Cost $MM	Cum. Ann. Cost $M	Bz Expos. Red'n %	Cost Eff. BzExRed $T/%BzE
5c	Sec. seals-all fltRfTk	VOC	s. red'n	0.16	0.16	18	9
9	Barge Loading	VOC	rec/treat	1.61	1.77	55	29
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	1.14	2.91	3	46
7a	Blowdown Upgrade	VOC	treatment	1.63	4.54	11	148
4	Elim. coker pond	VOC	s. red'n	0.63	5.17	2	316
1	Reroute desalter	VOC	recycle	0.33	5.50	1	329
7b	Drainage Upgrade	VOC	treatment	5.94	11.44	5	1,188
7c	Treatment Pit Upgrade	VOC	treatment	7.40	18.84	5	1,480
3b	Install FCU ESP	Cat. fines	disposal	3.58	22.42	0	
6	Soils Control	Listed HW	s. red'n	0.20	18.24	0	
8	Modify Sampling	VOC/HC	s. red'n	0.03	21.85	0	
10	Sour water improvement	H2S,NH3	treatment	0.20	18.04	0	
	Total			**22.85**		**100**	

EXHIBIT 14: OPTION SCORES BY RANKING TECHNIQUE

#	Project	Release reduction	Exposure Reduction	Cost	Cost-Effective Rel Red'n	Cost-Effective Exp Red'n	AHP
1	Reroute desalter				M	M	
3a	Replace FCU Cyclones						
3b	Install FCU ESP	M			M		
4	Elim. coker pond				M	M	
5a	Sec. seals-gas tks*	M	M	M	H	H	M
5b	Sec. seals-das/dist tks*	M	M	M	H	H	M
5c	Sec. seals-all fltRfTk*	M	M		H	H	M
5d	Opt 5c &flt on FixTk*						
5e	Opt 5d &S.seal FixTk*						
6	Soils Control	M		M	H		
7a	Blowdown Upgrade	H	M		H	M	M
7b	Drainage Upgrade						
7c	Treatment Pit Upgrade						
8	Modify Sampling			H	H		M
9	Barge Loading	M	H		M	H	H
10	Sour water improvement			M	M		
11a	Ann. LDAR (10,000 ppm)			M	H	H	M
11b	Quart LDAR (10,000 ppm)*	M		M	H	H	M
11c	Quart LDAR (500 ppm)*	M		M	H	H	M

Summary of Ranking Results

The scores achieved by each pollution prevention option under each of the ranking methods are summarized in **Exhibit 14**. Disregarding minor differences between option scores, the scores achieved under each method are grouped into high, medium, or low categories. Only the high (H) and medium (M) scores are shown; the absence of a score under a particular ranking method indicates that option received a low score for that method.

Those options (or alternatives) that received at least a high or medium score under all but one of the rankings are marked with an asterisk (*). These include all five double-seal alternatives, the blowdown system upgrade, barge loading emission reduction, and the two quarterly LDAR alternatives. By virtue of their consistently favorable ranking under a variety of perspectives, the Workgroup concluded that these four options show the most promise among the 12 considered. The three options faring next best across the ranking protocols are annual LDAR, sampling system modification, and soil control.

Several options also ranked consistently low and were thus least preferred. These included replacing the FCU cyclones (3a) and upgrading the drainage system (7b) and treatment plant (7c). None of these received a medium or high score. Just above this group, a third tier included Options 1, 2, 3b, 4, and 10. The table below separates the options into preference categories.

Most Preferred

5	Install secondary seals
7a	Upgrade blowdown system
9	Reduce barge-loading losses
11b, 11c	Quarterly LDAR program

Next Most Preferred

11a	Annual LDAR program
8	Modify sampling system
6	Keep soils out of sewers

Next Least Preferred

1	Reroute desalter effluent
3b	Install FCU ESP
4	Eliminate coker blowdown pond
10	Sour water system improvements

Least Preferred

3a	Replace FCU cyclones
7b	Upgrade drainage system
7c	Upgrade process water treatment plant