To be presented at 2003 International Oil Spill Conference, 6 – 10 April 2003

Assessing Progress and Benefits of Oil Spill Response Technology Development Since Exxon Valdez

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ABSTRACT

This paper describes a simple approach to quantifying progress and benefits associated with improvements in oil spill removal technology over the past decade, focusing on the most significant oil removal technologies: mechanical recovery, dispersant application and *in-situ* burning. All three technologies have been the focus of research and development (R&D) efforts since the Exxon Valdez spill. Notable progress has been made in refining the technologies and defining circumstances under which each option will be successful. These accomplishments have been *qualitatively* described in recent strategic technology assessments. The difficulty that arises in *quantitatively* predicting future benefits of these advances, is that expected increases in oil removal and associated cost savings are as much a function of specific circumstances of future spills as of advances in spill removal technologies. The specifics of future spills, particularly the larger more troublesome ones, are difficult to predict. In order to obtain representative quantitative estimates of these benefits, a hind-cast technique is demonstrated whereby the advanced technologies are applied to past spill scenarios to determine oil recovery and cost savings that would be realized if these spills were to occur in the future.

INTRODUCTION

The Exxon Valdez spill, like several major spills before it, underscored the limited capability to remove spilled oil from the marine environment and sparked a concerted US effort to upgrade oil spill countermeasures and cleanup technology. Over the past decade, advances have been made in mechanical recovery (*e.g.*, recovery in fast water, sinking oil), *in-situ* burning, and dispersants, as described qualitatively in the US Coast Guard (USCG) *Oil Spill Response*

Capability Review (CAPS) (1999), the USCG *Oil Spill Prevention, Preparedness and Response (OSPPR) Risk Assessment* (2001), and in past International Oil Spill Conferences. What has *not* been accomplished to date is a *quantitative* assessment of impacts of technology advancements.

The objective of the analysis is to provide an order of magnitude *quantitative* estimate of the level of progress and economic benefits associated with oil spill technology advances by examining impacts these technologies would have had in spills that have occurred since Exxon Valdez. The analysis focuses on selected major and more significant medium spills where these response technologies were or *could have* been employed. Quantitative benefits (costs saved) are estimated based on hypothetical decreased damages associated with more effective oil removal. These include cost savings associated with shoreline cleanup, environmental damage, and socioeconomic impacts that would be prevented or reduced by more effective oil removal.

There is general consensus in the spill response community that significant progress has been made since Exxon Valdez in upgrading oil removal technology and improving resource availability to successfully implement these technologies in the event of a spill. In May 1999, the USCG Office of Marine Safety and Environmental Protection completed a study to determine the adequacy of spill cleanup technology and resource availability to support raising expected oil spill response capabilities on the part of vessel and facility owners. The results of the *Response Plan Equipment CAPS Review* (referred to henceforth as the *CAPS Study*) indicated that, based on technology developments and resource availability, a 25% increase in mechanical recovery response capability was warranted. The study further recommended that contingency plan holders carrying or handling Group II, III, and V products within 50 nautical miles of shore and in areas where dispersants have been pre-approved, should be required to have resources to treat 24,000 bbl of spilled oil within 60 hours of authorization. The study also concluded that technology advances and resource availability for *in-situ* burning warranted that plan holders carrying or handling Group II, III, and V products within 50 nautical miles of shore and in areas where *in-situ* burning has been pre-approved or cleared for expedited approval, should be encouraged to maintain resources to treat 10,000 bbl of spilled oil. This reflects a significant improvement in technology and availability since Exxon Valdez.

Advances in spill response technology for mechanical recovery, dispersants and *in-situ* burning were addressed in the June 2001 *USCG OSPPR Risk Assessment*. The study concluded that technology advances had improved the "functional effectiveness" of these oil removal techniques, *i.e.*, the percentage of spilled oil that can be removed from a given spill where the technique *can be* applied. For mechanical recovery, a functional effectiveness of 10 – 30% can generally be realized, with effectiveness levels of 50% and greater being reached on certain spills. Mechanical recovery is widely applicable to various spill scenarios encountered. Dispersants can be highly effective under the right circumstances and improvements in formulations have improved the application "window of opportunity." However, the option remains applicable to a limited handful of spills, due to current restrictive application criteria. *In-situ* burning technology has been significantly improved with developments in fire-resistant boom, increased equipment availability, and growing acceptance of the technique. However, like dispersant application, its applicability is limited to a handful of situations.

Granting that improvements in all three removal techniques have been made, the question arises as to how much additional oil might be recovered and how many dollars might be saved in coming years because of these improvements. This is not simply an academic issue, as the continuation of R&D efforts for these technologies may well rest on providing *quantitative* estimates of these benefits to fiscal authorities. Since the passage of OPA 90 and the initial resurgence in oil spill technology R&D, funding has declined steadily. Obtaining additional funding in this area will depend on demonstrating *tangible* benefits in terms of cost savings.

An obvious question is "How many dollars will be saved in the coming years from technology advances accomplished during the past decade?" The main difficulty in answering this question is that cost savings depend both on technology effectiveness and the circumstances of future spills encountered that are yet unknown. The specific circumstances of a spill are important in that they determine whether a cleanup technique can be applied and the achievable level of effectiveness (% oil removal). Key parameters governing cleanup technique applicability and effectiveness are oil type, spill location (including distance from shore and water depth), and weather conditions. Statistical extrapolations of spilled oil recovery and cost savings are difficult because of this sensitivity to specific spill circumstances and the fact that dispersants and *in-situ* burning have rarely been used. Predictions based on current contingency planning scenarios are difficult as the probability of scenario occurrence is unknown. However, the adage "history repeats itself" suggests using a hind-cast approach whereby past spill scenarios are used to predict potential cost savings and provide insight into benefits that may be realized in the future.

METHODOLOGY

The first step was to identify a manageable set of spills for analysis. Because estimating the functional effectiveness and applicability of cleanup techniques depends on specific spill factors, the case histories must be reasonably well-documented for the spills analyzed. This analysis builds on previous efforts by focusing on two spill sets described in detail in the USCG CAPS and OSPPR studies. The first spill set is extracted from a larger set examined in the CAPS study, which was in turn taken from an analysis of applicability of mechanical recovery, dispersants, and *in-situ* burning for spills in 1993 - 1998 by Kucklick and Aurand (1997). Kucklick and Aurand established applicability of the three countermeasures for each spill based on oil type, wind conditions, and distance from shore, as well as applying both *existing* and *expanded* criteria for dispersant and *in-situ* burning authorization. The results are summarized in Appendix A-1 of the CAPS study. For the current analysis, only spills greater than 10,000 gallons were considered, as it is unlikely that dispersants and *in-situ* burning would be attempted for spills smaller than this. Table 1 lists the CAPS spills considered and cleanup technique applicability. The second spill set included the more significant US spills since Exxon Valdez addressed in the OSPPR study (Appendix C-2). Table 2 lists the OSPPR spills and applicability of each technique based on general criteria in Kucklick and Aurand (1997). In determining applicability, the general spill circumstances were taken into account (volume, oil type, location) but not exact details. e.g., in the spills considered, dispersants were never actually used because of factors encountered and response decisions. However, if circumstances dictated that dispersants *could be* used in a similar future spill, the technique was deemed applicable.

The overall strategy was to determine cost savings associated with applying the three oil removal technologies at their *previous* – pre-Oil Pollution Act of 1990 (OPA 90) – and *current* (post-OPA 90) levels of effectiveness to the spill sets. The difference in costs represents a quantitative measure of progress in developing each technology. This required selecting general effectiveness levels and specifying a cost savings calculation model. In doing so there were a number of assumptions and speculation that will certainly impact the magnitude of cost savings. It must be noted that the purpose of this exercise is *not* to *precisely* determine expected cost savings but to provide some quantitative insight into *levels of progress*.

The next step was to set response effectiveness levels. The mechanical recovery effectiveness levels (% removal) assumed for the CAPS spills were those specified in the CAPS study: 20% for pre-OPA 90 and 50% for post-OPA 90. For *in-situ* burning, a conservative effectiveness level of 50% was applied. For dispersants, conservative effectiveness levels were specified corresponding to the lower effectiveness CAPS study levels with % removal based on oil type: light oils and crude – 40%, and heavy fuels – 35%. The conservative effectiveness values were chosen in an effort to provide realistic estimates of projected oil removal taking into consideration oil encounter and treatment rates and the often limited "window of opportunity" for employing dispersants and *in-situ* burning. Effectiveness levels applied to the OSPPR spills were 10%, 20%, and 50% for mechanical recovery. To reflect pre-OPA 90 effectiveness, values of 10% or 20% were assigned to spills where mechanical recovery was applicable; for post-OPA 90 effectiveness, values of 20% or 50% were assigned. For dispersant and *in-situ* burning, the same effectiveness levels used in the CAPS spill analysis were used for post-OPA 90 effectiveness; for pre-OPA 90 it was assumed that neither option would be employed and a lower effective mechanical recovery was assumed. To determine post-OPA 90 costs for spills for which *in-situ* burning and/or dispersants were not applicable, low-effective mechanical recovery was assumed. For spills deemed untreatable by any option, it was assumed that a mechanical recovery was attempted (*i.e.,* accruing costs) but with no effectiveness and no impact reduction. Including the mechanical recovery costs in the post-OPA 90 dispersant and *in-situ* burning computations is important, as it means that the cost savings calculated reflect the total net cost savings for the whole spill set with the particular technology. In some cases, there would have been no cost advantage to having alternative technologies available as they were not applicable.

The next step was determining net cost savings associated with the technologies at pre- and post-OPA 90 levels. Net cost savings were calculated as the difference between pre-OPA 90 costs (response costs plus environmental and socioeconomic damages) and post-OPA 90 costs for each spill, following an approach similar to that described by Gautier et al. (2001). Response benefits include cost savings associated with reduced shoreline cleanup, socio-economic, and environmental damage costs with the increase in on-water oil removal.

Assigning per-gallon response, environmental, and socio-economic costs to a spill to perform this analysis such was a difficult task at best. Using generalized values can be misleading as costs are sensitive to oil type, location, and specific operational and environmental circumstances in each spill (Etkin 1999, 2000). Using bulk values to estimate costs was not very precise from an analytical standpoint, but attempting to estimate response and damage costs for each spill examined would be an enormous undertaking. At the same time, using *actual* reported spill costs and extrapolating based on oil removal levels was prohibited by incomplete actual cost data, and the often aberrantly high or low costs values due to specific spill circumstances.

A *consistent but simple* method for calculating "representative costs" if the general spill scenario was encountered in the future was desired. The model adopted for this study is an adaptation of the approach developed for estimating response, environmental, and socio-economic costs for hypothetical spills in San Francisco Bay (Etkin *et al*. 2002, 2003; French-McCay *et al*. 2002). The results of this study were used to derive formulae for per-gallon response costs by method for three oil types – heavy fuel oil (HFO), crude, and diesel (No. 2 fuel), with adjustments for response effectiveness and spill size. This takes into account decreased per-gallon costs for larger spills,, with initial mobilization costs are averaged over a larger volume, as well as lower costs for more efficient removal that prevents shoreline impact and expensive shoreline cleanup. Table 3 reflects *total response costs*, including on-water operations, spill management/monitoring, and necessary shoreline cleanup.

A similar matrix (Table 4) was developed based on the San Francisco Bay work to assign costs for natural resource damages and socio-economic costs specified by oil type and adjusted for spill size. The current analysis required an assumption that natural resource and socio-economic damages in the study spills would be *analogous to the magnitude of damages* that occurred in San Francisco Bay. While it is recognized that actual spill location has a tremendous impact on environmental and socio-economic damages, applying the study spills to this one well-documented and already modeled location, in essence, "normalizes" the differences in actual locations between the spills in projecting to future potential spills. Here again, the objective of this analysis was to provide representative quantitative measures of progress and not precise cost savings for each spill. Detailed modeling of environmental and socio-economic damages for the actual spills was prohibitively expensive and *reported* cost data on these spills is incomplete.

For each past spill analyzed, the response costs and damage costs were then calculated using Tables 3 and 4, based on the effectiveness level. Environmental and socio-economic damages were reduced based on % on-water oil removal. Total costs for each spill were calculated at pre- and post-OPA 90 levels of effectiveness for mechanical recovery, *in-situ* burning, and dispersants. Net cost savings were calculated by subtracting post-OPA 90 costs from pre-OPA 90 costs. The difference represents cost savings associated with more efficient oil removal and reduced costs associated with decreased socio-economic and environmental impact.

RESULTS

The cost saving analysis of the CAPS spills (Table 5) shows that for the 35 spills investigated, cleanup operations were possible in 19 spills that involved a total of 485,529 gallons of spilled oil. Mechanical recovery was applicable in 15 cases, dispersants were applicable in eight, and *in-situ* burning was applicable in six. The total net cost savings associated with development and application of augmented mechanical recovery (effectiveness increase from 20% to 50%) is $95.7 million. The total net cost savings associated with dispersant development and application is $38.1 million. *In-situ* burning development and application accounted for a $46.5 million net cost savings.

The cost savings results for the OSPPR spills are in Tables 6 – 8 for mechanical recovery, dispersants and *in-situ* burning. For the 28 medium and major spills investigated, cleanup operations were possible in 22 spills involving 15,009,500 gallons of oil. Mechanical recovery was applicable in 22 cases, dispersants were applicable in three, and *in-situ* burning was applicable in five. Total net cost savings associated with development and application of augmented mechanical recovery (effectiveness increase from 10-20% to 20-50%) was $633.9

million. Dispersant development and application accounted for $323.1 million and *in-situ* burning development and application accounted for $755.5 million net cost savings.

CONCLUSIONS

The analysis results are summarized in Table 9. For the medium spill scenarios represented by the CAPS spill set, the highest net cost savings is accrued from advanced mechanical recovery technology ($95.7 million), assuming a 50% effectiveness level. Net cost savings from dispersants and *in-situ* burning are roughly equivalent at $38.1 million and $46.5 million, respectively. Even though the oil volume represented by these spills is small (485,000 gallons), it appears that a substantial net cost savings would be realized if a similar future spill set could be responded to at the proposed effectiveness levels. For the OSPPR spills (representing 15 million gallons.of spilled oil), the results are similar with the net cost savings accrued from advanced mechanical recovery technology of $634 million, assuming a 20-50% effectiveness level. Net cost savings from dispersants and *in-situ* burning are $325 million and $755 million, respectively. Mechanical recovery net cost savings are proportionally lower than for the CAPS set, as the effectiveness level varies from 20% to 50%, while it was kept constant at 50% for the CAPS spills. A substantial savings is noted for *in-situ* burning, as there were several high volume spills in the OSPPR spill set where the technique was deemed applicable. The low on-water response cost for this oil-removal technology contributes to the high net cost savings.

Viewed together, the results suggest that the potential net cost savings that could be realized by R&D for these removal technologies over the past decade is substantial. From the OSPPR spill set analysis, it appears that net cost savings may be on the order of *hundreds of millions of dollars* assuming that similar spills were to occur in the next decade. This represents a *substantial* return on investment given that the expenditures on US oil spill R&D have probably not exceeded $100 million over the past decade. It also suggests that further significant gains can be made by modest expenditures in oil spill response technology development.

ACKNOWLEDGEMENTS
This project is an extension by-product of research funded by the USCG Headquarters Office of Response and ongoing projects of the USCG Research and Development Center, Groton, CT.

BIOGRAPHY
Dagmar Schmidt Etkin received her B.A. in Biology from University of Rochester, and her A.M. and Ph.D. in Biology (specializing in population biology, ecology, and statistical analysis) from Harvard University. She has analyzed and modeled oil spill data and impacts for 15 years.

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FIGURES

Table 1: Spills from the CAPS Study Analyzed for Cost Savings Using Mechanical Recovery, Dispersants and *In-Situ* Burning

Vessel Name	Qty. Spilled (Gals.)	Oil Type	Applicability of Oil Removal Methods for Existing and Expanded Criteria[1]				
			Mech. Recov.	Disp. Exist.	Disp. Exp.	ISB Exist.	ISB Exp.
New Janet Ann	11,000	Diesel	N	N	Y	N	N
Sea-Land Hawaii	25,200	Waste/Lube	Y	Y	Y	Y	Y
Frances Lee	16,000	Diesel	Y	N	N	N	N
Barge 155/Capt. Bouchard	330,000	No. 6 Fuel	N	N	N	N	N
Jin Shing Fa	96,000	Lube	Y	N	N	N	N
Morris J. Berman	750,000	No. 6 Fuel	N	N	N	N	N
IB 20131	40,150	Asphalt	N	N	N	N	N
Chevak	12,000	Diesel	N	N	N	N	N
Bow Sun	35,700	No. 6 Fuel	N	N	N	N	N
Umqua Fisher	20,000	Diesel	Y	N	N	N	N
RTC 20	15,000	Waste/Lube	Y	N	Y	N	Y
Island Enterprise	12,705	Diesel	N	Y	Y	N	N
USS Inchon	19,000	Diesel	N	N	N	N	N
Barge 101/Mercury	26,000	Diesel	Y	N	N	N	N
Skaubay/Berge Banker	37,716	No. 6 Fuel	N	N	N	N	N
Mormac Star	15,918	No. 2 Fuel	Y	N	N	N	N
American Express	12,500	Diesel	N	N	Y	N	N
Leslie	13,062	Naptha	N	N	N	N	N
Interstate 138	92,610	No. 6 Fuel	N	N	N	N	N
Northern Wind	20,000	Diesel	Y	N	N	N	N
M.B. McAllister	25,000	Diesel	Y	Y	Y	Y	Y
Defiant	30,000	Diesel	Y	N	N	N	N
North Cape	828,000	No. 2 Fuel	N	N	N	N	N
Buffalo 292	176,400	No. 6 Fuel	N	N	N	N	N
Anitra	40,000	Crude Oil	Y	N	N	N	Y
Buffalo 286	25,998	No. 6 Fuel	N	N	N	N	N
Unknown Vessel	12,000	Crude Oil	Y	N	N	N	N
Rosie G	16,000	Diesel	N	Y	Y	N	N
BFT No. 39	27,636	Gasoline	N	N	N	N	N
Barge No. 125	26,460	Gasoline	N	N	N	N	N
Kure	40,000	Diesel	Y	N	N	N	N
Barge No. 125	39,000	No. 6 Fuel	N	N	N	N	N
Stone Fuller	31,206	Crude Oil	Y	N	Y	N	Y
Red Seagull	21,000	Med. Crude	Y	N	N	Y	Y
Rosellen	14,300	Vegetable	N	N	N	N	N

[1]Y and N (yes or no) indicate whether oil removal method potentially applicable under conditions described for spill and application criteria specified. For dispersants and *in-situ* burning, two application criteria considered: *Existing Criteria* (≥3 nautical miles from shore) and *Expanded Criteria* (≥¼ mile from shore).

Table 2: Spills from the OSPPR Study Analyzed for Cost Savings Using Mechanical Recovery, Dispersants and *In-Situ* Burning						
Source	**Location**	**Volume (gal)**	**Oil Type**	**Mech**	**Disp**	**ISB**
Tankers						
World Prodigy	coast/harbor	294,000	No. 2 fuel	N	N	N
President Rivera	river/harbor	300,000	No. 6 fuel	Y	N	N
American Trader	coast/harbor	417,000	light crude	Y	Y	Y
Mega Borg	offshore/ocean	5,000,000	light crude	Y	Y	Y
Jupiter	river	840,000	Gasoline	N	N	N
Julie N	river/harbor	180,000	No.2/No.6 fuel	Y	N	N
Cape Mohican	bay/harbor	98,000	No. 6 fuel	Y	N	N
Command	offshore/ocean	51,500	No. 6 fuel	N	N	N
Barges						
Bouchard 155	coast/bay	333,000	No. 6 fuel	Y	N	N
Morris Berman	nearshore/coast	789,000	No. 6 fuel	Y	N	N
North Cape	nearshore/coast	828,000	No. 2 fuel	Y	N	N
Buffalo 292	nearshore/coast	189,000	IFO	Y	N	N
Buffalo 286	nearshore/coast	42,000	No. 6 fuel	Y	N	N
RTC 320	harbor	50,000	No. 6 fuel	Y	N	N
Offshore Platform						
Greenhill Well	offshore/ocean	687,000	crude	Y	N	N
Freighters and Fishing Vessels						
Sammi Superstars/ Maui	harbor	32,000	No. 6 fuel	Y	N	N
Tenyo Maru	offshore/ocean	173,000	IFO, No. 2 fuel	Y	N	N
Citrus	offshore/coast	9,000	No. 5 fuel	N	N	N
Kure	coast/harbor	4,500	IFO	Y	N	N
Kuroshima	offshore/coast	47,000	No. 2/No. 6 fuel	N	N	N
Star Evviva	offshore/ocean	24,000	No. 6 fuel	N	N	N
New Carissa	nearshore/coast	70,000	No.2/No.4 fuel	Y	N	Y
Onshore Facility						
Texaco Anacortes Refinery	harbor	210,000	crude	Y	N	N
Pipelines						
Exxon Bayway	harbor	567,000	No. 2 fuel	Y	N	N
Colonial, Potomac	river	407,000	No. 2 fuel	Y	N	N
4 Pipelines, San Jacinto R.	river	1,616,000	No.2 fuel, crude	Y	N	Y
Chevon, Oahu	coast/harbor	41,000	No. 6 fuel	Y	N	N
Texaco, Lake Barre	nearshore/coast	276,000	crude	Y	Y	Y

[1]Y and N (yes or no) indicate whether oil removal method potentially applicable under conditions described for spill and application criteria specified.

Table 3: Per-Gallon Oil Spill Response Costs Applied in Cost Savings Analysis[1]

Oil Type	Volume (gallons)	Mechanical[2,4]				Dispersants[3,4]		In-Situ Burn[5]	
		No Effect 0%	Lower Effect 10%	Low Effect 20%	High Effect 50%	Low Effect	High Effect	Low Effect 50%	High Effect 80%
Light Fuels	1,000 – 100,000	$85	$70	$58	$40	$25	$18	$18	$9
	100,000 – 1,000,000	$72	$60	$48	$25	$17	$10	$10	$5
	>1,000,000	$30	$25	$17	$12	$11	$6	$7	$3
Heavy Fuels	1,000 – 100,000	$400	$350	$300	$260	$100	$60	$100	$50
	100,000 – 1,000,000	$175	$150	$125	$100	$58	$53	$70	$40
	>1,000,000	$85	$75	$65	$35	$52	$48	$55	$25
Crude Oil	1,000 – 100,000	$190	$180	$170	$135	$72	$30	$60	$30
	100,000 – 1,000,000	$120	$115	$110	$90	$48	$28	$35	$16
	>1,000,000	$90	$80	$74	$62	$57	$13	$21	$11

[1]Per-gallon response cost based on hypothetical modeling in Etkin *et al.* (2002, 2003) with shoreline oil removal costs adjusted by % reduction of shoreline oiling. Modeling included oil fate by oil type and trajectory with Applied Science Associates' SIMAP (French-McCay *et al.* 2002). [2]Per-gallon costs include on-water mechanical recovery, shoreline oil removal, mobilization, and protective booming based on Area Contingency Plan. [3]Per-gallon costs include on-water dispersant response, shoreline oil removal, mobilization, sensitive site protective booming. [4]Removal assumed for on-water recovery or dispersants. Shoreline oiling assumed reduced by % on-water oil removal. Low/high removal by dispersants for diesel/crude 40%/80%, for HFO 35%/70% (Pond *et al.* 2000). [5]ISB costs based on per-gallon ISB operations costs in Allen and Ferek (1993) updated to 2001 $ plus costs of shoreline cleanup of oil not burned.

Table 4: Spill Impact Cost Matrix for Cost Savings Computations
Hypothetical Spill Impact Cost (Assuming No On-Water Response Effectiveness)[1]

Oil Type	Volume (gallons)	Environmental $/gallon	Socioeconomic $/gallon
Gasoline	1,000 – 100,000	$30	$400
	100,000 – 1,000,000	$30	$180
	>1,000,000	$10	$90
Diesel	1,000 – 100,000	$50	$500
	100,000 – 1,000,000	$50	$200
	>1,000,000	$20	$100
Heavy Fuels	1,000 – 100,000	$25	$900
	100,000 – 1,000,000	$20	$500
	>1,000,000	$10	$200
Crude	1,000 – 100,000	$140	$300
	100,000 – 1,000,000	$15	$140
	>1,000,000	$10	$70

[1]Based on hypothetical spills in Etkin *et al.* (2002, 2003) with oil fate modeling based with Applied Science Associates' SIMAP (French-McCay *et al.* 2002).

Table 5: Results of Cost Savings Analysis for CAPS Spills Over 10,000 Gallons							
Oil Removal Technology Impact Examined	Pre – OPA 90 Spill Costs (million $)			Post – OPA 90 Spill Costs (million $)			Cost Savings (million $)
	Resp	Enviro	Socio	Resp	Enviro	Socio	
Mechanical Recovery	$74.3	$24.6	$226.4	$60.5	$17.0	$145.7	**$102.1**
Dispersant Application	$74.3	$24.6	$226.4	$59.0	$22.1	$206.1	**$38.1**
***In-Situ* Burning**	$74.3	$24.6	$226.4	$54.0	$20.5	$197.9	**$52.9**

Table 6: Results of Cost Savings Analysis for OSPPR Spills – Mechanical Recovery								
Source Type	No. Spills	Pre – OPA 90 Spill Costs (million $) Mechanical Recovery 0-20% Effectiveness			Post – OPA 90 Spill Costs (million $) Mechanical Recovery 20- 50% Effectiveness			Cost Savings (million $)
		Resp	Enviro	Socio	Resp	Enviro	Socio	
Tanker	8	$670.4	$110.5	$1,106.8	$608.6	$101.1	$985.8	**$192.2**
Barge	6	$257.2	$61.7	$740.4	$211.7	$50.0	$541.7	**$255.9**
Offshore Platform	1	$79.0	$9.3	$86.6	$75.6	$8.2	$76.9	**$14.2**
Freighter	7	$95.1	$7.2	$232.1	$85.4	$6.0	$213.0	**$30.0**
Shore Facility	1	$24.2	$2.8	$26.5	$21.0	$2.5	$23.5	**$6.5**
Pipeline	5	$223.5	$57.5	$383.9	$189.8	$45.8	$294.9	**$134.4**
TOTAL	**28**	**$1,349.4**	**$249.0**	**$2,576.3**	**$1,192.1**	**$213.6**	**$2,135.8**	**$633.9**

Table 7: Results of Cost Savings Analysis for OSPPR Spills – Dispersants								
Source Type	No. Spills	Pre – OPA 90 Spill Costs (million $) Mechanical Recovery 0-20% Effectiveness			Post – OPA 90 Spill Costs (million $) Dispersants Available 35-40% Effectiveness			Cost Savings (million $)
		Resp	Enviro	Socio	Resp	Enviro	Socio	
Tanker	8	$670.4	$110.5	$1,106.8	$527.4	$94.3	$990.1	**$275.9**
Barge	6	$257.2	$61.7	$740.4	$257.2	$61.7	$740.4	**$0**
Offshore Platform	1	$79.0	$9.3	$86.6	$79.0	$9.3	$86.6	**$0**
Freighter	7	$95.1	$7.2	$232.1	$95.1	$7.2	$232.1	**$0**
Shore Facility	1	$24.2	$2.8	$26.5	$24.2	$2.8	$26.5	**$0**
Pipeline	5	$223.5	$57.5	$383.9	$189.0	$53.1	$273.5	**$47.2**
TOTAL	**28**	**$1,349.4**	**$249.0**	**$2,576.3**	**$1,139.9**	**$226.7**	**$2,280.8**	**$323.1**

Table 8: Results of Cost Savings Analysis for OSPPR Spills – *In-Situ* Burning								
Source Type	**No. Spills**	**Pre – OPA 90 Spill Costs (million \$) Mechanical Recovery 0-20% Effectiveness**			**Post – OPA 90 Spill Costs (million \$) *In-Situ* Burning Available 50% Effectiveness**			**Cost Savings (million \$)**
		Resp	**Enviro**	**Socio**	**Resp**	**Enviro**	**Socio**	
Tanker	8	\$670.4	\$110.5	\$1,106.8	\$342.0	\$88.6	\$949.3	**\$507.8**
Barge	6	\$257.2	\$61.7	\$740.4	\$257.2	\$61.7	\$740.4	**0**
Offshore Platform	1	\$79.0	\$9.3	\$86.6	\$79.0	\$9.3	\$86.6	**0**
Freighter	7	\$95.1	\$7.2	\$232.1	\$77.6	\$6.5	\$206.9	**\$43.4**
Shore Facility	1	\$24.2	\$2.8	\$26.5	\$24.2	\$2.8	\$26.5	**0**
Pipeline	5	\$223.5	\$57.5	\$383.9	\$99.3	\$51.3	\$310.0	**\$204.3**
TOTAL	**28**	**\$1,349.4**	**\$249.0**	**\$2,576.3**	**\$879.3**	**\$220.2**	**\$2,319.7**	**\$755.5**

Table 9: Cost Benefits From Response Technology Research and Development					
Response Type	**Spill Set**	**Cost Savings (million \$) Compared to Pre-OPA 90**			
		Response Cost	**Environmental Damages**	**Socioeconomic Damages**	**Total**
Augmented Mechanical	**OSPPR**	\$157.3	\$35.4	\$440.5	**\$633.9**
	CAPS	\$13.8	\$7.6	\$80.7	**\$102.1**
Dispersant Application	**OSPPR**	\$177.5	\$20.6	\$227.1	**\$323.1**
	CAPS	\$15.3	\$2.5	\$20.3	**\$38.1**
***In-Situ* Burning**	**OSPPR**	\$470.1	\$28.8	\$256.6	**\$755.5**
	CAPS	\$20.3	\$4.1	\$28.5	**\$52.9**