STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Sustainability Index

DOE-FIU SCIENCE & TECHNOLOGY
WORKFORCE DEVELOPMENT PROGRAM

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ABSTRACT

This technical report consists of a description of a green and sustainable remediation (GSR) tool developed by a team of three interns at the United States Department of Energy's Office of Environmental Management (DOE-EM) in the summer of 2016, as well has examples of how that tool can be practically put to use. The tool is a sustainability index, developed in support of a recent study published by scientists at the Pacific Northwest National Laboratory (PNNL), detailing an exit strategy for pump and treat remediation technologies as part of an effort to move away from active remediation in favor of passive techniques. The sustainability index attempts to quantify the relative sustainability of active and passive remediation strategies by examining a variety of metrics and perspectives from those involved in the decision-making process.

The analysis compares 10 metrics encompassing environmental, social, and economic aspects of sustainability for the two types of remediation techniques. It also incorporates the perspectives and values of the investors, regulators, scientists, and community members involved in the decision-making process. Data was input into the spreadsheet from active and passive remediation technologies at Hanford 100 and 200 area sites and the Mound, Ohio site. Based on this data, overall, passive remediation technologies performed better in terms of sustainability performance than active technologies.

The analysis showed that, in general, switching from active remediation to passive remediation techniques has the following impacts: aids in the conservation of local ecosystems, reduces community impacts and improves the community perception of the cleanup, lowers the life-cycle cost of the project, and contributes positively to global sustainability by using less energy and raw materials. By applying the analysis to future feasibility studies, EM takes the next steps towards being a leader in global sustainability.

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1. INTRODUCTION

Green and Sustainable Remediation

The US Environmental Protection Agency (EPA) defines green remediation as that which not only takes into account all of the environmental effects of the remedy implementation, but also utilizes available options to reduce or remove the environmental footprints of cleanup actions. Essentially, it is the integration of best management practices (BMPs) that may be employed during a project, especially considering sustainability aspects including emerging techniques that offer significant environmental and social benefits while still being economical. As environmental remediation is the main purpose of the Department of Energy's Office of Environmental Management (DOE EM), it aligns with the goals of the DOE Sustainability Performance Office (SPO) to consider this method before defaulting to using the cheapest or fastest remedies (ITRC, 2011).

CERLCA criteria

Before a remediation process begins, DOE evaluates all potential remediation technologies in terms of CERLCA criteria. CERCLA stands for Comprehensive Environmental Response, Compensation, and Liability Act (also known as Superfund), and was created in 1980 to provide federal funding to the remediation of hazardous waste sites across the country. It also holds the responsible parties accountable, if possible, for any release into the environmental and ensure their participation in the cleanup. CERCLA has nine criteria for the selection of the type of remediation: overall protection of human health and the environment; compliance with ARARS (applicable or relevant and appropriate standards); long-term effectiveness and permanence; reduction of toxicity; mobility or volume; short-term effectiveness; implementability; cost; state acceptance; and community acceptance (US EPA, 2016).

DOE Role and Goals

The mission of the DOE-EM is to address the nation's Cold War environmental legacy resulting from five decades of nuclear weapons production and government-sponsored nuclear energy research. Established in 1989, EM has been responsible for completing the cleanup of this legacy of over a hundred sites across the country, managing the remaining nuclear materials, and overseeing the world's largest soil and groundwater remediation program. The Office of Subsurface Closure (EM-4) works with legacy sites around the country to find solutions to specific technical issues, while also funding national labs around the country to perform research and demonstration projects to test new technologies and remediation approaches. EM-4 is focused on delivering approaches and technologies from highly leveraged and strategic investments that maximize the impact to reduce risk and life-cycle cleanup costs.

Pump-and-Treat Groundwater Remediation

Pump-and-treat (P&T) remediation is an established technology which is currently in use at numerous DOE sites across the country. The technology has three main characteristics: groundwater extraction, aboveground treatment, and groundwater monitoring. It is an active treatment method, which means it is human-run and quite energy and water intensive. Recent research has identified factors that impact the overall performance of the P&T remedies. Such information is important for assessment of optimization of performance or comparison of P&T to other remediation alternatives. Some benefits of using this treatment system include effective plume and source containment and reduction, strong aboveground operational performance, and ease of integration and co-performance with other technology elements of a remedy. However, there are also several negative aspects. They include difficult secondary waste handling and disposal, high energy and operational costs, poor sustainability performance, hydraulic gradients that induce accelerated downgradient contaminant migration, and injection well fouling. Primarily because of the many cons of using P&T remediation, it is important to explore other options when examining the best type of remediation for a site (Truex, 2015).

Enhanced Attenuation and Natural Monitored Attenuation

Enhanced attenuation (EA) and natural monitored attenuation (NMA) are both passive remediation methods, meaning they utilize the natural water flow and require little human input after their initial setup. Structured geochemical zones are an example of EA, created by the injection of vegetable oil (an electron donor) into the groundwater to deplete volatile organic compounds (VOCs). It facilitates this depletion by degrading electron-acceptor parent and daughter compounds [such as trichloroethene (TCE) and tetrachloroethene (PCE), and daughter compounds such as c/s-1,2-dichloroethene and vinyl chloride] rapidly and effectively. NMA would simply mean that the area has been cleaned to a certain standard and has been allowed to exist in its natural state with periodic monitoring for contaminant levels. These passive remediation methods are beneficial for minimizing the rebound of groundwater concentrations above regulatory targets and avoiding plume expansion while the P&T system is turned off, as well as transitioning completely away from P&T (Truex, 2015).

Investing in Sustainability

A 2016 study published by MIT Sloan in collaboration with the Boston Consulting Group (BGC) shows that sustainability matters to investors. The article states that three-quarters of executives in investment firms consider good sustainability performance as materially important when making investment decisions. It goes on to elaborate about the growing importance of environmental sustainability for staying competitive in the current market. As investors and stakeholders play a key role in the decision-making process for DOE national labs, this study is significant in many ways. The article also points out that integrating sustainability indicators into investment models has been difficult in the past because, as Banco Bilbao Vizcaya Argentaria's head of responsible business Antoni Ballabriga puts it, "Sustainability types speak in PowerPoint, and investors speak in Excel." The index described in this report aims to speak in both qualitative and quantitative terms to provide the data needed to show investors and others involved in decision making how to make more responsible, sustainable choices when it comes to cleanup.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2016, DOE Fellow interns Sarah Bird and Alexis Smoot spent 10 weeks doing a summer internship at DOE-EM Headquarters in Germantown, MD under the supervision and guidance of Grover Chamberlain, Physical Scientist (EM-4). The interns' project was initiated on June 6, 2016, and continued through August 12, 2016 with the objective of creating a quantitative sustainability index to complement PNNL's recent publication on exit strategies for pump and treat remediation methods.

3. RESEARCH DESCRIPTION

In order to generate a quantitative value for the relative sustainability of two remediation methods, a five step method was used: (1) choose and define the metrics, (2) create bins to normalize the data, (3) establish a weighting system, (4) design an algorithm to apply the weights, and finally (4) put it all together in an editable spreadsheet.

Defining the Metrics

There are countless parameters that could be used to describe sustainability, and there is no consensus on which ones should be used universally. This project narrowed down the parameters to 10 metrics that focus on three categories which are often referred to as the three pillars of sustainability, or the triple bottom line - the categories being economic, environmental, and social factors. The 10 parameters used were decided on because of their relevance to EM's sustainability goals, to the remediation process and to social and economic responsibility.

Once the metrics were chosen, they were defined as related to the remediation process and their environmental significance was noted (Table 1).

Table 1 Definitions and environmental significance of metrics used for sustainability index

Metric	**Definition**	**Environmental Significance**
1. Life Cycle Cost	Life cycle cost (LCC) – total cost of the remediation process	Feasibility of project
2. Time	Start of remediation to NMA	Feasibility of project
3. Materials	Percent of land and materials reused and recycled	Promotes conservation of resources
4. GHG emissions	Greenhouse gas emissions in **metric tons** of CO2, CH4, and NOx	Climate change/ atmospheric warming
5. Clean energy	Percent of renewable and sustainable energy being utilized (amount of energy from renewable and sustainable sources divided by the total amount of energy used)	Minimal environmental impact; mitigating climate change
6. Freshwater consumption	**Volume** of freshwater used for remediation in gallons	Local watershed, aquifers, water conservation and availability
7. Source removal	Time to endpoint of remediation, measured by year until ARARS compliance	Likelihood of implementation; overall impact
8. Ecological services	<u>Disposal</u> – acts as an absorptive sink for residuals (i.e. carbon sequestration); Change in pH as a result of remediation	Conservation of local ecosystems, biodiversity, air and water quality, prevention of overexploitation, etc.; monetary value of ecosystems

Metric	Definition	Environmental Significance
	Economic functions such as lumber and pharmaceuticals (biodiversity and ecosystem health are important factors); property value Recreational services for human beings such as public parks and natural areas	
9. Community impact	If/ how the community is affected by the cleanup & how people see the remediation as impacting them (i.e. turning the river green)	Likelihood of implementation; social responsibility
10. Worker safety/ Risk	Risk of fatality – number of deaths	Likelihood of implementation

Creating the bins

The second step was creating bins, or ranges of values, for which each metric could be assigned values on a scale of one to five - one being the worst, or least sustainable, and five being the best, or most sustainable. Putting all of the metrics on the same grading scale normalized the data and generated realistic quantitative scores.

Another advantage to using the bins was that the exact data was not needed, which made it easier to gather information and input information for the spreadsheet to see the overall strengths and weaknesses of each specific remediation process.

Table 2 Bins and units assigned to each metric

Metric	Units	Bins
1. Life Cycle Cost (LCC)	Dollars ($)	1. 1 billion+ 2. 100 mil – 1 billion 3. 10 mil – 100 million 4. 1 mil – 10 million 5. 0 – 1 million
2. Time	Years	1. 100 + 2. 51-100 3. 26-50 4. 6-25 5. 0-5
3. Materials	Percent recycled (%)	1. 0-20% 2. 20-40% 3. 40-60% 4. 60-80% 5. 80-100%

Metric	Units	Bins
4. GHG emissions (normalized to equivalents of CO_2 using GWP factors)	Metric tons	1. 8,000+ 2. 6,000-8,000 3. 4,000-6,000 4. 2,000-4,000 5. 0-2,000
5. Percent of **clean energy** used	Percent (%)	1. 0-20% 2. 20-40% 3. 40-60% 4. 60-80% 5. 80-100%
6. Volume of freshwater used	Gallons	1. 100,000 + 2. 75,000-100,000 3. 50,000-75,000 4. 25,000-50,000 5. 0-25,000
7. Source removal - time to ARARS compliance	Years	1. 100+ 2. 60-100 3. 30-60 4. 10-30 5. 0-10
8. Environmental services	+ or -	1. Net negative 2. Medium-negative 3. Neutral 4. Medium-positive 5. Net positive
9. Community impact	+ or -	1. Negative perception 2. Somewhat negative 3. Neutral 4. Somewhat positive 5. Positive perception
10. Risk – fatality	Number of fatalities	1. 4 + 2. 3 3. 2 4. 1 5. 0

The Weighting System

A survey was designed in order to collect information about which metrics different groups of people involved in the remediation process value as most and least important. When deciding which type of remediation to implement, four categories of contributors in the decision-making process were identified. The four categories looked at were:

1. Investors or stakeholders
2. Regulators
3. DOE scientists and engineers

4. Community members

Surveys were filled out by members of each category, ranking the metrics from 1 to 10, with 1 being the most important metrics and 10 being the least important to them based on the professional and personal values. At the bottom of the survey was an either/ or section that specifically looked at some opposing factors to gain further understanding of what people value. The survey response were solicited by sending out emails, making phone calls, having face-to-face meetings, and interviewing community members on the Washington mall.

Appendix A shows the document that was used to collect survey data.

The Algorithm

On one side of the scale is the 1 to 10 ranking system used in the weighting survey (Table 3). Recall that 1 is ranked the most important and 10 is the least important. On the other side is the weighting value each rank was assigned.

In the weighted score, the bin score is multiplied by a percentage based on its rank to either increase or decrease its relative value based on its importance to each group of people.

For example, the bin score of the highest ranked metric gets multiplied by 0.19 or 19% weight since it is the most important, compared to the metric with the lowest rank which gets multiplied by just 0.01 or 1% since it is the least important.

Table 3: Weighting factors used for each rank

Rank	Weight
1	19%
2	18%
3	17%
4	16%
5	15%
6	5%
7	4%
8	3%
9	2%
10	1%

The Index

All of the steps were combined into a table in an Excel spreadsheet to generate a template for the actual index (Figure 1). On the spreadsheet, the 10 metrics were listed down the middle so that two remediation techniques could be compared side by side. The inner columns are for the raw bin values or estimations obtained from the site being examined for each process. The outer columns then calculate the weighted values depending on the ranking given to each metric by the group being examined.

At the bottom of the table (rows 14, 15, and 16), the bin scores are added up to create a raw score in the inner columns, which is divided by the total possible score of 50. In the outer columns the weighted scores are added up and then divided by the total possible of five to obtain a decimal, which is subsequently multiplied by 100 to create a percentage.

Similar to a report card, the percentage from the raw score determines how sustainable the remediation strategy is (with 100% being the most sustainable scenario possible). The value of the weighted score shows whether the sustainability score correlates favorably or unfavorably with the weighted values of particular group being examined.

A1	B	C	D	E	F
2	=C*%	(Bin 1-5)		(Bin 1-5)	=E*%
3	**Weighted P&T**	**P&T**	**Metric**	**Oil Injection**	**Weighted Oil Injection**
4			**Life Cycle Cost**		
5			**Time**		
6			**Recycling/ Reuse**		
7			**GHG Emissions**		
8			**Renewable Energy**		
9			**Freshwater Consumption**		
10			**Contaminant Removal**		
11			**Ecological Conservation**		
12			**Community Impact**		
13			**Safety/ Risk**		
14	=sum(B4:B13)	=sum(C4:C13)	**TOTAL**	=sum(E4:E13)	=sum(F4:F13)
15	=B14/5	=C14/50		=E14/50	=F14/5
	=B15%	=C15%		=E15%	**=F15%**

Figure 1: The sustainability index template.

In order to generate examples of how the Sustainability Index could be practically put to use, data was obtained for two different sites. The first site was Mound, Ohio, which was originally treated using P&T and then transitioned to the Oil Injection/ Funnel and Gate passive remediation method. It has since been cleared to normal standards and is in the process of being re-integrated into the community.

The second set of data used in this analysis was a hypothetical example provided by DOE scientist Mike Truex at the Hanford Site. This data compared an appetite barrier with P&T at the 200 W area of the site. There were some key differences between these two sites that made a large impact on their overall sustainability scores, notability the use of clean energy by the Hanford Site because of its abundant availability in Washington, as well as the high scores of the Hanford Site in the community section because of some local pushback regarding the Ohio Mound site.

The same data from the ranking surveys was used for both of the examples, as it was assumed that the perceptions of the various groups would not vary significantly over the different areas. The surveys (Appendix A) also collected more detailed information about some specific comparisons for further analysis. This data has not yet been applied to the index.

4. RESULTS AND ANALYSIS

Surveys

The results from the ranking surveys distributed to the various groups highlighted the values of those involved in the decision-making hierarchy when choosing a remediation method. It was found that typically the values of the regulators and investors were somewhat in alignment, although this system is fairly objective and could vary depending on the regulator and the investor asked. The community members involved in this data had no experience with the cleanup process, and the ranking obtained was, again, very objective and somewhat varied. The most typical responses were used for the purposes of the weighting.

Table 4: Ranking survey results

Metric	EPA Regulator	SRS Scientist	Community Members	Investor
Cost	3	2	10	1
Time	2	10	9	5
Recycling	10	9	5	10
GHG Emissions	4	6	4	7
Clean Energy	7	8	3	8
Freshwater	8	7	1	9
Contaminant	1	3	7	3
Conservation	6	1	6	6
Community	5	5	8	4
Risk	9	4	2	2

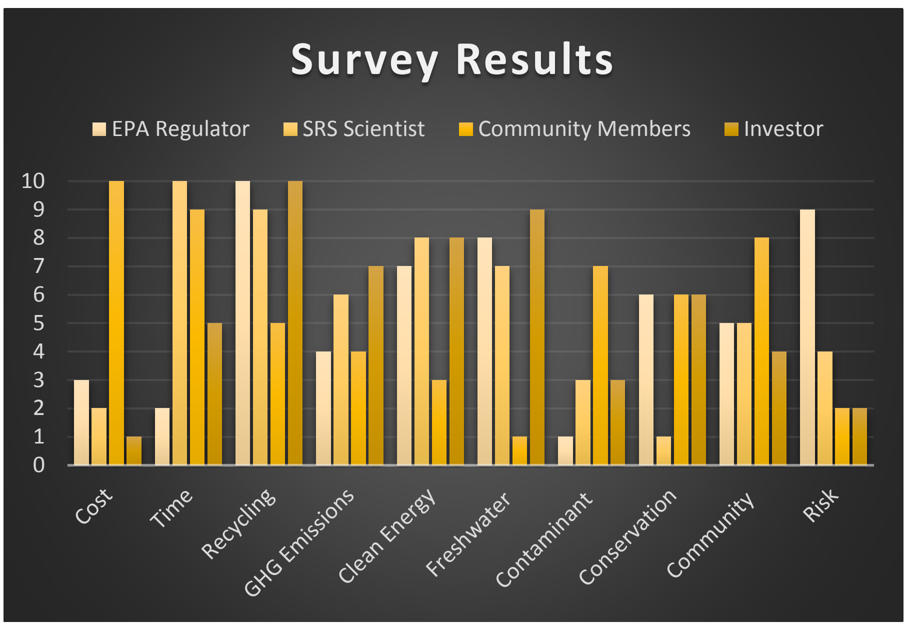

Figure 2: Bar graph exhibiting survey results.

Hanford Site

The Hanford Site data compares a pump and treat (active) remediation method with an appetite barrier (passive) remediation system. The raw data collected in the bins for each of the metrics showed that several of the parameters were exactly the same in terms of sustainability (Figure 2), while there was only a slight difference in the other parameters. This was unexpected, as from the research done prior to creating this index it was expected that the oil injection method would have a significantly higher bin score than the P&T method. Nevertheless, the oil injection did have consistently higher bin scores than P&T. It should be noted that some of the bins could still be optimized to properly highlight the relative sustainability within each metric.

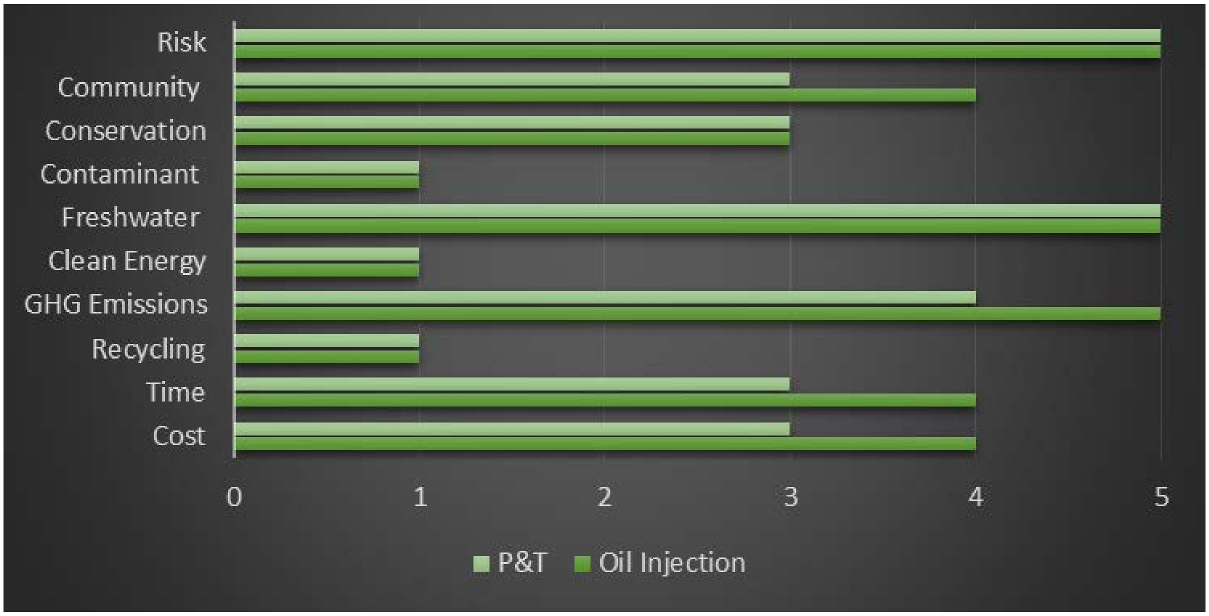

Figure 3: Raw bin data from the Hanford site

The results from the weighted data using the rankings given by the regulator who took the survey minimize the values of recycling, clean energy, and risk, while maximizing the values for freshwater consumption, greenhouse gas emissions, and community impact.

In the sustainability index table (Appendix B), the numbers come together for a total weighted score of 61.6% for the appetite barrier and 62.2% for the P&T method, showing a slight favorability for the appetite barrier from the regulator's perspective.

The differences in the sustainability scores become clearer in the scenario using the rankings obtained from community members. In this scenario, the weighted appetite barrier scored almost 10 percent higher than the weighted P&T method. This is because of the correlation between the values of the community members with high scoring metrics for the appetite barrier method. Interestingly, the difference between the scores for the passive and active remediation methods from the investor's point of view was negligible (less than 1%), while from the scientist's values the passive method scored 12% higher than the active method.

Ohio Mound Site

The data from the Mound, Ohio site compared the P&T (active) method with an oil injection (passive) system, both of which were used at the site while it was considered active. As such, the data used in this example was from actual estimated results and not hypothetical like the Hanford Site data. The raw data obtained for the bins, like the Hanford Site, had some surprising similarities, notably the low scores in contaminant removal and clean energy use, as well as the high bin scores for freshwater consumption and risk for both methods.

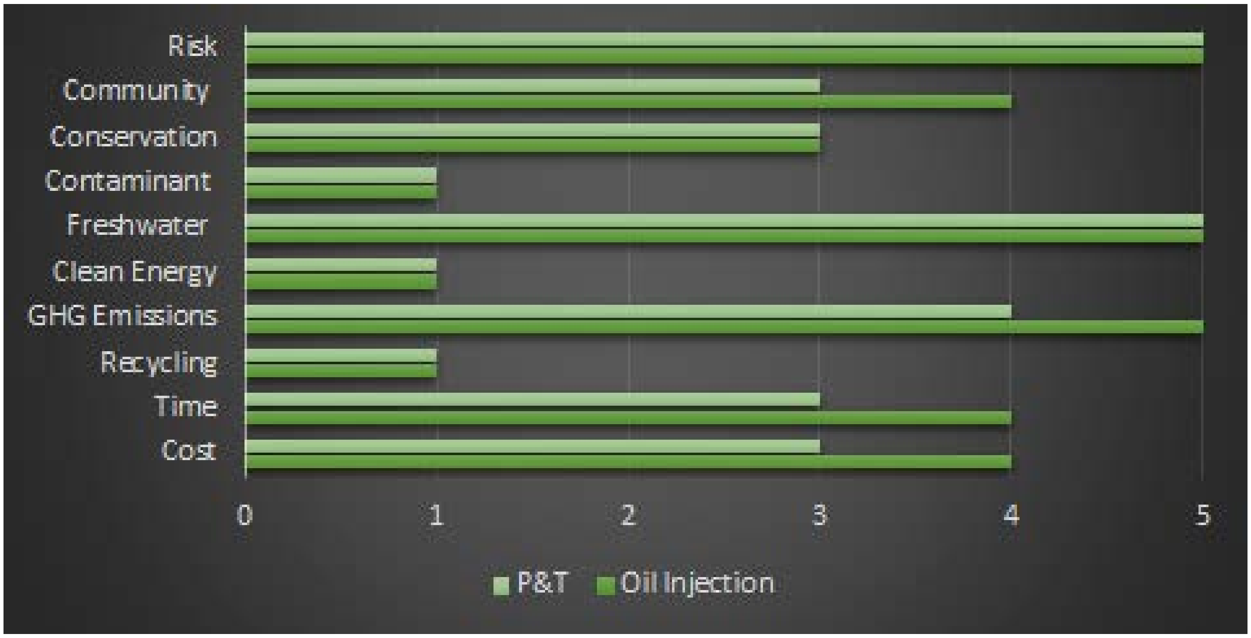

Figure 4: Raw bin data from the Ohio Mound site

The scores for each of the perspectives of the regulators, investors, scientists, and community members can all be found in Appendix B. It can be noted that the oil injection consistently scored significantly higher in terms of sustainability performance when weighted with the values of all four groups.

With further analysis of the charts, one can compare the bin scores with the values and determine why certain scores are low while others come out much higher. For example, for the regulator at the Hanford Site, contaminant removal and life cycle cost are both ranked highly, but the bin scores are low, while conservation is ranked highly for community members and scientists. This is important to address moving forward in order to reach a compromise and satisfy all groups involved.

5. CONCLUSION

Overall, passive remediation techniques scored much better than active techniques in terms of sustainability performance. Therefore, it can be concluded that switching to passive remediation techniques from active ones will increase the economic, environmental, and social sustainability of the system. Positive impacts of a more sustainable system include reduction of impact on communities by the cleanup, conservation of local ecosystems and preservation of ecological services, lower life cycle costs, and lower emissions and freshwater use. Switching from P&T to more passive remediation methods also aligns with EM's goals of reducing its carbon footprint by lowering its energy intensity, as well decreasing water use intensity. This also supports Mike Truex's Performance Assessment for Pump and Treat, reinforcing his point that it may be beneficial to evaluate remedy performance and the potential need for transition to alternative approaches at these sites.

The sustainability index spreadsheet created for this project can be edited to compare the relative sustainability of any number of systems used in the treatment process. It can be applied to any type of remediation technology, as it simply generates a numerical score by combining the raw bin data for each with the weighting obtained from the surveys. Therefore, if the bin data can be collected, the index can be used to understand the economic, environmental, social impacts of the technology, as well as the cumulative impact. Additionally, the surveys could be given to any person involved in the decision-making process to help understand his or her values and weight the raw data in the index accordingly. The template shown in this report is set up to compare two remediation technologies side by side, however, more columns could easily be added to the spreadsheet in order to compare more than two systems.

Moving forward, the index could be improved by optimizing the bin ranges for each metric based on actual data and statistical averages obtained from other sites which have previously switched from active to passive remediation methods. If the maximum, minimum, and median data points could be obtained for each metric, the bin values could be defined using this data, rather than approximations which are currently in use. This would greatly improve the validity of the data generated using the bins, and improved bin values would increase the accuracy of the final value obtained for the sustainability score. It is not representative of the values of DOE or of any group in general. In order to obtain the appropriate weights for another comparison, the survey in appendix A should be distributed to those directly involved with that project.

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APPENDIX A. Weighing Factors Survey

Company/ position (optional):

____

Are you a:

Stakeholder/ Investor	Regulator	Scientist/ Engineer	Community Member

Survey:
Rank in order of importance from 1 to 10, where 1 is the most important and 10 is the least important factor when considering type of remediation to implement, based on your professional and personal values.

____Total life-cycle cost

____Time

____Recycling (e.g. metals, land, water)

____Greenhouse gas emissions (CO_2, CH_4, and NOx)

____Renewable energy (e.g. solar, wind, geothermal, etc.)

____Freshwater consumption (e.g. groundwater and surface water)

____Contaminant removal

____Local ecosystem conservation

____Worker safety

____Community impact (e.g. recreational spaces, local economy, etc.)

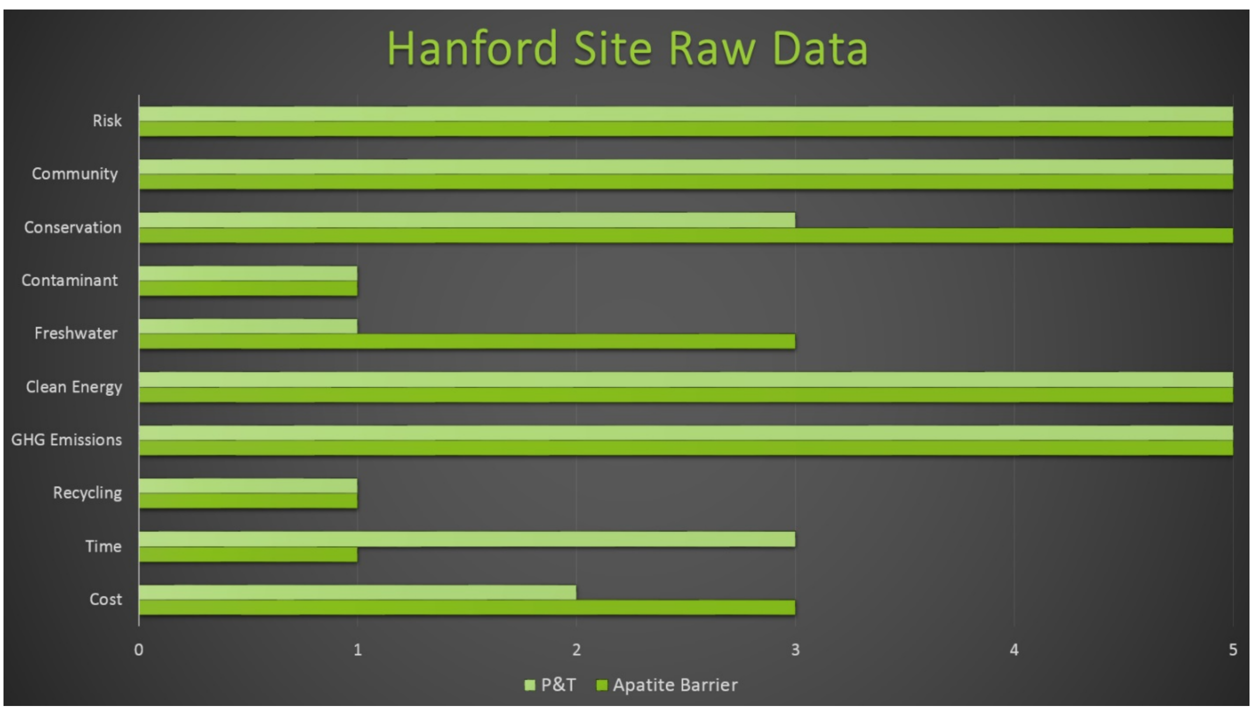
Which is more important to you?

Time	or	Greenhouse gas emissions
Local ecosystem conservation	or	Total cost
Contaminant removal	or	Freshwater consumption
Community perception	or	Local ecosystem conservation
Clean energy	or	Recycled materials
Familiar, established technology (e.g. air stripping)	or	Emerging technology with high potential (e.g. new biochemical methods)
Proven technique, but expensive (e.g. pump and treat)	or	Viable technique, but somewhat unproven (e.g. bioslurping)

APPENDIX B. Sustainability Index Examples

Hanford Site Raw Data

P&T	Metric	Apatite Barrier
2	**Cost**	3
3	**Time**	1
1	**Recycling**	1
5	**GHG Emissions**	5
5	**Clean Energy**	5
1	**Freshwater**	3
1	**Contaminant**	1
3	**Conservation**	5
5	**Community**	5
5	**Risk**	5



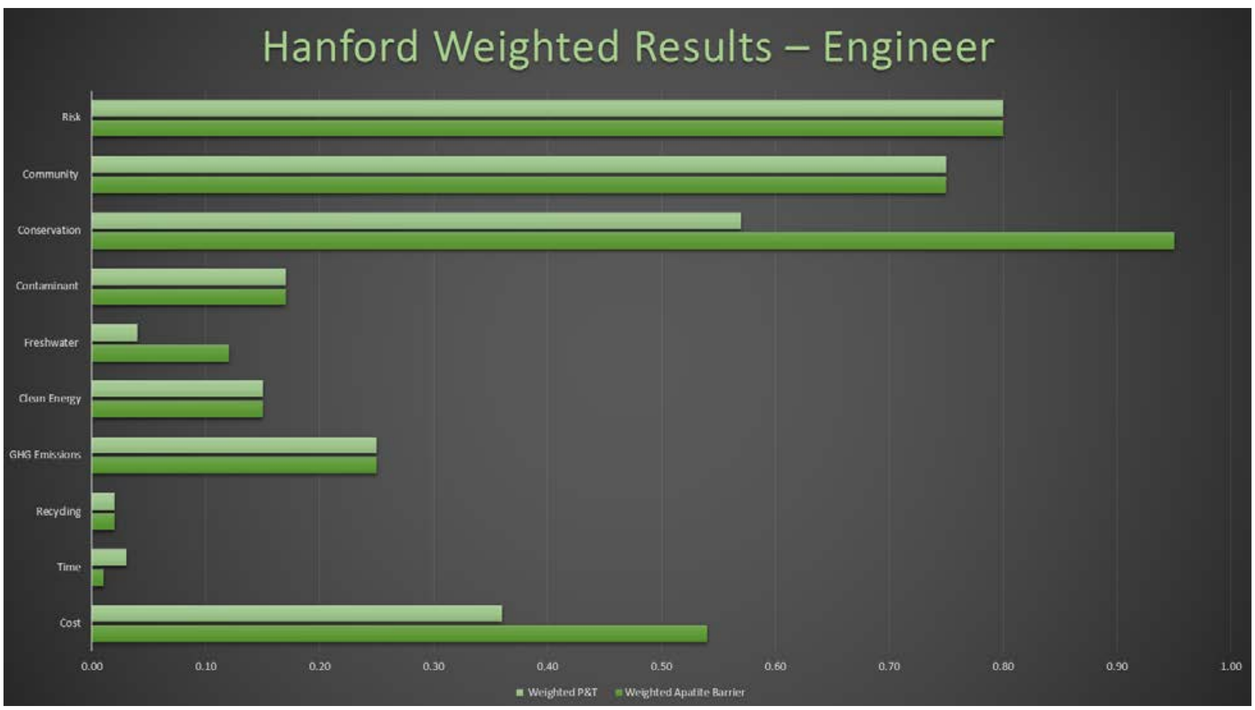
Hanford Results: DOE Engineer

Weighting Survey Results:

Weighted P&T	200 W P&T	Metric	Apatite Barrier	Weighted Apatite Barrier
0.36	2	**Life Cycle Cost**	3	0.54
0.03	3	**Time**	1	0.01
0.02	1	**Recycling/ Reuse**	1	0.02
0.25	5	**GHG Emissions**	5	0.25
0.15	5	**Renewable Energy**	5	0.15
0.04	1	**Freshwater Consumption**	3	0.12
0.17	1	**Contaminant Removal**	1	0.17
0.57	3	**Ecological Conservation**	5	0.95
0.75	5	**Community Impact**	5	0.75
0.80	5	**Safety/ Risk**	5	0.80
3.14	**31**	**TOTAL**	**34**	**3.76**

Rank	Weight
2	18%
10	1%
9	2%
6	5%
8	3%
7	4%
3	17%
1	19%
5	15%
4	16%

3.14/5 63%	31/50 62.0%		34/50 68.0%	3.76/5 75%

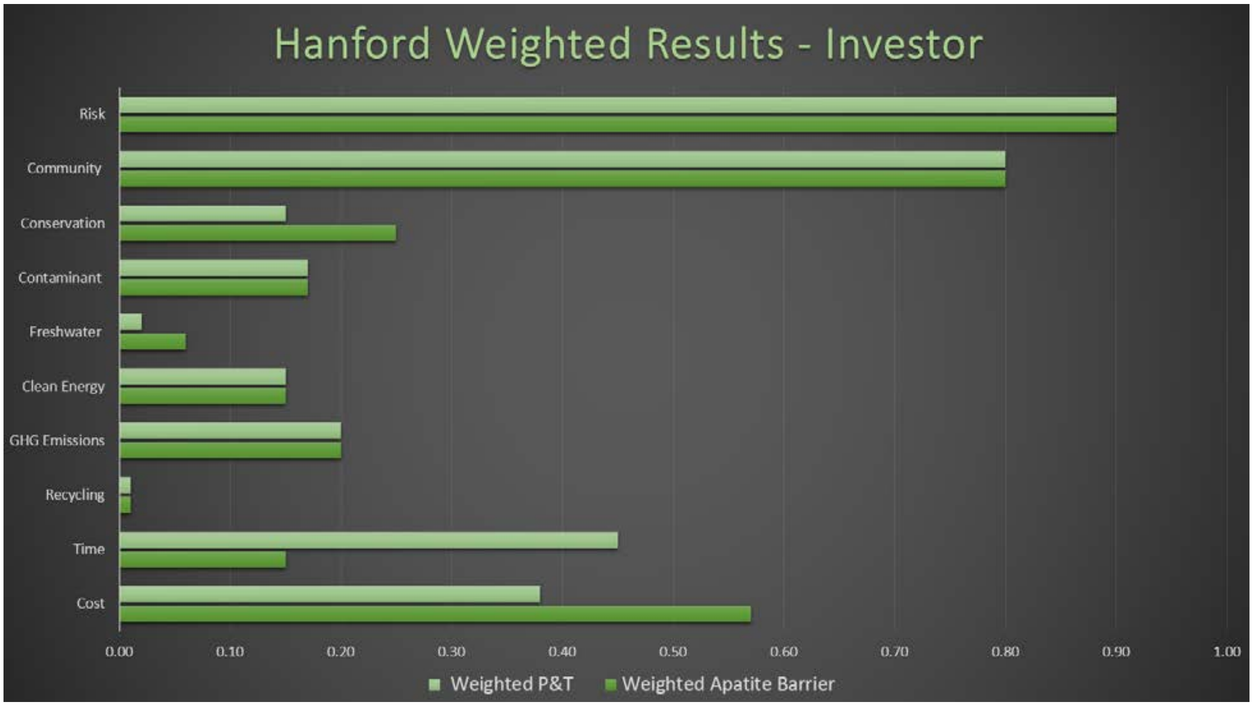


Hanford Results: Investor

Weighted P&T	200 W P&T	Metric	Apatite Barrier	Weighted Apatite Barrier
0.38	2	**Life Cycle Cost**	3	0.57
0.45	3	**Time**	1	0.15
0.01	1	**Recycling/ Reuse**	1	0.01
0.20	5	**GHG Emissions**	5	0.20
0.15	5	**Renewable Energy**	5	0.15
0.02	1	**Freshwater Consumption**	3	0.06
0.17	1	**Contaminant Removal**	1	0.17
0.15	3	**Ecological Conservation**	5	0.25
0.80	5	**Community Impact**	5	0.80
0.90	5	**Safety/ Risk**	5	0.90
3.23	**31**	**TOTAL**	**34**	**3.26**
3.23/5 64.6%	31/50 62.0%		34/50 68.0%	3.26/5 65.2%

Weighting Survey Results:

Rank	Weight
1	19%
5	15%
10	1%
7	4%
8	3%
9	2%
3	17%
6	5%
4	16%
2	18%

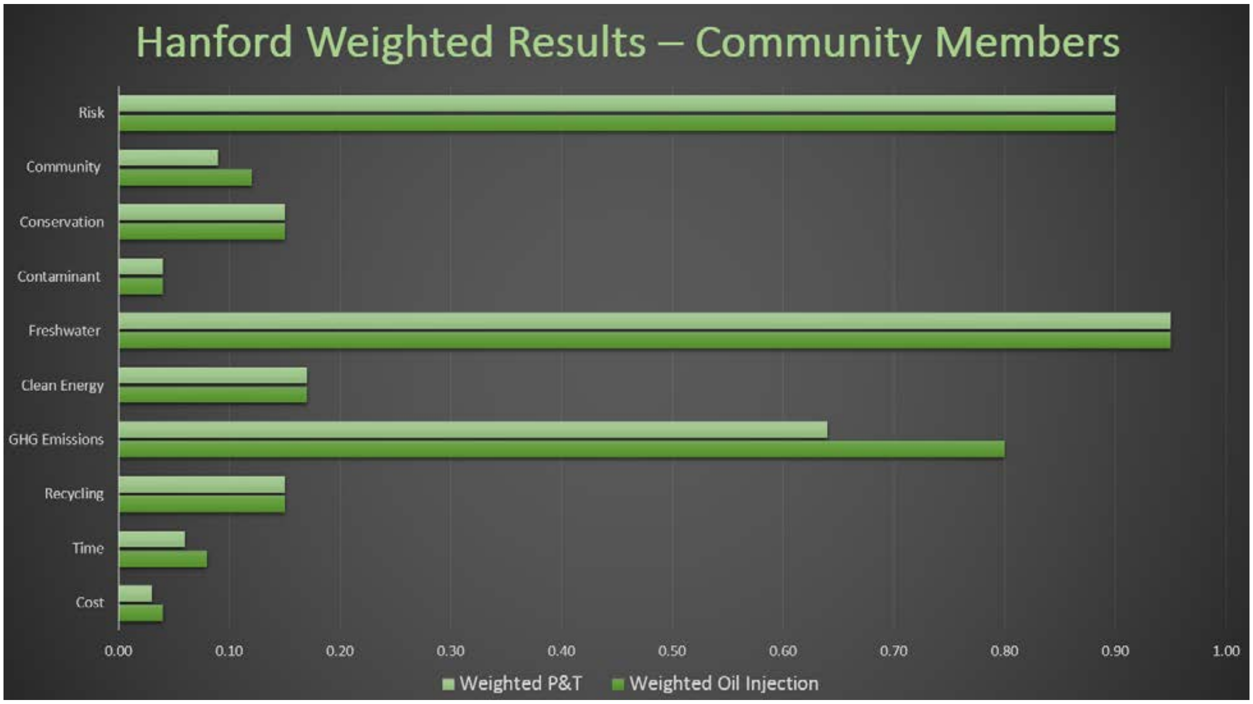


Hanford Results: Community Members

Weighted P&T	200 W P&T	Metric	Apatite Barrier	Weighted Apatite Barrier
0.02	2	**Life Cycle Cost**	3	0.03
0.06	3	**Time**	1	0.02
0.15	1	**Recycling/ Reuse**	1	0.15
0.80	5	**GHG Emissions**	5	0.80
0.85	5	**Renewable Energy**	5	0.85
0.19	1	**Freshwater Consumption**	3	0.57
0.04	1	**Contaminant Removal**	1	0.04
0.15	3	**Ecological Conservation**	5	0.25
0.15	5	**Community Impact**	5	0.15
0.90	5	**Safety/ Risk**	5	0.90
3.31	**31**	**TOTAL**	**34**	**3.76**
3.31/5 66.2%	31/50 62.0%		34/50 68.0%	3.76/5 75.2%

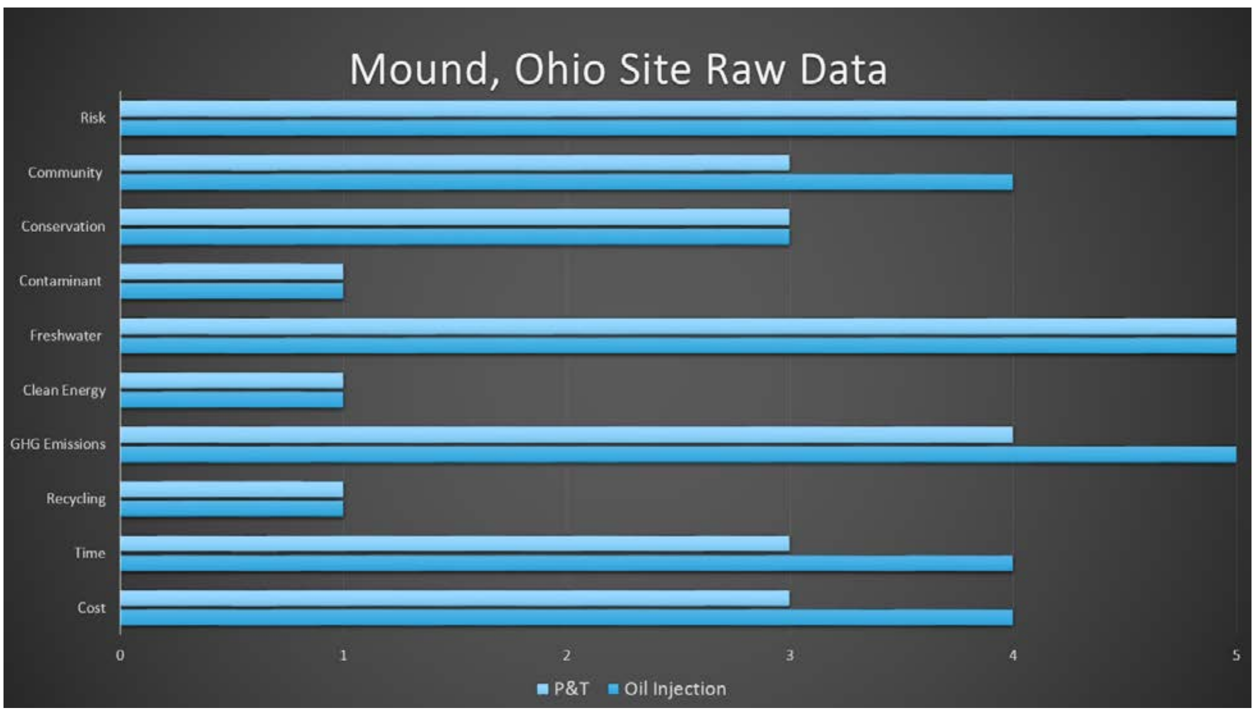
Weighting Survey Results:

Rank	Weight
10	1%
9	2%
5	15%
4	16%
3	17%
1	19%
7	4%
6	5%
8	3%
2	18%



Mound, Ohio Site Raw Data

P&T	Metric	Oil Injection
3	**Cost**	4
3	**Time**	4
1	**Recycling**	1
4	**GHG Emissions**	5
1	**Clean Energy**	1
5	**Freshwater**	5
1	**Contaminant**	1
3	**Conservation**	3
3	**Community**	4
5	**Risk**	5



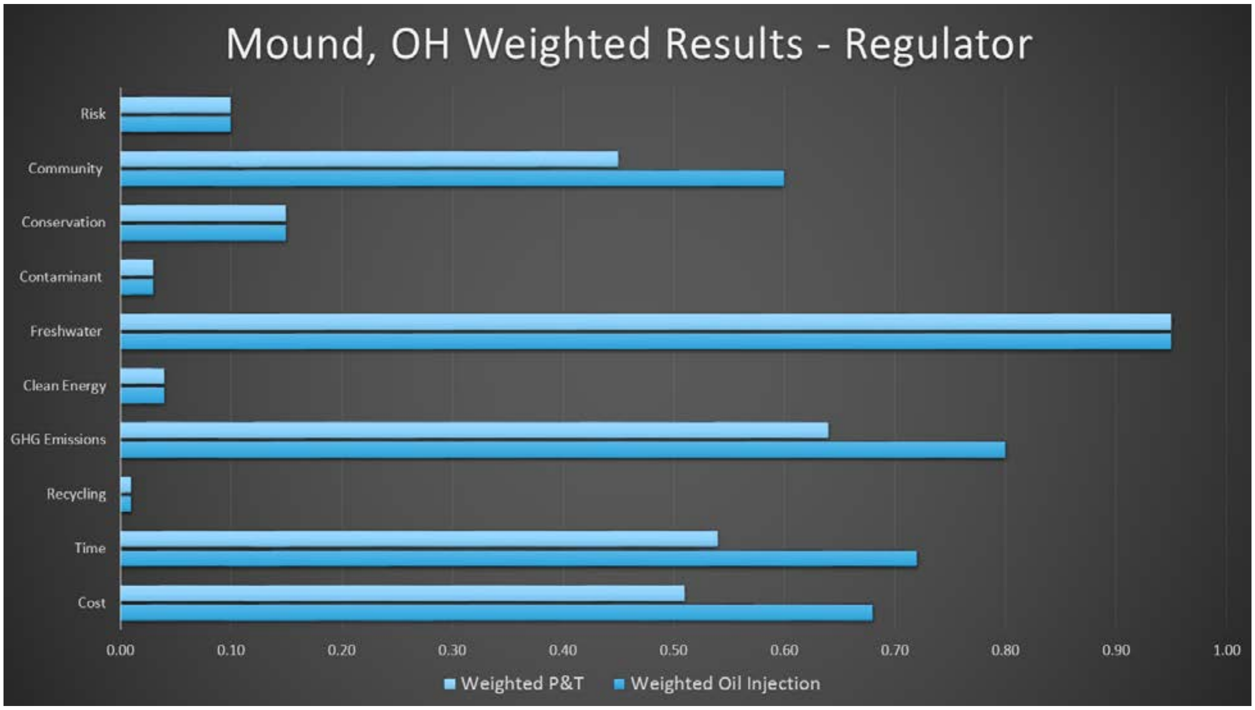
Mound
Results: EPA Regulator

Weighting Survey Results:

Weighted P&T	P&T	Metric	Oil Injection	Weighted Oil Injection
0.51	3	**Life Cycle Cost**	4	0.68
0.54	3	**Time**	4	0.72
0.01	1	**Recycling/ Reuse**	1	0.01
0.64	4	**GHG Emissions**	5	0.80
0.04	1	**Renewable Energy**	1	0.04
0.95	5	**Freshwater Consumption**	5	0.95
0.03	1	**Contaminant Removal**	1	0.03
0.15	3	**Ecological Conservation**	3	0.15
0.45	3	**Community Impact**	4	0.60
0.10	5	**Safety/ Risk**	5	0.10
3.42	**29**	**TOTAL**	**33**	**4.08**

Rank	Weight
3	17%
2	18%
10	1%
4	16%
7	4%
1	19%
8	3%
6	5%
5	15%
9	2%

2.42/5	27/50	35/50	4.08/5
68.4%	58.0%	70.0%	81.6%



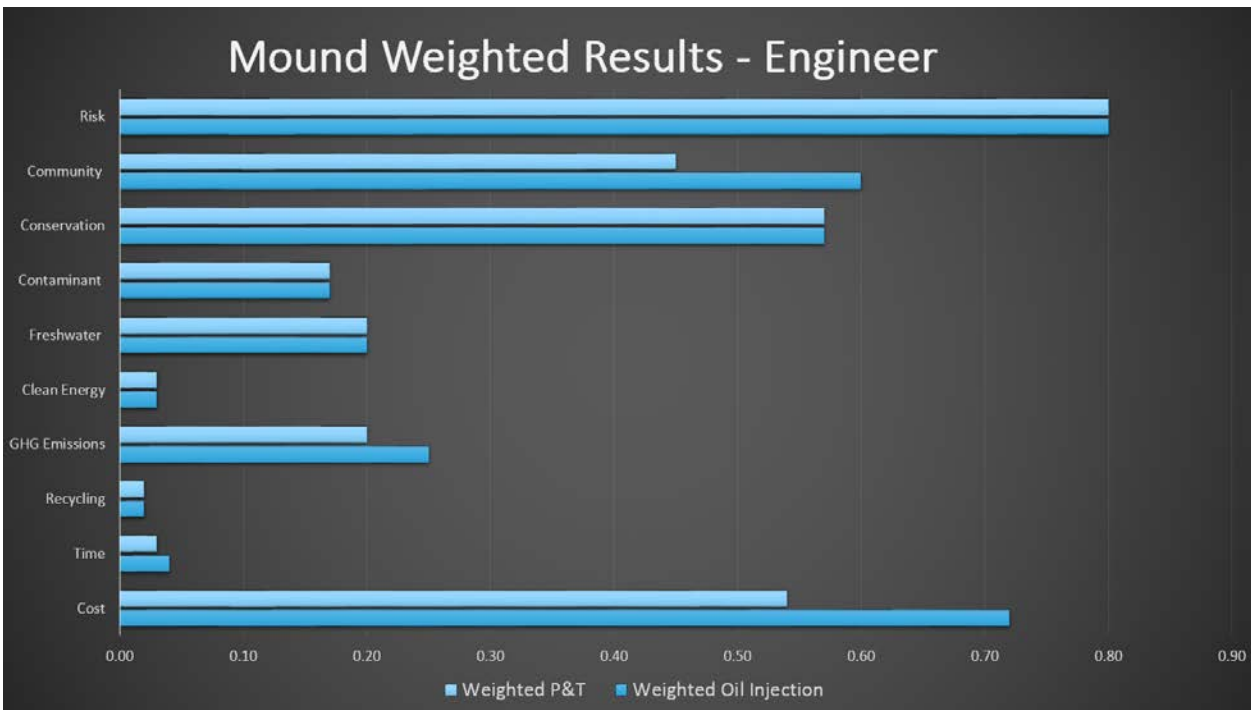
Mound
Results: DOE Engineer

Weighted P&T	P&T	Metric	Oil Injection	Weighted Oil Injection
0.54	3	**Life Cycle Cost**	4	0.72
0.03	3	**Time**	4	0.04
0.02	1	**Recycling/ Reuse**	1	0.02
0.20	4	**GHG Emissions**	5	0.25
0.03	1	**Renewable Energy**	1	0.03
0.20	5	**Freshwater Consumption**	5	0.20
0.17	1	**Contaminant Removal**	1	0.17
0.57	3	**Ecological Conservation**	3	0.57
0.45	3	**Community Impact**	4	0.60
0.80	5	**Safety/ Risk**	5	0.80
3.01	**29**	**TOTAL**	**33**	**3.40**

Weighting Survey Results:

Rank	Weight
2	18%
10	1%
9	2%
6	5%
8	3%
7	4%
3	17%
1	19%
5	15%
4	16%

3.01/5	29/50		33/50	3.40/5
60.2%	58.0%		66.0%	68.0%

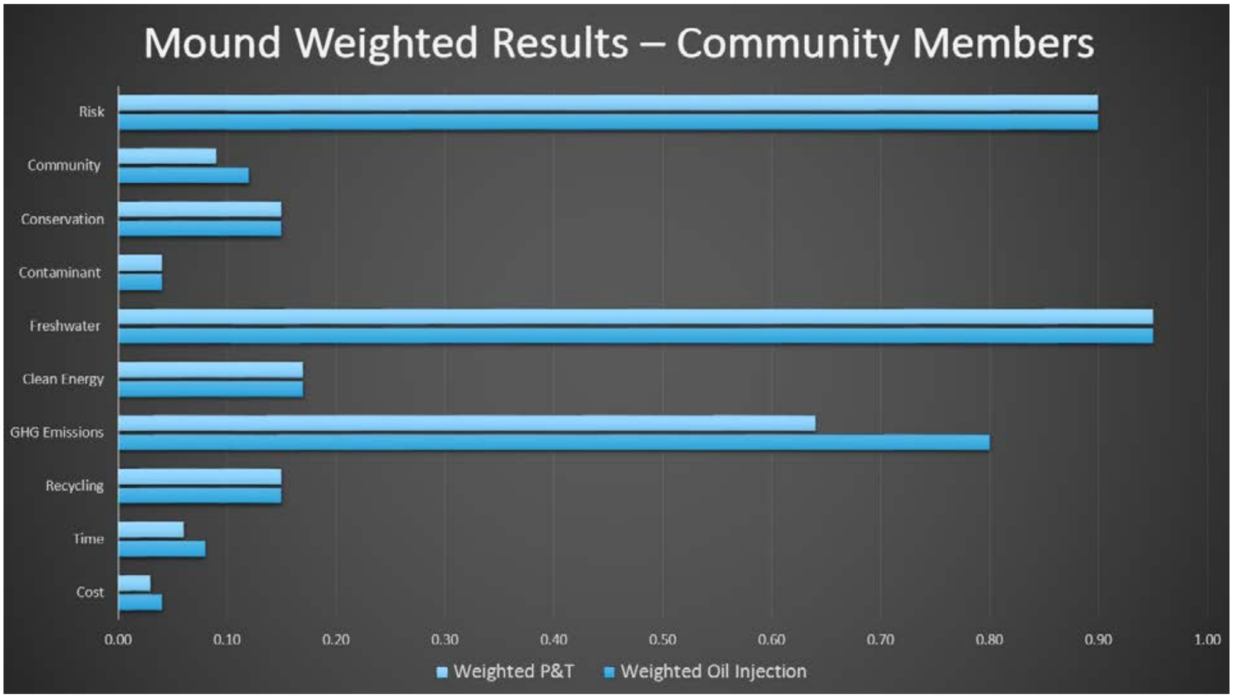


Mound
Results: Community Members

Weighting Survey Results

Weighted P&T	P&T	Metric	Oil Injection	Weighted Oil Injection
0.03	3	Life Cycle Cost	4	0.04
0.06	3	Time	4	0.08
0.15	1	Recycling/ Reuse	1	0.15
0.64	4	GHG Emissions	5	0.80
0.17	1	Renewable Energy	1	0.17
0.20	5	Freshwater Consumption	5	0.20
0.19	1	Contaminant Removal	1	0.19
0.15	3	Ecological Conservation	3	0.15
0.09	3	Community Impact	4	0.12
0.90	5	Safety/ Risk	5	0.90
2.58	**29**	**TOTAL**	**33**	**2.80**
2.47/5 **51.6%**	27/50 58.0%		35/50 70.0%	3.47/5 **56.0%**

Rank	Weight
10	1%
9	2%
5	15%
4	16%
3	17%
7	4%
1	19%
6	5%
8	3%
2	18%

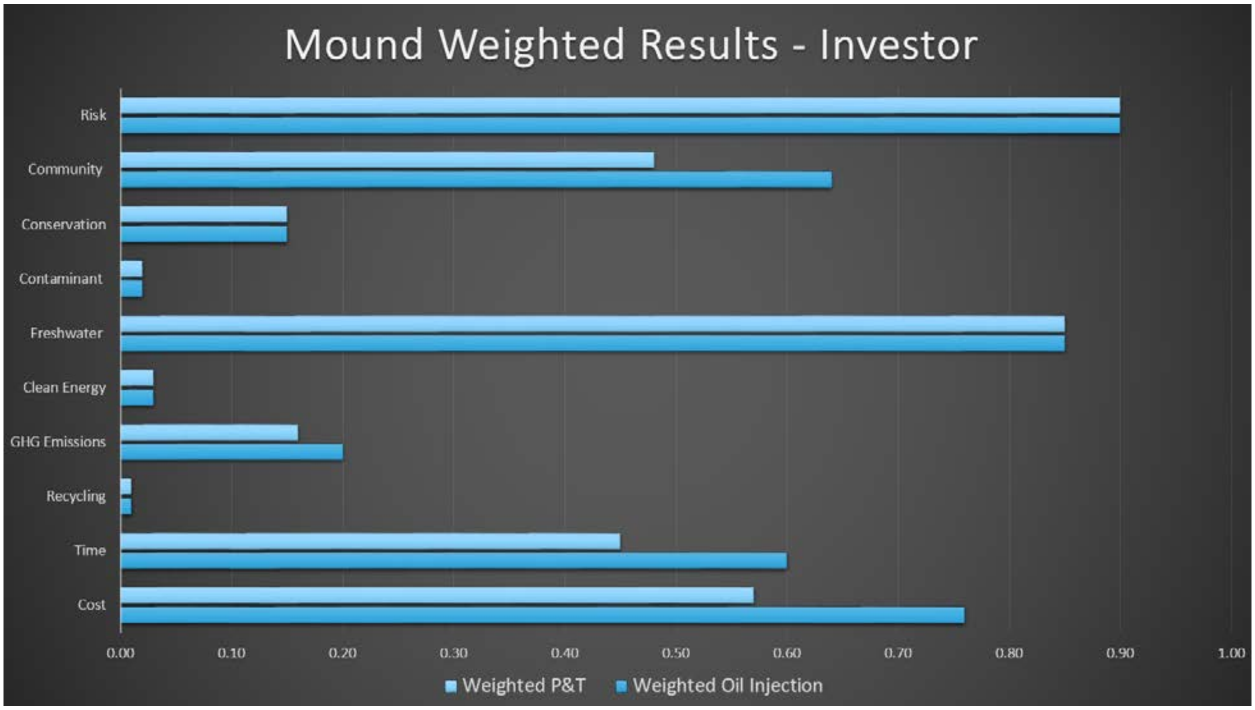


Mound Results: Investors

Weighting Survey Results:

Weighted P&T	P&T	Metric	Oil Injection	Weighted Oil Injection
0.57	3	Life Cycle Cost	4	0.76
0.45	3	Time	4	0.60
0.01	1	Recycling/ Reuse	1	0.01
0.16	4	GHG Emissions	5	0.20
0.03	1	Renewable Energy	1	0.03
0.85	5	Freshwater Consumption	5	0.85
0.02	1	Contaminant Removal	1	0.02
0.15	3	Ecological Conservation	3	0.15
0.48	3	Community Impact	4	0.64
0.90	5	Safety/ Risk	5	0.90
3.62	29	TOTAL	33	4.16
3.62/5 72.4%	29/50 58.0%		33/50 66.0%	4.16/5 83.2%

Rank	Weight
1	19%
5	15%
10	1%
7	4%
8	3%
3	17%
9	2%
6	5%
4	16%
2	18%


Mound Weighted Results - Investor
Risk
Community
Conservation
Contaminant
Freshwater
Clean Energy
GHG Emissions
Recycling
Time
Cost
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Weighted P&T
Weighted Oil Injection

APPENDIX C. Infographic