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Title of Design: Fuel Spill Containment at Bozeman Yellowstone International Airport (BZN)

Design Challenge addressed: III.B. Airport Environmental Interactions: Improving Methods for Containment and Cleanup of Fuel Spills

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Professional Recomendations on Spill Prevention and Recovery

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Executive Summary

PROSPR, a team of undergraduate students from the University of Colorado Boulder, evaluated and designed alternatives for fuel spill clean-up at Bozeman International Airport (BZN). BZN is a small airport, with a daily average of 200 operations, 1900 passengers, consuming 15,000 gallons/day of Jet A fuel, and 450 gallons/day of AvGas. All storm water at the site is infiltrated through the sandy soils to recharge groundwater, so the risk of fuel spill poses a significant threat to the groundwater resources in the area. However, BZN has had only two fuel spills over 10 gallons in the last 9 years.

The following options were evaluated: repaving the self-fueling apron with polymer modified asphalt, BuffVac fuel spill recovery vehicle, installing an oil-water separator downstream from the fueling aprons, implementing infrared detection on the fuel storage tanks, and applying the C.I. Agent® Water Cannon to surface spills. Historically, 90% of fuel spills are 10 gallons or less. Adding an order of magnitude safety factor, we designed for a medium sized spill of 100 gallons per year to compare the per-spill cost estimates. Using a decision matrix with criteria weighted by the BZN Airport Director, Brian Sprenger, the BuffVac recovery vehicle was determined to be the optimal solution.

The BuffVac is a small electric vehicle outfitted with foam sprayers to apply Micro-Blaze Microbial Product, which will reduce flammability hazards and create a benign waste product. Then a pneumatic spill vacuum will pick up the waste, and adsorbent rollers remove any oil residue left on the asphalt surface. The capital cost of the vehicle is estimated at $55,000, with an annual operations and maintenance cost of about $7,500. One of the biggest advantages of the BuffVac is that it requires no change in infrastructure, making it easy to implement at any airport and quick to respond in an emergency.

Table of Contents

1 Problem Statement

The goal of this project is to design a jet-fuel containment and response plan for the Bozeman International Airport (BZN). In this assessment, PROSPR will provide a thorough overview of each potential alternative as well as an alternative comparison in order to identify the best possible alternative for BZN. We will begin with a background containing a description of the problem as well as current conditions, and an evaluation of regulations. PROSPR's evaluation will include technical aspects, a financial analysis, as well as any social considerations. This assessment will conclude with an overall recommendation for the BZN and how it meets the Federal Aviation Administration's (FAA) current and future goals.

2 Problem Background

2.1 Description of the Problem

Over the past century, there have been countless jet fuel spills at airports around the United States and around the world. Table 2.1.1 outlines the most recent as well as most severe fuel spills that have occurred.

Table 2.1.1: Historical Fuel Spills

Year	Location	Operation in Progress	Gallons Spilled	Incident Description
1/13/13[1]	**Tokyo, Japan**	**De-fueling**	**26**	**During the de-fueling operations of Boeing 787, a valve was found open on aircraft wing. Unknown clean up measures.**
1/8/13[1]	**Boston, Mass.**	**Taxiing to runway**	**40**	**While the aircraft (Boeing 787) was taxiing to the runway, leak was discovered. Unknown cause and clean up measures.**
1/3/13[2]	**Marion, OH**	**Truck re-fueling**	**2,500**	**While a fuel truck was re-fueling, it overflowed and migrated into creek. Unknown cause of overflow. Booms and vacuums used for clean up.**
1/12[3]	**Milwaukee, WI**	**Pipeline fuel transport**	**Unknown**	**Fuel leaked from pipeline for two weeks discovered by a strange odor. Booms installed in water for clean up.**
7/12[4]	**Fresno, CA**	**Fuel truck transporting fuel to aircraft**	**200**	**While a fuel truck was driving on tarmac, it overturned. Unknown cause for overturn and clean up measures.**
1/27/12[5]	**Chicago, IL**	**Pipeline fuel transport**	**42,000**	**Pipeline burst that spilled fuel into ditch. The Coast Guard and EPA got involved for clean up.**
1999[6]	**Kirtland AFB, NM**	**Pipeline fuel transport**	**24 Million**	**Fuel coming up from underground at aircraft storage center. Monitoring wells are being installed to determine contamination levels.**

2.2 Fuel Type and Characteristics

Jet fuel, known as JP6 and JP8, is used globally to power larger aircrafts. Although the composition of jet fuel varies, it is primarily made up of kerosene (95%) [7]. Kerosene, also known as paraffin, is a highly combustible liquid made up of hydrocarbon chains of various lengths. Kerosene is used because it yields a very high energy output when burned. Kerosene is made up of a mixture of aliphatic and aromatic carbon chains, ranging from lengths of 9-13 carbon atoms. Common ranges of chemical properties of kerosene are summarized in Table 2.2.1 below.

Table 2.2.1: Common Properties of Kerosene[8]

Property	Value
Log K_{ow}	3-7
Log K_{oc}	9.6×10^2-5×10^6
Vapor Pressure (at 21 ^{0}C)	2-26 mm Hg
Henry's Law Constant	5×10^{-5} - 7×10^{-5} atm*m^3/mol
Explosive Limits	0.7% - 5.0%
Solubility	5 mg/L
Flashpoint	38 ^{0}C
Average Molar weight	~120 g/mol

2.3 Evaluation of Regulations

The main regulation driving fuel spill preparedness is the US EPA Spill Prevention, Control, and Countermeasure (SPCC) Rule. The SPCC Rule was first established in 1973 under the Clean Water Act, and has undergone various revisions since then. The SPCC Rule applies to most industrial facilities with a total aboveground oil storage capacity of 10,000 gallons or less. The Rule includes detailed requirements for oil spill prevention, preparedness, and response in order to protect nearby water supplies. Airport fueling operations must publish a detailed SPCC Plan periodically[9].

The US EPA also sets the regulations for soil and groundwater contamination levels. The following regulation standards are set for hydrocarbon-contaminated groundwater and soil in Montana where the jet fuel regulations are equivalent to the gasoline regulations:

Table 2.3.1: Clean-Up Standards for Hydrocarbon Contaminated Groundwater and Soil[10]

Product	Constituent	Groundwater		Soil	
		Notification Level	Clean-Up Level	Notification Level	Clean-Up Level
Gasoline	TPH	any amount	Site Specific	100ppm	Site specific >100 ppm
	Benzene	any amount	>MCL (site specific)	1 ppm	Site Specific >1 ppm
	Toluene	any amount	>MCL (site specific)		
	Ethylbenzene	any amount	>MCL (site specific)		
	Xylenes	any amount	>MCL (site specific)		
	Total BTEX			10 ppm	Site specific >10 ppm
Diesel	TPH	any amount	Site Specific	100 ppm	Site specific >100 ppm
	Benzene	any amount	>MCL (site specific)		
	Toluene	any amount	>MCL (site specific)		
	Ethylbenzene	any amount	>MCL (site specific)		
	Xylenes	any amount	>MCL (site specific)		
Waste Oil	TPH	any amount	Site specific	100 ppm	Site specific >100 ppm
	VOCs	any amount	See above for BTEX	10 ppm	Site Specific >10 ppm

Further guidelines and regulations are set forth by the EPA concerning underground storage tanks (UST) holding petroleum or hazardous substances and response action that is needed if and when a spill does occur. Within twenty-four hours after a confirmed release of substance has occurred owners and operators of the UST must report the release to the implementing agency, take immediate action to prevent any further release of the regulated substance into the environment, and identify and mitigate fire, explosion, and vapor hazards. After completing the initial response procedures the following must be done to begin the abatement process and check the site: removal of as much of the substance from the UST system, inspect above ground and visual below ground releases and prevent further spreading of the substance into the soil or groundwater, continue to monitor any fire or safety hazards, remedy hazards of the contaminated soils that are excavated or exposed, measure for the presence of a release where contamination is most likely to be present, measure presence of free product and begin free product removal, and submit a report within 20 days of release. After these initial containment practices have been implemented, the implementing agency and owners of the UST system must compile a report about the release and current status of the spill. Finally, the implementing agency and owner of the UST will devise an action plan to make sure the cleanup and remediation of the site will protect human health, safety, and the environment. Upon approval of this plan by the implementing agency, the owners and operators of the UST system must implement the plan and reach effective remediation of the site.

3 Airport Background

3.1 Current Conditions

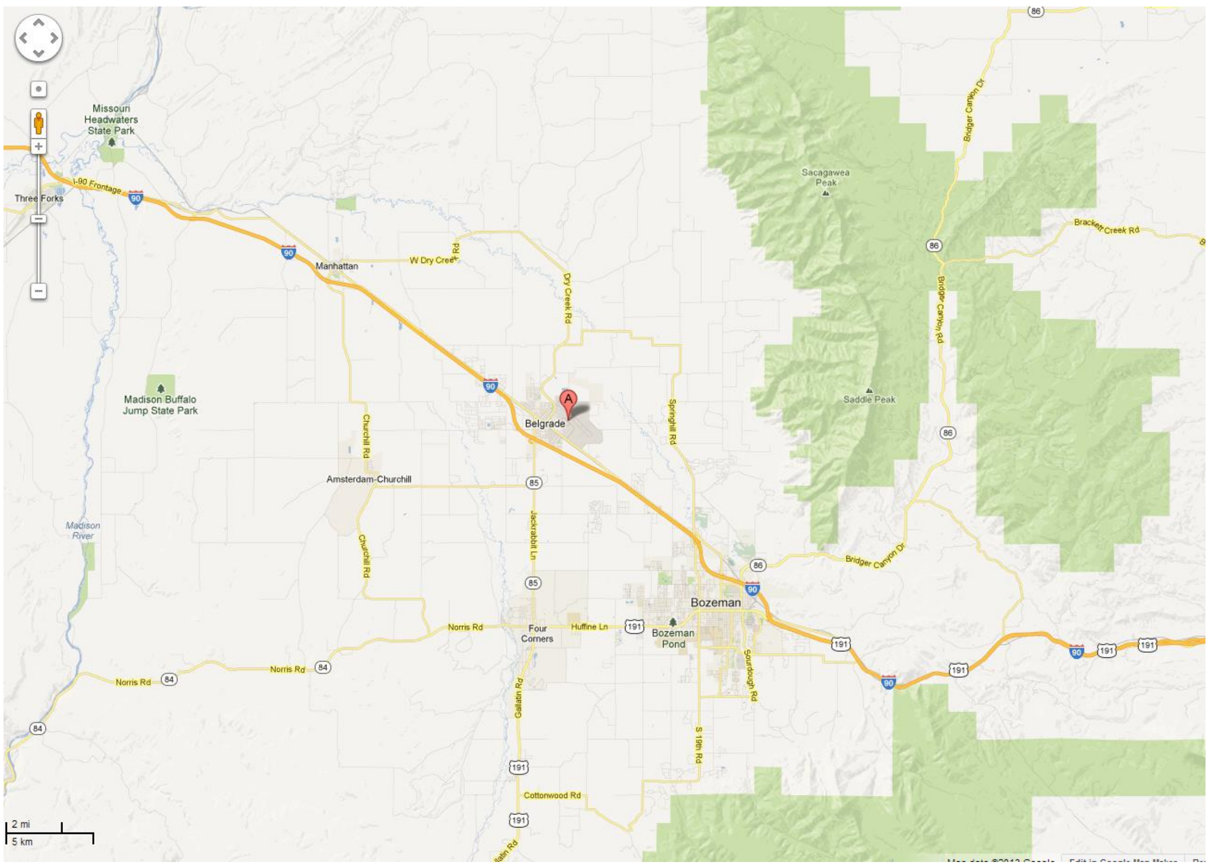


Figure 3.1.1: Map of Gallatin County Area

3.1.1 Climate

Bozeman Yellowstone International Airport is located in the town of Belgrade, Montana, in Gallatin County. Gallatin County is a fairly rural County, boasting a population density of about 34.4 persons per square mile[11]. In this mountain climate, temperature varies greatly with the season. Winter temperatures generally range between 9-33^0 F, while summer temperatures will range between 50-90^0 F. Precipitation also varies with season in Belgrade. Averaging roughly 14.12 inches of water in precipitation per year, almost a third (4.92 in) of the precipitation falls in the months of May and June. Due to its high elevation (4,459 ft above sea level), much of the precipitation falling between the months of November and March is in the form of snow[12].

3.1.2 Runways and Aprons

Bozeman International is small for an international airport, boasting only 3 runways, two of which are asphalt, one of which is turf. Combined, these 3 runways cover 1,789,215 ft^2. Of this, 1,533,375 ft^2 are asphalt. At the terminal, Bozeman boasts 109,500 ft^2 of concrete pavement, and 239,490 ft^2 of asphalt for commercial plane loading and taxiing. Additionally, there is a FedEx designated asphalt apron that is 4,200 ft^2, as well as 1,250,259 ft^2 of additional aprons for private plane use[13].

3.1.3 Geology and Storm Water Management

Bozeman Airport is located in the Gallatin Valley, which is composed of large alluvial deposits, sand, silt, and gravel. The nearest surface water is a river approximately 1.5 miles east of the airport, a tributary of East Gallatin River[14]. The depth to ground water at the site is approximately 50 ft, with groundwater flow moving from the southeast to northwest[15].

All storm water runoff from the site is ultimately infiltrated into groundwater. All runways and taxiways dishcharge to surface flow. The parking lot and fueling aprons have drains leading to piping. The water is moved through pipes and open trenches to a detention pond onsite.

3.1.4 Fuel Storage

Bozeman International has 11 fuel storage tanks, with a capacity to store up to 152000 gallons of fuel. Four tanks are located above ground, while seven tanks reside below ground. These tanks store Avgas, Jet A fuels, and JP8 fuels, shown in table 3.1.4.1[16].

Table 3.1.4.1: Jet Fuel Storage Tanks at BZN

Type	Above Grade	Below Grade
AvGas	12,000	
AvGas		12,000
Jet A	24,000	
Jet A	20,000	
Jet A		12,000
Jet A		12,000
Jet A		12,000
Jet A		12,000
Jet A		12,000
Jet A		12,000
JP8	12,000	
Total AvGas		24,000
Total Jet A		116,000
Total JP8		12,000
Total		152,000

3.1.5 Operations

In 2009, Bozeman international reported employing 27 airport professionals. Also in 2009, there were 74,897 airport operations, (meaning both take offs and landings), serving 691,276 passengers. This comes out to be roughly 200 operations a day, which means that Bozeman International handles roughly 100 planes per day (both private and commercial). Bozeman Internal sells/dispenses roughly 5.6 million gallons of Jet A, and 165,500 gallons of Avgas per year[17].

3.1.6 Fuel Response

The policy of the Bozeman Airport is essentially whoever is responsible for a fuel spill is also responsible for the cleanup and remediation of the spill. The fixed base operator (FBO) on site is Yellowstone Jet Center, which has an established SPCC Plan. However, this document was not made available to us upon request[18].

3.2 Future Conditions

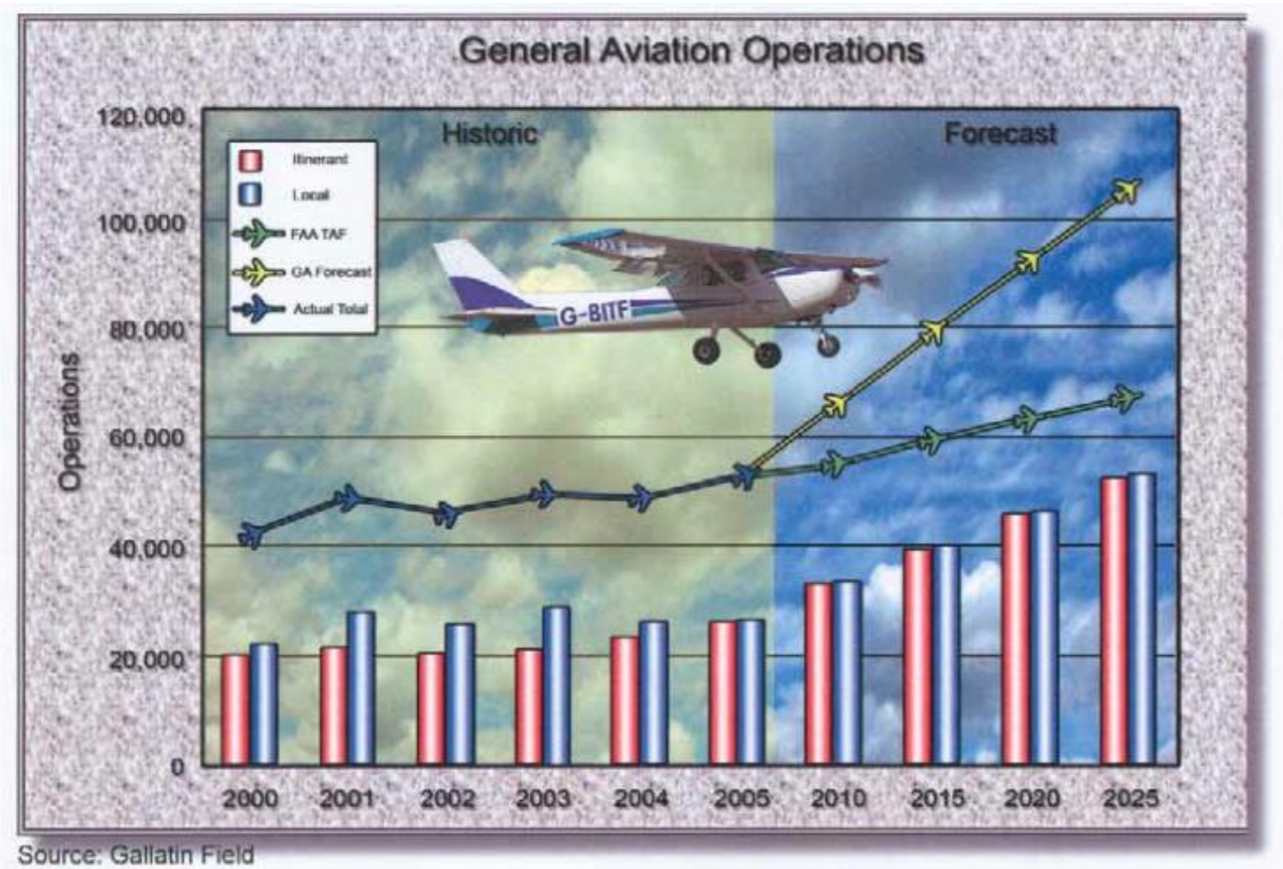


Figure 3.2.1: Aviation Operations at Gallatin Field

The Bozeman Yellowstone International Airport has forecasted historical trends in order to create guidelines for expansions and planning. Gallatin County was the fastest growing county in Montana from 2000 to 2005.[19] Based on several years of census data, the average annual growth of Gallatin County is two percent.19 An increase in population in the area will increase the foot traffic through the airport. With an increase in numbers at BZN, an expansion is inevitable.

Mark Maierle, a professional engineer working at BZN, confirmed a runway expansion. The first stage of construction will result in a runway that will be 100 feet by 5100 feet. After completion, however, the runway will be 100 feet by 6900 feet[20]. This new runway will bring up the total runway area from just over 1.5 million square feet to just less than 2.5 million square feet. With another runway, more flights can be added to the flight schedules increasing the general aviation operations.

4 Problem Solving Approach

In order to recommend the correct option for Bozeman International Airport PROSPR evaluated each alternative against a set of Design Criteria which take into account a social, technical, and economical basis. In order to make sure that PROSPR was designing and investigating each alternative properly we assumed that Bozeman International Airport experiences 100 total gallons of fuel spills each year. This number would account for many small spills ranging from 1-10 gallons, as well as, a medium-sized spill of approximately 100 gallons per year.

To accurately assess each alternative on a social, economic, and technical basis PROSPR evaluated every alternative in the following manner:

- Research with industry experts and literature consultation
- Review of the advantages and disadvantages of each system
- Safety risk assessment of each system
- A preliminary design to evaluate the ease of implementation
- An operations and maintenance analysis

An economic analysis consisting of capital cost, operation and maintenance cost, and equivalent uniform annual cost analysis will be calculated to fully characterize the cost of each alternative.

4.1 Design Criteria

All viable alternatives were taken through a thorough investigation and alternatives comparison to determine the most appropriate alternative for Bozeman International Airport at Gallatin Field. With the aid of BZN, PROSPR has determined the following constraints on which each alternative was thoroughly investigated:

Table 4.1.1: Design Constraints

Constraint	Description
Protect Infiltration to the Groundwater and Nearby Ecosystem	**Ability of each alternative to protect the natural resources, including but not limited to, groundwater and ecosystem.**
Withstand Variable Temperature and Precipitation	**Any system must have the ability to undergo extreme temperature or precipitation swings, which are to be expected at BZM.**
Cost Effective Implementation	**Any system must have feasible installation cost for the airport or airline.**
Manageable Operation and Maintenance Cost	**Any system must have a manageable operation and maintenance cost for the airport or airline.**

In order to ensure that the above constraints were met by any alternative selected, PROSPR has created the following decision criteria in which to base any decision off of:

Table 4.1.2: Design Criteria

Criteria	Description
Environmental Impact	**Rate the system's impact on the environment and it's compatibility with the surrounding ecosystem**
Reliability	**Rate the system's reliability in a variety of manners. It will consider the system's general reliability, ability to withstand variable temperatures, and it's reliability to continually protect infiltration to groundwater.**
Capitol Cost	**Access a system's initial cost of installation to the airport.**
Operation and Maintenance Cost	**Access a system's continual operation and maintenance cost.**
Compatibility with Existing Processes	**Access a future system's potential for any incompatibility with any current system's at BZM**
Ease of Implementation	**Access the relative ease of installation of the system and BZM**

4.2 Alternatives Screening

4.2.1 Table 4.2.1: Summary of Alternatives Eliminated in the First Phase of Screening

Solution	Reason for Screening
1. In-Situ Permeable Reactive Barriers (PRB)	**BZN uses surface ponds for storm water runoff, which prevents the use of PRB.**
2. Bio-Sparging	**Less applicable to heavier constituents such as diesel fuel and kerosene**[21]
3. In-situ Capping	**Poor long term solution for underground piping and BZN only uses surface ponds for runoff**
4. Underground Pipe Leak Containment, Detection, and Remediation Barrier	**Since BZN does not transport any fuel underground, the underground pipes would never be an issue**

4.3 Interactions with Industry Experts

Name	Agency/Position	Topic of Discussion
Brian Sprenger	Bozeman Airport, Director	Criteria Weighting
Paul Schneider	Bozeman Airport, Assistant Director of Operations	Fueling operations, future airport expansion, storm water system
Mark Maierle	Morrison Maierle, Inc., PE	Bozeman Airport expansion, runway/apron dimensions, storm water improvements
B.J O'Banion Daniel	Marketing Director, C.I. Agent®	C.I. Agent® Solidifying Agent and Water Cannon, and its' feasibility for a fuel spill
Bob Werner	Fuel Inspector, DIA	Pneumatic Spill vacuums and Micro-Blaze formula
Keith Pass	Environmental Services, DIA	Stormwater systems and oil water seperators
Dave Johnson, P.E.	Regional Engineer, Asphalt Institute	Background on PG ratings, FAA requirements for Northwest Region, cost estimate for PG 64-34 binder
Lee Lewis, P.E.	Regional Manager, AVCON, INC.	Bob Sykes Airport cost allocations, depth of milling and paving of PMA
Mark Boccella	Senior District Sales Associate at Flir	Gave pricing and whether or not the infra-red detection camera would work for kerosene

4.4 Literature Review of Possible Solutions

4.4.1 Polymer Modified Asphalt

Asphalt pavement is a mixture of graded stone aggregate and asphalt. Put simply, asphalt is the binder or glue that holds the aggregate together. When left unprotected or uncoated, traditional asphalt is subject to degradation from oxidation and water penetration. Kerosene, gas, oil and other hydrocarbon-based chemicals will dissolve the asphalt binder, causing holes and raveling. To reduce the damaging effects of fuel such as cracking and rutting, airports are switching over to PMA.

In 1996, PMA was first applied at the Kuala Lampur International Airport in Malaysia. For this project, the PMA had to meet the FAA requirements of performance grade (PG) 76-10. Six years later, PMAwas first applied in the United States was La Guardia Airport (New York) in 2002. La Guardia used a combination of PG 82-22 binder and PG 94-22 binder, which are much higher grades than the PMA used in Malaysia.[22] The most recent and comparable project occurred at Bob Sykes Airport in Florida. Starting in January 2011 and finishing in December 2011, Bob Sykes Airport installed PMA to the northwest part of the general aviation apron. In May 2012, the American Association of Airport Executives Southeast Chapter recognized the importance of the project by naming it the 2012 General Aviation Airfield Project of the Year.[23] The mix and binder used for this project was P-401-FR (Crestview Mix) and PG 82-22 respectively.

4.4.2 BuffVac Fuel Spill Recovery Vehicle

Fuel Spills are a liability for airports. Not only are they costly and disruptive, they also represent a significant fire risk, as well as a significant environmental risk if not properly contained. Because of this, it is imperative that fuel spills are quickly and efficiently controlled. Spills generally must be reported if they are equal to or greater than 3 gallons. Spills are classified as either minor or major spills. Spills are classified as major if they exceed 3 gallons, if the spill has entered the storm water drainage system or if it has the potential to migrate off the property, if the material is considered to adversely affect the environment, or if the spill cannot immediately be controlled by the responsible party.

Responding to fuel spills is fairly straight forward. The party responsible for the spill is also responsible for the remediation of the accident. First, responsible party must contact airport authority, and emergency services, generally being the fire department. If the spill is too large to be easily contained, the responsible party must contact, and pay for, a spill response contractor to deal with the situation. If the spill is easily containable, responsible party must quickly proceed with cleanup. To address small spills, general fuel absorbents are usually used. Approaching the spill from upwind/higher ground, respondents will cover the spill with absorbents. Absorbents are either absorbent pads or more commonly just loose granular absorbents. Absorbents must be placed over the whole spill area to ensure the entire spill is contained. Absorbents must then be collected into drums, and disposed of in accordance with local and state regulations. [24]

4.4.3 Oil Water Separator

Oil water separators are commonly used at industrial sites to protect receiving waters from potential fuel spill contamination. At Chicago O'Hare International Airport, oil water separators are placed at the inlets of Lake O'Hare to improve the water quality of the influent to the lake. Denver International Airport (DIA) also has several oil water separation installations throughout the airport site. DIA does not discharge to surface waters, but rather to Denver Metro Wastewater Treatment Plant. So in the case of DIA, the purpose of the oil water separators is to remove any residual or spilled oil and grease from the wastewater plant influent (Pass). The Airport Stormwater Guidance Manual published by The Washington State Department of Transportation also suggests the use of an oil water separator when oil control is required.

In terms of design guidance for oil water separators, the US Army Corps of Engineers published a study on the most effective coalescing unit configuration and material. Parallel plate coalescing units were examined, and the study concluded that polyethylene plates installed at a 60-degree angle with downward flow provided the most consistent treatment for a hydraulic loading rate of 0.37 gpm/ft^3. The US Army commonly uses oil water separators at vehicle wash racks[25].

4.4.4 Infrared Detection

Infrared (IR) cameras have just recently started being used for gas detection. In the past they have been used primarily for landscape photography or thermography. We are interested in the use of IR cameras for gas detection. This has recently been done with one study looking at gas leaking off landfills.**Error! Bookmark not defined.** The study was completed in Australia. They found that the cameras work very well to detect the leakage from the landfill; however, their conclusions stated the limitations and difficulties the IR camera presents. These include the cameras being sensitive to weather conditions, the nature of ground surfaces, and the distance from the sensor to source.**Error! Bookmark not defined.**

4.4.5 C.I. Agent® Water Cannon

Solidifiers are common spill recovery practices. In general, solidifiers change oil from liquid to solid form through the use of chemicals. These solids are liquid-solid masses that may be easily removed. Solidifiers are different from sorbents in that they bond the liquid with minimal volume increase, yet they retain the liquid for fast removal without difficulty. In the case of C.I. Agent's® Solidifier it is able to turn the oil into a "rubber-like" substance due to its extremely high molecular weight polymers.

Solidifiers have never been tested on large hydrocarbon spills. There a few significant problems associated with solidifiers including; over solidification and under solidification appearing in different areas, they will solidify all matter that contains hydrocarbons like weeds, the solidified mass may not be pumped, and the cost associated with the large amount of agent required.[26]

C.I. Agents® Solidifying Agent has been effective in removing contaminants in various locations. In the Mid-Atlantic Region in May of 2007 70 lbs. of C.I. Agents® Solidifying Agent was applied to a manhole contaminated with 35 gallons of oil. This was a test to see if the agent could effectively remove the spill from the contaminated water as an alternative to a vacuum truck. The granules were thrown into the manhole and the water was pumped back into the vault allowing the granules to mix into the oil. Once the solidified oil was allowed to settle to the surface the water level was pumped down. The remaining solidified oil was then promptly removed. The clean-up period for this test took 2 hours, with 6 man hours. The 70 lbs of granules effectively removed 35 gallons of oil and had 290 lbs of waste. The total price of this project was $1,770.00, which proved to be an effective alternative to a vacuum, which had an estimated cost of $10,000[27].

5 Alternatives

5.1 Fuel Resistant Asphalt

Table 5.1.1: Polymer Modified Asphalt Information

<table>
<tr><td colspan="4">Brief Description
FAA requires P-401-SP specifications for Northwestern states modified to their local climates. Since BZN must follow the state of Montana requirements, the airport must use a PG 64-34 binder.[28] The performance grading system defines whether an asphalt binder is modified or not—Take the absolute values of the two performance grade numbers and if its >92 then it has been modified and if its <92 then it has not been modified. [29] (First number relates to 5-day average maximum temperature and relates to the rutting resistance of the asphalt. Second number relates to a single event low temperature that results in thermal cracking). Furthermore, PG 64-34 binder is one of the highest performance graded binders and is used much less commonly than other binders.[30]</td></tr>
<tr><td colspan="2">Advantages
• Stiffer material meets FAA requirements for runways and taxiways
• Decrease in deformation when subject to kerosene for longer amounts of time
• Rut Resistant, so no maintenance is required after installation
• Fuel Resistant, so no extra work needs to be done on the pavement after a fuel spill</td><td colspan="2">Disadvantages
• High Capital Cost
• Low economies of scale for binder drives up price (not commonly used)
• Subject to thermal cracking in cold Montana winters
• Binder not available in Montana so the binder would need to be shipped from surrounding states</td></tr>
<tr><td colspan="4">Design Specifications</td></tr>
<tr><td>Apron Size</td><td>680’ by 185’</td><td>Asphalt</td><td>Roughly 150 lbs/ft3</td></tr>
<tr><td>Cost of Binder</td><td>$700/ton</td><td>Installation costs</td><td>$4.50/ft2</td></tr>
<tr><td>Depth</td><td>1.5”</td><td></td><td></td></tr>
<tr><td colspan="4">Cost</td></tr>
<tr><td colspan="2">Estimated Capital Cost</td><td colspan="2">$1.42 Million</td></tr>
<tr><td colspan="2">Estimated Annual Cost</td><td colspan="2">$0</td></tr>
<tr><td colspan="2">30 year EUAC</td><td colspan="2">$52,300</td></tr>
</table>

5.2 Oil-Water Separator 31 32 33 34

Figure 5.2.1: Airport sitmap [35]

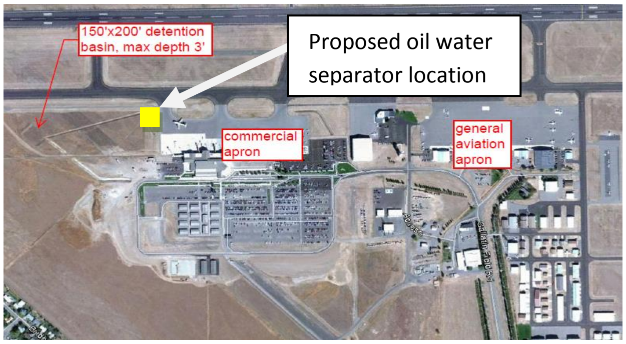


Figure 5.2.1: Parallel Plate Coalescing Oil Water Separator[36]

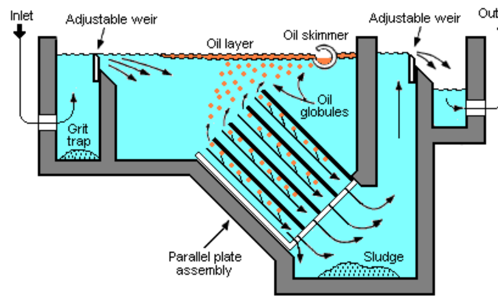


Table 5.2.1: Oil Water Separator Information

Brief Description: An oil water separator is commonly used to remove sediments from storm water, but is also effective in containment of free product spills. An oil water separator consists of three chambers, separated by vertical walls. The first is the sedimentation chamber, where sediment is removed by gravity settling. The sedimentation chamber feeds into the oil separation chamber, where any oily substances can float to the top, while effluent is drawn from the bottom of the tank. The discharge chamber then releases storm water into an outlet pipe. Oil water separators can be used in an "off-line" configuration, built near a storm drainage network so that flow can be diverted to the unit if a spill occurs or during a storm event.

The small capacity of oil water separators makes them unfeasible for large scale drainage basins, and the EPA suggests that the drainage area of the unit not exceed 1 acre. Oil water separators are commonly utilized at airports or industrial sites, where petroleum-contaminated flow is a consideration. In automotive and airport facilities, a separator can serve to remove oil and grease contamination from storm runoff, as well as protect receiving waters from surface fuel spills.

For low petroleum concentrations, a coalescing unit can be utilized at the unit inlet in order to increase oil/water separation efficacy. The coalescing unit uses oil attracting filter media to collect small oil droplets. The small droplets are attracted to one another and coalesce into larger droplets. Once the droplets are large enough to overcome the adhesion forces, they break free from the filter and float to the surface. Larger droplets separate from storm water much more quickly than small droplets, so using a coalescing unit significantly decreases the required residence time and volume of the unit[37].

Advantages	**Disadvantages**
• Effective removal of free petroleum product • Simple to maintain • Reliable performance if properly maintained • Coalescing unit increases oil separation effectiveness	• Limited removal of pollutants other than hydrocarbon free product • Accumulated sediments can become re-suspended during a storm event • Limited drainage basin size

Design Specifications

Tank Parameters		Coalescing Unit Parameters	
Length	25 ft	Plate Size	15 ft x 7 ft
Width	15 ft	Number of Plates	14
Inlet Height	12 ft	Plate Spacing	0.75 inches
Full Height	18 ft	Downflow Angle	60 degrees
Volume	5719 ft^3	Loading Rate	0.36 gpm/ft^2
Flow Rate	530 gpm		

Cost

Estimated Capital Cost	**$62,000**
Estimated Annual Cost	**$1600**
20 year EUAC	**$4889**

5.3 Infra-Red Detection

Table 5.3.1: Infra-Red Detection Information

Brief Description: Everything we are able to see with the naked eye is in the visible light electromagnetic spectrum. This is a small range of wavelengths from 380 (purple) to 700 (red) nanometers (nm). Infrared (IR) light has longer wavelengths than visible light. Infrared light has a wavelength range from 700 nm to 1 mm.[38] The sun's radiation comes to the earth as infrared radiation therefore the heat emitted by objects is also considered infrared. We cannot see these wavelengths with the naked eye, but there are special instruments that can help.

Infrared cameras were invented in the early 1900s with the first infrared picture taken in 1910 and became popular in the 1930s.[39] The cameras were mostly used for aerial landscape photos. However, it wasn't until the 1980s that cameras were being developed for airborne applications.**Error! Bookmark not defined.** And today these cameras are in their most advanced stage with leading developers around the world. These cameras are also now being used for more than landscape photography; they are used for inspecting building applications, electrical and mechanical devices, and optical gas imaging.

We would use an IR camera for the purpose of optical gas imaging. FLIR, the largest infrared camera distributor in the world, has essentially one camera that can detect kerosene: GF300/320. This camera detects wavelengths in the range of 3.2 to 3.4 micrometers.[40] Kerosene has two constituents that emit radiation within this range, n-dodecane and naphthalene.[41]

Advantages	**Disadvantages**
• Shows leaks on moving vehicles • Detects leaks from several meters away • Obtains complete picture – exclude non-problem areas quickly • Problems identified at early stage • Systems don't have to be shut down during inspection	• Expensive Capital Cost • Sensitive to weather conditions • Detects only a certain amount of VOCs associated with gas leaks • Used mostly for pipeline leak detection • Has not been tested for jet fuel detection

Design Specifications

GF3000	**GF320**
• Gas Detection Camera • Ultra telephoto lens 14.5° - 1.7x magnification • Telephoto lens 6° - 4x magnification	• Gas Detection Camera & Temperature Calibrated • Ultra telephoto lens 14.5° - 1.7x magnification • Telephoto lens 6° - 4x magnification

GF320 Camera with telephoto lens chosen, as temperature calibration is needed, but magnification not as important.

Cost

Estimated Capital Cost Error! Bookmark not defined.	**$101,425**
Estimated Annual Cost Error! Bookmark not defined.	**$2,500**
Estimated Training Course Cost Error! Bookmark not defined.	**$1,950**
15 year EUAC	**$9,813**

5.4 C.I. Agent® Water Cannon

Table 5.4.1: C.I. Agent® Water Cannon Information [42] [43] [44]

Brief Description

The C.I. Agent® Water Cannon is a tool for the application of the C.I. Agent® Oil Solidifying Agent on either land or sea. The solidifying agent quickly and effectively solidifies hydrocarbon spills into an easily disposable rubber-like mass. This mass is non-toxic, environmentally sustainable, may be disposed of as non-hazardous waste, and does not release any harmful vapors or gasses which reduce any potential exposure to cleanup crews and the environment.

The water cannon is a type of hose connected to a high volume portable fire pump .The tool works as a vortex with a mixture of water and solidifying agent. This vortex forces the agent to directly encounter the spill and eliminates the possibility of any agent becoming airborne.

The C.I. Agent® tool is very safe to use due to the easy to maintain and design of the water cannon. Because the solidifying agent suppresses any harmful vapors, and is completely non-toxic, the safety of the cleanup crew is maintained at a very high priority. Further, the cannon will spray up to a distance of 120 feet (for the 2" cannon) which allows for the crew to stand very far from the spill and avoid any potential of exposure to airborne toxins. However, the use of this system will cause the shutdown of the gate in which the spill occurred and any other surrounding areas that may get wet and slippery due to the use and wide spray of the water cannon. This may cause multiple airport delays. Finally, the use of this cannon will require a clean-up crew to walk out onto the tarmac and pick up the solidified mass (either by use of a broom, shovel, or mechanical vacuum), which although not overly time consuming may cause further delays.

Advantages	**Disadvantages**
• Non-toxic, non-carcinogenic, non-corrosive, non-hazardous • Turns hydrocarbons into a solid rubber-like mass • Solidified mass is 100% recyclable, or may be disposed of in most landfills • No temperature limits • Small capital cost • Easy to use: operated by one individual or mounted	• High annual cost • Potential shut down of airport operations • Cleanup crew must manually clean up solidified hydrocarbon • Brand new to marketplace and untested at airport operations

Design Specifications

Water Cannon Parameters		Solidifying Agent Specifications	
Hose Diameter	0.5 in	Agent/Hydrocarbon Ratio	2 lbs of agent to every 1 gallon of spilled hydrocarbon
Pressure	100 psi	Max Polymer Output	10% of the flow
Flow Rate	20 gal/min		

Cost

Estimated Capital Cost	**$17,500**
Estimated Annual Cost	**$5,700**
20 year EUAC	**$6,600**

Figure 5.4.1: Nozzle of Water Cannon[45]

Figure 5.2.2: Portable Fire Pump[46]

5.5 BuffVac

Table 5.5.1: BuffVac Information

Brief Description The BuffVac is a theoretical response vehicle that we designed to be capable of responding and handling fuel spills. The BuffVac utilizes a three step process to fully neutralize and recover spilled fuel. First is an application of microbial foam to begin decomposing fuel to reduce risk of ignition. The second step is to recover standing liquid. To do this the BuffVac will have two spill vacuums attached to the grill of the vehicle that will recover the majority of the fuel. Lastly, the BuffVac will have three absorbent rollers attached to the bottom of the vehicle, so as the vehicle drives over the spill, any fuel residuals will be absorbed to the rollers, and off of the tarmac.			
Advantages -Ensures Maximum fuel recovery - Low volume of waste from remediation - Easy to implement - Quick Response time		**Disadvantages** -Moderate initial cost -requires a trained operator - Complicates process of response - Untested	
Design Specifications			
Vehicle	Progator	Neutralizing agent	Microblaze
Absorbent rollers	3 rollers, 16” diameter, 60” long	Installation cost	$5000
Spill Vacuum	Spill Rite Drum Top Vac		
Cost			
Estimated Capital Cost		**$46218**	
Estimated Annual Cost		**$4225**	
30 year EUAC		**$6,722**	

6 Alternatives Cost Comparison

Table 6.1: Overall Cost Comparison

Alternative	Capital Cost	Annual Cost	EUA Cost
Fuel Resistant Asphalt	**$1.42 Million**	**$0**	**$52,287**
BuffVac	**$54,470**	**$7,435**	**$10,378**
Oil-Water Separator	**$62,000**	**$1,600**	**$4,889**
Infra-Red Detection	**$101,425**	**$2,500**	**$9,813**
Water Cannon	**$17,500**	**$6,600**	**$5,700**

7 Decision Matrix

PROSPR has created a decision matrix to determine the best alternative for the Bozeman International Airport. PROSPR surveyed Bozeman International Airport Director, Brian Sprenger, to assign relative weights to every decision criteria. He assigned each criterion a percentage based on the importance to the airport (out of 100%). Then, as a team, PROSPR assigned values (1-5) to each alternative within each decision criteria, which would be multiplied by the relative weight of the criteria to determine the total score of the alternative. The values (1-5) were assigned based on how well the alternative meets the individual criteria. A score of "1" would illustrate that the alternative does not satisfy the criteria at all, while a score of "5" would mean that the alternative completely meets the criteria's requirements. This decision matrix may be seen in Table 7.1.

Table 7.1: Decision Matrix

Decision Criteria	Weight	Fuel Resistant Asphalt	BuffVac	Oil Water Separator	Infrared Detection	C.I. Agent Cannon
Environmental Impacts	0.15	3	4	4	4	4
Reliability	0.25	5	2	4	2	3
Capital Cost	0.15	1	3	3	2	4
O&M Cost	0.20	5	3	3	4	1
Compatibility with Existing Processes	0.10	2	5	4	4	4
Ease of Implementation	0.15	2	5	2	4	4
Total	1	3.35	3.4	3.35	3.20	3.15

7.1 Overall Recommendation

Based on our decision matrix, we feel that the best option for implementation is the BuffVac. The decision matrix was weighted in accordance with the goals of the authority at Bozeman International. For each of these decision criteria, the BuffVac was scored, on a scale of 1-5. Regarding Environmental Impacts, the BuffVac scored a 4. It was scored this high because the BuffVac will generate significantly less waste than the use of traditional absorbents, reducing the amount of waste that the airport will have to dispose of. Additionally, the Buffvac will collect fuel residuals, preventing them from mobilizing into the environment. Considering the Reliability criteria, the BuffVac received a 2. The reason it scored low in this section is because it is a prototype, and has not been built yet, so all rates and costs are estimated. The capital and O&M costs were in the midrange of the options, giving it a score of 3. The Buffvac then scored

5's on both the compatibility and ease of implementation criteria. It scored high on these sections because it would require no change of infrastructure to the airport, and could be used as soon as the vehicle arrived at the airport. We believe that this option will be able to successfully address all fuel concerns brought up by the airport.

8 BuffVac Design

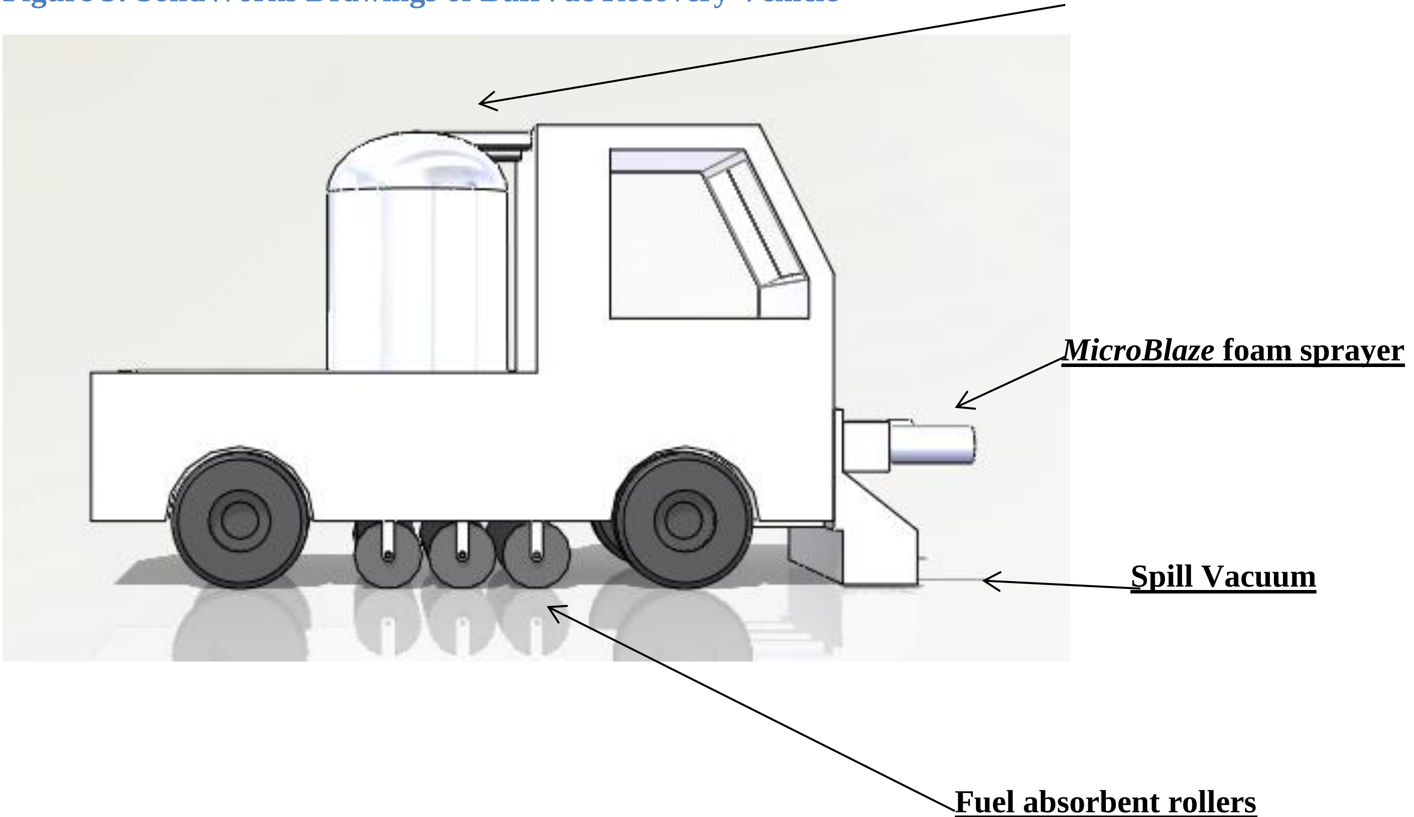
8.1 Description and Background:

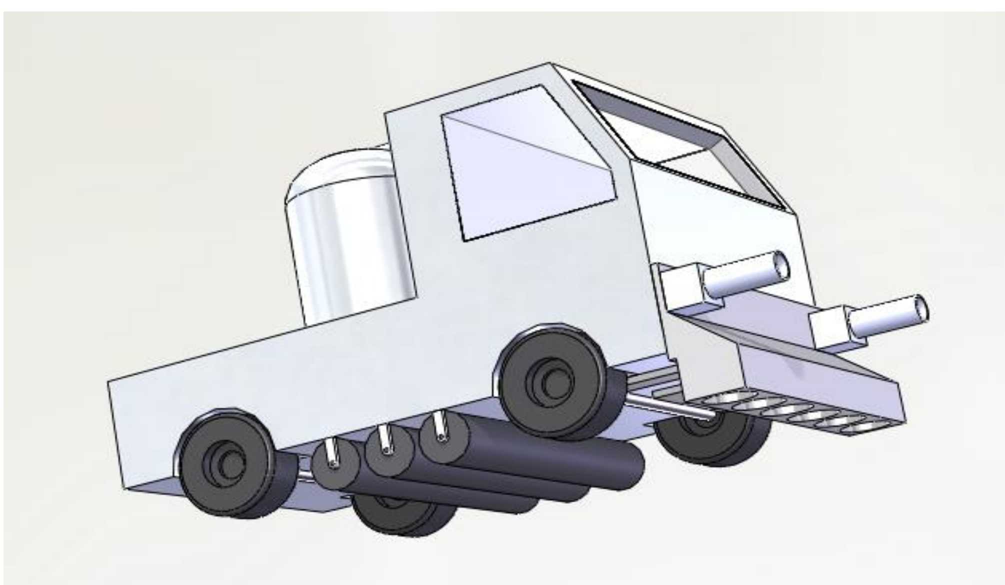
The majority of fuel spills happen either on the fueling apron by the terminal, or at the truck fueling station [47]. Although most of these fuel spills are less than ten gallons, they can range up to 200 gallons in worst-case scenarios[47]. At the majority of airports, it is standard protocol that the party responsible for the spill is also responsible for the spill's cleanup[48]. This means whichever individual or company that caused the spill is responsible for containing the spill with absorbents to prevent it from spreading or entering drains, ensuring the spill or leak has been stopped, and then collecting and disposing the spent absorbent. Also, granular absorbents fail to retrieve all of the fuel residuals, which will then be washed down the drain during rain events [47.] This increases the chance of fuel entering the soil or groundwater, which is undesirable. Not only are they somewhat ineffective, the large volumes of spent absorbent usually must be sent to a landfill to be disposed of.

Ideally, the responsible party would remediate their mistake. However, it can be challenging to know exactly how much absorbent to use, or how to properly manage and dispose of the fuel soaked absorbent waste. For the sake of cleaning up spills quickly, safely, and efficiently, it is important that the airport has designated personnel and equipment assigned to respond to all fuel accidents.

8.2 Design introduction: SolidWorks Drawings of BuffVac Recovery Vehicle

Figure 3: SolidWorks Drawings of BuffVac Recovery Vehicle





We propose, and have designed a concept response vehicle that we believe will be an efficient solution to this problem. This response vehicle, named the BuffVac, could be housed with the other utility vehicles, and could quickly respond to the apron or terminal of the airport manage small to medium sized spill events.

The BuffVac is a new and innovative design in the sphere of emergency response and fuel spill containment. This vehicle was designed to be capable of quickly and efficiently handling most small to medium sized on-site fuel spills. The BuffVac utilizes three steps in order to maximize the amount of fuel that it can efficiently and safely recover. The three steps include spraying the fuel with biological foam to reduce fire risk, a vacuuming of standing liquid using spill vacuums, and applying fuel absorbents to pick up remaining fuel residuals from the tarmac. These three steps will prevent any fuel from contaminating the surrounding environment, while minimizing any disruption to airport operations.

8.3 Advantages and Disadvantages

There are many advantages of the BuffVac. Primarily, we believe it will be effective. Because it utilizes both the pneumatic spill vacuum as well as fuel absorbent cloth, it will ensure a maximum recovery of spilled fuel. Another advantage is that the BuffVac is environmentally sustainable. Unlike its granular absorbent counterpart, the BuffVac will recover a high percentage of spilled fuel, reducing any stress the residuals would have on the surrounding ecosystem when mobilized in storm water. Lastly, the BuffVac is reliable. Rather than the responsible party dealing with the spill, a trained airport BuffVac operator will respond. This would ensure all fuel spills are handled correctly and quickly, minimizing negative effects on airport operations. For larger airports, airlines could pool resources to purchase BuffVac vehicles into their fleet of support vehicles, and operate independently from designated airport staff, which would reduce the cost for each airline wishing to use this solution.

There are several disadvantages to this new technology. First, the initial cost of the BuffVac is a fairly high. Since the vehicle must be purchased, retrofitted, and fueled, the initial expenses of this option are higher than using traditional absorbents. Secondly, the BuffVac adds a level of complication to the process of handling fuel spills. Because it uses three processes when handling a fuel spill, the BuffVac will require a trained operator. This means that a designated operator will have to respond to fuel spills at the airport. This could be a rough transition for airports that are used to expecting the responsible party dealing with a fuel spill.

8.4 Safety Risk Assessment and Management

Because of their light, granular nature, granular absorbents will not efficiently pick up fuel residuals[47]. As a result, during rain events, residuals will be mobilized. This can cause the tarmac to become slick, which can be dangerous for all vehicles operating over that area. Because a majority of fuel spills happen at the terminal, this danger is magnified by the high traffic in that area. All support vehicles would be subject to these slick conditions, increasing the chance of another accident. The BuffVac will ensure a high recovery of spilled fuel, thus removing any risk of the spill further affecting airport operations.

Additionally, in the event of a fuel spill it is necessary that the accident is managed in a timely manner. Events like this can be disruptive to airport operations, causing sections of the tarmac to be inaccessible, which will slow down traffic and cause delays[49]. The process of dealing with spills with granular absorbents is not only lengthy, but also unpleasant. The BuffVac will be able to quickly handle spills, minimizing any delays caused by a spill.

A safety risk management assessment was conducted based off the guidelines set forth in the "*FAA Safety Management System manual"* and the "*Advisory Circular*". This was done to ensure all hazards associated with this design will be addressed, to minimize any risk associated with the project. For the BuffVac, we completed an assessment, which included describing the system, identifying hazards, analyzing and assessing the risk, and finally treating the risk.

There were three possible hazards that we determined during this assessment. These hazards include the fuel catching fire, the response vehicle breaking down, and the operator coming into physical contact with the fuel, including breathing fuel vapors. The fuel fire was deemed to be a medium risk, requiring extensive pilot testing, tracking, and management. The likelihood was considered to be extremely improbable, but the severity was considered hazardous. The physical contact was also found to be of medium risk, with a probable likelihood, and a major severity. The vehicle breakdown hazard was considered to be a low risk, with a remote likelihood, and a minor severity.

Once these risks were assessed, they were addressed in order to make this solution as safe as possible. First we addressed the hazard of a fuel fire. There are two modes we used to address this problem. In the event of a spill, the BuffVac operator should respond, but fire responders should be put on hold, to ensure a quick response in the event of a fire. Also, this hazard is what led us to implement the Micro-Blaze formula, to further reduce any chance of ignition. For the physical contact, the BuffVac operator will be in an enclosed cab rather than an open one, reducing chance of contact. Also, operators should be trained in the physical symptoms associated with fuel exposure. Lastly, to address the possibility of the vehicle breaking down, granular or pad absorbents should be on hand as a backup solution.

8.5 Preliminary Design

The base of the BuffVac will be a small utility truck. Attached to the front of the BuffVac will be two foam sprayers. The sprayers will spray the fuel spill with “Micro-Blaze Emergency Liquid Spill Control”. This foam contains microbes, non-toxic strains of Bacillus bacteria, which will begin to break up the flammable hydrocarbons[50].This will remove any danger of explosion or fuel fire during the remainder of the cleanup process. Additionally, the foam formula will continue to breakdown the fuel, turning the fuel into water, carbon dioxide, and trace salts. However, due to some additives put into jet fuels, it is still important that this fuel foam mixture is collected, rather than let it percolate into the soil. To collect the liquid, two spill vacuums will be mounted to the grill of the vehicle, with the input ports flush with the ground, directly in front of the vehicle. The two fuel containment tanks, and pumps, will be housed in the bed of the truck, right behind the cab to reduce the connecter hose lengths as much as possible. Three fuel absorbent rollers will be mounted to the bottom of the truck, in between the 2 wheel axels. The absorbent rollers will essentially sponge any remaining fuel residuals from the tarmac as the vehicle drives over them. This means that the BuffVac will collect all fuel that the vehicle drives over. Once the BuffVac has recovered the fuel, it can quickly be returned to its holding bay, where the recovered fuel can be properly managed, out of the way of airport activity.

8.6 Component Specification

The BuffVac will be capable of recovering up to 445 gallons of liquid in one run, which, when considering that the diluted Micro-Blaze formula will also have to be collected, corresponds to a maximum spill recovery of 100 gallons of fuel. The two spill vacuums have been designed to have a capacity of 350 gallons, before the vacuum tanks must be emptied and the rollers must be replaced or cleaned. Below we will describe each component that makes up the BuffVac, and how we chose the specific products for it.

8.6.1 Vehicle Choice

In order to develop the BuffVac, we needed to start from the basic frame of the vehicle. Simple decisions were made upfront, such as ruling out a car due to the lack of space for the vacuum tanks and choosing a mini truck over a normal sized truck based on the size of clean up required. Moving forward with the general idea of a mini truck, the mechanics of the engine was our next big decision. An electric vehicle looked promising because it took away the danger of sparking the fuel spill and making the situation worse. However after including the absorbent sprayers as a neutralizing agent as a first step, the precaution taken is no longer relevant. Also, the amount the car is driven depends on the frequency of fuel spills, which is very low so the cost of a gas vehicle is more practical than an electric power vehicle. The focus then shifted to gas powered mini trucks. Several companies (all Japanese) produce mini trucks or Kei trucks such as Mitsubishi, Suzuki, Honda, Mazda, and Daihatsu.

We made the decision to use the Daihatsu Hijet based on the years the car has been in service and the general frame and reliability of the vehicle.[51] However, we encountered a very big problem when we realized the bed of the truck would not be able to handle the weight of the vacuums and absorbent and water components. As a general analysis the carry capacity of a mini truck is rated at 770 lbs.[52] This is extremely below the capacity we need to carry. After a thorough decision, we recognized that a heavy-duty truck was what we needed in order to handle the weight of the storage tanks and vacuum.

John Deere produces two heavy-duty vehicles that have a payload capacity greater than what we need: the 2020A and 2030A ProGator utility vehicle. Both vehicles have either a 2WD and 4WD option. We decided that the 4WD option is ideal based on the location and weather of BZN. The payload capacity of the 2020A is rated at 4073 lbs[53] whereas the 2030A is rated at

4255 lbs.[54] The difference between the 2020A and 2030A is the engine; the 2020A is gas powered and the 2030A is diesel. [54]Based on this information, we believe the 2030A ProGator is the best option as it is a diesel engine and has the highest carrying capacity. An estimated price for the 4WD 2030A ProGator is $31,350.[55] This is an open vehicle and in order to keep the operator safe while operating the vehicle, a glass windshield and door attachments are necessary. John Deere does not make attachments that are compatible for the ProGator series, but we understand that they are able to make custom attachments for any vehicle. Because we are requesting custom parts we don't know the additional cost they will add to the final capital cost. As a general thought, a custom glad windshield would probably cost around $1000 based on about a $300 price for a standard John Deere gator windshield.[56]

8.6.2 Micro-Blaze Formula and Application

Since safety is the top priority of the BuffVac, the first step in use of the vehicle to inactivate any fuel that has been spilled. This will be accomplished by spraying the spill with Micro-Blaze Microbial Product. The proprietary solution contains several strains of non-pathogenic Bacillus bacteria that have been shown to rapidly biodegrade a wide range of hydrocarbon compounds, including straight chained, branched chained, aromatic and polynuclear aromatic compounds.[57] The solution also contains nutrients for the microbes, as well as wetting agents to make the large molecules more available to microbes. Since the solution is biologically active, it is dependent upon environmental conditions including temperature, pH, and salinity. The specific ranges for effective use of Micro-Blaze are shown in Table 8.6.3.1.

8.6.3 Micro-Blaze Application

Table 8.6.3.1: Ranges for Micro-Blaze Application[58]

	Range	Optimal Conditions
Water Temperature	35°F - 180°F	45°F - 105°F
pH	4 to 11.5	5.9-9.0
Air Temperature	32°F - 120°F	45°F - 105°F
Salinity	Fresh, Brackish, or Brine	0-10%

Micro-Blaze can be applied with any equipment with foam spraying capabilities, including a fire extinguisher. In order to effectively inactivate a fuel spill, 1 gallon of Micro-Blaze concentrate should be used for every 10 gallons of fuel spilled. Furthermore, the Micro-Blaze concentrate should be diluted to a 3% solution. The BuffVac is designed for a 100-gallon spill. In order to handle a spill of this size, the tanks should carry 10 gallons of Micro-Blaze Concentrate to 333 gallons of water. [59]

For a 100 gallon fuel spill, the total Micro-Blaze solution volume amounts to 343 gallons. Summing the oil volume and the solution volume, the BuffVac should have a minimum storage capacity of 443 gallons. The BuffVac will be outfitted with four storage tanks, each 175 gallons. The two front tanks will contain the dilute Micro-Blaze solution and be connected to two foam spraying nozzles at the front of the vehicle. The two rear tanks connect to two pneumatic spill vacuums affixed to the lower front of the BuffVac. Since there are 443 gallons to be vacuumed up by the BuffVac, two rear tanks totaling to 350 gallons will not be sufficient. The rear tanks will be connected to the front tanks near the top of each tank, and separated by a controllable partition. When the rear tanks fill and spraying has ceased, the operator can connect the tanks and make use of the entire storage volume on board. The spray nozzles will utilize an educator pump setup.

Table 8.6.3.1:Costs of Micro-Blaze

Part	Cost/Unit	# Units	Total Cost
3375-PO5T4 Cleanload Chemical Eductor[60]	$761.40	2	$1522.80
175 gal Tank[61]	$190	4	$760
Micro-Blaze Concentrate[62]	$150/5 gallon pail +shipping	2	$353

8.6.4 Pneumatic Spill Vacuum

There will be two pneumatic spill vacuums attached to the front of the BuffVac. Each vacuum is capable of recovering 1 gallon/second of fuel, and the storage drums are each capable of storing 175 gallons of liquid[63]. PROSPR has looked into multiple models of pneumatic spill vacuums for the BuffVac, these are listed below:

Table 8.6.4.1: Pneumatic Spill Vacuum Alternatives

Vacuum Brand	Includes	Cost
Nilfisk Wet/Dry Pneumatic HEPA[64]	Requires no filter change, 15 gallon tank, water mildew and rot resistant, may be cleaned by wiping off, built in splash guard, detachable trolley, aluminum wand, 10' plastic hose, 14" wet floor nozzle, 3" round dust brush, 11" crevice nozzle, 25 polyliners	**$4,000**
Spillrite Drum Top Vac 200 cfm[65]	3 m hose, wand, floor tool, AS strap, AS filter, 200 cfm, 50 gallon tank	**$3,000**
Spill rite Drum Top Vac 60 cfm[66]	3 m hose, wand, floor tool, AS strap, AS filter, 200 cfm, 38 gallon tank	**$2,000**

Due to the price difference and the size of the tanks, PROSPR has decided to recommend the Spillrite Drum Top Vac at 200 cubic feet per minute (cfm) for a price of $3,000. This vacuum would meet all of the needs of the BuffVac. A pneumatic spill vacuum has a slight annual cost due to maintenance, labor, and waste disposal. Due to the high performance desired for the BuffVac, PROSPR would recommend that two vacuums be installed onto the BuffVac (for a total cost of $6,000). The annual cost associated with two vacuums is listed below, assuming, a 55 gallon tank, 100 gallons of fuel spilled annually, and labor at 30 dollars per hour which is the norm in the United States for this kind of work.[67]

Table 8.6.4.2: Annual Cost of Pneumatic Spill Vacuum

Operational (Pneumatic Spill Vacuum):	Cost (Annual):
Labor	$900
Material	$0
Energy	$240
System Maintenance	$600
Total Annual Operation Cost of Vacuum	$1,740

8.6.5 Adsorbent Rollers

There will be three absorbent rollers attached to the bottom of the vehicle. Each roller will be 60” long, and have a diameter of16”. The rollers will be supported by a 3” diameter metal rod in the center of the roller. This will give each roller an absorbent volume of 11640 in^3, and a capacity of absorbing 50 gallons of liquid. This means that the three rollers will have a total carrying capacity of 150 gallons of liquid.

Several different absorbent rolls were compared in order to determine the most effective and efficient material for the BuffVac rollers. Absorbents were compared based on the absorbent capacity of the material, and also the associated cost per gallon absorbed.

Table 8.6.2.1: Roller Comparison

Absorbent type	in^3	Gallons recovered	Gals/in^3	cost	cost/gal
ULINE heavy roll	3078	50	.016	$120	$2.40
AbsorbentOnline WRB15OH[68]	3078	55.2	.018	$87	$1.576
Spill 911 Double weight wide[69]	3078	50	.016	$134	$2.68

Because of its low cost per gallon, as well as it’s above average recovery efficiency (gal/in^3), we have chosen AbsorbentOnline’s WRB15OH model of absorbent for the rollers of the BuffVac.

It is important to note that the rollers attached to the bottom of the BuffVac should not be in contact with the ground when not directly over a fuel spill. To address this, the BuffVac must include a mechanism to raise and lower the rollers, so that the rollers will not be in contact with the ground when transporting the BuffVac to and from the fuel spill. This could be accomplished with the installation of a small lifting hydraulic. This addition is not expected to be overly expensive, nor is it expected to affect assembly time significantly.

Roller Re-use:

Although they must eventually be disposed of, absorbent cloths may be reused several times before they need replacing. Absorbent “wringers” have solid rollers that compress fuel soaked cloth as they pass through, squeezing out the fuel soaked into the absorbent cloth. Fuel is collected in a drum beneath the wringer, which then could be added to the fuel collected by the spill vacuums. This process allows for the re-use of the absorbent rollers, which would greatly reduce the annual costs associated with replacing absorbents. Priced at $1420 this wringer technology will pay for itself after about 16 uses.[70]

8.7 Operations and Maintenance:

Operating the BuffVac will require some training to use effectively. Because the pneumatic spill vacuums operate at a specific rate, the vehicle must also operate at a specific speed to ensure maximum recovery by the vacuums. If the BuffVac moves too quickly over a spill, the efficiency of the vacuums on the front of the vehicle will be diminished, causing a greater load on the absorbent rollers underneath the vehicle. Although the fuel will still be recovered, the rollers will absorb a larger percentage of the spill, which shortens the operating life of each individual roller. This added operating expense can be avoided with the training of personnel. Assuming it is properly maintained, the BuffVac is projected to have a lifespan of 20 years. The absorbent rollers are projected to have a lifespan of 2 years, at which point they will need to be replaced.

8.8 Waste Disposal

In order to help create a more sustainable solution to dealing with fuel spills, the BuffVac was designed to generate as little waste as possible. Recovered fuel will be fully neutralized using the Micro-Blaze fully, turning the fuel into water and trace salts. This waste could then theoretically be added to the regular waste stream of the airport. Spent absorbent rollers can be recycled sent to a landfill for disposal, depending on location. For Bozeman International specifically, spent absorbent rollers will have to be disposed of at the Logan landfill, outside of Bozeman, MT. Although this is not the zero waste solution we had hoped for, it is significantly more sustainable than current cleanup protocols.

8.9 Cost Analysis

Because the BuffVac is a new technology, there are no concrete costs associated with the production and operation of this vehicle. In order to estimate the costs of a BuffVac vehicle, we summed the known costs of each of the individual components, and then added a small assembly fee of $5000. The operation and maintenance costs were estimated under the assumption that the truck would be dealing with an average of 100 gallons of spilled fuel per year, and that operators must be trained and paid to operate the vehicle. Equivalent uniform annual cost (EUAC) estimation was conducted over the 20 year lifespan of the BuffVac response vehicle.

Table 8.9.1: Estimated Costs of BuffVac

Estimated Capital Cost	**$46,218**
Estimated Annual Costs	**$4,225**
20 year EUAC	**$6,722**

Although it has a moderate upfront cost, the reduced costs associated with absorbent acquisition and disposal make the BuffVac a more economically feasible option.

8.9.1 BuffVac Ownership and Funding

While some airports have host airlines that can cover many of the fees and split the collected revenues of that airport, BZN is not one of them.[71] In order for BZN to purchase the BuffVac, there are roughly three scenarios they can choose from in order to use this premier fuel spill cleanup technology. To help reduce the cost of implementing the BuffVac at BZN, we propose that they fund the new technology fully through FAA AIP grants and TSA-ARRA grants. This would reduce the initial costs from roughly $47,000 to $0 and BZN would only have to worry about affording the much less expensive periodic costs of $4,225 (costs associated with only running the BuffVac to cleanup a fuel spill). Furthermore, we propose that BZN charge the responsible airline for spilling the fuel to have to pay BZN to use the BuffVac as well to ensure that BZN maintained its pristine environmental conditions.

While the FAA and TSA could easily afford to allocate a $47,000 grant to BZN considering how much they have tolled out in the past ($21 million alone on the BZN terminal expansion), they may be unwilling to cover the entire purchasing cost.[72] In this case, we propose a similar payment system as the recent stone and wood terminal expansion completed in August 2011. Even though our costs hardly even compare to the $40 million price tag on the expansion, we hope to follow the same funding percentages for the project. The upfront cost of the BuffVac project totals roughly $47,000 and can be funded through FAA AIP grants, TSA-ARRA grants, Car Rental Customer Facility Charges, Revenue Bonds and local airport funds. [73] Table 8.9.1.1 below shows the percentage of cost covered by the funding in the terminal expansion and how that percentage covers the initial BuffVac cost.

Table 8.9.1.1: Allocations of Cost

Type of Payment	Percentage of Expansion	Allocation of BuffVac Cost
FAA Grant	46%	$21,620
TSA Grant	6.25%	$2,940
Rental Car Companies	5%	$2350
Internal Funding and Bond Sales	47.5%	$22,325
Total	104.75%	$49,325

The total funding of $49,325 would easily cover the actual cost of the BuffVac and any unforeseen additional costs required with implementing the BuffVac at BZN. The last payment option would be that internal funding is required to pay the entire initial cost of the BuffVac. While this is not ideal, it would not be too difficult for BZN to set aside roughly $50,000 to have the most innovative fuel spill product in the market.

9 Conclusion

In order to address the task of designing a solution to contain potential fuel spills at Bozeman Yellowstone International Airport, we evaluated 5 alternative solution technologies. To address fuel spill cleanup, we evaluated the C.I. Agents Water Cannon, as well as the PROSPR prototype BuffVac. To address spill containment, we researched oil water separators and fuel resistant asphalt. Finally, we evaluated infrared camera detection as a means for fuel spill prevention. After an extensive selection process, we have selected the BuffVac as the solution that aligns best with the airport's goal of safety and fuel spill preparedness.

9.1 Projected Impacts of Design

Implementation of the BuffVac for fuel spill containment at airports will have many positive impacts. First of all, using the BuffVac will result in expedited fuel spill cleanup, minimizing interruptions of airport operations and taking care of the problem safely. The BuffVac will also have positive impacts for the environment, since a quicker response time means that less fuel has the potential to contaminate the surrounding environment, including soil, groundwater, and surface water. Furthermore, the BuffVac biodegrades the spilled product, and the final waste product need not be treated as hazardous waste. The BuffVac is affordable and simple to operate, resulting in no change in infrastructure to dramatically increase fuel spill preparedness. The BuffVac can be easily implemented at airports across the country, and has the potential to revolutionize the way we clean up fuel spills. Currently, this product was designed to be a custom vehicle, but it could easily be scaled up to commercial production if the demand for this vehicle increased. All components are easily acquired, which would simplify the assembly process for this product.

10 Appendices

10.1 Appendix A: Contact Information For Advisors and Team Members

Advisor: Angela Bielefeldt: angela.bielefeldt@colorado.edu;

Project Manager: Nolan Wilkins: Nolan.wilkins@colorado.edu;

Contact Liaison: Holly Atkinson: holly.atkinson@colorado.edu;

Project Engineers:

Marie Bernardo: marie.bernardo@colorado.edu;

Adrienne Davis: adrienne.davis@colorado.edu;

Carteret Lawrence: (206) 390-3481; carteret.lawrence@colorado.edu;

10.2 Appendix B: Description of the University

The University of Colorado is nestled in the front range of the Colorado Rockies in the city of Boulder. Founded in 1876, Cu-Boulder is considered the flagship university in the state of Colorado. CU-Boulder enrolls roughly 30,000 students in over 150 different fields of study. The university boasts eleven Nobel Laureates, and has sent 18 astronauts to space. Primarily a research based University; CU-Boulder has made advancements in the field of fiber optics and biotechnology. The University is the only college in the Rocky Mountain region that is a member of the Association of American Universities, a prestigious honor.

CU-Boulder consists of nine colleges, most notably being the college of engineering. Nationally, the engineering program at CU is ranked 44th in the nation. The environmental engineering degree came into existence in 2002, and has grown steadily since. The EVEN (environmental engineering) mission pushes to provide a multidisciplinary education and to inspire service for the global public good. Environmental engineering ranked 22 in the nation.[74]

Although PROSPR is comprised of 5 environmental engineers, there is a significant level of diversity in their specialties. There is 1 water quality engineer, 1 air quality engineers, and 3 environmental remediation specialists. This diversity makes for a well-rounded team able to address all aspects of an engineering problem. [75]

10.3 Appendix C: Non-University Partners and Industry Contact Information

10.3.1 Bozeman Yellowstone International Airport

Paul Schneider, Assistant Director of Operations at Bozeman Airport

Interviewer: Holly Atkinson

Phone Interview: February 26, 2013. 10:00-10:20

Questions:

What is your current storm water configuration?
Storm drains on every ramp, pipes to holding ponds (big ditches). Nearest river 2 miles, all infiltration.
Geology: rocky area, ancient lakebed. DTW 55-85 ft.

What controls are in place in case of a fuel spill?
FBO: spill cover for every storm drain. If a spill gets into pipe (holding pond inlet), try to plug pipe.
Otherwise, soil cleanup. 3 holding ditches on site.
Fuel farm: containment ditch all the way around.
SPCC—FBO has.
Quarterly tank inspections—leaks.
Spill containment carts on ramps (2). Adsorbent booms.
Mobile fueler trucks carry buckets (1/2 drum) to catch spill.
Last spill 10 years ago, 150 gallons.
The fuel tankers offload on a berm to enhance stability.
French drain at south hangar.

DEQ: No de-icing restrictions

Fuel trucked or piped to site?
All fuel is trucked to fuel farm. Stored in mostly above ground tanks, a few below ground tanks. FBO mobile fueler.
Below ground tank monitoring (double walled tanks): periodic integrity testing--95% of tank intact at last inspection. (annual)

Runway expansion?
Starting environmental assessment to construct parallel runway north of (turf=1129) runway. This will be the 3rd runway, with ramp expansion to relieve extra traffic from MSU aviation program. 5000 ft long, 100 ft wide. The new runway will be restricted to general aviation--no commercial.

International Flights?
Non-commericial, corporate, started in July.

10.3.2 Morrison Maierle, Inc.: Engineering Consultants for Bozeman Yellowstone International Airport

Mark Maierle: PE

Interviewer: Holly Atkinson

Phone Interview: March 8, 2013; 8:00-8:20

Questions

Estimated square footage of each runway?

Main: 9000 by 150 ft

321 Smaller: 75 by 2450 ft

Commercial Apron: 1325 by 340

General Aviation Parking (fueling) Apron: 1300 by 440

Small Apron: 680 by 185 (self fueling)

Future plans for expansion?

Future Runway: 100 by 6900 (full build)

100 by 5100 (first stage)

Total airport property?

3200 acres under fees and easement

Storm water configguration?

Drain on aprons, parking lot

No storm drainage on runways (surface flow)

Commercial apron, gen aviation apron, parking lot to detention pond

Runways, other aprons runoff

Depth to water table~50 ft, sandy soil

Some parallel piping in place for future glycol separation. Separate pipes for parking lot (no glycol separation) and aprons (glycol separation).

Storm water: piping to open ditches (infiltration—possible UV treatment of glycol)) to piping.

Pond volume?

Detention pond: 150 ft x 200 ft x 3 ft; Overflow to surface runoff

10.3.3 Asphalt Institute: Trade Association of asphalt producers, manufacturers, and businesses

Dave Johnson, P.E., Regional Engineer

Phone Call and Email: Tuesday, March 5th and Wednesday, March 6th, 2013

Background on PG ratings, FAA requirements for Northwest Region, cost estimate for PG 64-34 binder

Background on PMA:

Late 80s,90s government spent roughly 50 million on the Sharp Research Program to research the shortcoming with polymer asphalt. Way to tell if asphalt binder is modified or not—Take the absolute values of the two performance grade numbers and if its >92 then it has been modified and if its <92 then it has not been modified.

How to go about picking a binder?

FAA requires P-401-SP specifications for NW states modified to their local climates.

Bozeman area requires PG 64-34 binder. As a result, there isn't a choice to really pick a different binder since the binder was chosen for the specific climate area and only a "better" binder can be applied. However, PG 64-34 binder is one of the top grade and is much less common than other binders. Downsind: -34°C —single event low temperature results in thermal cracking (pavement cools and naturally shrinks. As a result, internal stresses build and begin to break apart the pavement) and in cold areas such as this, -34°C is achievable temp.

How to alter grades in general?

First number relates to 5-day average maximum temperature and relates to the rutting resistance of the asphalt. For Bozeman, 64°C is higher than any average temperature that will be recorded. There are minor differences between aircraft and highway sealants so we base grades on highway usage. LTPP find program gives Bozeman binder grade: have to use 98% probability at airports.

Safety Risks?

Less than coal tar since there are no Polycyclic aromatic hydrocarbons (PAHs) let off from the asphalt. Only risks involve laying asphalt incorrectly and rutting, etc. can occur.

Lifetime estimation/maintenance requirements?

Since the incidence of cracking is greatly reduced, rutting will not happen unless there was a failure in implementation. As a result, no maintenance is required over the roughly 30 year lifespan for the asphalt. Additionally, the asphalt is relatively stiff, so it meets the grooving requirements of the FAA and will hold longer.

Costs?

PG 64-34 binder is the least commonly used binder, and Montana 64-34 stopped manufacturing it. Other states in use are Utah,Colorado, and Idaho to name a few. Low economies of scale so the cost/ton is roughly 60-100$ more expensive than average binder at 700$/ton. Can check with airport near grand junction that used binder.

10.3.4 Avcon, Inc.: Civil and Structural Engineering Consulting firm

Lee Lewis, P.E., Regional Manager

Phone Call and Email: Tuesday, March 12th, 2013

Bob Sykes Airport cost allocations, depth of milling and paving of PMA

Could you provide information on the depth of the asphalt layer (such as 4" of asphalt) or the cost allocations on installing asphalt (i.e. Mobilization, Preparation, Trucking Costs, and The installation or laydown costs, etc.) for the Bob Sykes Airport apron project?

Lee Lewis emailed us two documents answering these two questions. The first document was a bid tabulation for the North Apron Rehabilitation project, which allowed us to determine that installation costs totaled roughly $\$4.50/ft^2$. The second document was a geometry and paving plan drawing showing the limits of the paving for the North Apron Rehabilitation project. Furthermore, he determined that the depth of the material did vary from 1" to a total of 3.5" (in multiple lifts); however, he recommended that each lift be of a depth between 1" to 1.5" max due to the reduced aggregate sizes. The 1.5" max lift will enable better compaction of this stiffer material.

10.3.5 FLIR Systems Inc.: Manufacturer of Infrared Cameras

Mark Boccella, Sr. District Sales Manager

Email: Monday, March 4, 2013 and Tuesday, March 12, 2013

Infrared Camera operations and cost estimate

Which optimal gas-imaging camera, if any, would detect the presence of kerosene?

With regards to your question about Kerosene, I do not believe we can see this gas with any of our cameras, but I am confirming with our engineers now. Do you know where it absorbs IR energy? Attached is a general brochure that list lab tested compounds that we can see with the GF Series cameras.

I did some additional digging, and according to Wiki, “Major constituents of Kerosene include n-dodecane, alkyl benzenes, and naphthalene and its derivatives.”

We can see 2 of 3 with our GF320 camera.

What is the price for a single GF320 camera and the usual lifetime and maintenance costs associated with the camera?

Both the GF300 and GF320 should see Kerosene. They are the same camera, except that the GF320 is also calibrated to measure temperature. Datasheets and a guide to Optical Gas Imaging technology is attached.

Part Number	Model	Purchase Price
44401-0102	**FLIR GF320 – Gas Detection & Temperature Calibrated**	**$92,500**
44401-0202	**FLIR GF300 – Gas Detection Camera**	**$84,950**
T197385	**Lens MWB 14.5°, f=38 – Telephoto lens**	**$8,925**
T197388	**Lens MWB 6°, f=92mm - Ultra Telephoto lens**	**$13,390**
ITC_Gas_MA	**GasFindIR Training Course (per person) – 2.5 days**	**$1,950**

Lifetime is dependent on usage. Standard electronics should last for 15+ years. The stirling cooler is likely the first component that would require repair and MTBF is ~8000 hours.We recommend General Maintenance every 12-24 months, which carries a cost of $2,500. No calibration required for gas detection, as this is driven by a fixed hardware filter in the camera.

10.3.6 Micro-Blaze Microbial Products: Used in BuffVac

10.3.7 C.I. Agents: Water Cannon Manufacturer

PROSPR spoke with the C.I. Agents® manufacturer on the phone about the C.I. Agents® product and feasibility for a jet-fuel spill, as well as, the use of the C.I. Agents® Water Cannon. We spoke of the environmental impact of the solidifying agent and the workings of the cannon. Further communication with the manufacturer was made via email concerning the price and availability of the Water Cannon and Solidifying Agent. The C.I. Agents® Manufacturer greatly aided PROSPR in determining whether or not the C.I. Agents® Water Cannon and Solidifying Agent were the appropriate choice for PROSPR.

10.3.8 Denver International Airport

Bob Werner, Fuel Inspector

Emails and phone call: March 11 2013

On March 11, 2013, we had a very informative phone interview with industry expert Bob Werner. Bob Warner is the fuel inspector for Denver International airport, and has intimate knowledge with dealing with fuel spills. We asked Bob several questions about some of the fuel spill history at the airport, and also about some of the standard protocol they have in place for dealing with these spills. Probably the most valuable thing we learned from Bob was concerning pneumatic spill vacuums. Initially, our design did not implement the micro-blaze formula to render the fuel inert. We believed that due to the low vapor pressure of jet fuel, and the fact that our car, at that time, was going to be electric, that the explosion risk would be fairly low. Bob brought up the very interesting point that when you recover the fuel, some of the liquid will volatize in the tank due to the vacuum. When vacuuming, the spill vacuums will vent the off gas, which is far more volatile that the liquid fuel. This newly realized danger led us to see the necessity of either rendering the fuel inert before recovery, or somehow filtering the off gas of the vacuum. Bob also pointed us in the right direction to find the microbial solution to break up the fuel, reducing any chance of explosion, which really helped our project.

Denver International Airport

Keith Pass, Environmental Program Administrator

Email, phone calls, airport tour. March 4 2013

Keith Pass was one of the nicest, most helpful people we contacted. Keith Pass is the Environmental program administrator at Denver International Airport, and was always willing to talk with us, and get us in contact with other professionals in fields relevant to our project. Keith Pass also gave us the opportunity to take a tour of Denver International airport, which was invaluable, we really learned a lot during it. It was really cool to be able to see how big airports operate, and how the storm water systems operate. Before the tour, I was unaware how independent each airline is from each other, and how they have to contract companies to do operations for them, like de-icing operations, fuel spill recovery, or maintenance. This later affected how we thought about pricing the BuffVac, and how each company would have to buy into this new technology. Even though fuel spill recovery was not necessarily his expertise, Keith still had intimate knowledge of how the airport ran and dealt with issues like that, and it was really cool that he was willing to take time out of his busy day share some of this knowledge with us.

10.5 Appendix E: Evaluation of Educational Experience

This project has granted the team at the University of Colorado Boulder a unique experience to work with industry experts inside and outside the field of Environmental Engineering. We have been able to thoroughly investigate different current fuel response techniques, as well as, discover and design new potential techniques. By working closely with our professors, and outside resources, we have been granted the unique hands on experience that only a true design project can offer.

During our time at the University of Colorado Boulder we have taken many classes that teach the foundation to better understand engineering, however, these classes often fail to offer the hands-on experience which is necessary to more flawlessly enter the working world where your basic knowledge of understanding is less than enough. In order to succeed in a company or outside of academics one must understand teamwork, research, public speaking, and the creativity necessary for design. This project has offered our team all of these necessary foundations. It forced us to think outside of our typical engineering box, and research alternative and new approaches to our problem at hand. Not only did we learn of effective and safe ways to clean up a jet fuel spill, but also we learned the appropriate ways to interact and approach a difficult problem.

Most engineering students are expected to complete a design project during their senior year, but the unique experience of competing in a design competition has offered us a very different educational experience. We were forced to further think outside of the box, as we knew that many other students across the nation could easily come across a similar “easy” answer. Further, we were compelled to search for as many industry experts as possible in order to fulfill the requirements set forth by the Federal Aviation Administration. Our team was also forced to meet further deadlines, which better enhanced the experience of simulating a consulting firm.

The Federal Aviation Administration's Design Competition in conjunction with, our Senior Environmental Engineering Design Project has offered our team at the University of Colorado Boulder a unique and powerful educational experience. We have learned multiple aspects of design, as well as, the necessary tools to more effectively function in an engineering firm, or in other aspect of the working world. The skill sets we have gained from this experience will serve us for many years to come.

For faculty members:

l. **Describe the value of the educational experience for your student(s) participating in this Competition submission.**

The students benefitted from defining the scope of their project within the broad category of III Airport Environmental Interactions: B improved methods for containment and clean-up of fuel spills. This required them to research background information and contact airports. None of the students had previously coursework directly related to these issues, so they learned a lot of new information about airports and environmental issues on their own. Once they had defined the scope of the project, they independently did a literature review on relevant processes that could be used for fuel-spill clean-up or minimizing the negative impacts of fuel spills. Then they analyzed the options using a multi-criteria decision process. Writing the report to fit the strict guidelines of the FAA competition was also a challenge, in particular requiring them to be concise and focus on the most relevant aspects of the project.

So the educational value was in self-directed learning, finding how different options can be rigorously evaluated for ability to meet competing goals, and improved written communication abilities.

2. **Was the learning experience appropriate to the course level or context in which the competition was undertaken?**

The undergraduate students were all taking a required senior capstone design course. Their project was different than most of the other projects in the course. All of the other projects were pre-defined to a greater extent and had a client arranged from the start of the semester. The other course projects are more process design oriented. The course is intended to simulate an engineering consulting process, with a heavy emphasis on alternatives comparison. So the focus of the FAA competition on innovation and only the design phase isn't a great fit with the course goals. Therefore, the students did a significant amount of work for the course that could not be included in the submission to the FAA competition.

3. **What challenges did the students face and overcome?**

The first challenge was to find an airport partner with an interest or need in the realm of fuel spill clean-up. The second challenge was to find relevant background information on fuel spills and fuel spill clean-up methods. The literature search to find this information was outside the typical "peer-reviewed journal" arena with which the students are most familiar. The uncertainty of designing for a potentially rare event rather than designing a process to treat wastewater (for example) with known input characteristics was also a very different application of their environmental engineering knowledge. One of the greatest challenges was determining which information to include in the FAA competition submission, only 40 double-spaced pages long. Typically reports for the course deliverables are more on the order of 100 single-spaced pages. So the students had to determine the best way to tell the story of their alternatives assessment and design process in a very concise manner.

4. **Would you use this Competition as an educational vehicle in the future? Why or why not?**

I would use the Competition in the future. The students just need to be altered to the differences between these projects and the other projects in the course. This year the students chose between 10 different available projects, two of which were from the FAA competition. If the students like the freedom for greater definition of their project and are assertive to contact appropriate industry/airport professionals, then the projects can provide a good learning experience.

5. Are there changes to the Competition that you would suggest for future years?

I would allow the submission of additional supporting information in an Appendix of unlimited length. That allows better documentation of the design calculations and other aspects of the student work.

10.6 Appendix F: References

[1] Molnar, Matt. "Japan Airlines 787 Suffers Another Fuel Spill." *NYCAviation*. Aviation News, 13 Jan. 2013. Web. 03 Feb. 2013. <http://www.nycaviation.com/2013/01/japan-airlines-787-suffers-another-fuel-spill/>.

[2] Wright, Mishele. "Fuel Spills At Marion Municipal Airport." *AviationPros.com*. Chronicle Tribune, 3 Jan. 2013. Web. 03 Feb. 2013. <http://www.aviationpros.com/news/10847994/fuel-spills-at-marion-municipal-airport>.

[3] "Jet Fuel Leaks For 2 Weeks Into Sewer." *WISN*. ABC, 31 Jan. 2012. Web. 03 Feb. 2013. <http://www.wisn.com/Jet-Fuel-Leaks-For-2-Weeks-Into-Sewer/-/9374034/10936532/-/w014we/-/index.html>.

[4] Jacob, Mariana. "Fresno Airport Fuel Spill Keeps Cleanup Crews Busy." *ABC Local*. KFSN-TV, 8 July 2012. Web. 3 Feb. 2013. <http://abclocal.go.com/kfsn/story?section=news/local&id=8728638>.

[5] "Jet Fuel Spill Near Chicago Closes Canal, Highway." *Environment News Service RSS*. International Daily Newswire, 28 Aug. 2012. Web. 03 Feb. 2013. <http://ens-newswire.com/2012/08/28/jet-fuel-spill-near-chicago-closes-canal-highway/>.

[6] Gerken, James. "Kirtland Air Force Base Jet Fuel Spill Threatens Albuquerque Water Supply." *The Huffington Post*. TheHuffingtonPost.com, 20 July 2012. Web. 03 Feb. 2013. <http://www.huffingtonpost.com/2012/07/20/kirtland-air-force-base-fuel-spill_n_1688603.html>.

[7] *Material Safety Data Sheet: Kerosene*. Science Lab.com. Houston, Texas.

[8] Shepherd, J.E. *Flash Point and Chemical Composition of Aviation Kerosene*. Graduate Aeronautical Laboratories. California Institute of Technology. Pasadena, CA. May 26, 2000.

[9] US Environmental Protection Agency, (2013). *Spill prevention, control, and countermeasure (SPCC) plan*. Retrieved from website: http://www.epa.gov/oem/content/spcc/

[10] Environmental Protection Agency. Office of Underground Storage Tanks. *State Summary of Soil and Groundwater Cleanup Standards for Hydrocarbons*. By Tamlyn Oliver, Paul Kostecki, Ph.D., and Edward Calabrese, Ph.D. Amherst, MA: Association for the Environmental Health of Soils, 1993. Print.

[11] "Gallatin County, Montana" State and County QuickFacts. United States Census Bureau. US Department of Commerce. January 10 2013. http://quickfacts.census.gov/qfd/states/30/30031.html

[12] "Monthly Weather for Belgrade". The Weather Channel. TRUSTe. 2013 http://www.weather.com/weather/wxclimatology/monthly/graph/USMT0020

[13] "Chapter 4: Terminal and Landside Facility Requirements". Master Plan Update. Gallatin Field Airport. March 8, 2007. http://www.bozemanairport.com/pub/documents/Master%20Plan/Master%20Plan%20Chapter%204.pdf

[14] Blue Water Task Force et al (2008). *Gallatin watershed sourcebook: A resident's guide*. Retrieved from website: http://mtwatercourse.org/media/downloads/Gallatin_Watershed_Sourcebook_2ndEdition_FINAL.pdf

[15] Schneider, P. : Assistant Director of Operations, Bozeman Yellowstone International Airport. (2013, February 26). Interview by H. Atkinson [Personal Interview].

[16] "Chapter 4: Terminal and Landside Facility Requirements". Master Plan Update. Gallatin Field Airport. March 8, 2007. http://www.bozemanairport.com/pub/documents/Master%20Plan/Master%20Plan%20Chapter%204.pdf

[17] "Chapter 5: Financial Plan". Master Plan Update. Gallatin Field Airport. March 8, 2007. http://www.bozemanairport.com/pub/documents/Master%20Plan/Master%20Plan%20Chapter%205.pdf

[18] Schneider, P. : Assistant Director of Operations, Bozeman Yellowstone International Airport. (2013, February 26). Interview by H. Atkinson [Personal Interview].

[19] "2007 Master Plan Update." *Bozeman Yellowstone International Airport*. Morrison Maierle, 10 Aug. 2006. Web. <http://www.bozemanairport.com/pub/documents/Master%20Plan/Master%20Plan%20Chapter%202.pdf>.

[20] Maierle, M. : Professional Engineer, Morrison Maierle, Inc. (2013, March 8). Interview by H. Atkinson [Personal Interview].

[21] "Air Sparging." *Air Sparging*. N.p., n.d. <http://www.cpeo.org/techtree/ttdescript/airspa.htm>

[22] Van Rooijen, Ronald C., Arian H. De Bondt, and Ronald L. Corun. *PERFORMANCE EVALUATION OF JET FUEL RESISTANT POLYMER-MODIFIED ASPHALT FOR AIRPORT PAVEMENTS*. Rep. N.p.: n.p., 2004. FAA Worldwide Airport Technology Transfer Conference.

[23] Kanable, Rebecca. " Project Nominations." *Airport Improvement Magazine*. Airport Improvement, July 2012.

[24] "Spill Response Plan." Austin-Bergstrom International Airport. City of Austin, Department of Aviation. September 2012

[25]Gerdes, G. L., DeGuzman, A., & Gubrich, J. US Army Corp of Engineers, Engineer Research and Development Center. (2000). *Designing coaleascing oil/water separators for use at army washracks*. Retrieved from website: http://aec.army.mil/usaec/technology/ows-designing.pdf

[26] Ghalambor, A. 1997. The effectiveness of solidifiers for combatting oil spills, Louisiana Applied Oil Spill Research and Development Program, OSRADP Technical Report Series 96-006.

[27] C.I. Agents®. *Manhole/Vault Oil and Sheen Removal: Case Study*. Mid-Atlantic Region. May 2007. Print.

[28]United States. Federal Aviation Agency. *Northwest Region Standards for Specifying Construction of Airports*. Federal Aviation Agencry, n.d.

[29] Johnson, David R., P.E: Regional Engineer,Asphalt Institute. Personal interview by phone with Nolan Wilkins. 6 Mar. 2013.

[30] ibid

[31] US Environmental Protection Agency, (1991). *Storm water technology fact sheet: Water quality inlets* (832-F-99-029). Retrieved from Office of Water website:

[32] US Environmental Protection Agency, (1991). *Storm water technology fact sheet: Water quality inlets* (832-F-99-029).

[33] Schneider, P. : Assistant Director of Operations, Bozeman Yellowstone International Airport. (2013, February 26). Interview by H. Atkinson [Personal Interview].

[34] Maierle, M. : Professional Engineer, Morrison Maierle, Inc. (2013, March 8). Interview by H. Atkinson [Personal Interview].

[35] Maierle, M. : Professional Engineer, Morrison Maierle, Inc. (2013, March 8). Interview by H. Atkinson [Personal Interview].

[36] American Petroleum Institute (API) (February 1990). *Management of Water Discharges: Design and Operations of Oil-Water Separators* (1st Edition ed.). American Petroleum Institute.

[37] US Environmental Protection Agency, (1991). *Storm water technology fact sheet: Water quality inlets* (832-F-99-029). Retrieved from Office of Water website:

[38] "Infrared." *Electromagnetic Spectrum*. Web. 9 Mar. 2013. <http://hyperphysics.phy-astr.gsu.edu/hbase/ems3.html>.

[39] Garrad, Carl. "Infrared Photography." *Alpha Mount Digital Photography*. 13 Apr. 2010. Web. 12 Mar. 2013. <http://www.alphamountworld.com/photography-articles/infrared-photography>.

[40] FLIR Systems AB. *Gas Detection: The Professional Guide*. FLIR Systems AB. *FLIR*. 2009. PDF.

[41] Boccella, Mark. "FLIR Systems - Kerosene." Message to Marie Bernardo. 12 Mar. 2013. E-mail.

[42] C.I. Agents. Versatile and Proven Spill Clean Up Solutions. *C.I. Agent Water Cannon*. Louisville. Print.

[43] "C.I. Agents Interview with B.J. O'Banion Daniel." Telephone interview. 3 Mar. 2013.

[44] "Cost Interview with B.J. O'Banion Daniel." E-mail interview. 12 Mar. 2013.

[45] C.I. Agents. Versatile and Proven Spill Clean Up Solutions. *C.I. Agent Water Cannon*. Louisville. Print.

[46] C.I. Agents. Versatile and Proven Spill Clean Up Solutions. *C.I. Agent Water Cannon*. Louisville. Print.

[47] Werner, Bob. Fuel Inspector. Denver International Airport. (2013, March 11. 2013). Interview by C. Lawrence [Personal Interview].

[48] “Spill Response Plan.” Austin-Bergstrom International Airport. City of Austin, Department of Aviation. September 2012

[49] “Fuel Spill” City of Phoenix Aviation Department Rules and Regulations. City of Phoenix, Az. January 24, 2002.

[50] “Micro-Blaze Emergency Liquid Spill Control” Micro-Blaze: Microbial Products. Houston Texas

[51] "Japanese Kei Minivans." *Japanese Kei Minivans*. Far East Auto Literature, 2000. Web. 16 Apr. 2013. <http://mjs.home.xs4all.nl/cabover.html>.

[52] "FAQ." *FAQ*. MichTrucks, LLC, n.d. Web. 15 Apr. 2013. <http://michtrucks.com/faq.htm>.

[53] "John Deere 2020A ProGator Gator Turf Vehicles John Deere.com." *John Deere 2020A ProGator Gator Turf Vehicles John Deere.com*. N.p., 2013. Web. 16 Apr. 2013. <http://www.deere.com/wps/dcom/en_US/products/equipment/gator_turf_vehicles/progator/2020a/2020a.page>.

[54] "John Deere 2030A ProGator Gator Turf Vehicles JohnDeere.com." *John Deere 2030A ProGator Gator Turf Vehicles JohnDeere.com*. N.p., 2013. Web. 16 Apr. 2013. <http://www.deere.com/wps/dcom/en_US/products/equipment/gator_turf_vehicles/progator/2030a/2030a.page>.

[55] "Build Your Own John Deere." *John Deere Configurator*. John Deere, 2013. Web. 17 Apr. 2013. <https://configurator.deere.com/servlet/com.deere.u90947.eproducts.view.servlets.NavigationActionServlet?navigationUserAction=buildProduct>.

[56] "Build Your Own John Deere." *John Deere Configurator*. John Deere, 2013. Web. 17 Apr. 2013. <https://configurator.deere.com/servlet/com.deere.u90947.eproducts.view.servlets.QuoteServlet?userAction=configureProduct>.

[57] "Micro-Blaze® Microbial Products." *Micro-Blaze® Microbial Products*. Verde Environmental, Inc., n.d. Web. <http://www.micro-blaze.com/>.

[58] Lopez, David. "Environmental Protection Agency Micro-Blaze Recommendations." Letter to Verde Environmental, Inc. 21 Jan. 1997. *Micro-Blaze® Microbial Products*. Verde Environmental, Inc., n.d. Web. <http://www.micro-blaze.com/wp-content/uploads/2010/07/NCP-ProdNtbk_MBlaze.pdf>.

[59] "Application Rates for Micro-Blaze® Emergency Liquid Spill Control." *Micro-Blaze® Microbial Products*. Verde Environmental, Inc., n.d. Web. <http://www.micro-blaze.com/wp-content/uploads/2009/10/applicationrates.pdf>.

[60] "3375-P05T4 Cleanload Chemical Eductor." *Sprayer Depot*. N.p., n.d. Web. <http://www.sprayerdepot.com/Itemdesc.asp?ic=3375P05T4>.

[61] "175 Gallon Vertical Plastic Storage Tank." *Plastic Mart*. N.p., n.d. Web. <http://www.plastic-mart.com/product/468/175-gallon-vertical-plastic-storage-tank-vt0175-31?gclid=CKn_sJb9zLYCFYI-MgodBxIAEg>.

[62] "Micro-Blaze® Microbial Products." *Micro-Blaze® Microbial Products*. Verde Environmental, Inc., n.d. Web. <http://www.micro-blaze.com/>.

[63] Zitaglio, Mike. "Pneumatic Spill Vacuum". Joint Service Pollution Prevention Opportunity Handbook. US Navy. December 2000.

[64] "Nilfisk Wet/Dry Pneumatic HEPA Vacuum." *Spill911.com*. Spill 911, 2013. Web. 16 Apr. 2013.

[65] "Air Powered Vacuums - Pneumatic Vacuums Australia." *Spillrite.com*. SpillRite Air Powered Vacuums, 2012. Web. 16 Apr. 2013.

[66] "Air Powered Vacuums - Pneumatic Vacuums Australia." *Spillrite.com*. SpillRite Air Powered Vacuums, 2012. Web. 16 Apr. 2013.

[67] "6-I-10 PNEUMATIC SPILL VACUUM." *PNEUMATIC SPILL VACUUM*. United States Marine Corps, Mar. 2012. Web. 16 Apr. 2013.

[68] "Economy Oil Spill Clean Up Oil Absorbent Pads and Rolls ." *Economy Oil Spill Clean Up Oil Absorbent Pads and Rolls*. Absorbents Online, n.d. Web. <http://www.absorbentsonline.com/economy_oil_spill_cleanup_absorbent_pads_and_rolls.htm>.

[69] "Double Weight Wide Roll." *Spill 911*. N.p., n.d. Web. <http://www.spill911.com/double-weight-wide-roll.html>.

[70] "Pro Model Wringer - Item #1500." *Absorbent Recycling Wringer*. Absorbents Online, n.d. Web. <http://www.absorbentsonline.com/wringer.htm>.

[71] Portillo, Ely. "Local News." *Airline Shares Airport's Revenue*. Charlotte Observer, 17 Mar. 2013. <http://www.charlotteobserver.com/2013/03/17/3920551/airline-shares-airports-revenue.html>

[72] Gerber, Greg. "Gallatin Field Unveils Stone & Wood Expansion." *Airport Improvement Magazine*. Airport Improvement, Nov.-Dec. 2011. <http://www.airportimprovement.com/content/story.php?article=00323>.

[73] ibid

[74] "Environmental Engineering". University of Colorado at Boulder. March 12, 2013.

[75] "University of Colorado at Boulder." Wikipedia.