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16. ABSTRACT

Caltrans must remove snow in its maintenance yards. The current operation involves hauling snow away from these sites in trucks to relocate the snow in remote locations. This operation has significant economic, time, labor, and environmental costs. Use of a commercially available snow melter system could free up staff, cause less wear and tear on haul trucks, reduce fuel costs, and reduce the possibility of accidents for both Caltrans and the public while transporting snow off-site, all while reducing environmental impact. Snow melters work on site and apply heat to snow and ice, which may contain sediment or oil contaminants. The resulting water is filtered to remove the contaminants, reducing or eliminating contaminant release common even in natural snow melting. This summary report documents procurement, testing, evaluation, and cost analysis for a snow melter system.

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Evaluation of a Portable Snow Melter for Use in Caltrans Maintenance Yards

Dave Torick, Anh P. Duong &
Ty Lasky: Principal Investigator

Report Number: CA24-4133
AHMCT Research Report: UCD-ARR-23-07-31-01
Final Report of Contract: 65A0749 Task 4133

July 25, 2023

California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

This report focuses on evaluating the performance of the Snow Dragon, a portable snow melter, in Caltrans' Kingvale Maintenance Yard. The evaluation includes: (1) Performance, (2) Efficiency, (3) Cost, (4) Cost compared to current practice (trucking snow), and (5) Environmental impact. For items (1) through (4), the Advanced Highway Maintenance and Construction Technology (AHMCT) team recorded field data and obtained information from corresponding Caltrans personnel to make the evaluation. For item (5), water samples were sent to the UC Davis Analytical Laboratory for testing.

Problem, Need, and Purpose of Research

The California Department of Transportation (Caltrans) must remove snow in its maintenance yards. The current removal practice is trucking snow from a maintenance yard to a dump site, with significant economic, time, labor, and environmental costs. An alternative solution of using a commercially-available snow melter was proposed by Caltrans personnel. The roles of the AHMCT team were to observe, collect field data, perform analysis, and document snow melter performance. The results provided by the AHMCT team help determine whether using a snow melter is more efficient and cost-beneficial compared to the current trucking operation.

Overview of the Work and Methodology

To evaluate the Snow Dragon, the AHMCT team observed the system, documented the performance, collected field data, and interviewed Caltrans operators for feedback. In addition, the AHMCT team provided Caltrans personnel with log sheets and followed up through email and phone conversations when they were not on site. For cost, efficiency, and performance evaluations of the Snow Dragon, AHMCT used the data collected in the field, from the log sheets, and provided by Caltrans. In addition, Caltrans operators' inputs were considered in the evaluation since they had worked directly with the Snow Dragon.

Major Results and Recommendations

The cost to truck a cubic yard of snow is less than the cost to melt a cubic yard of snow using the Snow Dragon at this study location. Therefore, trucking snow costs less than melting snow using the Snow Dragon for this particular use case. Table E-1 lists different cost scenarios when comparing trucking snow to using the Snow Dragon.

Table ES-1: Trucking snow compared to using the Snow Dragon. The initial and maintenance cost of the Snow Dragon and traditional equipment was not factored in the following calculation (not amortized).

Description	Trucking Snow	Melting Snow Using the Snow Dragon
Cost to remove a cubic yard of snow	$2.77	$3.43
Cost per inch of snowfall using the time period from Jan 1 to Jan 22 (cover all of Kingvale yard)	$621	$1,111
Cost to remove snow for a season (from 2016 to 2023, the average snowfall was approximately 270 inches)	$575,654 per season	$712,814 per season

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Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ATM	Ajax Tocco Magnethermic
Caltrans	California Department of Transportation
CE	Conformité Européenne
COTS	Commercial Off–The-Shelf
CSA	Canadian Standards Association
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
SR	State Route
TSS	Total Suspended Solids

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Chapter 1: Introduction

Problem

The California Department of Transportation (Caltrans) must remove snow from its maintenance yards. The current operation involves hauling snow away from these sites to relocate the snow to remote locations. This operation has significant economic, time, labor, and environmental costs.

Use of a commercially-available snow melter system could free up staff, cause less wear and tear on haul trucks, reduce fuel cost, and reduce the possibility of accidents while transporting snow off site for both Caltrans and the public, all while reducing environmental impact. Snow melters work on site and apply heat to snow and ice, potentially containing sediment or oil contaminants. The resulting water is filtered to remove the contaminants, reducing or eliminating contaminant release common even in natural snow melting.

Objectives and Scope

The goal of the research was to assess the suitability of a snow melter system for Caltrans operations. At the start of the research, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center procured an appropriate commercially available snow melter system: a Snow Dragon model SND900. AHMCT developed features to be evaluated, supported field testing including assessment of features, obtained operator feedback on the system, and provided a summary report for the evaluation of the system. AHMCT tests were performed by, or in conjunction with, Caltrans Maintenance personnel operating in the Kingvale Maintenance yard, which was the most practical, realistic, and cost-effective approach, as the testing had to be performed in conditions matching those experienced by Caltrans personnel. The evaluation included feedback from Caltrans staff regarding their experiences with operating the snow melter. Snow melter efficiency was documented by calculating throughput rate.

Research Methodology

The research work included:

Task 1: Manage project

Task 2: Assess current Caltrans operating conditions

Task 3: Develop features to be evaluated, procure snow melter

Task 4: Field test system and solicit operator feedback

Task 5: Assess operational costs vs. existing practice

Task 6: Develop summary report

Overview of Research Results and Benefits

The key deliverables of this project include:

- Documentation of relevant Caltrans Maintenance operations for removal of accumulated snow
- List of specific features assessed in the field trials
- Testing results and feedback
- Cost assessment
- Summary report (this document)
- Snow melter at close of project

Chapter 2: Current Caltrans Operations vs. Potential New Practice

This chapter summarizes the current Caltrans operations regarding snow removal at the Kingvale yard. The goal was to assess the current practice, then compare the current to the new practice.

Current Practice

The current practice for snow removal is trucking it from the Caltrans Kingvale yard facility.

Methodology

The process of trucking snow in Kingvale often involves one loader and one to five trucks, depending on staffing and weather conditions. The loader obtains approximately five cubic yards of snow per scoop. Each truck carries approximately twelve cubic yards of snow per trip. The truck operators then drive from 0.8 to 1.6 miles to dump the snow at a Caltrans snow dump site. The snow trucking process is summarized in Figure 2.1.

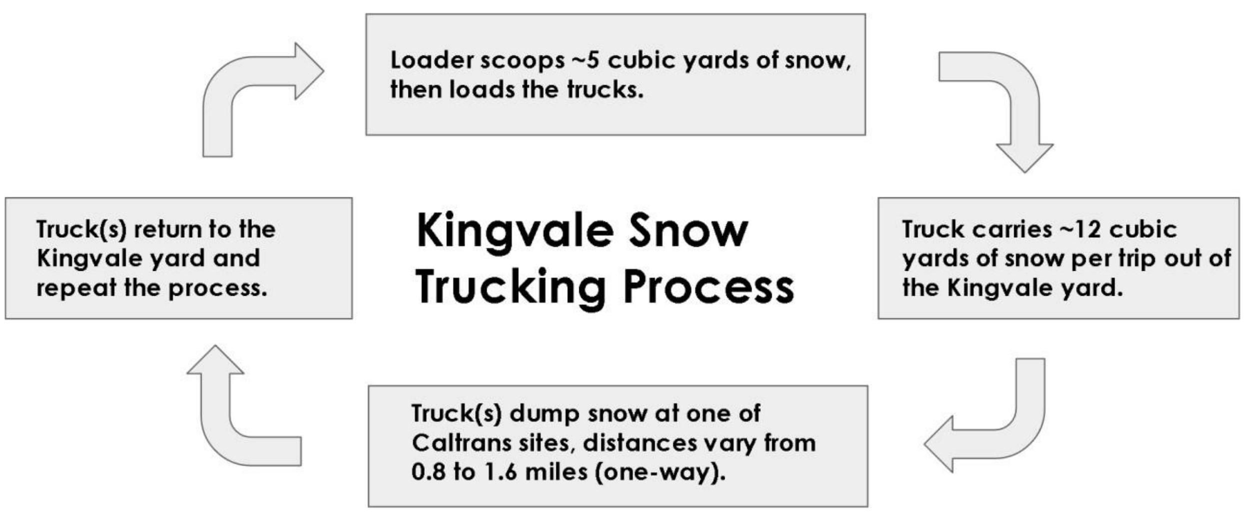


Figure 2.1: Kingvale snow trucking process

The loader brand and model is a CAT 930AM with a 2.5-yard (at water level) bucket. The truck year and model is either 2009 or 2013 International 7600. Each vehicle, including the loader, has one operator with Class A driving license. The cost breakdown for the snow trucking process is detailed in Chapter 6. The current practice cost is in dollars per cubic yard, the total cost to Caltrans for a snow event divided by the volume of snow that was removed.

Potential New Practice

A commercially available snow melter was considered to reduce cost and labor while promoting environmentally-friendly practices. The SND900 was purchased from Snow Dragon as it met Caltrans specifications, based on discussions with the Division of Equipment. The Snow Dragon is a potential solution to replace trucking snow.

Methodology with Snow Dragon

The loader loads snow into the Snow Dragon to remove snow from the maintenance yard. When the snow is loaded, the Snow Dragon melts the snow by spraying hot water. The Snow Dragon requires various setup and clean-out steps that are described below.

New-site startup steps

Upon delivery, Ajax Tocco Magnethermic (ATM) technician setup the Snow Dragon. The burner was calibrated to its compatible elevation (above sea level). Every time the Snow Dragon is moved to a different elevation, the burner may need to be re-calibrated. For example, if the Snow Dragon is moved 2,000 feet lower, the burner most likely would need a regular nozzle and a re-adjustment on the fuel delivery. The burner manual providing additional information about this was provided to Caltrans.

New-shift startup steps

The following setup steps are required every time the Snow Dragon is turned on for operation. The comprehensive setup guide provided by ATM was given to Caltrans.

1. Level the Snow Dragon during equipment setup
2. Fill the Snow Dragon with water
3. Fill the Snow Dragon with fuel/ensure the fuel is full. Equipment must be turned off during fueling.
4. Replace the fuel filters at the beginning of an operation and every eight hours during operation or as needed
5. Operate the control panel

Clean-out steps

There are clean-out steps every time a Snow Dragon operation finishes. However, the Snow Dragon might require clean-out in the middle of an operation when there is too much sand accumulated at the bottom of its tank. Excessive sand accumulation can affect the Snow Dragon's performance. Below are the **full cleanout procedures**:

1. Drain the Snow Dragon. Ensure that all the water has been drained before proceed to the next step.
2. Empty the debris-catching basket located on top of the Snow Dragon*

    * Note: The Caltrans operator decided to take out the top basket, as it is not relevant for the Kingvale snow removal operation. The basket is meant to catch tree branches and leaves, which the Kingvale maintenance yard does not have during the winter. According to the Snow Dragon manual, the top basket is not a requirement[1]

3. Hose down sediment accumulated in- and outside of the Snow Dragon
    - Thoroughly flush out the hopper and heat exchanger tubes
4. Clean out the bottom of the Snow Dragon tank
5. Clean out the Snow Dragon waterjets and melting pan at the top
6. Raise and secure stabilizing jacks

In addition to the full cleanout procedures, there are partial cleanout procedures. The operator can empty the debris basket mid-operation and resume once the basket is re-installed. Below are the **partial cleanout procedures**:

1. Turn the burner off
2. Turn pump 1 and pump 2 off
3. Turn the blower off
4. Attach chains and use a loader to pull the basket out, empty, and reinstall
    - Take caution as this area will be **hot** to touch
5. Turn the blower on
6. Turn the burner on
7. Turn pump 1 and pump 2 on
8. Continue melting snow

In Figure 2.2, the general snow removal process using the Snow Dragon is outlined. Although the process seems straightforward, there might be issues that can stop the operational cycle altogether. For instance, if there is too much

[1] Taking out the top basket should not affect the Snow Dragon's performance.

debris accumulated in the middle of an operation, the operator has to clean out the melter before continuing the operation. Also, if there is a fault issued by the Snow Dragon control panel, the operator has to stop the operation immediately and work with an ATM technician to resolve the fault.

Figure 2.2: Snow removal process using the Snow Dragon

The manufacturer also created a diagram to summarize how the Snow Dragon works, as shown in Figure 2.3.

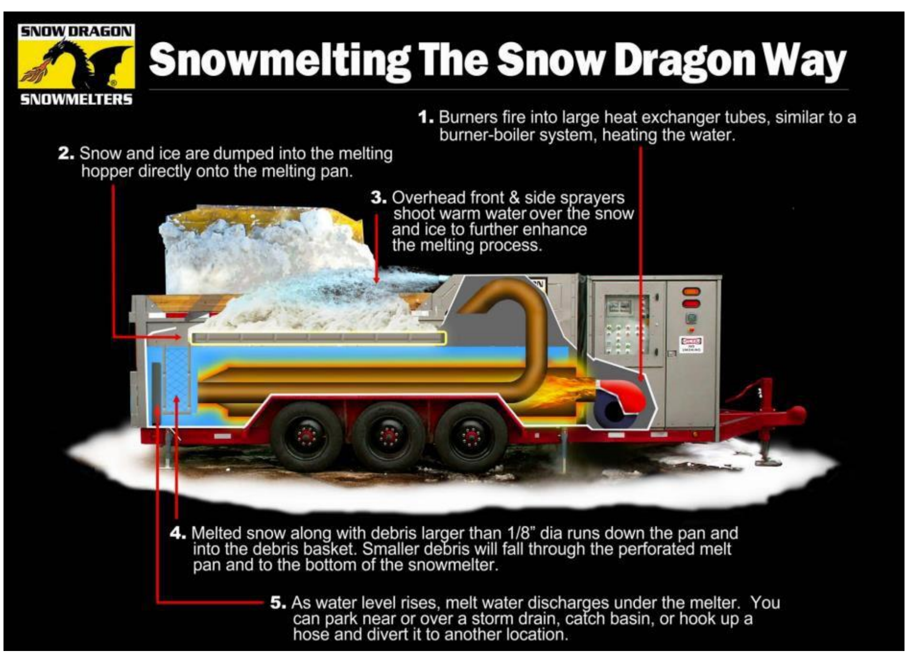


Figure 2.3: How the Snow Dragon works. Image courtesy of the Snow Dragon manufacturer.

Trucking Snow Operation vs. Melting Snow Operation

Table 2.1 below outlines the differences between the trucking snow operation and the melting snow (using the Snow Dragon) operation.

Based on Table 2.1, trucking snow requires more workers than melting snow, yet trucking snow has little to no setup steps. Overall, the advantage and disadvantage for trucking snow and melting snow are summarized in Table 2.2.

Table 2.1: Trucking snow versus melting snow using the Snow Dragon

	Trucking snow	Melting snow using the Snow Dragon
Number of workers needed	One loader operator At least one truck driver, up to five truck drivers	One operator (load and operate the Snow Dragon at the same time)
Setup steps before an operation	Fueling all the vehicles	Fueling the Snow Dragon and the loader Filling the Snow Dragon up with water Operating the control panel
Actions needed during an operation	None	Changing the fuel filters every eight hours and purging the fuel lines as needed
Clean up requirements at the end of an operation	Hosing the vehicles down	Draining the Snow Dragon Cleaning out the Snow Dragon

Table 2.2: Advantages and disadvantages of trucking snow vs. using Snow Dragon

	Advantages	Disadvantages
Trucking snow	Little to no setup required A straightforward process	Elevate accident risk (during transport) Require two or more workers with Class A license
Melting snow using the Snow Dragon	Reduce accident risk (travel within Caltrans yard) Only require one worker with Class A license Future policy may require snow to remain on site, large snow events can be melted on site	Multiple setup steps Clean-out takes time Training required to operate the Snow Dragon

Chapter 3: Features for Evaluation

In this chapter, the Snow Dragon features that affect cost, efficiency, and performance are identified for the evaluation.

Manufacturing Specifications

The Snow Dragon model SND900 is designed for use at malls, schools, stadium fields, and parking lots. Model SND900 measures 27' long, 8'4" wide, and 8'6" high. Figures 3.1 and 3.2 show the Snow Dragon model SND900 at the Caltrans Kingvale yard.

Figure 3.1: Left side (primary for operation) view of the Snow Dragon SND900

Figure 3.2: Right side view of the Snow Dragon SND900

Table 3.1: SND900 manufacturing specifications

Item	Specifications
Melting Capacity	100-300 cubic yd/hr at 32°F ambient temperature
Burner Output	9,000,000 BTU/hr
Fuel Type	#1 and #2 diesel, Jet "A" fuel. Stationary melters can run on natural gas or propane
Fuel Usage	40-60 US gallons per hour
Fuel Capacity	550 US gallons
Water Discharge Rate	Approximately 130 gallons per min
Water Discharge Temp	35-60 F
Water Tank Capacity	1,050 US gallons

Item	Specifications
Weights (approx.)	Empty: 19,335 lb With fuel: 23,350 lb With fuel and water (full): 32,120 lb With fuel and water (travel level): 26,200 lb
Dual Snow Loading Access	9'w x 7'3" h
Measurements (approx.)	27' long x 8'4" wide x 8'6" high
Towing Speed Empty	65 MPH
Towing Speed with Fuel	55 MPH
Towing Speed with Fuel and Water	50 MPH based on water at travel level

The Snow Dragon SND900 standard equipment, according to the specification sheets provided by the manufacturer, is listed below:

- National Electric Code (NEC) and National Fire Protection Association (NFPA) compliant
- Built per Conformité Européenne (CE) and Canadian Standards Association (CSA) compliant
- Automatic ignition (diesel)
- Engineered heat exchanger tubes
- 550 US gallon fuel tank, approximately eight to ten hours of operation
- Standard heavy gauge mild steel melting pan and tank with structural steel supports
- Heated operating enclosures with lockable access door protecting equipment, including burners, water pump spray system, and generator (Figure 3.3)
- Three clean-out hatches
- Heavy-duty tri-axle trailer with electric brakes, turn signals, marker lights with pintle hook for towing arrangements
- Wood rail guards positioned on the melter to prevent damage to loading sides
- Self-contained diesel fired 26 kw generator, 42 amps with 45 hp Mitsubishi engine located inside the heated enclosure
- Generator battery charger

- Auxiliary power plug wired to power the battery charger, generator block heater, and control panel heater when the melter is not in use or the generator is off
- National Electrical Manufacturers Association (NEMA) 4/12 main control panel with temperature controller, visual and audible alarm indication, pilot controls, indicators, gauges, relays, and terminals (Figure 3.4)
- Key switch to engage battery power
- Emergency shut-down buttons located on both sides of the melter
- Two 300 gallon/min water recirculating pumps, each 7.5 hp with removable filter screens
- Two high-pressure spray bars around the inside of the hopper to circulate and spray warm water onto loaded snow

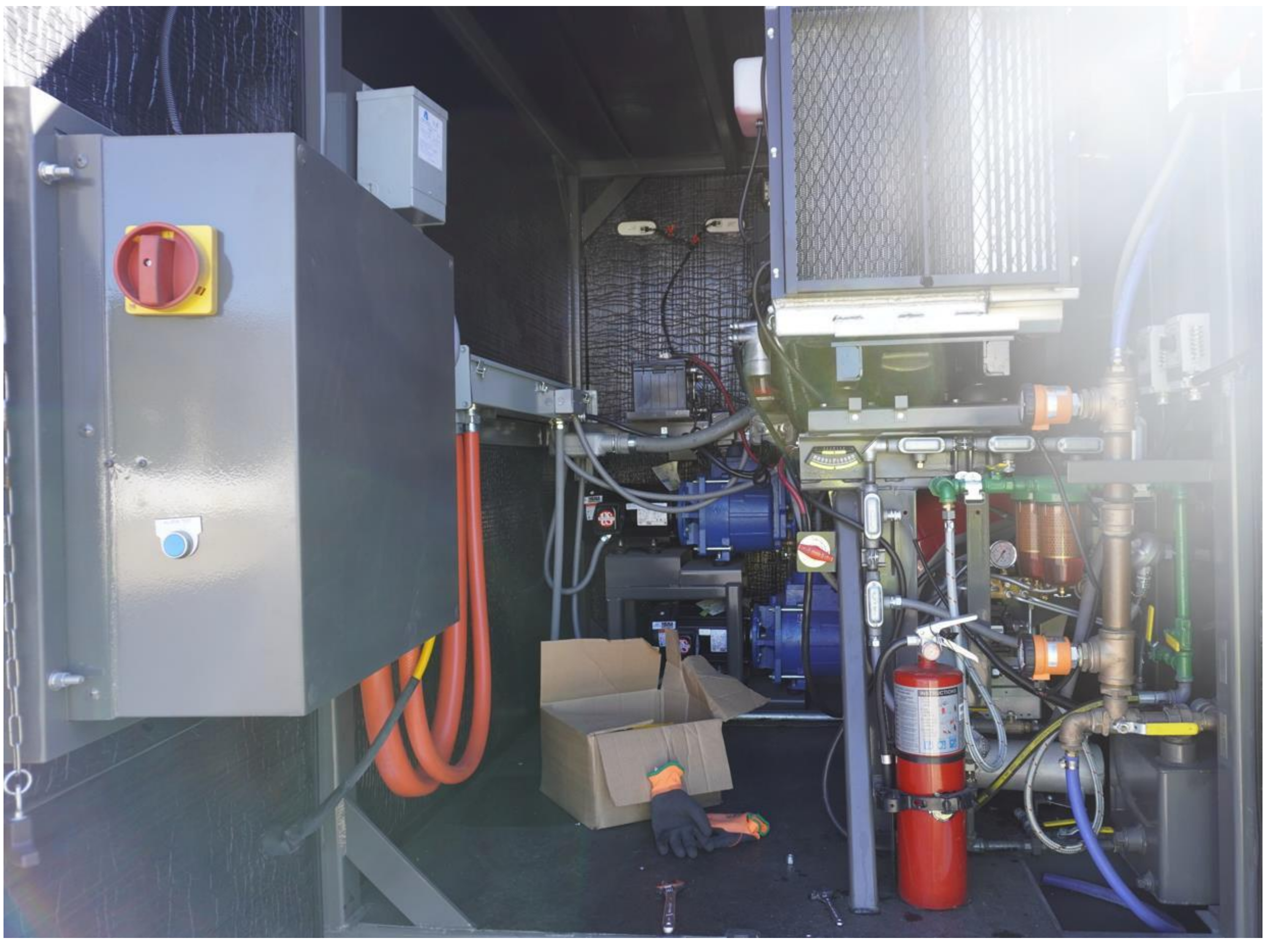


Figure 3.3: SND900 operating enclosure

Figure 3.4: The front control panel of the SND900

Features to be Evaluated

In this section, the features that affect the Snow Dragon cost, efficiency, and performance are identified.

Melting Rate

The snow melting rate was compared to the snow trucking rate. The variables that affect the melting rate are:

- Snow purity

Personnel at the Caltrans Kingvale yard mix snow with sand to provide traction and salt to decrease the melting point. Therefore, the snow at the Kingvale yard often has sand and sediment in it. The AHMCT team observed and took photos of how the sediment in the snow impacted the Snow Dragon performance.

- Snow Dragon water temperature

Every time the snow is dumped into the Snow Dragon, the water temperature in the tank drops. Initially, the Snow Dragon heats the water up to 125°F. When the snow is dumped into the tank, the water temperature drops. To establish a quantitative baseline, snow was only added to the Snow Dragon when the temperature of the water was above 50°F. At this temperature there was still water flowing from the outlet pipes. The AHMCT team observed and recorded the behavior of the Snow Dragon as the water temperature in the tank fluctuated around 50°F or higher.

- Volume of snow being input to the Snow Dragon

The ATM technician recommended an intake of 3 to 5 cubic yards of snow per dump. A Caltrans loader can scoop approximately a maximum of 5 cubic yards of snow per load. The AHMCT team recorded the snow density in the Kingvale yard to determine the Snow Dragon performance at this particular snow density as well as the number of buckets added to the Snow Dragon.

Table 3.2: Variables that determine the Snow Dragon melting rate

Variable	Description
Snow purity	Sand and sediment in the snow impacted the Snow Dragon performance.
Water temperature used to melt the snow	Water temperature in the Snow Dragon tank impacted its efficiency.
Snow bucket volume	Snow volume intake impacted the Snow Dragon cost. The amount of snow being melted and the amount of snow being trucked were compared to determine which method is more cost effective. Snow density was factored in the calculation.

Clean-Out Time and Frequency

Whole system clean-out

Clean-out consists of opening the hatches and scooping out/removing the sediment inside the Snow Dragon. It was recommended that the Snow Dragon be cleaned out after each operation; the Snow Dragon was cleaned out at the end of the shift, unless the level of sand in the Snow Dragon impacted operations, then it was cleaned out immediately. Melting snow at Kingvale yard is challenging due to the snow being mixed with sand. **The amount of sand in the snow will definitely affect the clean-out frequency**. Therefore, a field test was carried out to determine how often the Snow Dragon needs to be cleaned out.

The Snow Dragon has a large debris basket. The ATM field technician advised Caltrans that it is intended for large debris such as cups and fast-food wrappers that can be found in a parking lot. Since the Kingvale yard did not have this size of items, Caltrans removed the basket and did not operate the Snow Dragon with the basket. In later discussions, ATM indicated that, the debris basket has the ability to hold contaminants as small as 1/8 inch diameter. This may allow more efficient clean-out and operations with sandy snow. It is recommended that this is evaluated in the future.

Fuel line clean-out

The fuel line clean-out consists of changing two fuel filters and purging the fuel lines. It was recommended that the Snow Dragon fuel filters be changed out every eight hours during operation. However, the fuel line performance at Kingvale yard was unknown. Therefore, a spreadsheet was created to record how often the fuel filters need to be changed during operation.

Usage Frequency

It is anticipated that the Snow Dragon will operate 24 hours continuously (until the snow is cleared out) at Kingvale. Field data were collected to determine whether the Snow Dragon can perform the expected 24 hours of operational time.

In summary, melting rate, clean-out frequency, and usage frequency were variables evaluated in the field. These variables determine the cost, efficiency, and performance of the Snow Dragon at the Kingvale yard.

Chapter 4: System Procurement

In this chapter, the process of obtaining the Snow Dragon and troubleshooting it upon delivery is documented. When the Snow Dragon arrived at the Caltrans Kingvale site, it was expected that the machine would be fully operational. However, there were manufacturing and technical issues that needed ATM troubleshooting before the Snow Dragon could be used.

Procurement Issues

Upon receiving the Snow Dragon, there are terms and conditions that the purchaser must follow. Prior to shipment, the purchaser must pay 90% of the cost up front. The model Caltrans and the AHMCT team agreed to purchase was the Snow Dragon SND900. The cost breakdown for the SND900 at the time of the purchase (2023) is shown in Table 4.1.

Table 4.1: SND900 Investment Summary

SND900 Investment Summary	
SND900 Mobile Snow Melter	$290,000
One Year Standard Factory Parts Warranty	Included
Two Days Setup and Training at Customer Location	Included
One Removable Debris Basket	Included
SND900 Add-on Options	
Spare Trailer Tire Mounted onto the Snow Melter	$3,750
Labor & Parts Warranty for 2 Years. This includes a post season maintenance visit between year 1 and year 2	$18,100
Shipment Cost (3rd-Party)	
Shipping from Warren, Ohio to Soda Springs, California	$6,685
Breakdown Cost and Total Cost	
15% Payment with Return of Purchase Order	$46,778

75% Payment Prior to Shipment	$233,888
Total 90% Payment Prior to Shipment (plus local tax of 7.25%)	$280,665 (+ $20,348)
10% Payment 30 Days after Delivery	$31,185
Shipment Cost	$6,685
Total Cost (plus local tax of 7.25%)	$318,535 (+ $23,094)

Failures and Troubleshooting at Delivery

The following paragraphs detail the sequence of events from when the Snow Dragon was delivered to when issues upon delivery were resolved. A summary table for the sequence of events is also provided.

First visit: Dave Torick and Anh Duong from the AHMCT team went to Kingvale on January 24, 2023. Originally, the trip was planned for two days (from January 24 to 25); however, the two-day trip became a four-day trip due to issues with the Snow Dragon upon delivery. Dave and Anh observed the Snow Dragon performance throughout the four days. The events below were recorded using hand-written notes, photos, and videos.

1) Events following January 24, 2023

Upon arrival, an ATM technician tried to turn on the Snow Dragon. As observed, every time the ATM technician attempted to turn on the burner, a fault would occur, which was indicated by a red light bulb and an alert sound. The ATM technician purged the fuel lines and changed the fuel filters, but the Snow Dragon's burner did not turn on. The ATM technician found that the fuel line to the burner was leaking, thus he requested Caltrans provide a temporary solution until the replacement part arrived in the mail. Even after the ATM technician replaced the leaking fuel line, the Snow Dragon's burner did not turn on.

The front jack of the Snow Dragon was also damaged upon delivery. The shaft was not secured properly in the housing. The front jack was fixed later in the season.

The servo motor setting was not correct upon delivery.

As a result, the scheduled training with Caltrans at 12 pm was moved to January 25.

2) Events following January 25, 2023

On January 25, the fuel pipe replacement for the burner arrived. However, the ATM technician did not make the replacement since he thought the one Caltrans provided was better than the original.

When the burner fuel line was removed, the ATM technician suspected that air might have gotten into the pipes. The ATM technician attempted to bleed the fuel lines to remove the potential vacuum. The burner did not turn on. The ATM technician requested to review the burner manual as the burner was not manufactured by ATM but by the third-party company Riello Burner. The ATM technician found that the burner igniters did not follow the specifications in the manual. The igniters were too far apart to be able to trigger a spark. After the fix, the ATM technician sat inside the Snow Dragon to observe if a spark would come on, but a spark was still undetected.

As a result, the scheduled training was cancelled. Multiple Caltrans operators and managers were on-site for the demonstration, yet the Snow Dragon was not operational. Caltrans expressed dissatisfaction with the Snow Dragon performance due to the loss of time and resources.

3) Events following January 26, 2023

The ATM technician found that the fuel pressure sensor was set incorrectly. The ATM technician then changed the pressure from 10 bar to 3 bar. After the fix, the vacuum pressure gauge changed from being in the yellow and red zone to being in the yellow and green zone. The control panel relays kept popping due to over-current. The burner only made movement up to cam #1, so the ATM technician checked the servomotor. After the check, burner was still making movement only up to cam #1. The ATM technician then checked the control box of the burner and found that there were loose wires around terminal 10. After the wires were re-tied, the burner turned on. After this process, the burner was no longer in its housing.

When the burner was pushed back to its housing, it did not turn back on. The ATM technician re-primed the system and bled out the fluid pump to remove a potential vacuum. The ATM technician changed out the fuel filters, but the suction gauge was still in the red zone. The burner control box displayed ERROR 1, which indicated no flame in the ignition. The error was reset. The burner turned back on.

To ensure the burner was working consistently, the burner was reset. First, all the doors of the Snow Dragon were closed. The blower had been running since the last ignition. The burner was turned to auto. The burner went up to 125°F, but it failed to re-ignite at 114°F. The burner then continued to have ten faults afterward.

A second try was initiated. All the switches were turned off. The trailer was re-leveled. The Snow Dragon was restarted. An ERROR 1 fault would appear every 2 minutes 30 seconds when the burner was restarted. As a result, Dave and Anh drafted a troubleshooting summary report and sent it to the Snow Dragon team.

4) Events following January 27, 2023

The ATM technician performed a voltage test for the transformer. There was no output from the transformer. The ATM technician verified that the ceramics were good on the igniters. The ATM technician also re-adjusted the igniters (spark-electro) gap. The ATM technician then checked the terminal blocks for voltage readings. All the terminals in the control box worked except for terminal 16, which directed power to the transformer. There was no signal to get the expected 120 volts in the terminal. The Riello Burner engineer advised to force the oil pressure switch to work. When the ATM technician checked the oil pressure switch, the wires were loose. The ATM technician re-tied the wires, then jumped the oil pressure switch. The burner turned back on after the oil pressure switch was jumped. The transformer also received 120 V to start ignition.

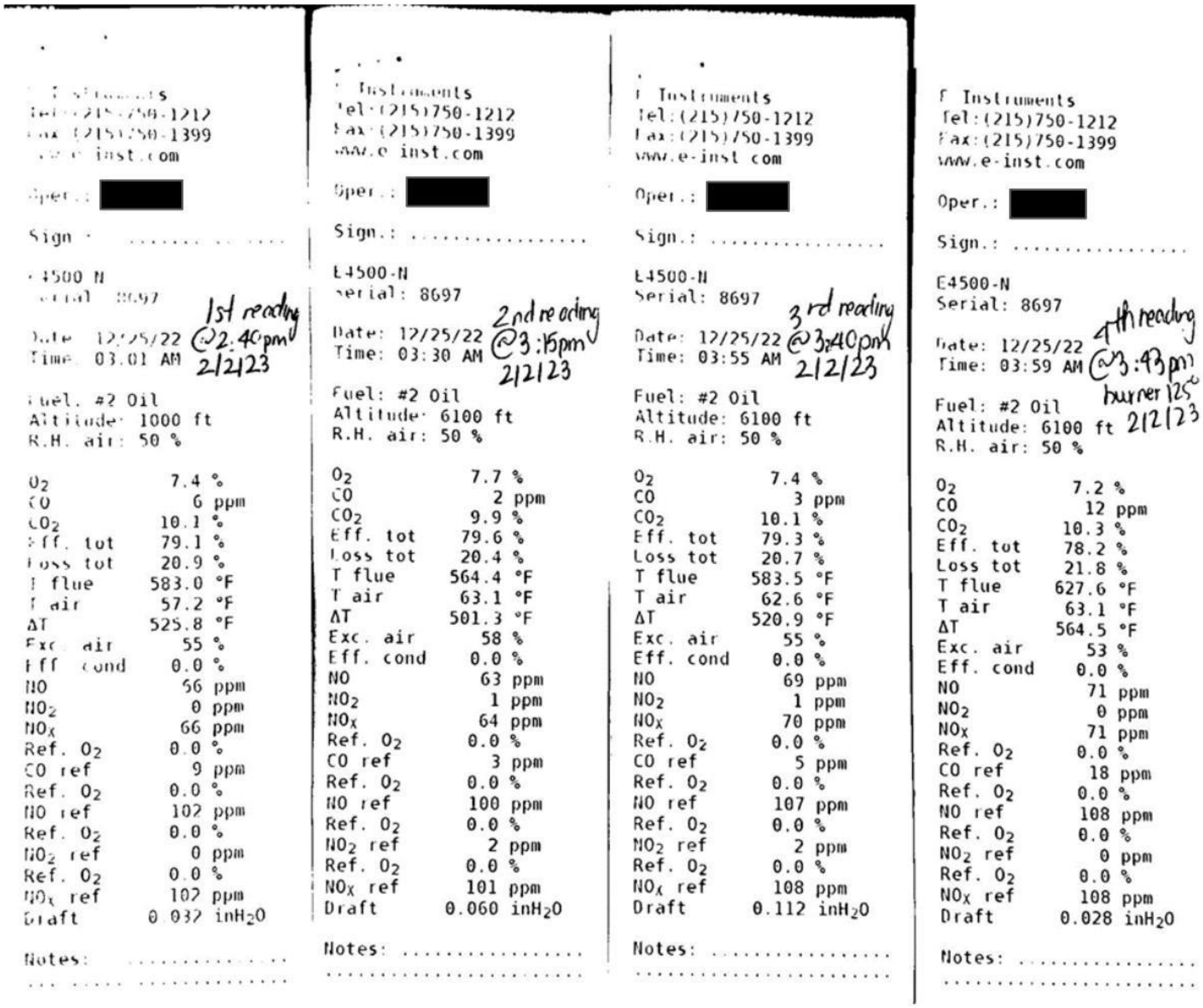
The Snow Dragon then worked consistently for six trials. The Snow Dragon was expected to reach 125°F, automatically shut down, and then fired back to 115°F. The Snow Dragon was restarted three times, and it worked as expected.

As a result, Dave signed off on the paperwork with the ATM technician. ATM agreed to send out a new oil pressure switch during the week of January 30. Dave and Anh were scheduled to come back to Kingvale on February 2 and 3.

Second visit: Dave and Anh returned to Kingvale on February 2 and 3. The focus on February 2 was to make sure the Snow Dragon worked properly. The training was set to begin on February 3 if things went smoothly on February 2.

5) Events following February 2, 2023

The ATM technician switched out the pressure switch. The burner turned on, and the Snow Dragon was cycled. In addition, the Snow Dragon was purposely tripped to ensure that it was working consistently. The ATM technician then took four air analyzer tests. The raw results are shown below:



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Serial:	8697	8697	8697	8697
	1st reading	2nd reading	3rd reading	4th reading
Date:	12/25/22 @2:40pm	12/25/22 @3:15pm	12/25/22 @3:40pm	12/25/22 @3:43pm
Time:	03:01 AM 2/2/23	03:30 AM 2/2/23	03:55 AM 2/2/23	03:59 AM burner 125° 2/2/23
Fuel:	#2 Oil	#2 Oil	#2 Oil	#2 Oil
Altitude:	1000 ft	6100 ft	6100 ft	6100 ft
R.H. air:	50 %	50 %	50 %	50 %
O_2	7.4 %	7.7 %	7.4 %	7.2 %
CO	6 ppm	2 ppm	3 ppm	12 ppm
CO_2	10.1 %	9.9 %	10.1 %	10.3 %
Eff. tot	79.1 %	79.6 %	79.3 %	78.2 %
Loss tot	20.9 %	20.4 %	20.7 %	21.8 %
T flue	583.0 °F	564.4 °F	583.5 °F	627.6 °F
T air	57.2 °F	63.1 °F	62.6 °F	63.1 °F
ΔT	525.8 °F	501.3 °F	520.9 °F	564.5 °F
Exc. air	55 %	58 %	55 %	53 %
Eff. cond	0.0 %	0.0 %	0.0 %	0.0 %
NO	56 ppm	63 ppm	69 ppm	71 ppm
NO_2	0 ppm	1 ppm	1 ppm	0 ppm
NO_x	66 ppm	64 ppm	70 ppm	71 ppm
Ref. O_2	0.0 %	0.0 %	0.0 %	0.0 %
CO ref	9 ppm	3 ppm	5 ppm	18 ppm
Ref. O_2	0.0 %	0.0 %	0.0 %	0.0 %
NO ref	102 ppm	100 ppm	107 ppm	108 ppm
Ref. O_2	0.0 %	0.0 %	0.0 %	0.0 %
NO_2 ref	0 ppm	2 ppm	2 ppm	0 ppm
Ref. O_2	0.0 %	0.0 %	0.0 %	0.0 %
NO_x ref	102 ppm	101 ppm	108 ppm	108 ppm
Draft	0.032 inH_2O	0.060 inH_2O	0.112 inH_2O	0.028 inH_2O
Notes:	....	....	....	....

Figure 4.1: Air analyzer results. The air analyzer model was E4500 from E-Instrument. Test results were performed by the ATM technician.

To enhance readability, Figure 4.1 is translated into Table 4.2.

Table 4.2: Air analyzer results

Content	First Reading (@2:40 pm on Feb 2nd, 2023)	Second Reading (@3:15 pm on Feb 2nd, 2023)	Third Reading (@3:40 pm on Feb 2nd, 2023)	Fourth Reading (@3.43 pm on Feb 2nd, 2023, burner was at 125°F)
O_2	7.4%	7.7%	7.4%	7.2%
CO	6 ppm	2 ppm	3 ppm	12 ppm
CO_2	10.1%	9.9%	10.1%	10.3%
Efficiency total	79.1%	79.6%	79.3%	78.2%
Loss total	20.9%	20.4%	20.7%	21.8%
Flue temperature	583.0°F	564.4°F	583.5°F	627.6°F
Air temperature	57.2°F	63.1°F	62.6°F	63.1°F
Difference in temperature	525.8°F	501.3°F	520.9°F	564.5°F
Excess air	55%	58%	55%	53%
Efficiency condensing	0.0%	0.0%	0.0%	0.0%
NO	66 ppm	63 ppm	69 ppm	71 ppm
NO_2	0 ppm	1 ppm	1 ppm	0 ppm
NOx	66 ppm	64 ppm	70 ppm	71 ppm
Ref. O_2	0.0%	0.0%	0.0%	0.0%
CO ref	9 ppm	3 ppm	5 ppm	18 ppm
Ref. O_2	0.0%	0.0%	0.0%	0.0%

Content	First Reading (@2:40 pm on Feb 2nd, 2023)	Second Reading (@3:15 pm on Feb 2nd, 2023)	Third Reading (@3:40 pm on Feb 2nd, 2023)	Fourth Reading (@3.43 pm on Feb 2nd, 2023, burner was at 125°F)
NO ref	102 ppm	100 ppm	107 ppm	108 ppm
Ref. O_2	0.0%	0.0%	0.0%	0.0%
NO_2 ref	0 ppm	2 ppm	2 ppm	0 ppm
Ref. O_2	0.0%	0.0%	0.0%	0.0%
NO_x ref	102 ppm	101 ppm	108 ppm	108 ppm
Draft	0.032 inH_2O	0.060 inH_2O	0.112 inH_2O	0.028 inH_2O

Upon inspection, there was visible rust and small water leaks on the front, back, and rear of the Snow Dragon. The locations were recorded by the AHMCT team.

Figure 4.2: Examples of rust and small water leaks on the Snow Dragon

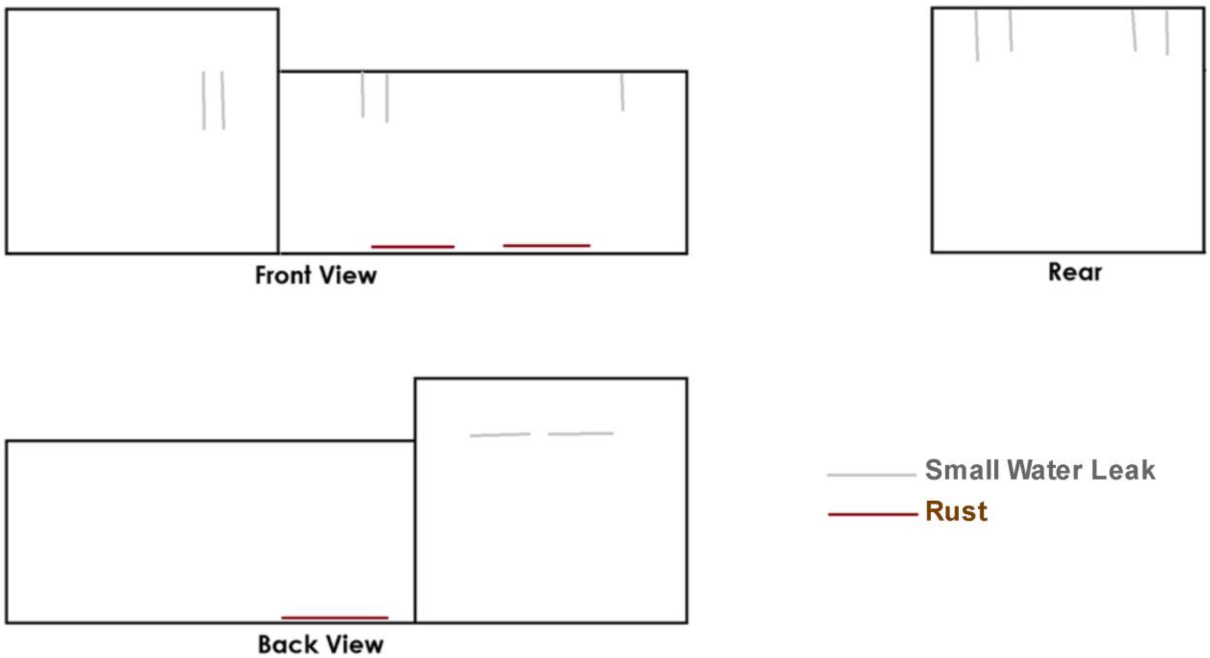


Figure 4.3: Locations where rust and small water leaks were detected on the Snow Dragon. Note that these spots only reflect problems documented on February 2.

6) Events following February 3, 2023

Since the Snow Dragon was working as expected on February 2, the training happened at noon as scheduled on February 3. After the training, Caltrans personnel performed test runs with the Snow Dragon as shown in Figure 4.4.

7) Events following February 3, 2023

The AHMCT team continued to make trips to the Kingvale yard for field testing and data collection.

Table 4.3 provides an overall summary of the sequence of events from the first and second visits.

Figure 4.4: Caltrans personnel trying out the Snow Dragon for the first time using the CAT loader to add snow

Table 4.3: Summarized timeline of the failures and troubleshooting actions for the Snow Dragon

Date (2023)	Failures	Troubleshooting Actions	Outcomes
Jan 24	The front jack was not housed properly. The servo motor setting was not correct. Burner did not turn on. The burner fuel line was leaking.	Front jack replacement was expected. The servo motor setting was corrected. Continued to troubleshoot the burner the next day. The burner fuel line was replaced, and the part was provided by Caltrans.	The scheduled noon training was moved to the next day.

Date (2023)	Failures	Troubleshooting Actions	Outcomes
Jan 25	The burner igniters did not follow drawing specifications. Burner did not turn on.	The burner igniters were re-adjusted. Continued to troubleshoot the burner the next day.	The training was cancelled. Caltrans expressed dissatisfaction with the Snow Dragon.
Jan 26	The fuel pressure sensor was set incorrectly. There were loose wires in the burner control box. The burner turned on after the wires were re-tied but then failed afterwards. The Snow Dragon continuously exhibited a fault error that is ERROR 1 – no flame detected.	The fuel pressure sensor was re-adjusted. The wires were re-tied. A reset was initiated, but it did not solve the burner problem.	AHMCT drafted a troubleshooting report and sent it to ATM.
Jan 27	There was no voltage output to the burner transformer. There was no signal sent to Terminal 16 in the burner control box. The oil pressure switch wires were loose.	The wires were re-tied. The oil pressure switch was bypassed.	The burner turned on, and the Snow Dragon worked as expected. ATM agreed to send a new oil pressure switch. The AHMCT team and ATM technician agreed to come back to Kingvale on Feb 2 and 3.

Date (2023)	Failures	Troubleshooting Actions	Outcomes
Feb 2	Rust and water damage spots.	No solution for rust and water damage spots.	The Snow Dragon worked as expected after the oil pressure switch was replaced, thus it was ready for training. Air analyzer tests were conducted.
Feb 3	N/A	N/A	Training happened. Caltrans personnel performed test runs.
After Feb 3	N/A	N/A	The AHMCT team collected field data.

Chapter 5: Field Testing Procedures, Results, and Operator Feedback

In this chapter, the field testing results and operator feedback are summarized. The results and feedback are based solely on the use of the Snow Dragon being at the Kingvale yard. The Snow Dragon location is depicted in Figure 5.1.

Figure 5.1: Snow Dragon Placement at the Kingvale Yard. The elevation at this location is approximately 6,099’ according to the [United States Geological Survey tool topoView] [1]. Image courtesy of Google Earth.

Field Testing Procedures

The AHMCT team observed, recorded, and collected data to evaluate the Snow Dragon performance. The goal was to find the "sweet spot" where the Snow Dragon would perform most efficiently.

- Events in the field
  - There were two different types of snow used in the field testing: snow with more sand (East side of Kingvale), and snow with less sand (West side of Kingvale). The two different types of snow were being dumped into the Snow Dragon in two separate test runs (one test run focused on snow with more sand, the other test run focused on snow with less sand).
  - The AHMCT team observed that the Snow Dragon had a performance pattern at around 50°F for snow with less sand. This behavior was recorded.
  - The AHMCT team decided to monitor the Snow Dragon while it was operating at 50°F or higher. When the water temperature in the Snow Dragon tank dropped below 50°F, the operator would wait until the water temperature recovered to 50° or higher before dumping in the next bucket of snow. During this time, the water continued to flow from the outlets.
- Data collected
  - Snow with more sand: the number of snow buckets melted for a time duration.
  - Snow with less sand: the number of snow buckets melted for a time duration.
  - The performance pattern at around 50°F for snow with less sand
  - The density of Kingvale yard snow, both locations
  - The setup duration whenever an operation is initiated
  - The clean-out duration during and after operations

Snow Dragon Performance based on Field Testing Results

Log Sheet for the Snow Dragon

The AHMCT team created a log sheet to keep track of the Snow Dragon's performance, as shown in Appendix A. The log sheet was filled out by Caltrans operators. To enhance readability, Figure A.1 from Appendix A was converted to Table 5.1.

Table 5.1: Snow Dragon performance record based on the log sheet

Date (M/DD)	Setup Time (hours)	Running (hours)	Number of Buckets (water level)	Loader Fuel (gallons)	Shutdown Time (including the clean-out time) (minutes)	Dragon Fuel (gallons)
2/05	1	1.5	10	-	15	73
2/06	2	1.75	19	3.5	90	94
2/07	Could not get running, fault					
2/15	The blower was repaired & fuel filters were changed					
2/23	1.5	8	80	-	90	318
2/25	1	9	93	-	60	325
2/26	3	5	51	-	120	216
2/27	1.5	9	74	-	120	376
2/28	1.5	8	88	-	120	370
3/05	1.5	8	67	-	120	311
3/06	1.5	6	49	-	120	271

The log sheet was used to keep track of the Snow Dragon's activity when AHMCT was not on site. The data from the log sheet were used for the Snow Dragon evaluation.

Duration of the New-Shift Setup

1) <u>Fill the Snow Dragon with water</u>

Before operating the Snow Dragon, it needs to be filled up to the operational level. The setup duration was recorded by AHMCT. The total fill time is longer than the manufacturer would have expected. The wash rack hose that was used, was connected to valves and piping that were smaller in diameter and this may have caused the extended time to fill the Snow Dragon.

- Transporting the water hose to the Snow Dragon took approximately 2 minutes 13 seconds. The water hose in this scenario is normally used to spray down the vehicles.
- Filling the water from the empty tank level to the dry level took approximately 17 minutes 44 seconds when using the hose.
- Filling the water from dry level to the operational level took approximately 28 minutes 53 seconds when using the hose.
- Filling the water from the empty tank level to the operational level took approximately 46 minutes 47 seconds when using the hose.

2) Fuel the Snow Dragon

The fuel capacity for the Snow Dragon is 550 US gallons. Fueling the Snow Dragon to its full capacity takes approximately 30 to 45 minutes.

3) Average setup time (i.e., filling the Snow Dragon up with water and fuel)

Based on the AHMCT team estimations, the average time to setup the Snow Dragon is approximately 1 hour 17 minutes. **Based on the log sheet results, the average time to setup the Snow Dragon is approximately 1 hour 36 minutes.**

4) The fuel filter changing frequency

According to the operators, the fuel filters get changed between 50 to 70 hours.

The Snow Dragon team recommended that the filters should be changed as needed, with a new set at the beginning of a melting event. Operators can also make judgement on when they should change the fuel filters since they can be visibly checked.

Snow with More Sand

Field Data

The snow on the east side of the Kingvale yard was used since it contained more sand than snow from the west side. The ambient temperature was 14°F, and the wind was blowing at 16 mph. The findings are as follows:

- The Snow Dragon was operated for 100 minutes before a fault occurred.
- During the 100 minutes, 23 buckets of snow with debris were dumped into the Snow Dragon. Each bucket contained approximately 5 cubic yards of snow, and each bucket was above water level.

- A fault occurred due to the Snow Dragon being low on water. There was a significant amount of sand accumulation. The water was overflowing, thus there was not enough water to melt the incoming snow.

Table 5.2 depicts the water temperature per minute of operation.

Table 5.2: Water temperature inside the Snow Dragon per minute of operation (snow with debris)

Operational minutes	Water temperature (°F)
0	110
20	60
40	62
60	60
80	64
100	49 (FAULT OCCURRED)*

*Note: ATM advised that this fault might have occurred since the burner was not going to run at high fire due to the water level being low. The Snow Dragon should be cleaned out before getting to this point.

Conclusion: It took 100 minutes for the Snow Dragon to melt 23 buckets of snow with more sand. 100 minutes converted to hour is 1.67 hour. 23 divided by 1.67 hours yields 13.77 buckets per hour. In other words, the Snow Dragon melted approximately 13.77 buckets per hours, or 68.85 cubic yards of snow with more sand per hour.

Clean-Out Frequency

When dumping snow with more sand into the Snow Dragon, the Snow Dragon operated for 100 minutes before top and bottom clean-outs were required. The clean-outs took 45 minutes. Figures 5.2 and 5.3 depicted the conditions of the Snow Dragon after 100 minutes of operation.

Figure 5.2: The top of the Snow Dragon and its condition after melting snow with more sand for 100 minutes straight


Figure 5.3: The bottom of the Snow Dragon tank and its condition after melting snow with more sand for 100 minutes straight

Overall Observation

According to the Kingvale yard manager, one truck can take 12 cubic yards of snow per trip. The AHMCT team estimated that 24 to 36 cubic yards of snow can be removed in one hour using one truck (if two to three trips were made). In addition, the content of the snow does not matter when the snow is being trucked as the limiting factor is volume, not weight. The Snow Dragon melted approximately 13.77 buckets, or 68.85 cubic yards of snow with more sand per hour. Although the Snow Dragon can remove a larger amount of snow with more sand within one hour when compared to one truck, two trucks being would be more efficient than using the Snow Dragon. Table 5.3 outlines the amount of snow with more sand being removed when trucking snow versus when melting it with the Snow Dragon.

Table 5.3: Amount of snow with debris being removed in different scenarios

Scenarios	Amount of snow with more sand being removed per hour
Having one truck to remove the snow	24 to 36 cubic yards per hour*
Having two trucks to remove the snow	48 to 72 cubic yards per hour
Using the Snow Dragon to melt the snow	~68.85 cubic yards per hour (Snow Dragon requires clean out after 100 minutes in operation)

*If a truck carries 12 cubic yards of snow (or approximately two buckets) per trip, two trips result in 24 cubic yards of snow being removed, and three trips result in 36 cubic yards of snow being removed.

Snow with Less Sand

Field Data

The snow on the west side of the Kingvale yard was used for this test since it contained less sand than the east side. The ambient temperature was 15°F, and the wind was blowing at 12 mph. The findings are as follows:

- The Snow Dragon operated for 205 minutes. At the 25-minute mark, a fault occurred. The Snow Dragon was then reset and continued to operate for the rest of the shift.
- During the 205 minutes, 57 buckets of snow with less sand were dumped into the Snow Dragon. Each bucket contained approximately 5 cubic yards of snow, and each bucket was above water level.

Table 5.4 demonstrates the water temperature per minute of operation, if the water temperature went below 50°F, the operator would not dump their bucket. Table 5.5 outlines the Snow Dragon recovery time when a bucket of snow with less sand is added. In this context, the recovery time means the Snow Dragon water tank temperature was **equal to or above 50°F**; thus, it was ready to take another bucket of snow.

Table 5.4: Water temperature inside the Snow Dragon per the minute of operation (snow with less sand)

Operational minutes	Water temperature (°F)
0	124
5	71
10	62
15	52
20	47
25	50 (Fault occurred)*
30	45
35	48
40	50
45	52
50	56
55	48
60	53
85	55
145	48
205	43

*The cause of the fault was undetermined. The Snow Dragon was reset by shutting down the whole system and then turning it back on. After the reset, the Snow Dragon operated until the end of the shift.

Table 5.5 illustrates the Snow Dragon performance pattern.

Table 5.5: Time for the Snow Dragon to recover after a bucket of snow with less sand was added

Time (seconds)	Water tank temperature for run 1 (°F)	Water tank temperature for run 2 (°F)	Water tank temperature for run 3 (°F)	Water tank temperature for run 4 (°F)
0	51	50	53	50
10	53	49	55	50
20	54	50	56	50
30	55	52	57	52
40	55	50	54	50
50	54	50	50	49
60	52	50	50	48
70	49	49	50	47
80	48	49	50	48
90	48	48	52	49
100	47	48	50	48
110	48	48	51	48
120	47	48	50*	48
130	49	47	-	47
140	51*	48	-	45
150	-	47	-	45
160	-	45	-	46
170	-	46	-	48
180	-	46	-	48
190	-	46	-	49

Time (seconds)	Water tank temperature for run 1 (°F)	Water tank temperature for run 2 (°F)	Water tank temperature for run 3 (°F)	Water tank temperature for run 4 (°F)
200	-	47	-	50*
210	-	47	-	-
220	-	48	-	-
230		50*		

*A new bucket was added when the temperature was **equal to or above 50°F**

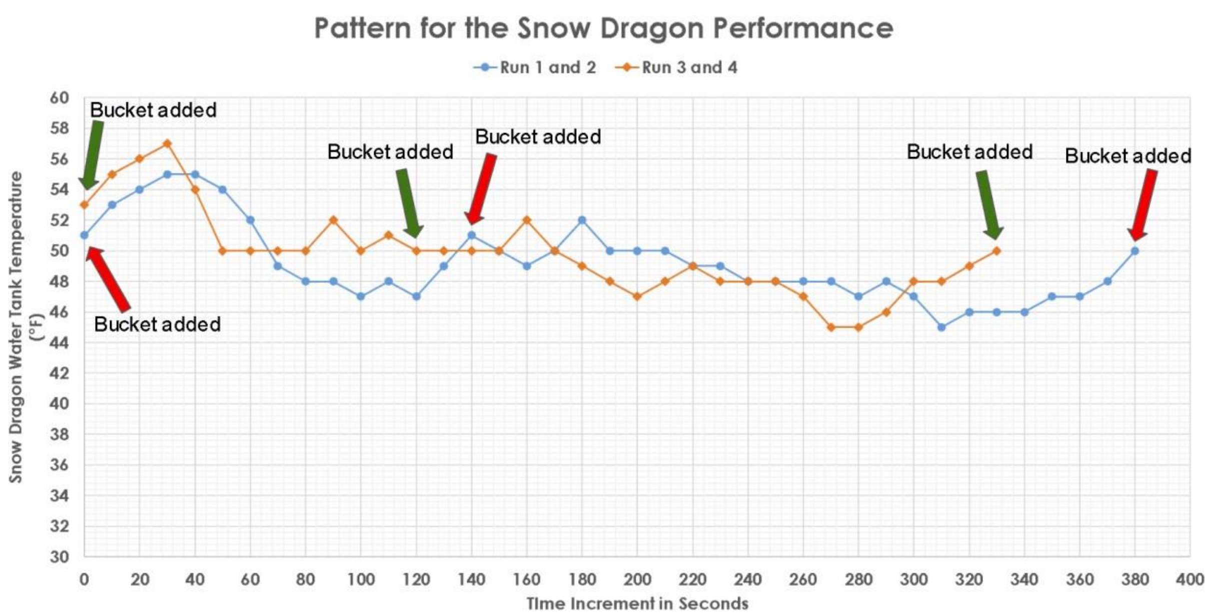


Figure 5.4: Snow Dragon performance pattern. Red arrow indicates data line "Run 1 and 2". Green arrow indicates data line "Run 3 and 4". "Bucket added" means a bucket was being dumped into the Snow Dragon. All test runs were for snow with less sand.

Based on Figure 5.4, one bucket generally led to a shorter recovery time, and the next bucket caused a longer recovery time. For "Run 1 and 2", it took 140 seconds (2 minutes 20 seconds) for the first bucket to be dumped. For the second bucket to be dumped, it took 240 seconds (4 minutes). For "Run 3 and 4", it took 120 seconds (2 minutes) for the first bucket to be dumped. For the second bucket to be dumped, it took 210 seconds (3 minutes 30 seconds). **The pattern showed that after the first bucket was dumped, the recovery time before the second bucket could be dumped was approximately 4 minutes. In other**

words, the Snow Dragon tended to exhibit a pattern of temperature recovery every two buckets. The first bucket of the pair tended to recovery quicker (approximately 2 minutes) compared to the second bucket (approximately 4 minutes).

Clean-Out Frequency

When dumping snow with less sand into the Snow Dragon, the machine operated for 205 minutes before top and bottom clean-outs were required. The clean-outs took 30 minutes. Figures 5.5 and 5.6 depict the conditions of the Snow Dragon after the 205-minute operation.

Figure 5.5: The top of the Snow Dragon and its condition after melting snow with less sand for 205 minutes

Figure 5.6: The bottom of the Snow Dragon and its condition after melting snow with less sand for 205 minutes

Overall Observation

According to the Kingvale yard manager, one truck can take 12 cubic yards of snow per trip. The AHMCT team estimated that 24 to 36 cubic yards of snow can be removed in one hour using one truck (if two to three trips are made). In addition, the content of the snow does not matter when the snow is being trucked as the limiting factor is volume, not weight. The Snow Dragon melted approximately 16.68 buckets, or 83.41 cubic yards of snow with less sand per hour. The Snow Dragon performed more efficiently with snow with less sand than snow with more sand. Table 5.6 outlines the amount of snow with less land being removed when trucking snow versus when using the Snow Dragon.

Table 5.6: The amount of snow with less sand being removed in different scenarios

Scenarios	Amount of snow with less sand being removed per hour
Having one truck to remove the snow	24 to 36 cubic yards per hour*
Having two trucks to remove the snow	48 to 72 cubic yards per hour
Using the Snow Dragon to melt the snow	~83.41 cubic yards per hour

*If a truck carries 12 cubic yards of snow (or approximately two buckets) per trip, two trips result in 24 cubic yards of snow being removed, and three trips result in 36 cubic yards of snow being removed.

Operator Feedback

The AHMCT team sent out a questionnaire to the Caltrans operators regarding their experience working with the Snow Dragon. The feedback was as follows:

- Advantage of using the Snow Dragon:
    - The Snow Dragon requires only one operator to remove snow in the yard
- Disadvantage of using the Snow Dragon:
    - The clean-out at the end of the shift is very time-consuming. The sediment and sand must be cleaned out at least every 12 hours during operation
    - The operator cannot continuously feed snow into the Snow Dragon, thus the operator must pause between loads.
    - If the operator overloads the Snow Dragon, the water tank temperature will drop too low. The operator has to wait until the water tank temperature recovers enough to melt the next snow bucket.
    - There is a fine line between how fast the operator can load the Snow Dragon and how fast the water tank temperature recovers after a bucket. In addition, the recovery of the water tank temperature is dependent on the ambient temperature and the density of the snow.

Feedback from Caltrans Maintenance

In addition to the survey response, AHMCT received direct feedback from Caltrans Division of Maintenance personnel. This feedback is provided as-is with no editorial revisions or commentary.

Pros

- Could be useful in areas with long distance to material storage sites.
- Could be useful in areas with less snowpack.

Cons

- High fuel usage.
- The snow takes some time to melt between bucket loads. Faster to load dump trucks and haul offsite.
- High maintenance, such as cleaning every 12 hours, too much sand can cause damage, etc.
- Slow repair time when it breaks down.
- Higher volume of water discharge can affect the current facility drainage system or cause erosion if proper BMPs are not implemented.
- Hasn't worked for any demonstration.

Environmental Impact

According to manufacturer claim, the water from snow being melted by the Snow Dragon is cleaner than the regular melted snow. The claim is as follows:

> *"Water exits the Snow Dragon cleaner than the snow that was dumped into it" (Snow Dragon)*

Water samples before and after using the Snow Dragon were collected and tested to verify manufacturer claims. The tests were conducted by the UC Davis Analytical Lab. The lab team tested each sample twice. The tests are summarized in Table B.1 in Appendix B. The raw results are provided as Figures B.1-B.4 in Appendix B.

The samples were collected on February 23, 2023 and tested from April 10 to May 26, 2023. Each sample was tested twice, hence results are provided for "Test #1" and "Test #2". From the results, most elements decrease in concentration, one element (zinc) increases in concentration, and some elements remain unchanged. Table 5.7 summarizes the concentration results.

The data shows that the Snow Dragon decreased the concentration of certain elements. However, those elements were still present at the end of the shift clean-out which could potentially get back to the water stream, i.e. clean-out must be handled properly to see this benefit. Through the clean-out process, the TSS were in their concentrated form that allowed easier sand reclamation at the maintenance yard.

Table 5.7: Summary of the concentration results

Description	Element(s)
Elements that remained unchanged after the Snow Dragon	Carbonate, NO_3-N, PO_4-P (soluble P), Cadmium, Copper – Soluble, Cadmium – Soluble, Chromium - Soluble, Lead – Total, Nickle – Soluble.
Elements that increased in concentration after the Snow Dragon	Zinc – Soluble.
Elements that decreased in concentration after the Snow Dragon	Alkalinity, Bicarbonate, TOC, DOC, Chlorine, EC, Hardness, Nitrogen – Total, TKN, pH, SAR, SO_4-S – Soluble S, TDS, TSS, Turbidity, Aluminum – Total, Boron – Soluble, Calcium – Soluble, Chromium – Total, Iron – Soluble, Magnesium – Soluble, Manganese – Soluble, Nickel – Total, Potassium, Sodium – Soluble, Aluminum – Soluble, Calcium – Total, Copper – Total, Magnesium – Total, Manganese – Total, Phosphorus – Total, Potassium – Total, Sodium – Total, Zinc – Total, Iron – Total.

Field Testing Conclusions

Overall, the Snow Dragon has the capability of removing snow faster than one truck in an hour when removing snow with more sand. The Snow Dragon has the capability of removing snow faster than two trucks in an hour when removing snow with less sand. Table 5.8 summarizes the Snow Dragon capability when compared to the amount of trucks used to truck snow.

Table 5.8: Snow Dragon's capability when compared to the amount of trucks used to truck snow

Scenarios	Amount of snow being removed per hour
Having one truck to remove the snow	24 to 36 cubic yards per hour*
Having two trucks to remove the snow	48 to 72 cubic yards per hour
Using the Snow Dragon to melt the snow with more sand	~57.75 cubic yards per hour (require clean out after 100 minutes in operation)
Using the Snow Dragon to melt the snow with less sand	~77.7 cubic yards per hour (no issue after 205 minutes in operation)

*If a truck carries 12 cubic yards of snow (or approximately two buckets) per trip, two trips result in 24 cubic yards of snow being removed, and three trips result in 36 cubic yards of snow being removed.

Optimizing the Snow Dragon

The complete optimization of the Snow Dragon was not completed in this research project and ATM has offered to assist next season in optimizing the performance of the Snow Dragon. During the initial training from ATM, Caltrans was informed to keep the water temperature at 110°F. However, after further conversations with ATM, it was learned that this is not required, much of the optimization work that was performed was intended to address this misconception. ATM and AHMCT believe that the Snow Dragon can perform better if a different approach is followed, one that depends on observing the water discharge as an indicator of when to add more snow.

During field testing, the AHMCT team observed that the best approaches to optimize the Snow Dragon performance is to **maintain the Snow Dragon water temperature at around 50°F. This temperature allows the Snow Dragon to melt the most amount of snow buckets.** For instance, the operator can dump the snow bucket any time the Snow Dragon water temperature is equal to or above 50°F. When the Snow Dragon water temperature drops below 50°F, the operator should wait approximately two to four minutes for the Snow Dragon to recover the 50°F threshold.

According to the Snow Dragon's operating patterns, the following tips were developed:

- Water temperature needs to be recovered every two snow buckets. The first bucket takes approximately 2 minutes to recover the 50°F threshold. The second bucket takes approximately 4 minutes to recover the 50°F threshold. In other words, every time 2 buckets are dumped into the Snow Dragon, it will take approximately 6 minutes to recover the 50°F threshold.
- While waiting for the Snow Dragon to recover the 50°F threshold, the operator may be able to perform other tasks

Chapter 6:
Current Operational Costs vs. New Practice Costs

Cost Analysis for Trucking Snow

To have an objective measurement for the cost, the cost to truck a cubic yard of snow is calculated. **The cost trade-off depends on distance to the dump site, availability, reliability, and capacity.**

General Equipment and Operation Cost

The cost to truck a cubic yard of snow can be calculated based on the equipment and operational costs provided by the Caltrans. The snow trucking cost includes the following criteria:

- Operational hours: 24 hours continuously
    - One CAT 930AM loader
    - One to five International 7600 truck(s)
    - Operator salary with overhead

The cost based on the criteria listed above is shown in Table 6.1.

Table 6.1: Snow trucking cost based on equipment and operation cost

Item	Description	Cost provided by Caltrans
CAT 930AM Loader	Operational cost, not including repair cost	$43.85 per hour
CAT 930AM Loader fuel cost per gallon	The operational cost does not include fuel cost	$4.40 per US gallon The full fuel tank capacity is 51.5 US gallons[2]

[2] Reference from 930M Wheel Loader | Cat | Caterpillar

Item	Description	Cost provided by Caltrans
CAT 930AM Loader fuel cost	Assume one full refill last a 24 hours work shift	$226.60 for a full refill
Loader operator cost (with overhead)	One loader for every operation	$58.86 per hour
International 7600 Truck	Varies from one to five trucks. Operational cost, not including repair cost	$60.77 per hour per truck
International 7600 Truck fuel cost per gallon	The operational cost does not include fuel cost. The trucks fuel economy is 3 to 4 miles per gallon according to the yard manager	$4.40 per US gallon Full fuel tank varies in size. Assume the full fuel tank capacity is 100 US gallons[3]
International 7600 Truck fuel cost	Assume one full refill last a 24 hours work shift	$440 for a full refill
Truck operator cost (with overhead)	One to five operators, depending on the snow volume	$58.86 per hour per operator
Cost to operate 1 loader and 1 truck for 24 hours		$6,002.76
Cost to operate 1 loader and 2 trucks for 24 hours		$9,313.88
Cost to operate 1 loader and 3 trucks for 24 hours		$12,624.60
Cost to operate 1 loader and 4 trucks for 24 hours		$15,936.60
Cost to operate 1 loader and 5 trucks for 24 hours		$19,247.60

[3] Reference from International 7600 Fuel Tanks For Sale | MyLittleSalesman.com

The Cost to Truck a Cubic Yard of Snow

The cost to truck a cubic yard of snow can be calculated based on the amount of precipitation and area of coverage. The Kingvale yard perimeter and area were estimate by using Google Earth measuring tool. The estimated perimeter was 3,251 feet, and the estimated area was 324,435 square feet including buildings, as shown in Figure 6.1, which corresponds to an estimated perimeter of 1,084 yards and estimated area of 36,048 square yards including buildings.

Figure 6.1: Kingvale yard outlined by a yellow line. The estimated perimeter is 3,251 feet. The estimated area is 324,435 square feet including buildings. Image courtesy of Google Earth.

The estimated area that needs snow trucking excludes buildings. In the Kingvale yard, there are 12 main buildings as shown in Figure 6.2. The building measurement values and the estimated Kingvale area value excluding buildings are listed in Table 6.2.

Figure 6.2: Buildings to be removed from estimated area for snow trucking. Image courtesy of Google Earth.

Table 6.2: Estimated area that needs snow removal

	Area of coverage (square yard)*
Total area (with buildings)	36,048
Building 1	948
Building 2	1,905
Building 3	3,450
Building 4	211
Building 5	160
Building 6	160
Building 7	506
Building 8	89
Building 9	491
Building 10	131
Building 11	44
Building 12	244
Total area (excluding the 12 buildings)	27,709

*Values are rounded to the nearest whole number

After the snow removal area is calculated, the amount of precipitation can be collected from weather stations. The Caltrans weather stations are located in Baxter – Junction State Route 20 (SR-20) and Junction SR-20 – Kingvale. The approximate locations of the two weather stations are shown in Figure 6.5.

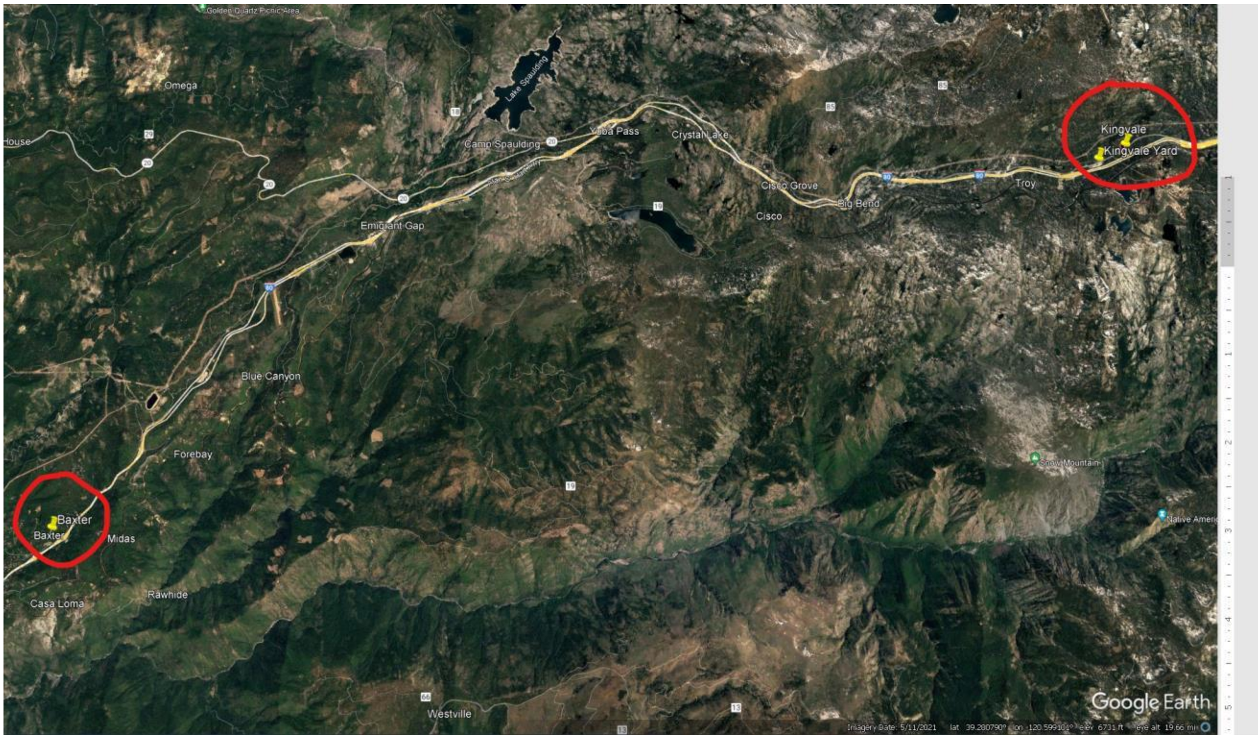


Figure 6.3: Distance between Baxter, Kingvale, and Kingvale yard. Image courtesy of Google Earth.

Caltrans keeps a record of snowfall at their weather stations. The AHMCT team requested access to the weather stations' data from Caltrans. The amount of snowfall from the period of January 1, 2023 to January 22, 2023 is summarized in Table 6.3.

Table 6.3: Snow height recorded by Caltrans weather stations

Duration	Snow accumulated at Baxter (inches)	Snow accumulated at Kingvale (inches)
Jan 1 to Jan 8	44	66
Jan 9 to Jan 15	58	62
Jan 16 to Jan 22	16	20

Since the weather station at Baxter is relatively far from Kingvale, its snow accumulation data are not as applicable compared to the data from the

Kingvale weather station. **Only the snow accumulation data from Kingvale weather station were used in the calculation.**

To calculate the volume of snow, the total area excluding the 12 buildings was multiplied with the height of accumulated snow. The volume of snow calculated in this step was not the actual snow volume in the Kingvale yard. The snow density was taken into account to obtain the actual snow volume at the Kingvale yard.

To calculate the actual volume of snow in the Kingvale yard, the density of the snow was determined. A cubic yard of Kingvale snow weighed 411 pounds. A cubic yard of water weighed 1,685 pounds. From the weight values, the density ratio was calculated to be four-to-one. The density ratio was incorporated in the calculation so that the actual snow volume could be obtained.

After the AHMCT team obtained data for cost (provided by Caltrans) and snow volume in cubic yard, the average cost to truck a cubic yard of snow was calculated. The results are shown in Table 6.4.

Table 6.4: Average cost to truck a cubic yard of snow for Kingvale yard

Time period (2023)	Total cost (provided by Caltrans)*	Calculated snow volume (yd^3)	Cost to truck a cubic yard of snow
Jan 1 to 8	$26,588	12,700	$2.09
Jan 9 to 15	$16,393	15,521	$1.06
Jan 16 to 22	$48,945	5,007	$9.78
Average cost to truck a cubic yard of snow from Jan 1 to Jan 22			$2.77

*Note: the total cost values were rounded (e.g. $26,587.95 was rounded to $26,588).

The total trucking cost is divided with the total snow accumulated to obtain the cost of trucking a cubic yard of snow from the period of January 1, 2023 to January 22, 2023. Using this method, **the average cost to truck a cubic yard of snow in Kingvale is $2.77. The amount of snow being removed correlates with the cost of removing snow. In other words, the more snow being removed in a period, the more cost-effective the snow removal operation will be.**

Cost Analysis for Melting Snow Using the Snow Dragon

To compare with the cost of trucking a cubic yard of snow, the cost of melting a cubic yard of snow was calculated. The life cycle cost of the Snow Dragon was also calculated.

General Equipment and Operation Cost

First, the equipment and operational cost is considered. The loader and the loader operator cost are the same as trucking snow. The trucking cost is no longer part of the equation. In case the Snow Dragon breaks down, there is an on-site Caltrans maintenance worker to diagnose the issues. The overall equipment and operation cost for the Snow Dragon is shown in Table 6.5.

Table 6.5: Equipment and operational cost when using the Snow Dragon

Item	Description	Cost provided by Caltrans
CAT 930AM Loader	Operational cost, not included in repair cost.	$43.85 per hour
Loader operator cost (with overhead)	One loader for every operation	$58.86 per hour
Maintenance worker (not applicable if the Snow Dragon operates smoothly)	Diagnose the Snow Dragon if it breakdowns	$60.86 per hour
Water	To fill up the Snow Dragon before each operation	$0, Caltrans water cost has a flat rate.
Fuel	To run the Snow Dragon	$4.40 per gallon
Fuel filter	Change out every eight hours during operation	$13.94 per filter (not including tax, and may vary based on the market)

Using Table 6.5, the cost to operate the Snow Dragon for 24 hours straight was calculated, and the results are shown in Table 6.6.

The Cost to Melt a Cubic Yard of Snow

Table 6.6: Cost to operate the Snow Dragon for 24 hours. Calculation does not include initial cost of obtaining the Snow Dragon (not amortized).

Item	Cost per hour	Cost in 24 hours
CAT 930AM Loader	\$43.85	\$1,052
Loader operator	\$58.86	\$1,413
Fuel – 40 to 60 US gallons per hour	\$176 for 40 US gallons \$264 for 60 US gallons Average fuel cost: \$220	\$5,280 (average)
Fuel filter (2 filters every 8 hours)	\$3.49	\$83.64 (not including tax)
Total	**\$326**	**\$7,829**

According to the data recorded in the field, the Snow Dragon was able to melt up to **95 cubic yard of low sediment snow** (or snow with less sand) per hour. 95 cubic yards per hour was the best rate the AHMCT team recorded; therefore, this rate was used to calculate the melting cost. The operating cost results in this section are applied for the 95 cubic yards per hour rate. The Snow Dragon operating cost may vary based on how it is operated and other environmental conditions (i.e. snow density, ambient temperature, etc.). **The cost to melt a cubic yard of snow using the Snow Dragon is \$3.43 in an ideal situation (i.e., the Snow Dragon runs smoothly).**

Lifecycle Cost of the Snow Dragon

For the second calculation, the cost to obtain the Snow Dragon was considered. The purchasing cost breakdown is shown in Table 6.7.

Table 6.7: Cost to obtain the Snow Dragon

SND900 Investment Summary	
SND900 Mobile Snow Melter	\$290,000
One Year Standard Factory Parts Warranty	Included
Two Days Setup and Training at Customer Location	Included

One Removable Debris Basket	Included
SND900 Add-on Options	
Spare Trailer Tire Mounted onto the Snow Melter	\$3,750
Labor & Parts Warranty for 2 Years. This includes a post season maintenance visit between year 1 and year 2	\$18,100
Shipment Cost (3rd-Party)	
Shipping from Warren, Ohio to Soda Springs, California	\$6,685
Total Cost (plus local tax of 7.25%)	\$318,535 (+ \$23,094)

The lifecycle cost analysis for the Snow Dragon breaks down the lifetime cost of operating the Snow Dragon. The cost items are also listed in Table 6.8.

- Purchase costs: \$341,629 including local tax
- Maintenance costs: Warranty for two years, then maintenance cost \$60.86 per hour for a Caltrans technician
- Operational costs: \$326.20 per hour
- Financing costs: Not applicable as the Snow Dragon was fully paid
- Annual depreciation costs:
    - 10-year lifespan: \$34,163 per year
    - 15-year lifespan: \$22,775 per year
    - 20-year lifespan: \$17,081 per year
- End of life costs: \$0. Assume that the machine will be recycled, but the removal cost will cancel out the recycling money.

The operational cost depends on the amount of snowfall. The recorded total annual snowfall at Soda Springs, according to historical data [2], is:

- 2016 - 2017: 267 inches in 22 days
- 2017 - 2018: 208 inches in 19 days
- 2018 - 2019: 171 inches in 13 days
- 2019 - 2020: 113 inches in 20 days
- 2020 - 2021: 184 inches in 23 days
- 2021 - 2022: 457 inches in 40 days

- 2022 - To Date: 494 inches in 35 days
- Average snowfall from 2016 to date: 270.6 inches

Table 6.8: Lifecycle Cost breakdown

Item	Description	Cost
Purchase costs	Including local tax	$341,629
Maintenance costs	Assume that the Snow Dragon needs 10 hours of maintenance per season Excluding hardware replacement cost Warranty for the first two years	$608.60 per year 10 years (including two-year warranty): $4869 15 years (including two-year warranty): $7912 20 years (including two-year warranty): $10,955
Operational costs	Assume the average snow fall per season is 270 inches Assume the Snow Dragon operates at its optimal performance where cost to remove a cubic yard of snow is $3.43	$712,814 per season $7,128,140 for 10 years $10,692,210 for 15 years $14,256,281 for 20 years
Financing costs	Snow Dragon was paid in full	$0
Annual depreciation costs	The value of the Snow Dragon decreases every year The formula: The purchase cost is divided by the amount of years in service	10 years lifespan: $34,163 per year 15 years lifespan: $22,775 per year 20 years lifespan: $17,081 per year
End of life costs	Removal cost equals to recycle cost	$0
Lifecycle cost over the lifespan of 10 years		**$7,508,801**
Lifecycle cost over the lifespan of 15 years		**$11,064,526**
Lifecycle cost over the lifespan of 20 years		**$14,625,946**

Comparison between Practices

Table 6.9: Cost comparison between trucking snow and melting snow

	Trucking Snow	Melting snow using the Snow Dragon
Maintenance cost (not including hardware and fluid replacement) Assume a loader takes 10 hours to maintain per season Assume a truck takes 10 hours to maintain per season Assume the Snow Dragon takes 10 hours to maintain per season	Cost to maintain one loader and one truck per year: $1,217 Cost to maintain one loader and two trucks per year: $1,826 Cost to maintain one loader and three trucks per year: $2,434	Cost to maintain one loader and the Snow Dragon per year: $1,217
Operational cost (including labor cost with overhead)	Cost to operate one loader and one truck for 24 hours: $5,336 Cost to operate one loader and two trucks for 24 hours: $8,207 Cost to operate one loader and three trucks for 24 hours: $11,078	Cost to operate one loader and the Snow Dragon for 24 hours: $7,829
Cost to remove 100 cubic yard of snow **Both costs are at optimal circumstances**	**Trucking cost: $2.77 per cubic yard** **$277 to remove 100 cubic yard**	**Melting cost: $3.43 per cubic yard** **$343 to remove 100 cubic yard**
Cost to remove 200 cubic yard of snow **Both costs are at optimal circumstances**	**$554 to remove 200 cubic yard**	**$686 to remove 200 cubic yard**

	Trucking Snow	Melting snow using the Snow Dragon
Cost to remove 300 cubic yard of snow Both costs are at optimal circumstances	$831 to remove 300 cubic yard	$1,029 to remove 300 cubic yard

Chapter 7: Deployment and Implementation

Problems and Issues that Affected Product Deployment

The Snow Dragon is currently in the Caltrans - Kingvale Maintenance Yard. The Snow Dragon might be moved to another Caltrans maintenance yard which has little or no sand in its snow. The move has not yet been initiated, as the second site is environmentally sensitive, and issues must be considered carefully.

The problem that can affect product deployment is the Snow Dragon's inconsistent performance. Upon the delivery to Kingvale Maintenance Yard, the Snow Dragon had the following issues:

1. The front jack was not housed properly. This has been fixed.
2. The servo motor setting was incorrect
3. The burner fuel line leaked
4. The burner igniters did not follow drawing specifications
5. The fuel pressure sensor was set incorrectly
6. There were loose wires in the burner control box
7. There was no voltage output to the burner transformer
8. There was no signal to Terminal 16 in the burner control box
9. Oil pressure switch wires were loose
10. Rust and water damage

According to the Caltrans operators, issue (1) was resolved. Issues (2) through (9) were resolved when the AHMCT team was on-site. The main corrective actions included re-tying loose wires, changing the burner fuel line, and changing the oil pressure switch. Issue (10) is expected to occur.

Solutions to Noted Problems and Issues

In the list of issues, if item (10) has not yet been addressed, the suggested solutions are:

- For item (10), the Snow Dragon should be re-painted every summer per manufacturer recommendations.

Issues Expected to Affect Full Implementation

It is difficult to determine future issues that may occur when the Snow Dragon is fully functional.

The Snow Dragon current status as of June 2023 is operational and stored for the season.

Other Considerations for Reaching Full Product Deployment

Maintenance Issues

The Snow Dragon should be re-painted every summer according to manufacturer recommendation. The cost of the paint and labor are not included in the two-year warranty. **In addition, the material and labor cost for painting was not considered when calculating the Snow Dragon cost.**

Operational Issues

The Snow Dragon works more effectively when melting snow with less sand. If the amount of sediment in the snow is low, the clean-out frequency decreases.

Policy Issues

According to the Colorado Department of Public Health and Environment [3], there should be a proper way to release the heated water from the Snow Dragon. Water exiting the Snow Dragon is heated and can approach temperatures ranging from 60°F to 70°F. The direct release of substantially heated water from the Snow Dragon into natural waters, without an intermediate cooling step, can create thermal pollution, and thus, this specific release practice is not recommended. This document is attached in Appendix C.

Chapter 8:
Conclusions and Future Research

Conclusion

In conclusion, the cost to truck a cubic yard of snow with minimal sediment (or snow with less sand) is less than the cost to melt a cubic yard of snow with minimal sediment using the Snow Dragon at this study location. Table 8.1 provides the overall cost summary comparing trucking snow to using the Snow Dragon.

Table 8.1: Trucking snow compared to using the Snow Dragon for snow that has minimal sediment. The initial and maintenance cost of the Snow Dragon and traditional equipment was not factored in the following calculation (not amortized).

Description	Trucking Snow	Melting Snow Using the Snow Dragon
Cost to remove a cubic yard of snow with minimal sediment	$2.77	$3.43
Cost per inch of snowfall using the time period from Jan 1 to Jan 22 (cover all of Kingvale yard)	$621.12	$1,111
Cost to remove snow for a season (from 2016 to 2023, the average snowfall is approximately 270 inches)	$575,654 per season	$712,814 per season

Description	Trucking Snow	Melting Snow Using the Snow Dragon
Amount of low sediment snow being removed per hour	Using one truck: 24 to 36 cubic yards Using two trucks: 48 to 72 cubic yards Using three trucks: 72 to 108 cubic yards Using four trucks: 96 to 144 cubic yards Using five trucks: 120 to 180 cubic yards	Up to 95 cubic yards in optimal conditions* Approximately ~77.7 cubic yards typical
Amount of high sediment snow being removed per hour	Using one truck: 24 to 36 cubic yards Using two trucks: 48 to 72 cubic yards Using three trucks: 72 to 108 cubic yards Using four trucks: 96 to 144 cubic yards Using five trucks: 120 to 180 cubic yards	Approximately ~57.75 cubic yards typical
Advantages	Little to no setup steps Straightforward process	Reduce accident risk (travel within Caltrans yard) Require only one worker with Class A license
Disadvantages	Elevated accident risk (during transport) Require two or more workers with Class A license	Multiple setup steps Clean out takes time Need training to operate the Snow Dragon

*Optimal conditions mean the Snow Dragon runs smoothly with no issues.

From the water testing results conducted by the UC Davis Analytical Lab, most elements decreased in concentration, some elements remained unchanged, and one element increased in concentration after being processed by the Snow Dragon. Raw results are attached in Appendix B. The entire system, including clean-out, should be in taken into consideration when analyzing the environmental impact on water quality. The benefit of using the Snow Dragon is having the TSS concentrate inside the Snow Dragon, allowing for easier TSS (sand) reclamation than the current approach.

According to Caltrans operators, the advantage and disadvantage of using the Snow Dragon is:

Advantage: The Snow Dragon only requires one operator for the snow removal process.

Disadvantage: The clean-out after a work shift is very time-consuming, and a clean-out is required every 12 hours (for the snow in Kingvale yard). The operator cannot continuously feed snow into the Snow Dragon due to the water tank temperature recovery conditions. The operator must pause between loads.

Future Work

There are testing elements that should be re-considered to optimize the Snow Dragon performance:

- Further observation of the discharge rate of water as an indicator of when to add snow should be included. According to conversations with ATM, when the discharge rate of water slows, it is time to add another bucket of snow. This is the only way ATM recommend in determining when to load the machine; either a visual inspection of the discharge water or the snow on the melt pan.
- The snow at the Kingvale yard contained a fair amount of sand and sediment that affected the Snow Dragon performance. The Snow Dragon should be tested with cleaner snow.
- The Snow Dragon is designed to be used with debris basket to capture debris as small as 1/8th of an inch. The recommendation should be tested to determine whether using the debris basket decreases clean-out times. Future testing sites should have cleanout time noted for with and without debris basket as it will help determine if the basket works for this location.
- The more sand and sediment used in a melting application will result in more frequent basket cleanouts (partial cleanout). However not using the debris basket can result in more frequent full cleanout. Debris basket may not want to be used due to too many frequent changes needed, slowing the melting. The Snow Dragon should be tested with different sediment

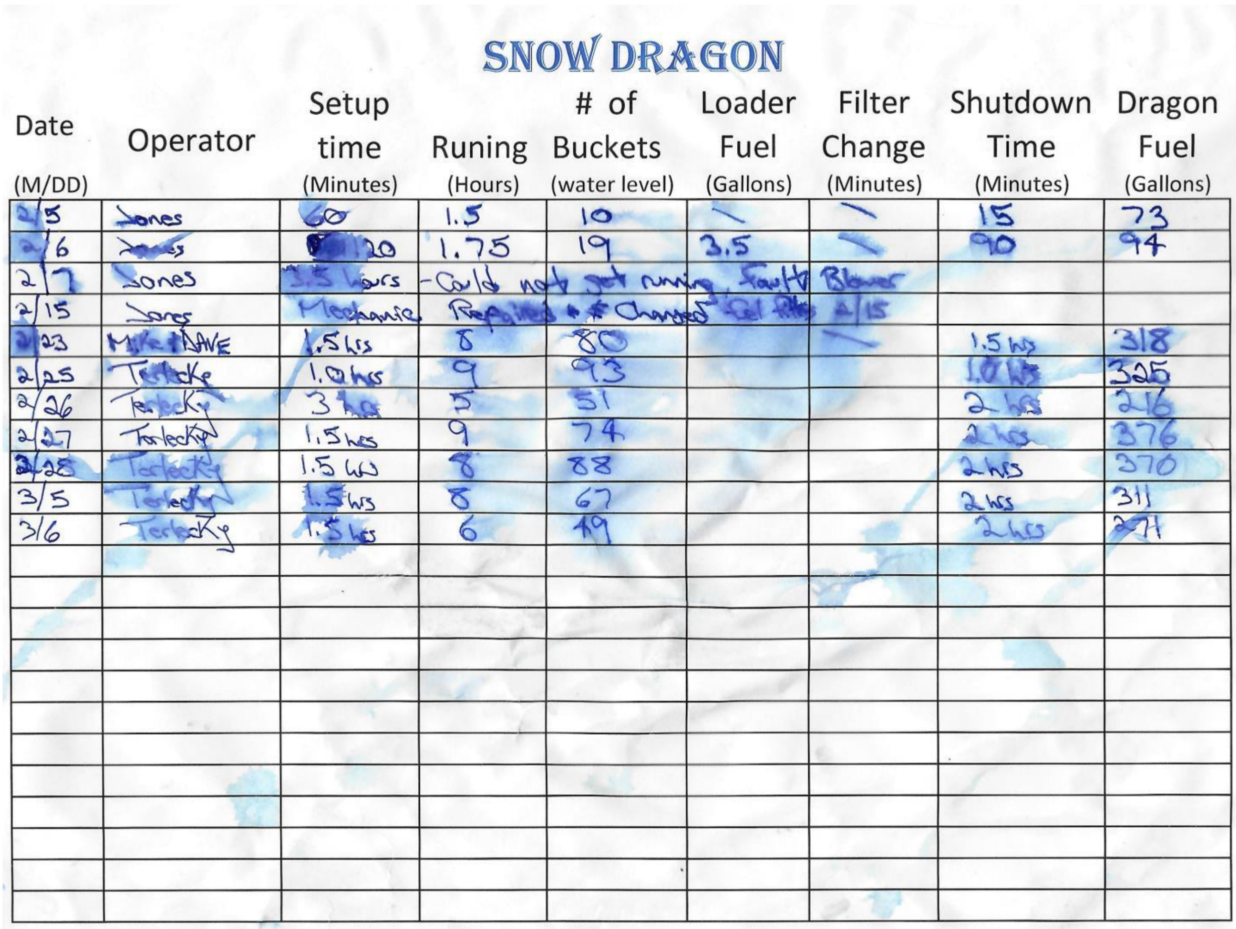
levels to determine which site the melter performs best (with or without the basket). Testing should note the time the basket was removed, time to empty basket and start melting again, picture of debris/basket when removed (for visual appearance of sediment), and time a full cleanout was needed, and time to conduct full cleanout.

- To quicken the pace of filling the Snow Dragon with water during startup, the recommended hose diameter should be used. If the hose cannot be changed, ATM will provide suggestions to help quicken this process.
- Involving ATM in future testing to optimize the Snow Dragon performance.

References

[1] "topoView," USGS. [Online]. Available: https://ngmdb.usgs.gov/topoview/viewer/#15/39.3171/-120.4379
[2] "Soda Springs Historical Snowfall," *On the Snow*. [Online]. Available: https://www.onthesnow.com/california/soda-springs/historical-snowfall
[3] B. Owens and D. E. Ellis, "Release of Water from Snow Melter (Snow Dragon)," Sep. 27, 2006.

Appendix A:
Snow Dragon Performance Logs



SNOW DRAGON

Date (M/DD)	Operator	Setup time (Minutes)	Runing (Hours)	# of Buckets (water level)	Loader Fuel (Gallons)	Filter Change (Minutes)	Shutdown Time (Minutes)	Dragon Fuel (Gallons)
2/5	Jones	60	1.5	10	\	\	15	73
2/6	Jones	[illegible]20	1.75	19	3.5	\	90	94
2/7	Jones	3.5 hours	- Could not get running,	Faulty Blower				
2/15	Jones	Mechanic	Repaired + Changed	Fuel filter 2/15				
2/23	Mike + DAVE	1.5 hrs	8	80		\	1.5 hrs	318
2/25	Terlecky	1.0 hrs	9	93			1.0 hrs	325
2/26	Terlecky	3 hrs	5	51			2 hrs	216
2/27	Terlecky	1.5 hrs	9	74			2 hrs	376
2/28	Terlecky	1.5 hrs	8	88			2 hrs	370
3/5	Terlecky	1.5 hrs	8	67			2 hrs	311
3/6	Terlecky	1.5 hrs	6	49			2 hrs	271

Figure A.1: Snow Dragon log sheet. The log sheet was filled out by Caltrans operator(s) who worked with the Snow Dragon. Image courtesy of Caltrans.

Appendix B:
UC Davis Analytical Laboratory – Water Testing Results

Table B.1: Water tests and results

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
	Test #1	**Test #2**	**Test #1**	**Test #2**
Alkalinity [meq/L]	2.2	2.1	0.5	0.5
Bicarbonate (HCO_3) [meq/L]	2.2	2.1	0.5	0.5
Carbonate (CO_3) [meq/L]	<0.1	<0.1	<0.1	<0.1
Carbon – Total Organic Carbon (TOC) [mg/L]	44.8	93.6	33.9	41.2
Carbon – Dissolved Organic Carbon (DOC) [mg/L]	2.6	2.3	1.1	1.0
Chloride (Cl) [meq/L]	181.7	175.2	19.5	18.5

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
Electrical Conductivity (EC) **[dS/m]**	19.43	19.50	1.85	1.85
Hardness **[mg/L as $CaCO_3$]**	165	164	30	30
Nitrate-Nitrogen (NO_3-N) **[mg/L]**	<0.05	<0.05	<0.05	<0.05
Nitrogen – Total (N) **[mg/L]**	1.58	1.79	0.74	0.85
Nitrogen (Total Kjeldahl Nitrogen) **[mg/L]**	4.4	2.9	1.3	1.4
pH **[no unit]**	7.51	7.53	7.10	7.14
Phosphate-Phosphorus (PO4-P, soluble P) **[mg/L]**	<0.05	<0.05	<0.05	<0.05
Sodium Adsorption Ratio (SAR) **[no unit]**	144.0	157.9	25.8	26.2

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
Sulfate-Sulfur (SO4-S, soluble S) [mg/L]	15.3	15.2	1.8	1.7
Total Dissolved Solids (TDS) [mg/L]	11050	11130	900	950
Total Suspended Solids (TSS) [mg/L]	5400	5310	868	770
Turbidity [NTU]	3689	3619	827	854
Aluminum – Total (Al) [mg/L]	115.1	110.0	23.6	22.4
Boron – Soluble (B) [mg/L]	0.05	0.05	0.02	0.01
Cadmium – Total (Cd) [mg/L]	<0.05	<0.05	<0.05	<0.05
Calcium - Soluble (Ca) [meq/L]	2.98	2.95	0.54	0.54
Chromium – Total (Cr)	0.16	0.20	<0.05	<0.05

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
[mg/L]				
Copper - Soluble (Cu) [mg/L]	<0.010	<0.010	<0.010	<0.010
Iron – Soluble (Fe) [mg/L]	0.098	0.091	0.046	0.043
Lead – Soluble (Pb) [mg/L]	<0.010	<0.010	<0.010	<0.010
Magnesium – Soluble (Mg) [meq/L]	0.33	0.33	0.07	0.07
Manganese – Soluble (Mn) [mg/L]	0.299	0.296	0.101	0.101
Nickel –Total (Ni) [mg/L]	0.11	0.13	<0.05	<0.05
Potassium – Soluble (K) [mg/L]	5.69	5.93	0.98	0.98
Sodium - Soluble (Na) [meq/L]	185.2	202.2	14.3	14.5
Zinc – Soluble (Zn)	0.011	0.009	0.040	0.037

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
[mg/L]				
Aluminum – Soluble (Al) [mg/L]	1.24	1.18	0.74	0.80
Cadmium – Soluble (Cd) [mg/L]	<0.005	<0.005	<0.005	<0.005
Calcium - Total (Ca) [mg/L]	93.8	103.1	19.4	18.9
Chromium - Soluble (Cr) [mg/L]	<0.005	<0.005	<0.005	<0.005
Copper – Total (Cu) [mg/L]	0.22	0.23	<0.05	<0.05
Lead – Total (Pb) [mg/L]	<0.10	<0.10	<0.10	<0.10
Magnesium – Total (Mg) [mg/L]	30.4	33.9	5.5	5.4
Manganese - Total (Mn) [mg/L]	1.86	2.06	0.35	0.34
Nickel – Soluble (Ni)	<0.005	<0.005	<0.005	<0.005

Test name and its respective unit	Water sample before using the Snow Dragon		Water sample after using the Snow Dragon	
[mg/L]				
Phosphorus – Total (P) [mg/L]	3.27	3.39	0.69	0.64
Potassium - Total (K) [mg/L]	21.7	29.1	4.6	4.4
Sodium – Total (Na) [mg/L]	4342	4331	346	337
Zinc – Total (Zn) [mg/L]	1.00	1.03	0.27	0.27
Iron – Total (Fe) [mg/L]	112.2	128.5	21.5	21.1

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UC DAVIS ANALYTICAL LABORATORY

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http://anlab.ucdavis.edu

Analytical Report

SUBMITTED BY:	LASKY, TY — talasky@ucdavis.edu	WORK REQ #:	23W043
AFFILIATION	FAC: UCD	# OF SAMPLES:	2
COPY TO:	DUONG, ANH — apnduong@ucdavis.edu	DATE RECEIVED:	04/10/23
CLIENT ID #:	LAST1	DATE REPORTED:	05/26/23

Client Provided Info: *COMMODITY: Not Specified Date Sampled: 2/23/23; Grower/Location/Project: Snow Dragon Project*

LAB SAMPLE #	Client Description	pH [SOP 805.3]	EC [SOP 815.03] dS/m	SAR [SOP 840.2]	Ca (Soluble) [SOP 835.3] meq/L	Mg (Soluble) [SOP 835.03] meq/L	Na (Soluble) [SOP 835.03] meq/L	Cl [SOP 830.2] meq/L	B (Soluble) [SOP 835.03] mg/L	HCO3 [SOP 820.04] meq/L	CO3 [SOP 820.4] meq/L	TOC [SOP 822.1] mg/L	DOC [SOP 822.1] mg/L
1	PRESD	7.51	19.43	144.0	2.98	0.33	185.2	181.7	0.05	2.2	<0.1	44.8	2.6
1 dup		7.53	19.50	157.9	2.95	0.33	202.2	175.2	0.05	2.1	<0.1	93.6	2.3
2	POSTSD	7.10	1.85	25.8	0.54	0.07	14.3	19.5	0.02	0.5	<0.1	33.9	1.1
2 dup		7.14	1.85	26.2	0.54	0.07	14.5	18.5	0.01	0.5	<0.1	41.2	1.0
Analysis Date:		5/19/23	5/19/23	5/18/23	5/2/23	5/2/23	5/2/23	5/22/23	5/2/23	5/19/23	5/19/23	5/23/23	5/23/23
Method Detection Limit:		0.01	0.01	0.1	0.01	0.01	0.01	0.10	0.01	0.1	0.1	0.5	0.5
Blank Concentration:		-	-	-	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0
Standard Ref as Tested:		6.45	0.26	1.3	0.78	0.66	1.12	0.34	0.09	1.40	-	77.15	75.43
Standard Ref Acceptable:		6.45±0.06	0.26±0.03	1.3±0.1	0.79±0.04	0.67±0.05	1.14±0.12	0.34±0.03	0.08±0.04	1.47±0.2	-	76.7±11.51	76.7±11.51
Standard Reference:		UCD 004	UCD 006D	UCD 006D	UCD 006D	UCD 006D	UCD 006D	UCD 006D	UCD 006D	UCD 006D	-	DEMAND B	DEMAND B

Figure B.1: Water testing results, page 1 of 4

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UC DAVIS ANALYTICAL LABORATORY

One Shields Ave. / 224 Hoagland Hall / Davis, CA 95616

http://anlab.ucdavis.edu

Analytical Report

SUBMITTED BY:	LASKY, TY — talasky@ucdavis.edu	WORK REQ #:	23W043
AFFILIATION	FAC: UCD	# OF SAMPLES:	2
COPY TO:	DUONG, ANH — apnduong@ucdavis.edu	DATE RECEIVED:	04/10/23
CLIENT ID #:	LAST1	DATE REPORTED:	05/26/23

Client Provided Info: *COMMODITY: Not Specified Date Sampled: 2/23/23; Grower/Location/Project: Snow Dragon Project*

LAB SAMPLE #	Client Description	Total N [SOP 855.1] mg/L	NO3-N [SOP 847.3] mg/L	TKN [SOP 850.3] mg/L	Hardness [SOP 875.02] mg/L as CaCO3	PO4-P(Sol P) [SOP 865.3] mg/L	SO4-S(Sol S) [SOP 835.03] mg/L	Zn (Soluble) [SOP 835.03] mg/L	Cu (Soluble) [SOP 835.3] mg/L	Mn (Soluble) [SOP 835.03] mg/L	Fe (Soluble) [SOP 835.03] mg/L	Al (Soluble) [SOP 835.3] mg/L	Cd (Soluble) [SOP 835.3] mg/L
1	PRESD	1.58	<0.05	4.4	165	<0.05	15.3	0.011	<0.010	0.299	0.098	1.24	<0.005
1 dup		1.79	<0.05	2.9	164	<0.05	15.2	0.009	<0.010	0.296	0.091	1.18	<0.005
2	POSTSD	0.74	<0.05	1.3	30	<0.05	1.8	0.040	<0.010	0.101	0.046	0.74	<0.005
2 dup		0.85	<0.05	1.4	30	<0.05	1.7	0.037	<0.010	0.101	0.043	0.80	<0.005
Analysis Date:		4/18/23	5/24/23	5/25/23	5/18/23	5/24/23	5/2/23	5/2/23	5/2/23	5/2/23	5/2/23	5/23/23	5/2/23
Method Detection Limit:		0.10	0.05	0.1	1	0.05	0.1	0.005	0.010	0.005	0.010	0.05	0.005
Blank Concentration:		0.00	0.00	0.0	-	0.00	0.0	0.000	0.000	0.000	0.000	0.00	0.000
Standard Ref as Tested:		29.1	3.32	26.8	72	1.65	11.6	0.48	0.47	0.49	0.47	0.50	0.485
Standard Ref Acceptable:		26.2±4.7	3.37±0.50	26.2±4.7	72±3	1.69±0.18	11.7±0.4	0.50±0.05	0.50±0.05	0.50±0.05	0.50±0.05	0.50±0.02	0.50±0.050
Standard Reference:		Complex M	SIMPLEJ	Complex M	UCD 006D	SIMPLEJ	UCD 006D	0.5 mg/L	0.5 mg/L	0.5 mg/L	0.5 mg/L	0.5 mg/L	0.5 mg/L

Figure B.2: Water testing results, page 2 of 4

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Analytical Report

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SUBMITTED BY:	LASKY, TY — talasky@ucdavis.edu	WORK REQ #:	23W043
AFFILIATION	FAC: UCD	# OF SAMPLES:	2
COPY TO:	DUONG, ANH — apnduong@ucdavis.edu	DATE RECEIVED:	04/10/23
CLIENT ID #:	LAST1	DATE REPORTED:	05/26/23

Client Provided Info: *COMMODITY: Not Specified Date Sampled: 2/23/23; Grower/Location/Project: Snow Dragon Project*

LAB SAMPLE #	Client Description	Cr (Soluble) [SOP 835.03] mg/L	Pb (Soluble) [SOP 835.03] mg/L	Ni (Soluble) [SOP 835.03] mg/L	P (Total) [SOP 890.02] mg/L	K (Total) [SOP 890.02] mg/L	Ca (Total) [SOP 890.2] mg/L	Mg (Total) [SOP 890.02] mg/L	Na (Total) [SOP 890.02] mg/L	Zn (Total) [SOP 890.02] mg/L	Mn (Total) [SOP 890.02] mg/L	Fe (Total) [SOP 890.02] mg/L	Cu (Total) [SOP 890.2] mg/L
1	PRESD	<0.005	<0.010	<0.005	3.27	21.7	93.8	30.4	4342	1.00	1.86	112.2	0.22
1 dup		<0.005	<0.010	<0.005	3.39	29.1	103.1	33.9	4331	1.03	2.06	128.5	0.23
2	POSTSD	<0.005	<0.010	<0.005	0.69	4.6	19.4	5.5	346	0.27	0.35	21.5	<0.05
2 dup		<0.005	<0.010	<0.005	0.64	4.4	18.9	5.4	337	0.27	0.34	21.1	<0.05
Analysis Date:		5/2/23	5/2/23	5/2/23	4/21/23	4/21/23	4/21/23	4/21/23	4/21/23	5/2/23	5/2/23	5/2/23	5/2/23
Method Detection Limit:		0.005	0.010	0.005	0.10	0.5	0.5	0.5	0.5	0.05	0.05	0.05	0.05
Blank Concentration:		0.000	0.000	0.000	0.00	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Standard Ref as Tested:		0.492	0.495	0.499	2.3	30.5	101	199	49	1.94	2.02	2.02	1.98
Standard Ref Acceptable:		0.50±0.050	0.50±0.050	0.50±0.050	2.4±0.3	31.2±3.9	100±10	200±20	50±5	2.00±0.20	2.00±0.20	2.00±0.20	2.00±0.20
Standard Reference:		0.5 mg/L	0.5 mg/L	0.5 mg/L	Complex M	PW34H	100 mg/L	200 mg/L	50 mg/L	2MG/L	2MG/L	2MG/L	2MG/L

Figure B.3: Water testing results, page 3 of 4

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Analytical Report

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SUBMITTED BY:	LASKY, TY — talasky@ucdavis.edu	WORK REQ #:	23W043
AFFILIATION	FAC: UCD	# OF SAMPLES:	2
COPY TO:	DUONG, ANH — apnduong@ucdavis.edu	DATE RECEIVED:	04/10/23
CLIENT ID #:	LAST1	DATE REPORTED:	05/26/23

Client Provided Info: *COMMODITY: Not Specified Date Sampled: 2/23/23; Grower/Location/Project: Snow Dragon Project*

LAB SAMPLE #	Client Description	Cd (Total) [SOP 890.2] mg/L	Cr (Total) [SOP 890.02] mg/L	Pb (Total) [SOP 890.02] mg/L	Ni (Total) [SOP 890.02] mg/L	Al (Total) [SOP 890.2] mg/L	TDS [SOP 870.3] mg/L	TSS [SOP 870.3] mg/L	Alkalinity [SOP 820.4] meq/L	Turbidity [SOP 810.2] NTU	K (Soluble) [SOP 835.3] mg/L		
1	PRESD	<0.05	0.16	<0.10	0.11	115.1	11050	5400	2.2	3689	5.69		
1 dup		<0.05	0.20	<0.10	0.13	110.0	11130	5310	2.1	3619	5.93		
2	POSTSD	<0.05	<0.05	<0.10	<0.05	23.6	900	868	0.5	827	0.98		
2 dup		<0.05	<0.05	<0.10	<0.05	22.4	950	770	0.5	854	0.98		
Analysis Date:		5/2/23	5/2/23	5/2/23	5/2/23	5/23/23	5/22/23	5/4/23	5/19/23	5/19/23	5/2/23		
Method Detection Limit:		0.05	0.05	0.10	0.05	0.5	10	4	0.1	0.1	0.05		
Blank Concentration:		0.00	0.00	0.00	0.00	0.0	0	1	0.0	0	0.00		
Standard Ref as Tested:		1.96	1.97	1.94	1.99	1.89	440	97	1.4	96.0	0.00		
Standard Ref Acceptable:		2.0±0.20	2.0±0.20	2.00±0.20	2.0±0.20	2.00±0.20	450±50	100±10	1.5±0.1	100±10	31.2±3.9		
Standard Reference:		2MG/L	2MG/L	2MG/L	2MG/L	2MG/L	Solids T	Solids T	UCD 006D	100 NTU	PW34H		

NOTE: The SOP # (Standard Operating Procedure number) is a reference to the laboratory method used.
The SOP heading in this Excel file is linked to the method summary on the Laboratory website. http://anlab.ucdavis.edu

NOTE: No result within this report is accurate to more than 3 significant figures. More figures may be present due to software rounding rules.

NOTE: Nitrate and/or salt in large quantities cause a negative bias to the TKN tests.

NOTE: Samples are not routine water samples. They are non-homogenous and submitted in glass mason jars with metal lids that rusted, which may have affected results. Please submit future samples in plastic bottles.

NOTE: Analysis for TKN was repeated due to high variability. Additional results: #1=2.1mg/L, #1d=2.5mg/L, #2=1.0mg/L, #2d=0.7mg/L

Checked and Approved: *{electronically signed by Rani Youngman}*
Rani Youngman, Director

Please address questions regarding these results to the Lab at (530) 752-0147 or anlab@ucdavis.edu.

Unless otherwise noted, all samples were received in acceptable condition. The result(s) in this report relate only to the portion of the sample tested. This report does not authorize a release of product for consumption. This report shall not be reproduced except in full without the written permission from UC Davis Analytical Laboratory.

Please arrange for the return of samples for this Work Request (23W043) when satisfied with the results, but before 6/25/23.
Samples will be discarded after that date.

Figure B.4: Water testing results, page 4 of 4

Appendix C:
Release of Water from Snow Melter (Snow Dragon)

STATE OF COLORADO

Bill Owens, Governor
Dennis E. Ellis, Executive Director

Dedicated to protecting and improving the health and environment of the people of Colorado

4300 Cherry Creek Dr. S.
Denver, Colorado 80246-1530
Phone (303) 692-2000
TDD Line (303) 691-7700
Located in Glendale, Colorado

Laboratory Services Division
8100 Lowry Blvd.
Denver, Colorado 80230-6928
(303) 692-3090

http://www.cdphe.state.co.us

STATE OF COLORADO 1876

Colorado Department of Public Health and Environment

September 27, 2006

Mr. Ralph L. Hrovat
National Sales manager
Snow Dragon, LLC
1441 Chardon Road
Cleveland, Ohio 44117

Re: Release of Water from Snow Melter (Snow Dragon)

Dear Mr. Hrovat:

This letter is in response to your written inquiry (September 6, 2006) about the need for state permit to authorize the discharge of water from the Snow Dragon product. This response is not to be interpreted or used as our endorsement of your product.

Based on the information you provided (http://www.snowdragonmelters.com/products.aspx), the operation of the Snow Dragon involves a heat exchanger in conjunction with 9,000,000 BTU/hr burners, without the addition of any chemicals to the snow, and the release of produced water into local storm water collection systems. This water routing practice requires the permission of the owner of the storm water and does not require a discharge permit from our agency.

If the water is released directly to natural waters (i.e., stream, lake, pond, wetlands, etc), the assumption is that the released water has sufficiently cooled down before entering ambient waters and a permit is not needed. Water exiting the Snow Dragon is heated and can approach temperatures in the 60-70 °F range. As this water moves across impervious surfaces and/or adjoining land surfaces to the natural waters, the temperature should drop substantially and should be comparable to the temperature of the receiving natural water at the point of entry. This condition would not require a permit from our agency. However, the operators of your product shall be informed that the direct release of substantially heated water from the Snow Dragon into natural waters, without an intermediate cooling step, can create thermal pollution and, thus, this specific release practice is not allowed.

If you or any operators of Snow Dragon products have any questions, please contact Ray Nalepa (303-692-3515, Rwnalepa@cdphe.state.co.us) in our Industrial Permits Unit.

Sincerely,

Gary D. Beers
Industrial Permits Unit

Cc: Ray Nalepa

Figure C.1: The State of Colorado's response to the release of water from Snow Melter (Snow Dragon)