Suncor Energy (U.S.A.) Inc.

Investigation Findings and Responsive Actions

Type of Event: Commerce City Refinery Cold Weather and Shutdown Events
Dates of Events: December 21, 2022 to January 3, 2023

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Executive Summary

Starting on the afternoon of December 21, 2022, the Denver, Colorado area, including Commerce City, experienced an extreme and record-setting rapid temperature drop. The temperature fell from about 50 Degrees Fahrenheit ("**°F**") in the afternoon of December 21, 2022, to -24 °F on the morning of December 22, 2022. This was the second-largest two-day temperature swing in Denver history. The average daily temperature of -15 °F on December 22 was the second coldest day in Denver's history and the coldest since 1963.[1] At one point, the temperature dropped 37 °F in one hour, the largest one-hour temperature drop in Denver history, and the morning low on December 22 was only one degree warmer than the all-time December low temperature set in 1886 and matched in 1990.[2,3]

Between December 21, 2022, and December 23, 2022, the Suncor Energy (U.S.A.) Inc. ("**Suncor**") Commerce City Refinery ("**Commerce City Refinery**" or "**Refinery**") (see Figure 1.) experienced 11 events resulting from the rapid ambient temperature drop to significantly below freezing (the "**Freeze Events**").[4]

The ambient temperature in Commerce City remained below freezing until the morning of December 24, 2022. The Refinery experienced three process safety events as the frozen equipment thawed and released products (the "**Thawing Events**").

Consistent with Suncor's emphasis on safe operating practices, on December 24, 2022, at approximately 18:00, the Refinery leadership team determined that the entire facility would be shutdown and put into safe mode to allow for inspecting all units and repairing the damaged equipment.

Between December 27, 2022, and January 3, 2023, the Refinery experienced five events that occurred during the shutdown activities (the "**Shutdown Events**" and together with the Freeze Events and Thawing Events, collectively the "**Events**").

The Events were spread geographically across a substantial portion of the nearly 230-acre Refinery and impacted all of the facility's 13 major processing units across all three operating plants. Multiple events required onsite response by Suncor's Emergency Response Team, including Suncor's onsite Fire Department. The diligent response of Refinery operations and other Suncor personnel mitigated the potential impacts of these unique cold-weather events.

Immediately after the Events, through April 2023, Suncor conducted an extensive repair and restart process. Items that were physically broken by the extreme cold weather Events were repaired or replaced, as appropriate, to ensure a safe, compliant, and reliable restart. Over $97 million was spent on the repair and restart process; and the Refinery successfully and safely restarted in early April 2023.

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[1] Denver Post. https://www.denverpost.com/2022/12/23/denver-weather-second-coldest-day-history/
[2] CNN. https://www.cnn.com/2022/12/22/weather/christmas-arctic-winter-storm-thursday/index.html
[3] National Weather Service. https://www.weather.gov/media/bou/December2022Climate.pdf
[4] The Commerce City Refinery comprises two refineries and three operating plants.

As described above, the Events were determined to fall into one of three categories: (1) Freeze Events, which were directly related to the rapid drop of temperature from the 21 to 22 of December; (2) Thawing Events, which were related to the thawing of ruptured frozen lines and losses of primary containment as the temperature rose; and (3) Shutdown Events, which occurred during the shutdown activities.

This report (a) reviews each of these Events; (b) identifies the but-for cause and contributing factors for each event; (c) identifies thematic areas of learning; and (d) identifies the responsive actions that Suncor has taken and plans to take.

Figure 1. Looking southwest toward the Commerce City Refinery, Plant 3 (L), Plant 2 (C), and Plant 1 (R) with Brighton Blvd (Colorado State Highway 265) bisecting Plants 1 and 2.

In this report, "cause" is the causal factor without which an event would not have occurred. "Contributing factors" are the key factors that resulted from the cause and contributed to the final result. In identifying contributing factors, factual certainty cannot always be established, and certain factors were identified based on inference or hypothesis.

Summary of Events

On December 24, 2022, at approximately 18:00, the Commerce City Refinery leadership team decided to shutdown all operating units at the Refinery into safe mode for an extended time.

Leading up to the Events, the ambient temperature in Commerce City, Colorado, dropped quickly starting on the afternoon of December 21, 2022. The temperature fell from about 50 "**°F**" (10 Degrees Celsius ("**°C**")) in the afternoon of December 21, 2022, to -22 °F (-30 °C) on the morning of December 22, 2022. The ambient temperature in Commerce City, Colorado, remained below freezing until the morning of December 24, 2022.

Each of the 19 distinct Events that occurred at the Refinery from December 21, 2022, to January 3, 2023, are addressed herein. These Events were spread geographically across a substantial portion of the nearly 230-acre Refinery and impacted all of the facility's 13 major

processing units across all three operating plants. Figure 2 below shows the locations of the Events.

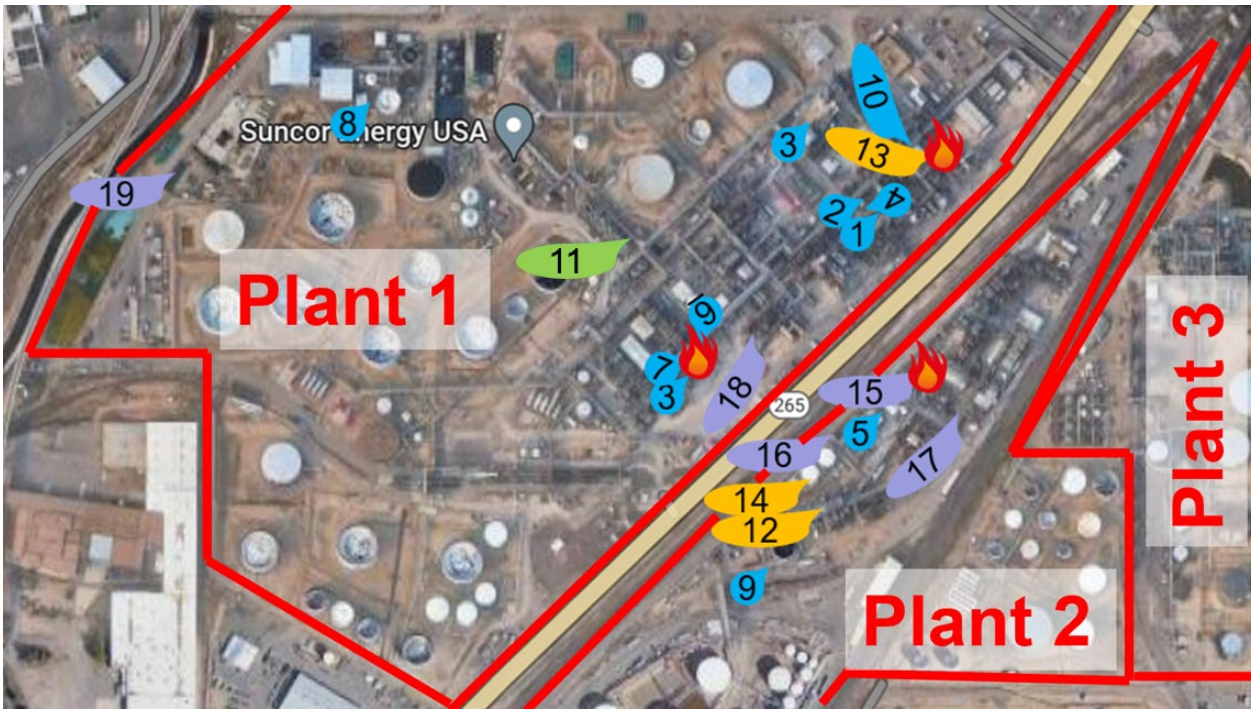

Figure 2. The location of the Refinery's 19 Cold Weather and Shutdown Events—December 21, 2022, to January 4, 2023.

These Events are listed in Table 1 below, which are grouped by colors that represent the following:

- Blue/Green: The Freeze Events resulting from the extreme, rapid freeze on December 21 and 22, 2022 and the continued subfreezing weather on December 23.
- Orange: The Thawing Events on December 24, 2022.
- Purple: The Shutdown Events between December 27, 2022, and January 3, 2023.

The red line in Table 1 below signifies the decision by the Refinery leadership team that the entire facility would be shut down and put into safe mode to allow for inspecting all units and repairing the damaged equipment.

Table 1, Cold Weather and Shutdown Events.

#	Event Name	Time	Plant #	Date
1	Wet Gas Compressor Issues	18:53	1	Dec. 21-22
2	Plant 1 Boiler Issues	22:29	1	Dec. 21-22
3	Hydrogen Plant Tripped w/ Exchanger Flange Fire	00:16	1	Dec. 21-22
4	#1 FCC Emergency Shutdown	01:31	1	Dec. 21-22
5	Plant 2 Boiler Issues	02:09	2	Dec. 21-22
6	Flare Gas Recovery Compressor Issues	02:45	1	Dec. 21-22
7	Fin Fan Header Box Rupture	03:00	1	Dec. 21-22
8	High Level in Dissolved Gas Floatation System	08:47	1	Dec. 21-22
9	Operator Exposure Flare System LOPC	11:40	2	Dec. 21-22

10	Fin Fan Tube Rupture	12:00	1	Dec. 21-22
11	Flare Header High Back Pressure	03:00	1	Dec. 23
12	Diesel Stripper Sight Glass Drain LOPC	09:30	2	Dec. 24
13	#2 HDS Fire and Injury to Personnel	10:40	1	Dec. 24
14	Exchanger Thermal Relief Valve LOPC	16:29	2	Dec. 24
15	Sour Water Stripper Sewer Fire	Dec 27	2	Dec. 27
16	Middle API Inflow Above Outflow Capacity	Dec 28	2	Dec. 28
17	H_2S Sensor Alarm Sounded in SRU	Dec 31	2	Dec. 31
18	Crude Oil Sewer Restriction	Jan 02	1	Jan. 2
19	Oil in Water Treatment System	Jan 03	1	Jan. 3

Figure 3., depicts two graphs with four trend lines from December 21, 2022, to January 4, 2023. The upper graph depicts the ambient temperature experienced in Denver, Colorado, where the Refinery operates. The lower graph illustrates the steam header pressure in pounds per square inch-gauge (the "**psig**") for both Plant 1 (and 3) and Plant 2. Figure 3., also depicts the 19 Events included in this report; see Table 2., above for the associated color coding. The red vertical line depicted in Figure 3., denotes when the Refinery leadership team chose to shutdown all operating units at the Refinery for the Events.

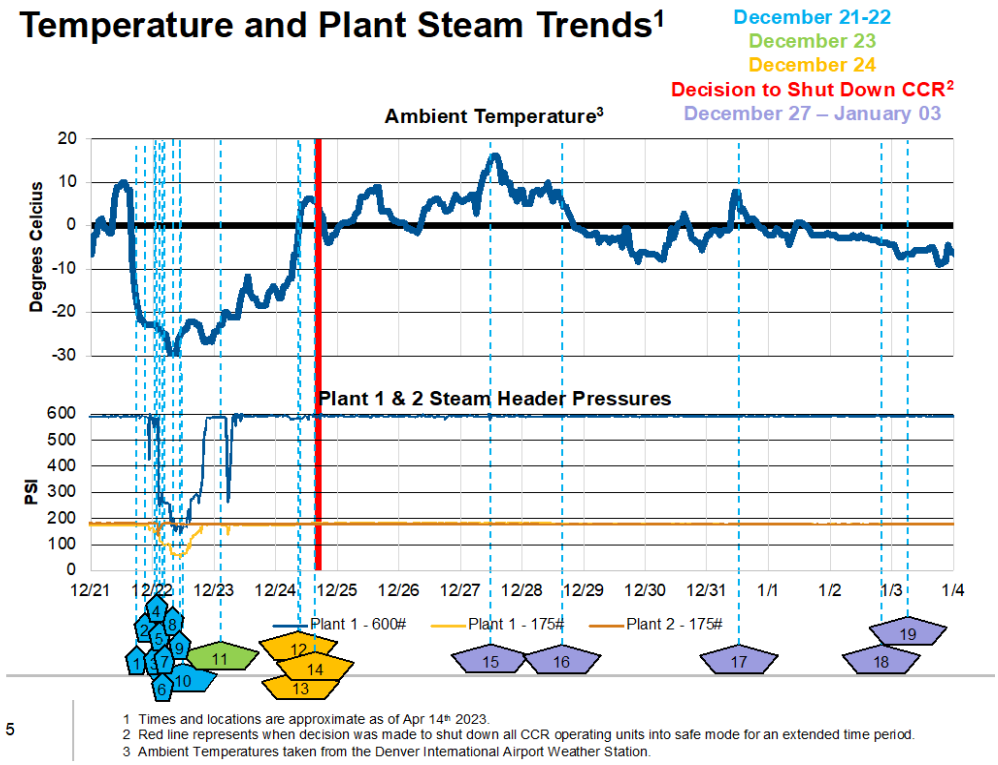

Figure 3., Refinery Ambient Temperatures Trend, Plants Stream Trends, Shutdown Decision (Red Line), and 19 Cold Weather and Shutdown Events—December 21, 2022, to January 4, 2023.

Freeze Events

These Events are directly related to the rapid drop in temperature from the 21st to 23rd of December. The extreme cold weather significantly impacted the Refinery's steam generation assets (e.g., the boilers), which then impacted the Refinery's ability to keep equipment warm during the period of cold weather. The rapid drop in temperature and subsequent boiler events resulted in material drops in plant steam header pressures, which posed immediate operational concerns for operating units, equipment, and heat/freeze protection to key assets.

1. Wet Gas Compressor Issues

The ambient temperature change was the cause of two separate issues with the wet gas compressor for the #1 fluid catalytic cracking unit ("**FCC**") in Plant 1, impacting its operation and damaging its thrust bearings. Contributing factors were:

i. An upstream flow instrument froze, resulting in liquid carryover to the compressor's suction knockout drum. The compressor's safety systems responded and tripped the compressor a total of three times as operations worked to resolve the situation and restart the compressor.

ii. During subsequent operation, a frozen level instrument on the seal oil drum resulted in seal oil filling the balance line between the compressor stages, resulting in damage to the compressor's thrust bearings.

2. Plant 1 Boiler Issues

The ambient temperature change was the cause of multiple issues (e.g., trip conditions and operational issues restarting) with two of the three Plant 1 boilers, B8 and B6, resulting in producing less steam than Plant 1 required. Contributing factors were:

i. B8 experienced a total of eight safety system trips resulting from the rapid drop of temperature's impact on the fuel system feeding fuel to the boiler, as well as the air systems feeding air to the boiler.

ii. While working to restart the B8 boiler following the trips, operations encountered additional restart delays due to a range of issues, including:
    1. Valve position "**permissives**" not being met due to frozen instruments.[5]
    2. Burner and pilot valves not re-opening when required due to frozen instruments.
    3. Air louver position permissives not being met due to frozen instruments.

iii. B6 experienced a safety system trip (relating to high combustion air flow) resulting from the unusually high demand for steam production during the B8 performance issues described above, as well as the hydrogen plant issues described below in Event 3.

iv. While working to restart the B6 boiler following the trip, operations encountered additional restart delays due to a range of issues including:
    1. Valve position permissives not being met due to frozen instruments.

[5] A "permissive" is a control condition, or interlock, used to prevent actions from taking place until certain criteria are met.

2. Burner and pilot valves not re-opening when required due to frozen instruments.
3. Air blower motors not being able to re-start due to significant volumes of steam condensing in the turbine.

3. Hydrogen Plant Tripped w/ Exchanger Flange Fire

The ambient temperature change was the cause of the freezing of a steam flow meter in the hydrogen plant, tripping the hydrogen plant, resulting in the loss of make-up hydrogen to the #3 Hydrodesulphurization ("**HDS**") reactor in Plant 1. The contributing factors were: operations initiated a shutdown of the #3HDS due to the loss of hydrogen, and a heat exchanger bank in the unit experienced a sufficient transient thermal gradient during the shutdown that resulted in a flange releasing flammable hydrocarbon that ignited on release. There were no injuries to personnel from this small fire.

4. #1 FCC Emergency Shutdown

The ambient temperature change was the cause of a hydraulic valve no longer responding adequately to maintain catalyst levels in the #1 FCC regenerator in Plant 1. The contributing factor was that operations activated the emergency shutdown of the FCC to prevent any potential process safety concerns.

5. Plant 2 Boiler Issues

The ambient temperature change was the cause of multiple issues (e.g., trip conditions and operational issues restarting) with one of the two Plant 2 boilers, B504, resulting in producing less steam than Plant 2 required. Contributing factors were:

i. B504 experienced a total of two safety system trips resulting from the rapid drop of temperature's impact on the fuel system feeding fuel to the boiler, as well as the pressure instruments on the firebox.
ii. While working to restart the B504 boiler following the trips, operations encountered additional restart delays due to a range of issues including:
    1. Valve position permissives not being met due to frozen instruments.
    2. Pilot valves not re-opening when required due to frozen instruments.
    3. Fuel gas pressure permissives not being met due to frozen instruments.
    4. Air louver position permissives not being met due to frozen instruments.

6. Flare Gas Recovery Compressor Issues

The ambient temperature change was the cause of the freezing of the second-stage suction pressure indicator, tripping the flare gas recovery compressor in Plant 1 a total of three times. The compressor was left offline following the third trip, necessitated by the operational impacts of other concurrent events in the plant (Events 3 and 7).

7. **Fin Fan Header Box Rupture**

The ambient temperature change was the cause of the freezing of water in a heat exchanger in the #3 HDS in Plant 1, rupturing the header boxes on each end. The contributing factor was that the heat exchanger had stagnant water in the tubes as a result of operations following emergency procedures to complete the emergency shutdown of the #3HDS unit following the fire in that unit described in Event 3 above.

8. **High Level in Dissolved Gas Floatation System**

The ambient temperature change was the cause of the freezing of a differential pressure indicator, tripping a pump, resulting in a temporary high level in the dissolved gas floatation effluent tank in Plant 1 while operations worked to resolve the issue and restart the pump.

9. **Operator Exposure Flare System Loss of Primary Containment ("LOPC")**

The ambient temperature was the cause of the freezing of a drain pot at the base of the Plant 2 flare. The contributing factor was the ice layer on the pot yielded resulting in aerosolized process fluids spraying out from the pot, and an operator was exposed to the process fluid mist while doing rounds on a nearby tank. There were no injuries to personnel from this exposure.

10. **Fin Fan Tube Rupture**

The ambient temperature change was the cause of the freezing of water in the heat exchanger in the tail gas unit in Plant 1, rupturing multiple tubes. Contributing factors were that the heat exchanger had stagnant water in the tubes as a result of the reduced steam production from the boiler issues described above, as steam is needed to drive water up the tower for collection to feed this exchanger. The make-up water line was also frozen, which normally provides an alternative source of water during upsets.

11. **Flare Header High Back Pressure**

The ambient temperature change was the cause of the condensation and freezing of water vapor in the Plant 1 main flare header, resulting in a temporary partial restriction impacting the higher-than-normal flare flows due to many units being in abnormal operating modes following the events described above.

Thawing Events

The following three events are related to the thawing of ruptured frozen lines and losses of primary containment as the temperature rose:

12. Diesel Stripper Sight Glass Drain LOPC

The ambient temperature change was the cause of the freezing of a drain line off a tank level sight glass in Plant 2 and the mechanical parting /yielding from ice of a coupling on this drain line. The contributing factor was that when the ambient conditions returned above freezing, this line leaked a small quantity of diesel from the process, which was contained and cleaned up on site.

13. #2 HDS Fire and Injury to Personnel

The ambient temperature change was the cause of the freezing of an offline pump (including its piping and valving) in the #2 HDS in Plant 1, resulting in damage to the pump, piping, valves, and flange gaskets. The contributing factors were:

i. When the ambient conditions returned above freezing, light straight run leaked from the connected process through the damaged isolation valve and the damaged flange gasket to grade.
ii. Operations quickly responded to the developing vapor cloud by shutting down the process, turning on fire monitors to suppress the vapor cloud, and was in the process of shutting down an adjacent furnace when the vapors ignited, injuring two operators.

14. Exchanger Thermal Relief Valve LOPC

The ambient temperature change was the cause of the freezing of a pressure safety valve discharge line in Plant 2, and the mechanical parting /yielding from ice of a piping union on this line. When the ambient conditions returned above freezing, this line leaked a small quantity of crude oil from the process, which was contained and cleaned up on site.

Shutdown Events

The following five events occurred during the shutdown activities:

15. Sour Water Stripper Sewer Fire

The cause of this event was the unscheduled shutdown of the Refinery in response to the impacts of the ambient temperature change and subsequent events. Contributing factors were the unavailability of certain lines to drain equipment as part of the shutdown activities (due to certain lines being frozen, as well as other temporary lines not being available for this unscheduled shutdown), resulting in various refinery equipment being de-inventoried through the oily water sewer system in Plant 2. Hydrocarbon vapors from this system ignited resulting in a fire in the Sour Water Stripper area in Plant 2. There were no injuries to personnel from this small fire.

16. Middle API Above Outflow Capacity

The cause of this event was an unscheduled shutdown of the Refinery in response to the impacts of the ambient temperature change and subsequent events. Contributing factors were the

unavailability of certain lines to drain equipment as part of the shutdown activities (due to certain lines being frozen, as well as other temporary lines not being available for this unscheduled shutdown), resulting in various refinery equipment being de-inventoried through the oily water sewer system in Plant 2. Hydrocarbon vapors were detected by operations in the Plant 2 reformer unit and they responded by adding fire water to the sewers to condense the vapors and flush out the hydrocarbon to the API systems for treatment. For a brief period of time, the amount of water added to the system exceeded the API's outflow capacity, backing up the sewer flow from the units.

17. H_2S Sensor Alarm Sounded in SRU

The ambient temperature change was the cause of a steam hose being used to thaw a pressure instrument in the Plant 2 sulfur recovery unit ("**P2 SRU**"). This steam hose discharged steam on one of the H_2S detectors in the P2 SRU causing false alarms to sound in the unit.

18. Crude Oil Sewer Restriction

The cause of this event was an unscheduled shutdown of the Refinery in response to the impacts of the ambient temperature change and subsequent events. Contributing factors were the unavailability of certain lines to drain equipment as part of the shutdown activities (due to certain lines being frozen, as well as other temporary lines not being available for this unscheduled shutdown), resulting in various refinery equipment being de-inventoried through the oily water sewer system in Plant 1. Hydrocarbon from the desalter unit partially vaporized in the sewers, resulting in flow restrictions through the sewer system, briefly overflowing the sewers to grade in the #3HDS unit in Plant 1. The overflow was contained and cleaned up on site.

19. Oil in Water Treatment System

As described above, the crude oil flow into the oily water sewer briefly overwhelmed the reduced capacity of the oily water sewer, resulting in crude oil coming out of the oily water sewers and flowing into the stormwater sewer in the #3HDS unit in Plant 1. Despite going through various stormwater treatment systems, the amount of oil in the stormwater sewer temporarily overwhelmed the treatment capacity of these units resulting in an oil sheen in the water treatment system and a subsequent exceedance of the Refinery's discharge limit for benzene.

Learning Themes

After completing the investigation into each of the Events, the following learning themes were identified:

(1) Instrumentation Reliability in Cold Weather and Winterization of Process Equipment;

(2) Managing Risks Due to Temporary Operational Changes;

(3) Boiler Cold Weather Reliability; and

(4) Sewer Management and Communication.

These learning themes were used to develop responsive actions.

Responsive Actions

The following actions have been taken, or are planned to be taken, in response to the Events and the identified learning themes:

1. ***Instrumentation Reliability in Cold Weather and Winterization of Process Equipment***
    a. Complete winterization repairs and upgrades to improve the Refinery's resilience during extreme weather conditions, including:
        i. Steam tracing system repairs.
        ii. Insulation upgrades and repairs.
        iii. Installing upgraded wireless systems to monitor the performance of electrical heat tracing systems (with alarms that alert Refinery personnel to issues).
        iv. As part of annual winterization process, installing temporary hoardings to protect critical instruments and equipment.

    This work has been completed ahead of the 2023-2024 winter season.

2. ***Managing Risks Due to Temporary Operational Changes***
    a. Update process for managing risks of short-term dead-legs created during temporary modes of operation (e.g., temporary isolation of a pump to complete planned maintenance).

3. ***Boiler Cold Weather Reliability***
    a. Evaluate improvements to solenoid valves on the Refinery's boilers to improve boiler reliability during extreme weather operation.
    b. Evaluate improvements in fuel gas supply system to boilers to improve boiler reliability during extreme weather operation.

4. ***Sewer Management and Communication***
    a. Update preventative maintenance plans for sewer systems to improve performance and reliability.
    b. Update operational procedures to improve hydrocarbon management during abnormal operational situations, including with respect to sewer systems.

    Responsive Actions 2 through 4 are in the process of being progressed.