U.S. Chemical Safety and
Hazard Investigation Board

Fired Heater Tube Rupture and Fire at Marathon Martinez Renewables Facility

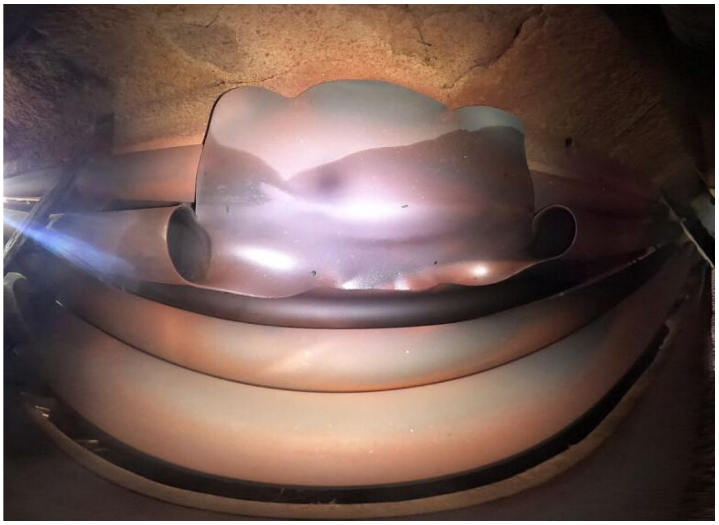
Martinez, CA | *Incident Date: November 19, 2023* | **No. 2024-01-I-CA**

Investigation Report

Published: March 2025

Safety Issues:

- **Safe Operating Limits**
- **Worker Proximity to Fired Heater**
- **Low Flow Through Fired Heater**
- **Burner Operation**
- **Valve Misalignment**
- **Corporate Oversight**



U.S. Chemical Safety and Hazard Investigation Board

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ABBREVIATIONS

AFPM	American Fuel & Petrochemical Manufacturers
AMP	Automation Modernization Program
API	American Petroleum Institute
CalARP	California Accidental Release Prevention
Cal/OSHA	California Occupational Safety and Health Administration
CCPS	Center for Chemical Process Safety
CCHHMP	Contra Costa Health Hazardous Materials Program
CSB	U.S. Chemical Safety and Hazard Investigation Board
CO	carbon monoxide
EPA	U.S. Environmental Protection Agency
HDO	hydrodeoxygenation
HLVE	high learning value event
IOW	integrity operating window
MOOC	management of organizational change
NC	normally closed
NOx	nitrogen oxide
NTE	Not-to-Exceed
P&ID	piping and instrumentation diagram
PHA	process hazard analysis
ppm	parts per million
PSV	pressure safety valve
RAGAGEP	Recognized and Generally Accepted Good Engineering Practices

RP	recommended practice
SIS	safety instrumented system
USW	United Steelworkers
TDL	tunable diode laser

EXECUTIVE SUMMARY

On November 19, 2023, at 12:21 a.m., a metal tube ruptured within a fired heater during the initial startup of a renewable diesel hydroprocessing unit at the Marathon Martinez Renewables ("Marathon Martinez") facility in Martinez, California.[a] The ruptured tube released renewable diesel and hydrogen, resulting in a fire that seriously injured one Marathon Martinez employee. The incident occurred while the unit was starting up for the first time as a renewable diesel hydroprocessing unit.

Leading up to the tube rupture, a manual valve upstream of the heater was open when it should have been closed, causing a significant amount of process flow to divert around the heater. Concurrently, the air supply to some of the heater's in-service burners was blocked while the heater was operating, which caused poor combustion conditions and high temperatures in the convection (upper) section of the heater—a process condition called afterburning. The significant reduction in process flow through the fired heater combined with afterburning in the convection section caused the heater's convection section tubes to overheat well above their design temperature, bulge, and lose their strength—a damage mechanism called short-term overheating.

There was no control system data available to alert the board operators of the flow diversion or the combustion conditions that led to afterburning. The flow diversion occurred downstream of a safety instrumented system flow meter that continued to indicate adequate flow to the heater. There was also insufficient flame detection and combustibles monitoring capability to detect afterburning conditions inside the heater. Without this information, Marathon Martinez facility personnel were unaware of the flow diversion or afterburning and continued to troubleshoot the fired heater operation, even though they had the capability to shut down the heater remotely from the control room. In an effort to reduce the tube metal temperatures, Marathon Martinez facility personnel directed a field operator[b] to turn off some of the heater's burners—an operation that placed the field operator immediately next to the fired heater—rather than shutting down the heater remotely from the control room. While the field operator was standing near the burner controls, one of the overheated tubes weakened to the point that it could no longer contain the process pressure and ruptured, releasing renewable diesel and hydrogen into the fired heater. The flammable mixture ignited and escaped from the heater, engulfing the heater in flames. The field operator was seriously injured by the fire, receiving third-degree burns to over 80 percent of his body. He remained in critical condition for over six months before being transferred to a rehabilitation center for further recovery.

Marathon Petroleum Corporation ("Marathon") estimated that the ruptured tube released over 200,000 pounds of renewable diesel and approximately 2,200 pounds of hydrogen. No off-site impacts were reported. The incident resulted in approximately $350 million in property damage. The unit involved in the incident was shut down for approximately one year until it was restarted in November 2024.

[a] The Martinez Renewables facility is owned and operated by a subsidiary of the Marathon Petroleum Corporation.

[b] Field operators are Marathon employees who perform manual tasks on unit equipment.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Safe Operating Limits.** Safe operating limits are process parameters that, if exceeded, could cause a significant process safety incident unless immediate action is taken to bring the process to a safe state. Operating limits are a basic component of local and federal process safety management regulations. On the day of the incident, the fired heater's tube metal temperatures rose to 1,710 °F, far exceeding the 1,120 °F design tube metal temperature. Marathon had not equipped the fired heater at the Martinez facility with adequate safe operating limits (Not-to-Exceed limits) and alarms to alert personnel that the tube metal temperatures had exceeded their mechanical design limits and that the fired heater was in an unsafe state. As a result, Marathon Martinez facility personnel continued to troubleshoot high tube metal temperatures instead of evacuating personnel and remotely shutting down the heater, which put an operator in an unsafe location when the fire erupted. (Section 4.1)
- **Worker Proximity to Fired Heater.** The field operator was at risk when the fired heater tube ruptured because he was standing directly next to the heater in order to turn off individual burners during the troubleshooting activities. The CSB found that the Marathon Martinez tube rupture incident is not an isolated event in the industry. From 2020 through 2024, the CSB has received reports of at least eight fired heater tube rupture incidents at several companies that resulted in accidental releases of regulated or extremely hazardous substances that meet the CSB's reporting criteria. In one incident at a different company, operators were performing troubleshooting activities in the vicinity of the fired heater shortly before the tube ruptured. Despite the frequency and severity of these hazardous tube rupture events, neither Marathon's corporate standards nor recommended engineering controls and practices issued by the American Petroleum Institute (API) adequately prevent workers from being in close proximity to fired heaters while tube temperatures are dangerously high, such as by requiring for troubleshooting to stop at certain conditions and to remove personnel from the vicinity of the fired heater. (Section 4.2)
- **Low Flow Through Fired Heater.** The Marathon Martinez fired heater was equipped with a safety instrumented system that was intended to automatically shut down all burners upon detecting low process flow to the heater. The safety instrumented system's flow meter did not detect the low flow to the fired heater, however, because the process material was diverted through piping that was downstream of the flow meter, which led to the incident. Marathon had not identified the potential flow diversion either in process hazard analyses (PHAs) or when specifically looking for flow diversions around fired heaters after a similar 2018 incident at another Marathon refinery. (Section 4.3)
- **Burner Operation.** During the hour before the tube rupture, two of the four burners in service were operating with cover plates that blocked air flow into the burners, which likely prevented proper air-fuel mixing at the burners. Without proper air-fuel mixing, some unburnt fuel likely moved upward in the fired heater where it subsequently came into contact with the available air at or near the lower convection section and ignited, causing afterburning and high tube temperatures until a tube overheated and ruptured. Marathon had not adequately implemented operating procedures or operator training to ensure that cover plates were to be removed before lighting burners. Furthermore, Marathon had not equipped the heater at the Martinez facility with adequate combustion safeguards that could have alerted operations personnel to the afterburning taking place in the fired heater, such as an effective burner

flame detection system or combustibles monitoring available to board operators in the control room. (Section 4.4)

- **Valve Misalignment.** Leading up to the incident, a valve was misaligned (open when it should have been closed), allowing process material to bypass the fired heater and contribute to the tube overheat and rupture. Marathon had not used effective operator training, equipment labeling and operating procedures, inherently safer design, or "Walk the Line" practices (an industry framework to minimize valve alignment errors) to help ensure that valves were correctly aligned during startup activities. (Section 4.5)

- **Corporate Oversight.** When Marathon acquired the Martinez facility in 2018, the facility operated as a petroleum refinery. In 2020, the facility idled its refining operations, operated as a terminal for about three years, and restarted as a renewable diesel facility in 2023. Marathon did not adequately ensure that the Martinez facility met the company's minimum safety expectations before it started up as a renewable diesel facility. As a result, the Martinez facility lagged behind in conforming to Marathon's corporate standards, leading to deficiencies in local policies and their implementation that contributed to the November 19, 2023, incident. (Section 4.6)

CAUSE

The CSB determined that the cause of the incident was overheating of the fired heater's tubes because (1) a misaligned (open) valve diverted a significant amount of process flow away from the fired heater; and (2) two of the four burners were operating with cover plates blocking their air inlets, leading to afterburning in the convection section.

Contributing to the severity of the incident was the presence of a field operator next to the fired heater when the tube ruptured because (1) personnel directed the field operator to conduct troubleshooting actions in close proximity to the fired heater while the heater was in an unsafe condition (had high tube temperatures); and (2) Marathon had not established effective Not-to-Exceed limits (safe operating limits) for the fired heater tube temperatures to indicate when the fired heater was in an unsafe condition, which resulted in personnel continuing to troubleshoot high tube metal temperatures until the tube ruptured instead of shutting down the fired heater remotely from the control room.

Marathon Martinez's failure to identify the potential for the flow diversion that defeated the heater's safety interlock system and inadequate engineering and administrative controls to prevent the valve misalignment contributed to the incident. Marathon Martinez's inadequate operating procedures and operator training for safe burner operation and inadequate engineering controls for operators to identify combustion issues inside the fired heater also contributed to the incident. Marathon's inadequate oversight of the Martinez facility's conformance to company standards allowed these deficiencies that contributed to this incident.

RECOMMENDATIONS

To Marathon Martinez Renewables

2024-01-I-CA-R1

Implement engineering safeguards to detect and prevent afterburning in the fired heater involved in the November 19, 2023, incident. The safeguards may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The safeguards shall be capable of being monitored from the control room.

2024-01-I-CA-R2

For the fired heater involved in the incident, after Marathon Petroleum Corporation's "Process Heater Not-to-Exceed (NTE) Limits and Alarms" standard is updated according to 2024-01-I-CA-R5, implement tube metal temperature alarming consistent with corporate guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater.

2024-01-I-CA-R3

Implement changes to improve Walk the Line performance at the Martinez facility by ensuring that the facility's practices are consistent with tools in the AFPM Safety Portal and guidance in Marathon Petroleum Corporation's refining reference document titled Operations Excellence. At a minimum:

(a) Require that operator field walkdowns ensure that valves are correctly aligned before all unit startup activities from planned or unplanned shutdowns, such as those due to non-normal operations, emergencies, turnarounds, and major maintenance;

(b) Improve policies and practices for communications among and between shifts to ensure that operators understand abnormal line-ups in their units; and

(c) Reinforce Walk the Line concepts, including the expectation for only trained operators to control valve line-ups at their units, through training for all levels of management in the Operations department.

2024-01-I-CA-R4

Complete a comprehensive gap assessment of the Martinez facility against Marathon Petroleum Corporation policies. At a minimum, address the following policies:

(a) Operating Limits;

(b) Process Hazard Analysis; and

(c) PSM/RMP Refining Operating Procedures.

Develop and implement action items to effectively address findings from the assessment.

To Marathon Petroleum Corporation

2024-01-I-CA-R5

Update the corporate “Process Heater Not-to-Exceed (NTE) Limits and Alarms” standard with tube metal temperature alarming guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater.

2024-01-I-CA-R6

Update the corporate “Heater Application Standard” with the following requirements:

(a) Requirements for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system; and

(b) Engineering safeguard requirements to detect and prevent afterburning in fired heaters. The safeguards may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The safeguards shall be capable of being monitored from the control room.

2024-01-I-CA-R7

Confirm the results of the Martinez facility’s comprehensive gap assessment required in 2024-01-I-CA-R4. Upon completion, conduct an Operations Excellence full assessment on the Martinez facility. Develop and implement action items to effectively address findings from the assessment.

To American Petroleum Institute (API)

2024-01-I-CA-R8

Revise API RP 556 *Instrumentation, Control, and Protective Systems for Gas Fired Heaters,* or successor API products, with the following:

(a) Requirements for proper response to high tube metal temperatures, including guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater;

(b) Design requirements (“shall” rather than “should” language) for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system; and

(c) Engineering safeguard requirements (“shall” rather than “should” language) to detect and prevent afterburning in fired heaters. These requirements may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The requirements shall address monitoring capability from the control room.

1 Background

1.1 Marathon

The Marathon Petroleum Corporation ("Marathon") is a petroleum, biofuel, and renewable fuel refining company headquartered in Findlay, Ohio. Marathon currently operates 13 petroleum refining and two renewable fuel facilities in 12 states [1, 2].[a] The November 19, 2023, incident occurred at the Marathon Martinez Renewables facility in Martinez, California.

1.2 Martinez Renewables Facility

The Marathon Martinez Renewables ("Marathon Martinez") facility is a 50/50 joint venture between Marathon and Neste,[b] operated by a subsidiary[c] of Marathon [3]. The Marathon Martinez facility began operations in 1913 as a petroleum refinery [4]. During its 100-year operation history, the facility ownership changed several times to include, among other owners, Phillips Petroleum, Tosco Corporation, Valero Refining Company, Tesoro Refining & Marketing, and Andeavor. Marathon purchased the facility in 2018 [4].

Marathon idled the Martinez refinery and transitioned the facility to terminal operation in 2020.[d] In September 2022, Marathon announced its joint venture with Neste to convert the facility from a petroleum refinery to a renewable fuels facility [5]. The newly converted site began production in early 2023 with plans to start up other additional units, including the renewable diesel hydroprocessing unit in which the incident occurred, by the end of 2023 [6].

Marathon employed approximately 220 people at the Martinez facility in 2023.[e] At the time of the incident, there were 51 workers on-site, including 27 employees, eight of whom were renewable fuels operators, and 24 contractors.

Under previous owners, four major process safety events at this facility in 1997, 1999, and 2014 resulted in federal safety investigations, three of which were investigated by the U.S. Chemical Safety and Hazard Investigation Board (CSB) [7, 8, 9].[f]

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[a] According to its website, Marathon has ownership interest in nine additional ethanol and other renewable fuel facilities in eight states [1, 2].

[b] Neste is a renewable diesel and sustainable fuel supplier headquartered in Espoo, Finland [48, 49].

[c] The Martinez Renewables facility is operated by Tesoro Refining & Marketing Company LLC, a subsidiary of Marathon [50].

[d] A limited number of units, such as some utility and tank systems, continued to operate in terminal mode, which was not the same as the refining mode of the units.

[e] The United Steelworkers (USW) union estimated that it represented approximately 96 Marathon Martinez Renewables facility employees around the time of the incident.

[f] In 1997, a hydrocracker unit explosion and fire fatally injured one worker and injured 46 other workers at the facility. The U.S. Environmental Protection Agency (EPA) investigated this incident before the CSB began operation in 1998 [7]. In 1999, a crude unit fire fatally injured four workers and seriously injured another worker at the facility. The CSB investigated this incident and published a report of the agency's findings: Tosco Avon Refinery Petroleum Naphtha Fire [8]. On February 12 and March 10, 2014, sulfuric acid releases seriously injured workers in the alkylation unit of the facility.[f] The CSB investigated both of these incidents and published a report on the agency's findings: Tesoro Martinez Sulfuric Acid Spill [9].

1.2.1 Process Safety Regulatory Coverage

Due to its quantities of flammables and hydrogen sulfide, the hydroprocessing unit involved in the incident is subject to the California Occupational Safety and Health Administration (Cal/OSHA) *Process Safety Management of Acutely Hazardous Materials* regulation,[a] the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) rule,[b] and California's Accidental Release Prevention (CalARP) Program 3 regulation.[c] These federal and state process safety regulations include requirements for process safety information, process hazard analysis (PHA), operating procedures, training, and the use of Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) [10], which will be discussed later in this report.

In addition to federal and state regulations, the Marathon Martinez facility is also subject to the Contra Costa County Industrial Safety Ordinance (ISO), which expands on the CalARP requirements to also include inherently safer systems analysis, safeguard protection analysis, a human factors program, and other requirements [11, 12].[d, e]

Prior to its idling in 2020, the Marathon Martinez facility was subject to California's regulations implemented in 2017 for petroleum refineries.[f] Similar to the Contra Costa County Industrial Safety Ordinance, the California petroleum refinery regulations included additional requirements such as conducting hierarchy of controls analysis, safeguard protection analysis, and human factors programs.[g] After the Martinez facility converted to a renewables facility in 2023, it was no longer subject to the petroleum refinery regulations. After the November 19, 2023, incident, the United Steelworkers union initiated a petition that led to the California State Assembly approving a bill to replace the term "petroleum refinery" with "refinery" in its labor code regulations, and requiring Cal/OSHA to propose revisions to its PSM standard for refineries by 2026 [13].[h]

[a] CA Title 8 §5189

[b] 40 CFR Part 68

[c] CA Title 19 Division 5, Chapter 2

[d] Contra Costa County Code Title 4 Division 450, Chapter 8

[e] Contra Costa County's Industrial Safety Ordinance has been in effect since December 1998. The County makes facilities' safety plans and investigation reports for any major chemical accident or release publicly available. In addition, the County is required to audit each facility under the Industrial Safety Ordinance every three years to ensure that they are following the requirements of the ordinance [78].

[f] Cal/OSHA *Process Safety Management for Petroleum Refineries* (CA Title 8 §5189.1) and CalARP Program 4 Prevention Program for petroleum refineries (CA Title 19 Division 5, Chapter 2, Article 7) came into effect in 2017.

[g] Many of California's petroleum refinery process safety regulatory requirements originated from the CSB's recommendations from its investigation of the Chevron Richmond Refinery Fire that occurred in Richmond, California in 2012 [69].

[h] The USW submitted Petition File No. 601 to the California Occupational Safety and Health Standards Board to amend Section 5189.1, *Process Safety Management for Petroleum Refineries,* to also include refineries that process renewable feedstocks, on the basis that renewable fuels are chemically equivalent to petroleum fuel products and pose similar hazards to those found in petroleum refineries [61]. On September 29, 2024, California Governor Gavin Newsom signed Assembly Bill 3258 into law to replace the term "petroleum refinery" with "refinery," with the following definition: "an establishment that produces gasoline, diesel fuel, aviation fuel, or biofuel through the processing of crude oil or alternative feedstock." The bill includes corresponding amendments to the California Labor Code to include renewable fuel refineries under PSM coverage originally written for petroleum refineries [13].

1.3 RENEWABLE FUELS

There is a growing demand for renewable fuels [14], which are manufactured from grain starch, vegetable oils, animal fats, and other biomass [15]. To address this increasing demand, as of early 2024, four of the 13 California refineries had converted to, or were in the process of converting to, renewable fuel production [16, 17, p. 15].[a]

The Marathon Martinez facility manufactures renewable diesel, a type of renewable fuel, from feedstocks of fats, soybean oil, corn oil, and greases [18, 19]. Renewable diesel is a flammable liquid with a flash point ranging between 135-168 °F [20], and has similar properties to conventional diesel.

1.4 HYDROPROCESSING

Feedstocks from renewable fuels have a higher oxygen content than petroleum feedstocks [21], and this oxygen content must be lowered to avoid adverse performance of the renewable fuel [22, p. 241]. The Marathon Martinez facility removes oxygen from renewable feedstock via a hydroprocessing operation[b,c] in which hydrogen reacts with the feedstock material to remove the oxygen [23].

A process flow diagram depicting a portion of the Marathon Martinez hydroprocessing unit where the incident occurred is shown in **Figure 1** below. The fresh feedstock (green) was to be fed directly into the reactor where the oxygen-removal reaction was to take place.[d] There, it was to combine and react with hydrogen (blue) under approximately 680 pounds per square inch gauge (psig) of pressure. Two sources of hydrogen were to feed the reactor: recycle hydrogen and makeup hydrogen. The recycle hydrogen continually circulated through the unit, and the makeup hydrogen was meant to replenish the hydrogen chemically consumed in the reactor.

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[a] California has provided incentives for investments in cleaner technologies since it passed Assembly Bill 32, the California Global Warming Solutions Act of 2006 [51, 52]. In September 2020, the governor of California signed Executive Order N-79-20 to, among other goals, "support the transition away from fossil fuels," including "expedite regulatory processes to repurpose and transition upstream and downstream oil production facilities" [60]. In 2023, the California Air Resources Board announced that California had replaced over 50% of diesel used in the state with clean fuels for the first time, crediting the programs created under Assembly Bill 32 [53].
At the federal level, the EPA Renewable Fuel Standard aims to reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel used in the United States by expanding renewable fuel production. It establishes annual renewable fuel blending targets, requiring refiners or importers of gasoline or diesel to comply by blending renewable fuels into transportation fuel or by obtaining credits [54].
The federal government also provides tax incentives for renewable fuels. The Biodiesel Mixture Excise Tax Credit, also known as the Blender's Tax Credit, allowed registered renewable diesel blenders to receive tax credits of $1.00 per gallon of renewable diesel sold [87, 55, 56]. In addition, the federal Advanced Energy Project provides a tax credit of 30 percent for investments in manufacturing facilities that produce renewable energy [57].

[b] The hydroprocessing unit was called a hydrodeoxygenation (HDO) unit.

[c] Hydroprocessing is also used in traditional petroleum refining. In petroleum refining, high sulfur and nitrogen content are the more significant concern, and they are removed via similar hydroprocessing processes called hydrodesulfurization and hydrodenitrification [21].

[d] At the time of the November 19, 2023, incident, fresh feed had not yet been introduced into the reactor.

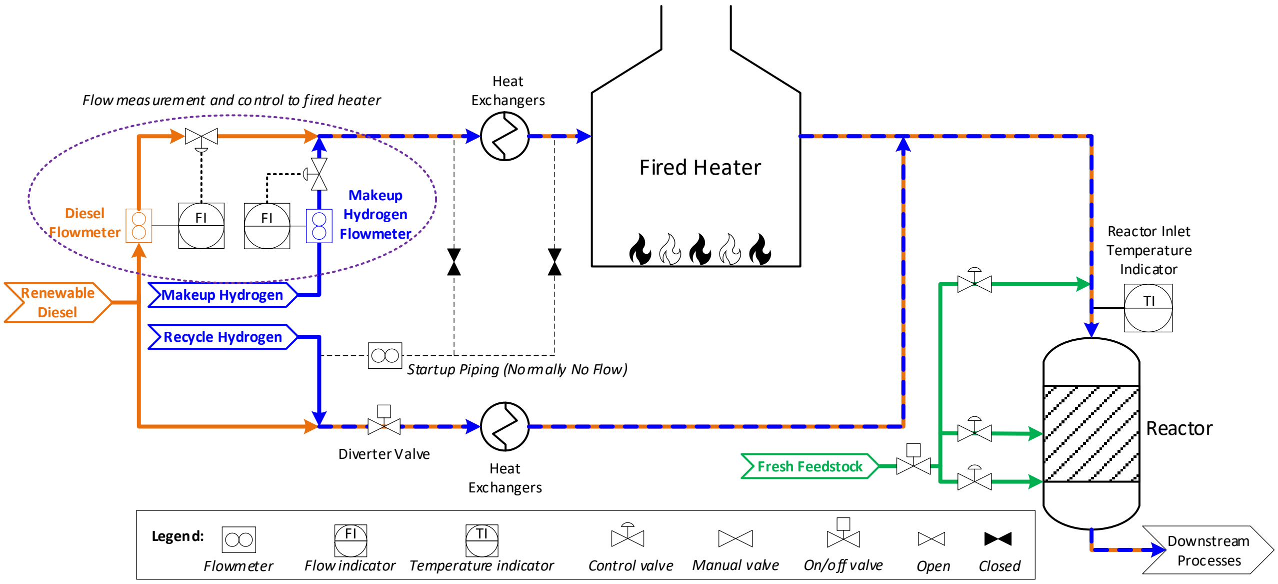


Figure 1. Reactor preheat section simplified process flow diagram, normal operation. (Credit: CSB)

The chemical reaction was an exothermic reaction that could generate a large amount of heat. To help control temperatures inside the reactor, the unit was designed to continually circulate recycled renewable diesel (**Figure 1**, orange) and recycle hydrogen to carry away the generated heat.

A reactor inlet temperature of 500 °F to 700 °F was required for the hydroprocessing reaction to take place. For the reactor inlet to reach those elevated temperatures, Marathon Martinez designed the unit to heat a portion of the recycled renewable diesel and makeup hydrogen using the fired heater involved in the November 19, 2023, incident. The rest of the process flow was to bypass the heater and feed directly into the reactor. This process flow was able to be routed to the reactor when the Diverter Valve was in the open position (**Figure 1**, bottom).

Flow instrumentation was installed to monitor and control the renewable diesel and makeup hydrogen flows individually before the materials mixed together and entered the fired heater. The diesel flow meter measured the liquid renewable diesel flow rate, and the makeup hydrogen flow meter measured the gaseous hydrogen flow rate to the fired heater. Control valves were installed to control the measured flow rates to the heater (**Figure 1**, circled).

1.5 FIRED HEATER

The fired heater was a "cabin-type" heater with horizontal tubes to carry the process fluid (**Figure 2**). The tubes on the lower portion of the walls were in the "radiant section," and the upper tubes were in the "convection section," with each section named based on the primary mode of heat transfer to the tubes. The recycled renewable diesel and hydrogen mixture flowed through these tubes, which were arranged in four parallel coils, called passes [24, pp. 7, 13]. The heater used a natural draft, which means that the burners drew air in from the bottom of the heater, and the flue gas traveled up the stack, without the assistance of fans.

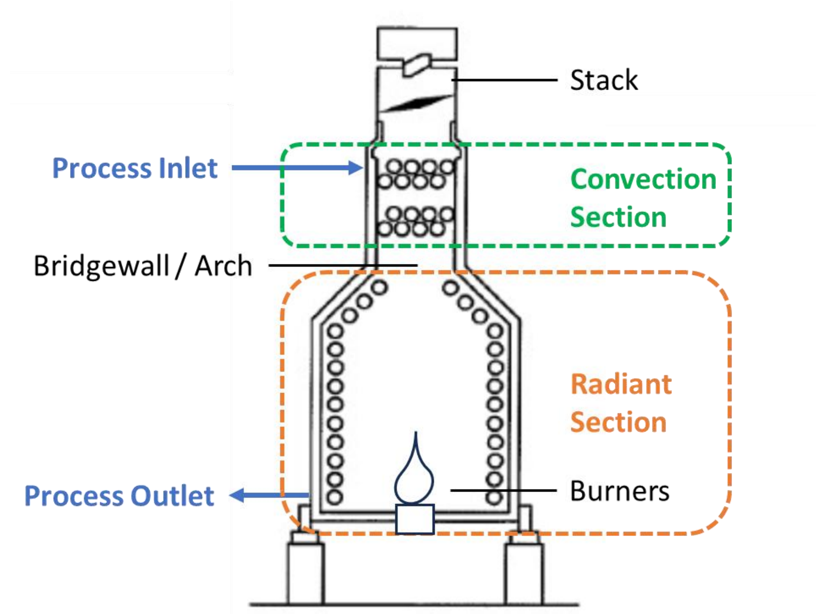


Figure 2. General layout of a cabin fired heater with horizontal tubes.
(Credit: API [25, p. 18] annotations by CSB)

Figure 3 depicts the interior of the fired heater. The heater had 11 floor fired burners, which burned fuel gas to generate the flames and heat the material in the tubes. The fired heater operation was monitored, in part, by measuring temperatures at three location types: (1) process fluid flowing through the heater tubes, (2) tube metal walls,[a] and (3) the flue gas (**Figure 4**). The locations of the thermocouples that measured these temperatures are shown in **Figure 3**.[b]

[a] Fired heater tube metal temperatures are measured via thermocouples attached to the outer surface of the tubes inside the heater.
[b] Ten thermocouples measured the tube metal temperatures: six located in the radiant section and four in the convection section.

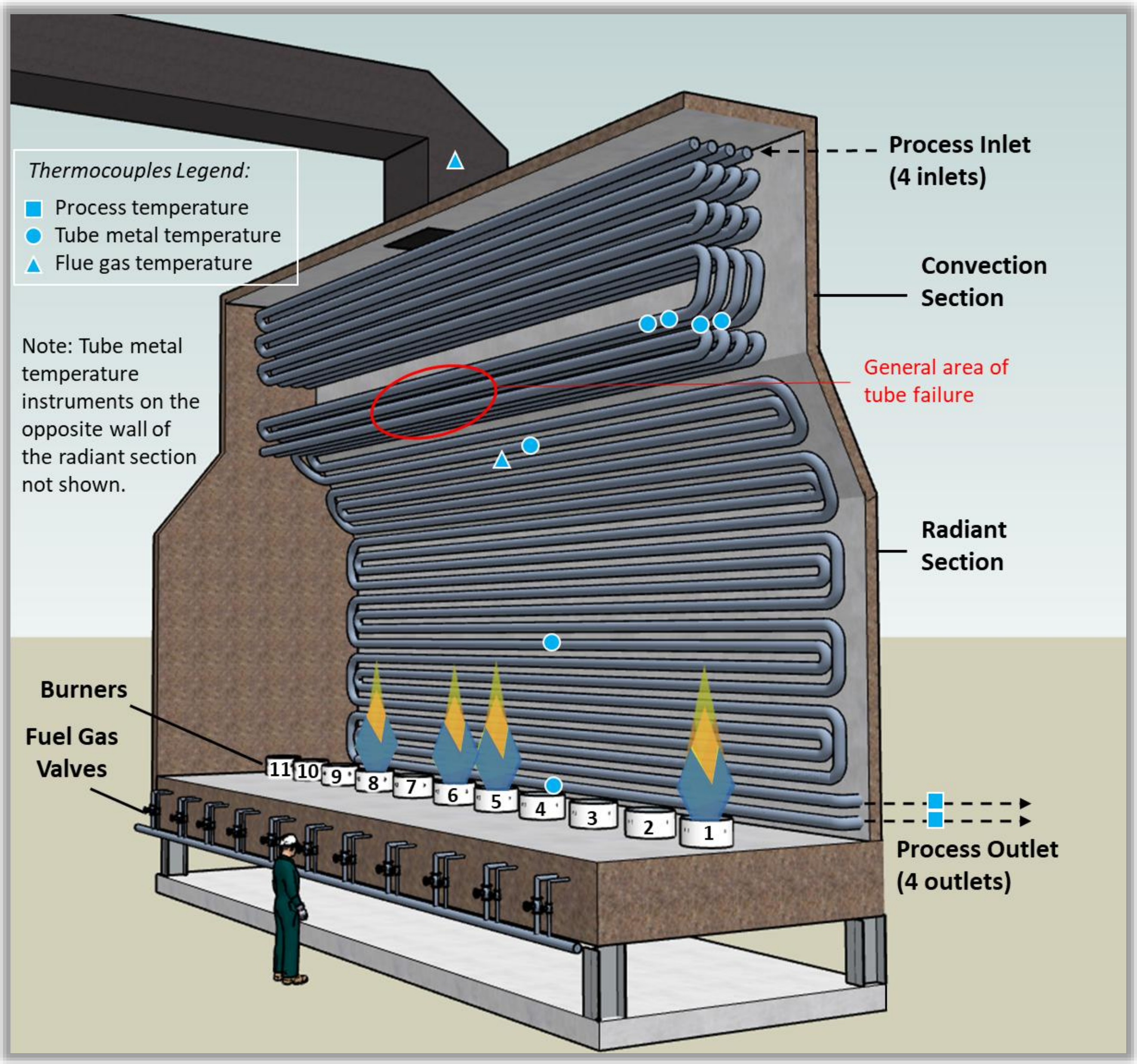


Figure 3. Interior of the fired heater. Note: The lit burners in the illustration do not necessarily depict their actual state at the time of the incident. (Credit: CSB)

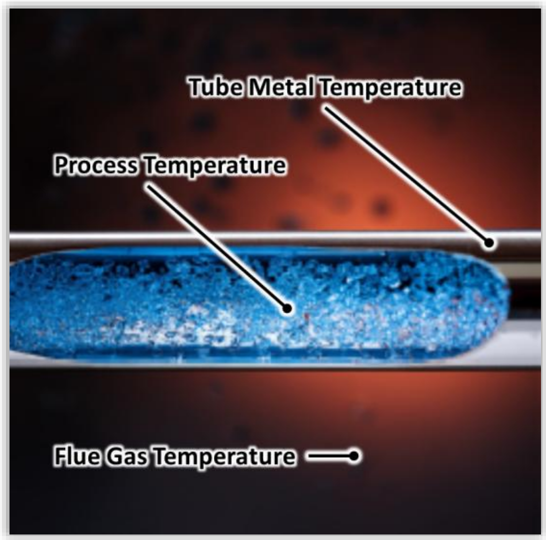


Figure 4. Depiction of the three types of temperature monitoring locations typically used during fired heater operation. (Credit: CSB)

Fuel gas entered each burner through piping, and air entered each burner through combustion air intake openings (**Figure 5**). The proper air-fuel ratio at each burner is important for the heater to operate safely and efficiently. Too little air can lead to lack of proper mixing of air and fuel and result in incomplete combustion of the fuel gas inside the heater, and too much air can increase nitrogen oxide (NOx) emissions, an environmental pollutant [26, p. 907]. Cover plates are often used to cover the air intakes of out-of-service burners to prevent excess air from entering the fired heater [23, p. 16].

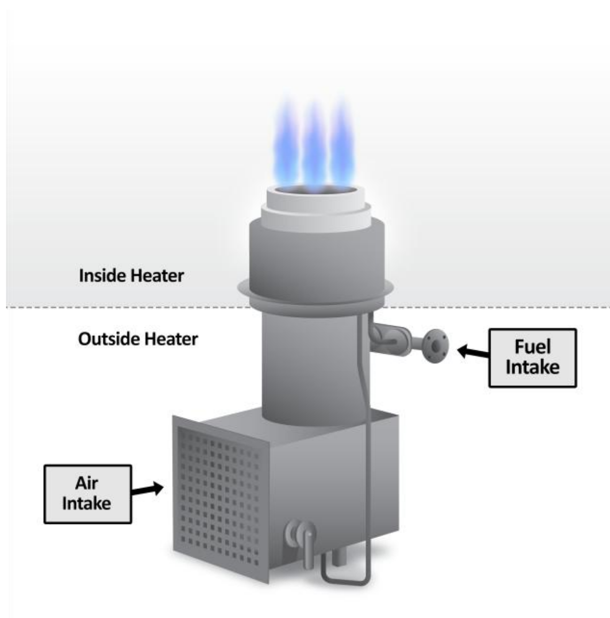


Figure 5. Generic diagram of a fired heater burner. (Credit: CSB)

The fired heater had a minimum process flow requirement through the tubes. Below the minimum requirement, the process flow cannot carry sufficient heat away from the tube walls, which can cause the tubes to overheat and ultimately rupture [27, pp. 114-118, 25, p. 16].[a] The fired heater was equipped with a safety instrumented system (safety interlock) designed to automatically stop the common fuel supply to all burners when process flow to the heater was detected to be lower than the minimum flow requirement.[b] As will be described in this report, however, this safety feature did not prevent the incident because a low process flow condition during unit startup was never detected—either by instrumentation or by unit personnel.

The heater involved in the incident was installed as part of the original hydroprocessing unit commissioned in 1956.[c] In 2022, as part of the renewable fuels project, Marathon redesigned and replaced the tubes inside the fired heater in a new configuration.[d] The tubes were designed to normally operate up to a tube metal temperature of 780 °F and had a design temperature of 1,120 °F, meaning that they were not designed to withstand the process pressure beyond this temperature.[e] All the tubes in the heater were installed new and had been in service for less than two weeks before the incident.

1.6 Description of Surrounding Area

Figure 6 shows the Marathon Martinez facility and depicts the area within approximately one, three, and five miles of the facility boundary. Summarized demographic data for the approximate one-mile vicinity of the Martinez facility is shown below in **Table 1**. There were over 6,872 people residing in over 2,223 housing units, most of which were single units, in the two census blocks within one mile from the facility. Detailed demographic information is included in Appendix B.

[a] Because the tubes are the pressure-containing boundary, a tube failure could lead to a dangerous release of pressurized, flammable process materials into the atmosphere, endangering people, other process equipment, and the environment [75, p. 27].

[b] The pilot gas supply valve to the burners was configured to remain open during a low process flow trip of the burners.

[c] In 1998, Tosco replaced the burners, tube metal thermocouples, and the heater access doors. In 2010, Tesoro replaced the convection section of the heater.

[d] Marathon replaced the former hydrotreater two-pass heater tubes with Type 321 stainless steel tubes in a four-pass configuration.

[e] Marathon used API Standard 530 (API 530), *Calculation of Heater-tube Thickness in Petroleum Refineries* [31], to determine tube design criteria in the fired heater involved in the incident. The design pressure of the tubes was 975 psig. During the unit startup, process pressure at the heater varied between 550 and 800 psig and was approximately 640 psig at the time of the tube rupture.

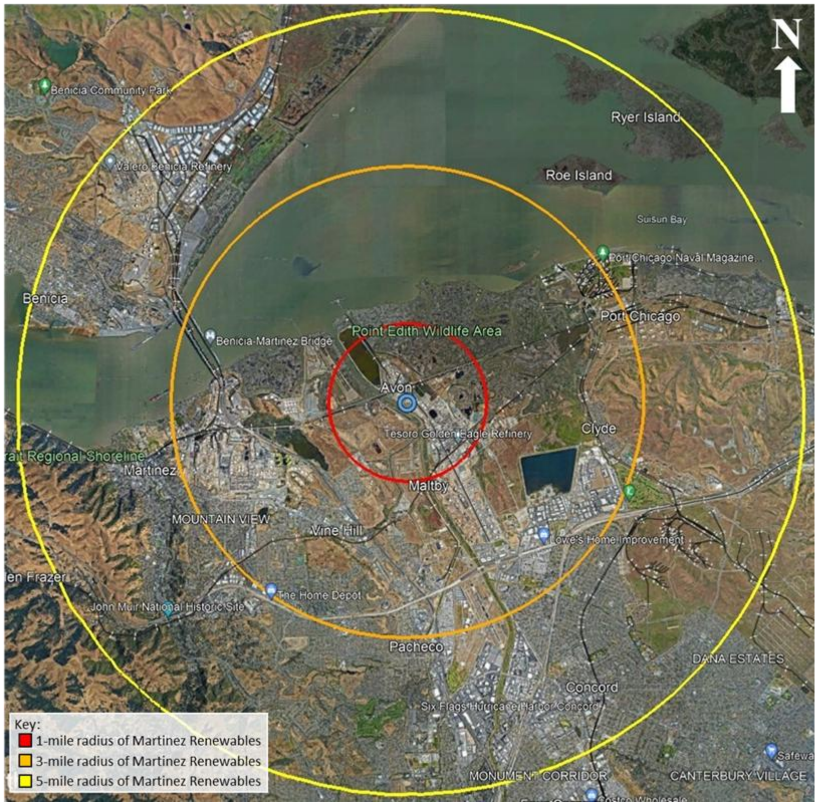


Figure 6. Overhead satellite image of the Marathon Martinez facility and the surrounding area (Credit: Google Earth, annotated by CSB)

Table 1. Summarized demographic data for approximately one-mile vicinity of the Marathon Martinez facility[a] (Credit: CSB using data obtained from Census Reporter)

Population	Race and Ethnicity		Per Capita Income	% Persons Below Poverty Line	Number of Housing Units	Types of Housing Units	
6,872	White	42%	$43,235	6	2,223	Single Unit	93.4%
	Black	8%				Multi-Unit	6.1%
	Native	0%				Mobile Home	0.5%
	Asian	11%				Boat, RV, Van, etc.	0.0%
	Islander	0%					
	Other	0%					
	Two+	3%					
	Hispanic	35%					

[a] Census Reporter reports that in 2023, California's per capita income was $45,591 and that the overall per capita income for the United States was $41,804 [46].

2 Incident Description

The incident occurred while the renewable diesel hydroprocessing unit was starting up for the first time. Startup activities began around November 1, 2023. Below is the sequence of events leading up to the November 19, 2023, incident.

2.1 Opening of Both Startup Hydrogen Valves

Unit startup required first heating the unit with hydrogen only (no diesel), which was achieved by flowing both makeup and recycle hydrogen to the fired heater (**Figure 7**). To achieve this, the startup procedure called for closing the Diverter Valve and opening one of the startup hydrogen valves to direct hydrogen into the fired heater. As will be discussed in *Section 4.5*, the startup procedure did not clearly indicate which startup piping valve was to be opened, but historically (when the unit was a petroleum refinery), only Valve A would be opened at this step. At some point during the initial startup sequence, both Valves A and B were opened.[a]

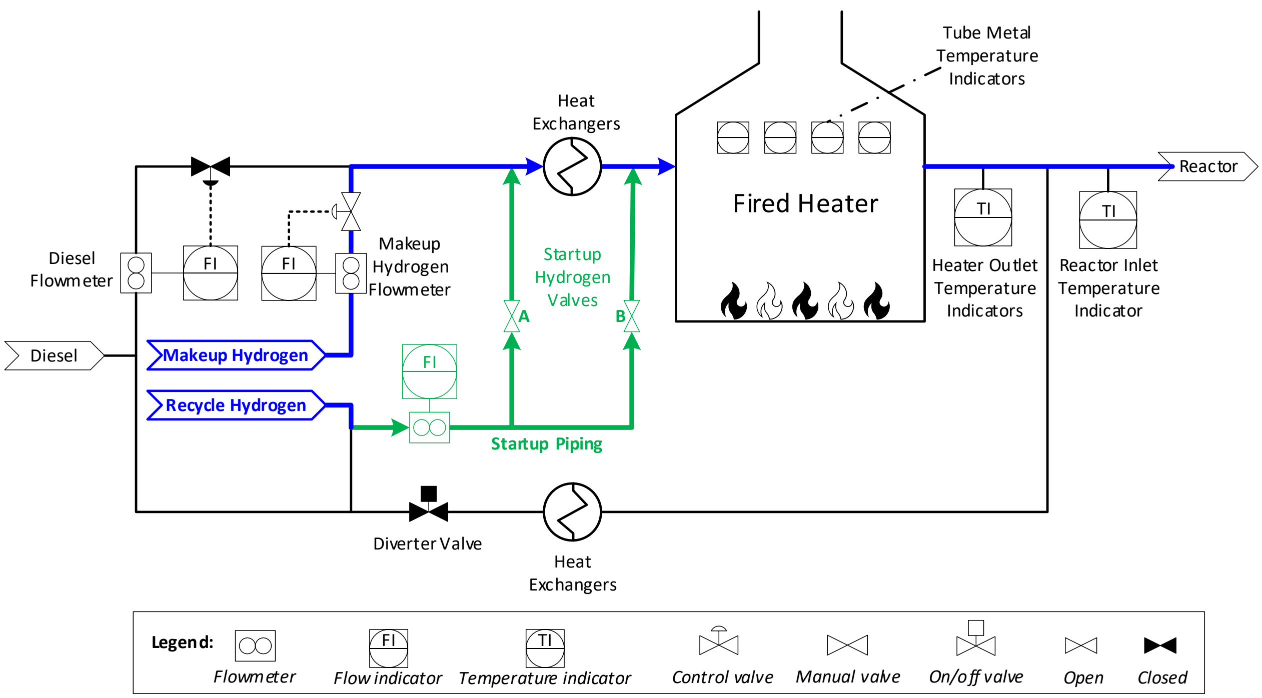


Figure 7. Unit heat-up through startup piping with both startup hydrogen valves open. (Credit: CSB)

Neither of the startup valves was equipped with a position indicator that could be monitored from the control room screen. Both valves being open did not adversely impact the process during the initial heat-up step. However, Valve B remained open through subsequent startup steps, and key Marathon Martinez engineering and operations personnel were not aware that Valve B was open until after the November 19, 2023, incident.

[a] Prior to the initial startup, Marathon documented that Valve B was closed (see *Section 4.5.3*). During startup activities, process data indicates that the startup hydrogen piping was in service even when Valve A was reportedly closed (see *Section 3.2*). Marathon found Valve B open after the incident on November 19, 2023.

2.2 First Flow Diversion

On the morning of November 11, 2023, Marathon Martinez operations personnel began feeding renewable diesel to the fired heater for the first time. This step required stopping hydrogen flow through the startup piping and establishing the normal diesel and hydrogen routings to the unit. Marathon Martinez personnel closed Valve A and opened the Diverter Valve to achieve the normal process flow routings. Valve B remained open, however, and a portion of the diesel-hydrogen mixture reverse-flowed through the open Valve B and bypassed the heater (**Figure 8**, flow diversion in red). Marathon Martinez personnel did not detect the flow reduction to the heater because the flow diversion occurred downstream of available flow meters. In addition, the hydrogen flow meter on the startup piping was not configured to read reverse flow. Consequently, the flow meter indicated zero flow—an expected condition at this point in the startup sequence.

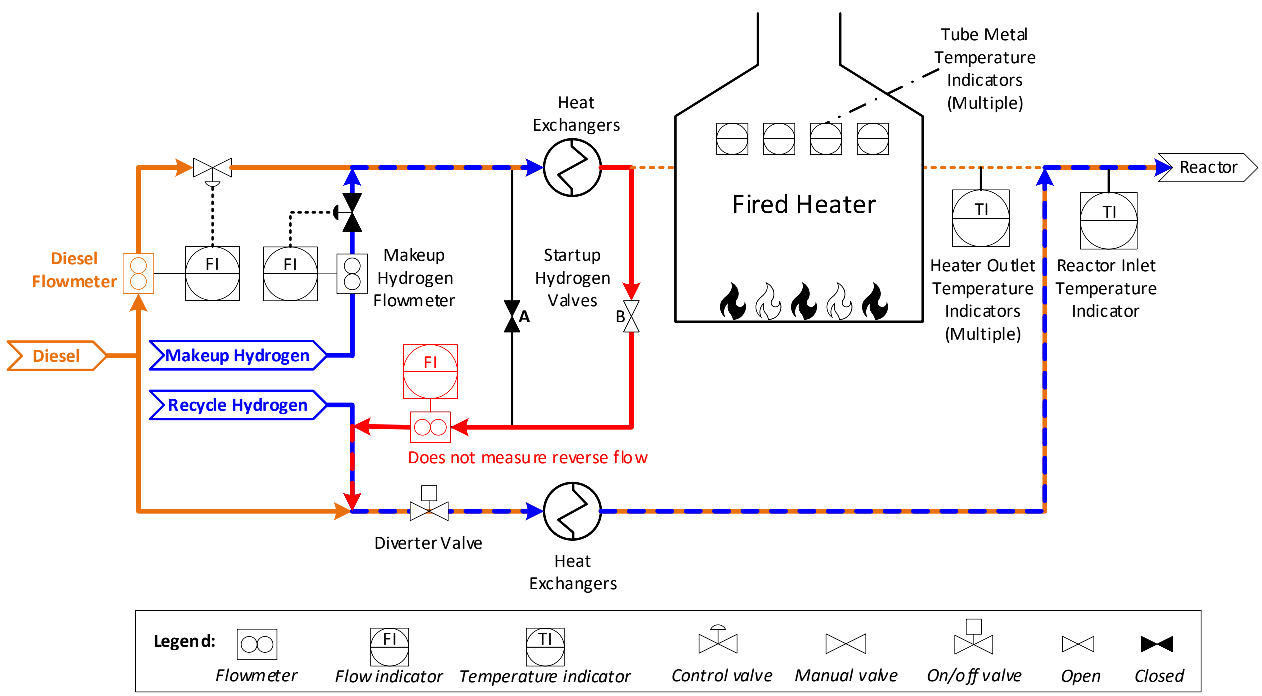


Figure 8. A portion of the diesel-hydrogen mixture diverted around the heater on November 11. (Credit: CSB)

With reduced process flow through the fired heater tubes, tube metal temperatures began to rise. Some of the convection section tube metal temperature indicators triggered high-temperature alarms at 790 °F within the first half hour of the routing change and eventually reached approximately 900 °F.[a]

Seeing the high temperature alarms, operations personnel verbally requested an infrared scan to verify the temperature readings.[b,c] The supervisor who volunteered to perform this task mistakenly interpreted the request

[a] The convection section tube metal temperatures were operating between approximately 650 and 900 °F, occasionally coming into alarm at 790 °F.

[b] An infrared camera can capture a temperature color-coded image of heater tubes to approximate temperatures during operation [30, p. 48, 28, p. 282, 90, p. 315].

[c] Infrared thermography camera inspections often require special equipment, appropriate training, and a "trained eye" to properly interpret the readings [90, pp. 315-316]. See Appendix E, incidents #5 and #6, where proper infrared scans could have prevented the incidents.

as pertaining to the heater exterior, however, and thermally imaged the heater exterior instead of the interior. The supervisor then reported back the temperatures that he measured, which were approximately 300 to 400 °F lower than the convection section temperature readings displayed in the control room. Additionally, because the supervisor was not familiar with how to inspect the inside of a fired heater with the infrared camera, he also performed a visual inspection of the interior by looking through the viewports without the camera and reported that there were no issues with the inside of the heater that he could see.[a] These events led the board operator to understand that the tube metal temperature readings displayed in the control room could be 300 °F higher than the actual tube temperatures, and he observed that the tube temperatures otherwise appeared responsive to process changes as expected.

Several hours later, a fire erupted in a different area of the unit, and Marathon Martinez shut down and depressurized the unit.[b] During a shift turnover meeting later that evening, Marathon personnel restated the infrared scan results to technical staff. After both hearing the infrared scan results and reviewing the process data, Marathon technical personnel did not determine a process-related cause of the high convection section tube metal temperature readings and concluded that the thermocouples themselves may have failed. No subsequent investigation or follow-up on the tube metal temperatures occurred.

2.3 Unit Restart from Unplanned Shutdown

The fire on November 11 caused equipment damage that took several days to repair. Marathon Martinez resumed startup activities on November 15, approximately four days after the unplanned shutdown.[c] There was no formal effort to verify all valve positions before this second startup attempt, and as a result, personnel did not identify that Valve B was open. Marathon Martinez personnel lit the fired heater on November 17 and began warming up the unit with hydrogen.

On November 17, during the startup activities, Marathon Martinez personnel installed cover plates[d] on six of the fired heater burners that were not in service (**Figure 9**) in an effort to lower NOx emissions.

[a] The supervisor told the CSB that when he performed a visual inspection, he did not see any indication of glowing tubes, damaged refractory, bad flame patterns, or flame impingement on the walls or on the tubes. The supervisor was not familiar with how to inspect the inside of a fired heater with the infrared camera and did not capture photographs with the infrared camera.

[b] A fire occurred at the feed pump during startup activities. Approximately 4.8 barrels of renewable diesel ignited upon its release from a separated pipe flange. The fire was extinguished by on-site Marathon personnel, and Marathon reported that no off-site impacts were observed.

[c] Marathon Martinez personnel used the same startup procedure but started at later steps to re-establish hydrogen circulation through the unit.

[d] Prior to the initial startup, Marathon Martinez had ordered replacement cover plates, as they were missing from some burners. The replacement cover plates arrived at the Marathon Martinez facility on November 11.

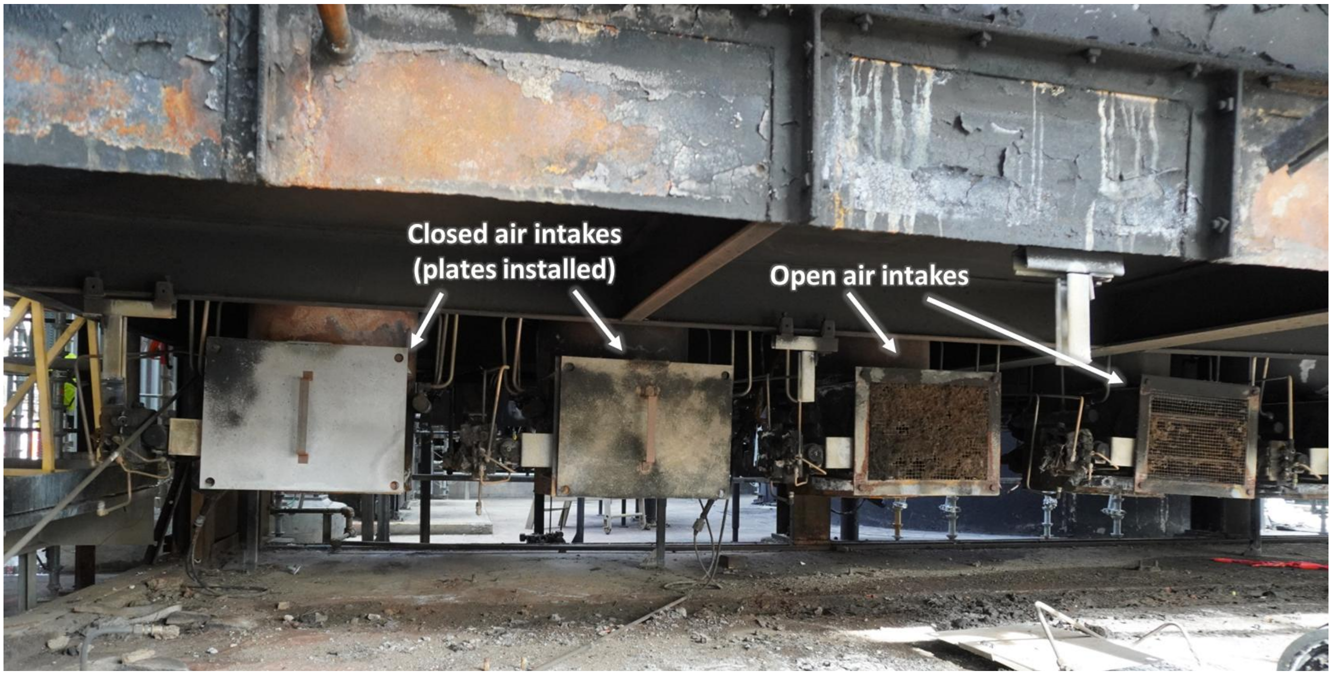


Figure 9. Post-incident as-found condition of the air side of four of the burners. (Credit: CSB)

2.4 Second Flow Diversion

On November 18, 2023, at approximately 10:25 p.m., operations personnel attempted to establish normal process flow routings. A board operator opened the Diverter Valve and requested over the radio that a field operator close Valve A, intending to stop flow through the startup piping (Figure 10). The operator training material did not discuss the startup piping, and the field operator responsible for this task had no prior knowledge of the startup piping until that shift. With the help of another field operator, he identified Valve A by its labeling and did as the board operators instructed, closing the valve. The field operator was not instructed to close Valve B, and Valve B remained open. Neither Valve A nor Valve B was equipped with position indicators that the board operators could see on the control room display to confirm their alignment, and operations personnel did not field-verify the position of Valve B.

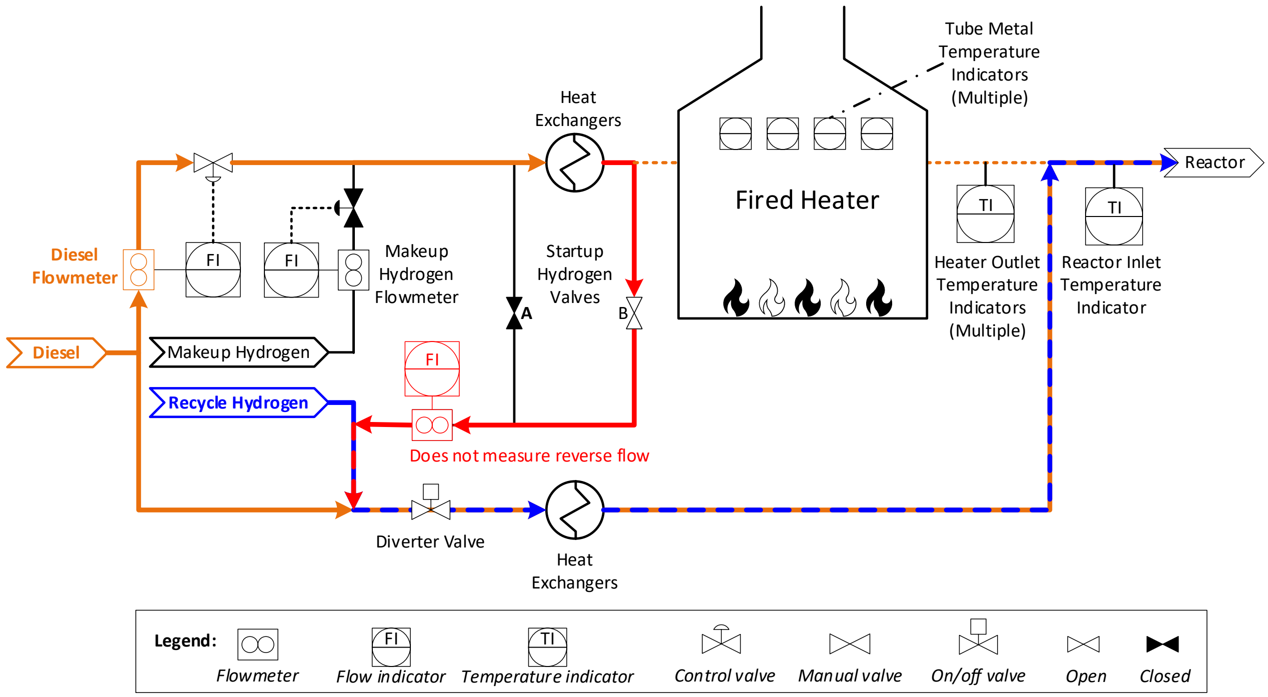


Figure 10. Flow diversion from the heater. Reverse flow indicated in red. (Credit: CSB)[a]

Unbeknownst to the operators, most of the renewable diesel again reverse-flowed through the startup piping on which the open Valve B was installed (**Figure 10**). Again, the board operator did not see this flow diversion on his display because the startup piping flow meter was not configured to detect flow in the reverse direction.[b]

Tube metal temperatures began to rise but did not yet trigger high temperature alarms.

2.5 Heater Shutdown and Restart

Believing that the diesel was now routed to the heater, Marathon Martinez operations personnel began to light additional burners to achieve the target reactor inlet temperature. At approximately 10:45 p.m. on November 18, during burner lighting activities, the safety instrumented system detected a loss of flame on one of the burners and automatically shut down the heater. Operators had to wait for a timed heater purge to finish before they could safely re-light the burners.

Marathon Martinez personnel restarted the heater at approximately 11:15 p.m., and two field operators lit four burners (**Figure 11**, burners 1, 5, 6, and 8). There was no specific guidance or requirement specifying which burners needed to be lit, and two of the burners that were lit had cover plates blocking their air intakes (**Figure 11**).[c] The cover plates, which had just been installed the day before, were not visible to the operators from where

[a] During this second startup attempt, the makeup hydrogen compressors were off but were available for operation when needed.

[b] A zero flow on the startup hydrogen flow meter should have triggered an automatic shutdown of the heater; however, this safety interlock was disabled, likely because no hydrogen flow was expected through this line.

[c] Previously, burners 4,5, and 7 were in service. After the heater restart, operators lit burners 1, 5, 6, and 8.

they stood to light the burners, and the operating procedure did not require the operators to remove the cover plates when lighting the burners.

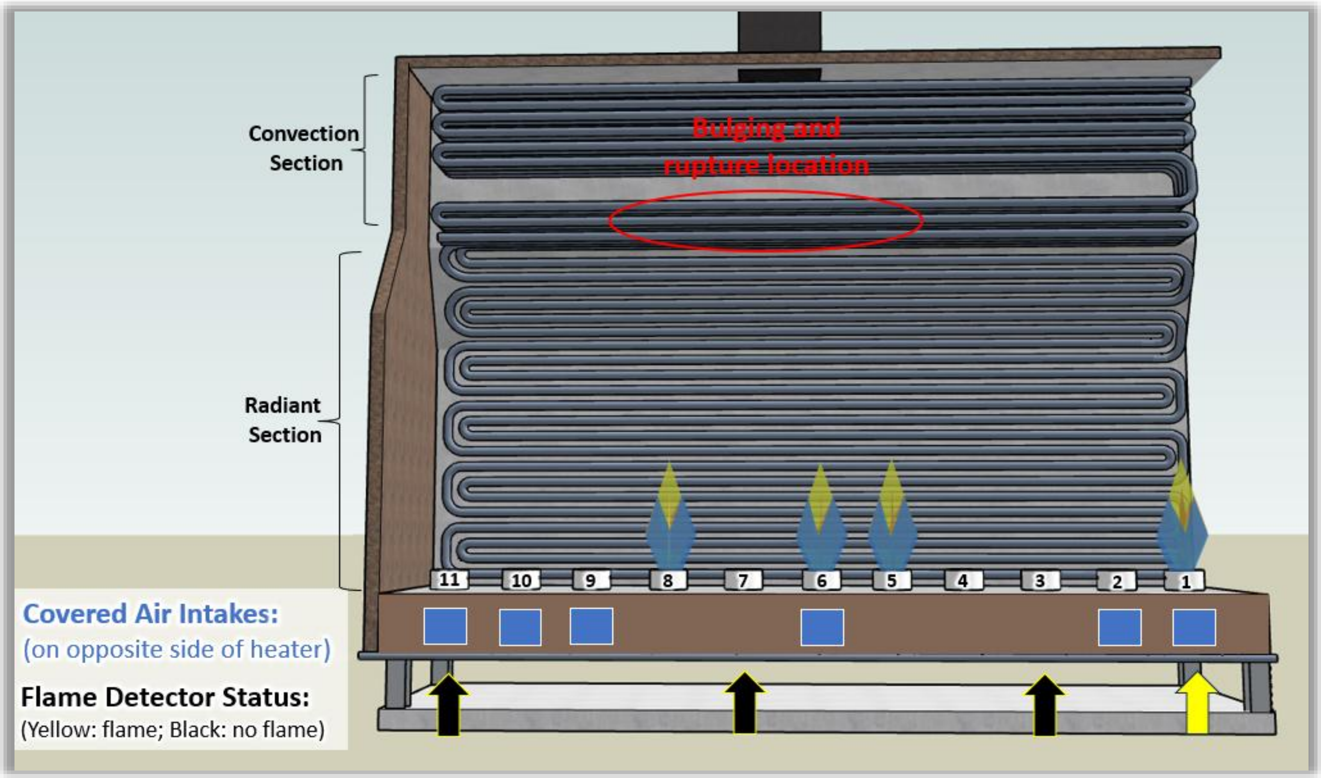


Figure 11. Burner configuration when heater was restarted approximately one hour before the incident. (Credit: CSB)

The blocked air intakes likely prevented the required combustion air flow through these burners and affected the air-fuel mixing at the burners. Without proper air-fuel mixing at the burners, some unburnt fuel likely moved upward in the fired heater where it subsequently came into contact with available air at or near the convection section and ignited there, a condition known as afterburning (see *Section 3.3*). Only one of the four burners that were lit (burner 1) was equipped with a flame detector, which indicated that the burner remained lit until the incident.[a] The flame status of the other three burners that were lit, however, was unknown. The heater began to operate with higher temperatures in the convection section than in the radiant section (**Figure 12**), indicative of afterburning.

2.6 Temperature Control Troubleshooting

The board operators and the night shift process engineer observed that although the heater outlet temperature had increased (**Figure 12**, pink and purple trends), a corresponding temperature rise did not occur at the reactor inlet (gray trend). Then, at approximately 11:30 p.m., the convection section tube metal temperatures (brown trend) exceeded 790 °F, activating high temperature alarms.

[a] Flame detectors were installed on burners 1, 3, 7, and 11. Burners 1, 5, 6, and 8 were in service.

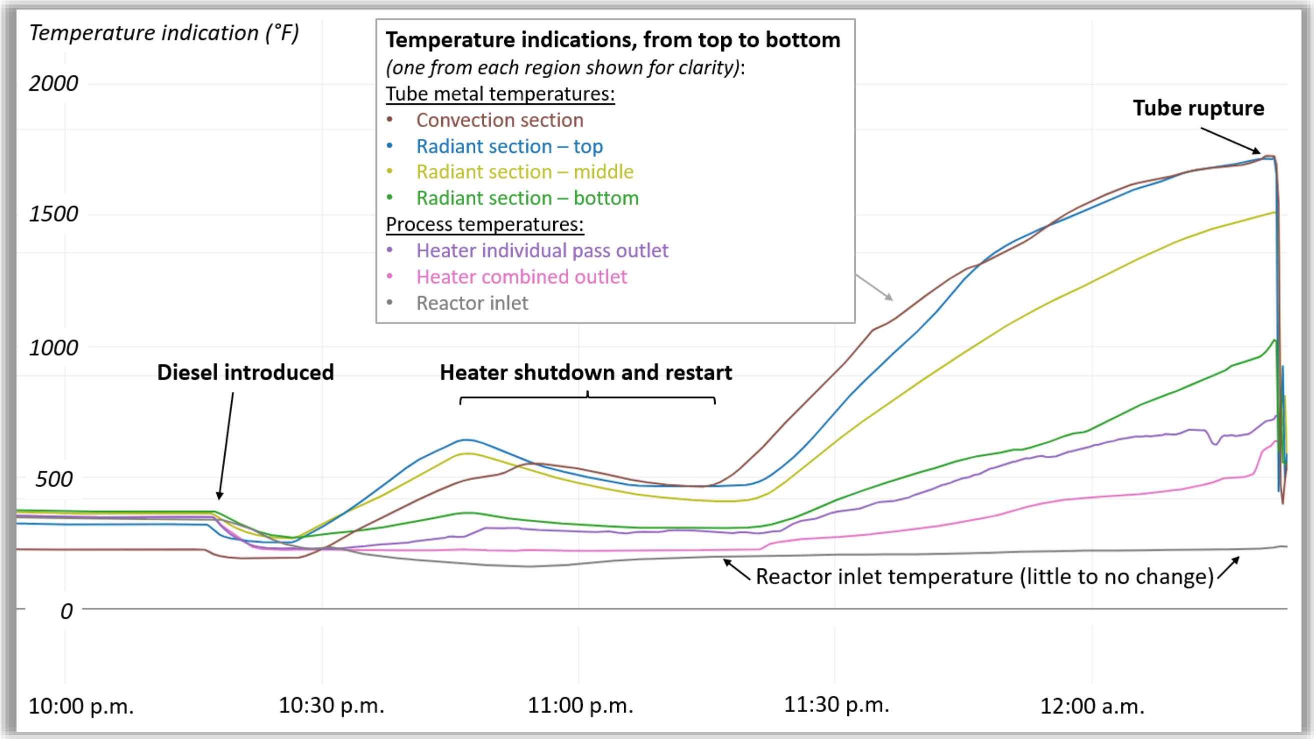
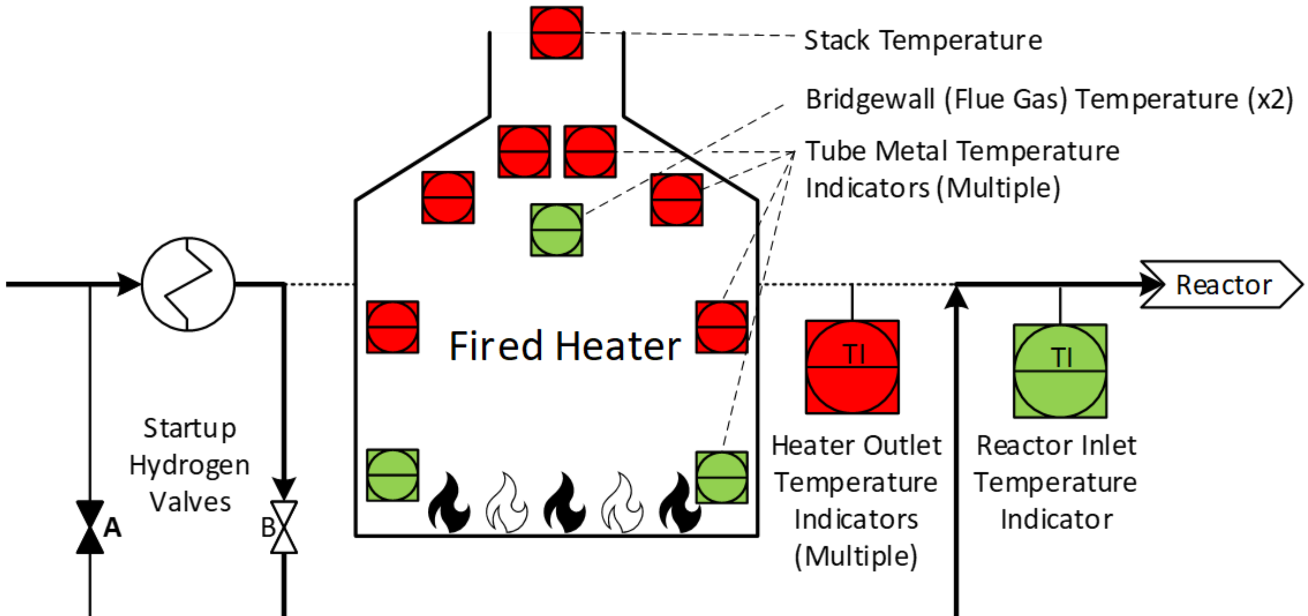


Figure 12. Process and tube metal temperatures in the two hours leading up to the tube rupture. (Credit: CSB)

The board operators increased diesel flow to the heater, expecting that additional flow would remove heat from the tube walls and cause the tube metal temperatures to decrease. They also made heater draft adjustments to draw in more combustion air in an attempt to cool the tubes, and they lowered the fired heater feed temperature. Unknown to Marathon Martinez personnel, the added diesel flow continued to bypass the fired heater through the open Valve B, and tube metal temperatures continued to increase. At 11:45 p.m., tube metal temperatures in the radiant section exceeded 1,100 °F and activated additional high-temperature alarms (**Figure 12**, blue trend). By this time, some of the convection tube metal temperatures had already exceeded 1,100 °F (**Figure 12**, brown trend).

Marathon Martinez personnel continued troubleshooting efforts but were not able to lower the tube metal temperatures. By 12:20 a.m. on November 19, 9 of the 13 temperature indicators inside the heater were in alarm (**Figure 13**).[a] Two of the tube metal temperatures had exceeded 1,700 °F, far above the high-temperature alarm limit of 1,100 °F and the tube metal design temperature of 1,120 °F. As will be discussed in *Section 4.1*, none of the activated alarms required personnel to shut down the fired heater. Rather, per Marathon policies, the alarms that activated were intended to prompt troubleshooting efforts. As a result, Marathon Martinez personnel did not shut down the fired heater remotely from the control room, even though they had the capability to do so.

[a] The two bridgewall temperatures (configured to alarm at 1,800 °F) and the two radiant tube metal temperatures nearest to the floor of the heater were not in alarm.



Parameter	Alarm Setpoints	Actual
Tube metal temperature – Convection	790 °F	1,634 – 1,724 °F
Tube metal temperature – Radiant	1,100 °F	1,041 – 1,719 °F
Stack temperature	800 °F	971 °F
Bridgewall temperature	1,800 °F	1,566 – 1,610 °F
Heater pass outlet temperatures	High: 730 °F Emergency: 1,100 °F	709 – 871 °F

Figure 13. Temperatures in alarm approximately one minute before the tube rupture. Red indicates in alarm state, green indicates not in alarm state. (Credit: CSB)

2.7 Tube Rupture and Heater Fire

As a final troubleshooting step, Marathon Martinez personnel radioed the field operators to shut down some of the fired heater's burners. Shutting down an individual burner involved closing the manual fuel gas valve physically located at the burner.[a] One of the field operators responded to the call and approached the manual fuel gas valves to burners 5 and 6, located immediately next to the fired heater, to close them (**Figure 14**). The field operator shut down burner 5, and at the request of the board operator, he shut down a second burner (burner 6).

[a] Operators had the capability to shut down the fuel supply to all burners from a remote location, but the manipulation of individual burners was only available at the heater itself.

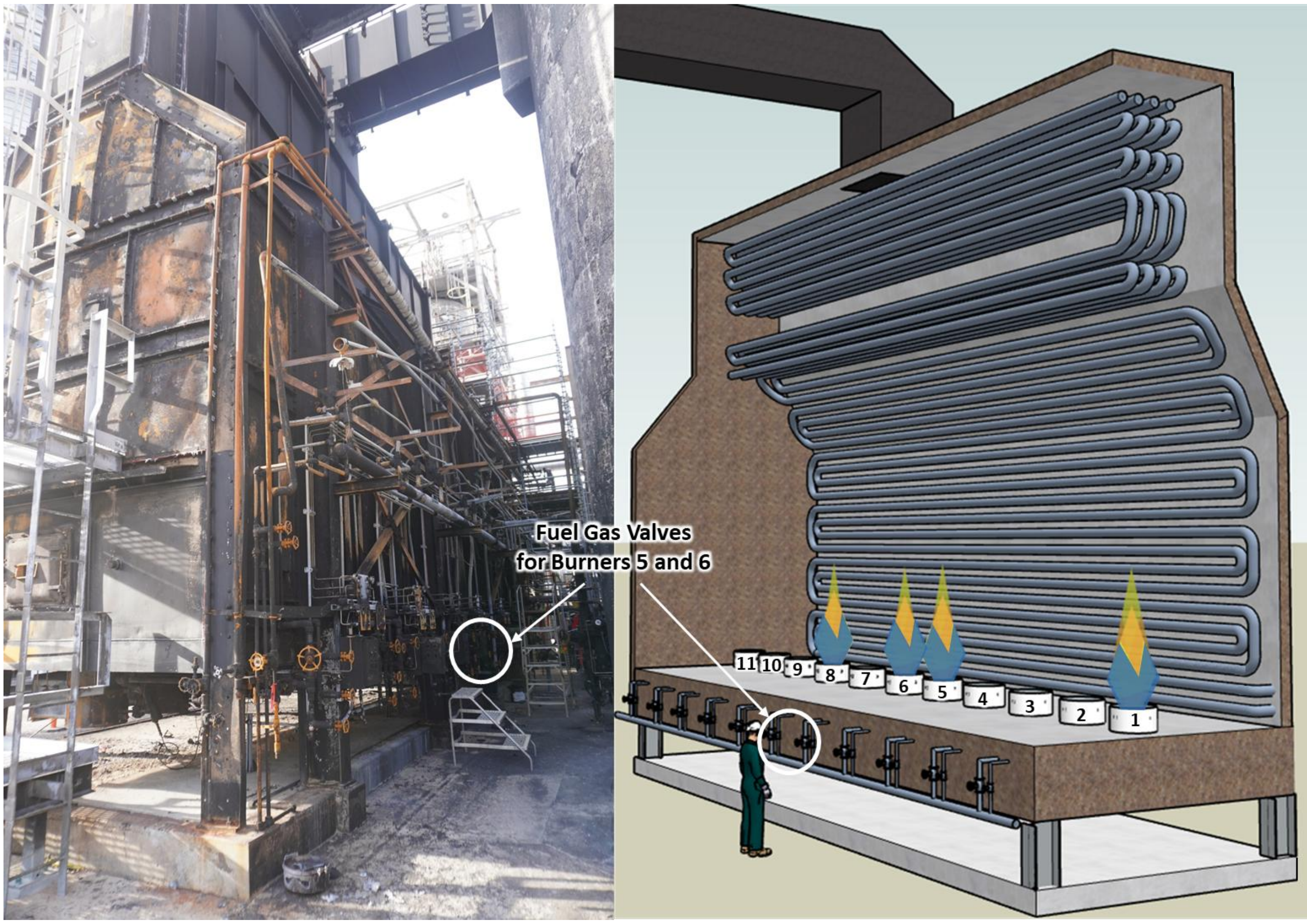


Figure 14. Location of manual fuel gas valves. The lit burners in the figure do not necessarily depict their actual state at the time of the incident. (Credit: CSB)

At 12:21 a.m., just after the field operator had shut down the second burner, one of the fired heater's convection section tubes ruptured (**Figure 15**). The tube had become dangerously hot and suddenly failed from short-term overheating of the tube metal (see *Section 3.1*). The ruptured tube, which had been operating with an internal pressure of approximately 620 psig, released renewable diesel and hydrogen into the firebox (the fired heater enclosure). The released flammable material suddenly ignited, and a fire erupted (**Figure 16**). The release and ignition increased the pressure inside the firebox, forcing the flame and unburnt fuel out of openings in the fired heater. Some of the flammable material was likely released out of the burner view ports, which were located directly above the fuel gas valves and were equipped with free-swinging doors that opened outward (**Figure 17**). The field operator, who was standing next to the heater to access the manual fuel gas valves, became engulfed in flames. Marathon Martinez operations personnel initiated an emergency shutdown within less than one minute of the tube rupture, depressurized the unit, and responded to the fire.[a] The fire was mostly extinguished after about 15 to 20 minutes.

[a] The emergency depressurization command was configured to shut down sources of pressure within the unit and depressurize the reactor. In addition, the outlet piping of the heater was equipped with two check valves designed to limit backflow of pressurized process material from the reactor. The board operators were not able to immediately shut down the heater involved in the incident, because the emergency shutdown valve for the fuel gas remained open due to fire damage. An operator had to close the unit's main fuel gas supply to stop fuel gas flow to the heater and stop the fire.

Figure 15. Post-incident image showing the failed heater tube from above. (Credit: Marathon)

Figure 16. Surveillance footage of heater fire. (Credit: Marathon)

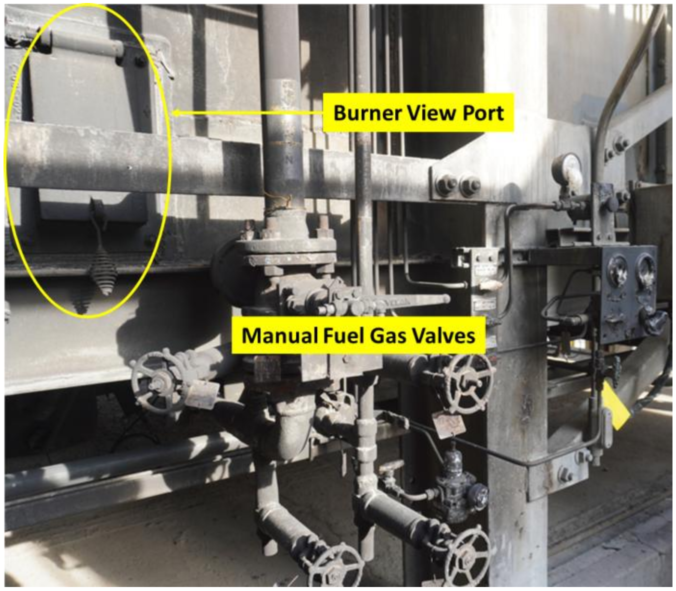


Figure 17. Location of burner view ports in relation to the manual fuel gas valves at the burners. (Credit: CSB)

2.8 Incident Consequences

The field operator was seriously injured by the release and fire, suffering third-degree burns to over 80 percent of his body. Despite his severe injuries, he made his way approximately 80 yards from the heater area to the field operator shelter, leaving behind a trail of personal belongings and pieces of burnt coveralls. He was discovered by another Marathon Martinez employee and was soon transported to a nearby hospital by helicopter for treatment. In the months after the incident, he underwent multiple reconstructive surgeries on his face, body, eyes, and hands, including skin grafting and amputation at various levels of all 10 of his fingers. In June 2024, more than six months after the incident, he was transferred to a rehabilitation facility near his family in Houston, Texas.

Marathon estimated that the tube rupture incident released over 200,000 pounds of renewable diesel and approximately 2,200 pounds of hydrogen. Marathon did not report off-site or community impacts.[a]

Marathon estimated that the incident resulted in property damages of approximately $350 million. The unit remained shut down for approximately one year until its restart in November 2024.

[a] Marathon reported that fenceline air monitors did not detect parameters above background conditions, and Marathon did not receive off-site complaints [73]. Contra Costa Health issued a public health advisory through its community warning system [73, 74], but there were no evacuation orders for the general public.

3 Technical Analysis

The November 19, 2023, incident occurred when a fired heater tube ruptured due to short-term overheating (see *Section 3.1*) caused by both a significant process flow reduction to the fired heater (see *Section 3.2*) and afterburning inside the heater (see *Section 3.3*).

3.1 Short-Term Overheating

Post-incident metallurgical analysis confirmed that the fired heater tube that ruptured failed due to a damage mechanism called short-term overheating stress rupture, also known as hot tensile rupture. The American Petroleum Institute (API) Recommended Practice (RP) 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*, defines short-term overheating as “permanent deformation occurring at very high temperatures and […] low stress levels as a result of localized overheating” [28, p. 281]. Particularly, a critical factor is that “the local overheating is well above the design temperature” [28, p. 281]. Fired heater tubes are typically designed to a thickness sufficient to contain the working process pressure up to a certain temperature.[a] At considerably higher temperatures, the tube weakens to the point where the working pressure inside the tube pushes the tube wall outward, causing its diameter to increase and the metal to thin, further weakening the metal. The bulged tube eventually fails by an elastic (“fish-mouth”) rupture (stress rupture).[a]

Short-term overheating damage is typically characterized by localized bulging exceeding 3 percent of the tube’s original diameter [28, p. 281]. Post-incident, the CSB and Marathon identified tube bulging immediately around the ruptured area, as well as bulging in nearby tubes that had not ruptured (**Figure 18**). The bulging was indicative of tube metal temperatures being highest in the convection section (**Figure 19**).[b]

Figure 18. Convection section tubes showing more than 3% outer diameter growth. (Credit: CSB)

[a] Marathon required the use of API Standard 530 (API 530), *Calculation of Heater-tube Thickness in Petroleum Refineries* [32], to determine tube design criteria in its fired heaters. The Martinez fired heater’s tube design was based on design specifications involving process pressures, temperatures, metallurgy, and tube thickness.

[b] Marathon collected outer diameter measurements of all heater tubes in the radiant section and the convection section up to the ruptured tube. No damage was noted on the tubes in the middle and lower radiant section. The finned tubes in the upper convection section were not measured.

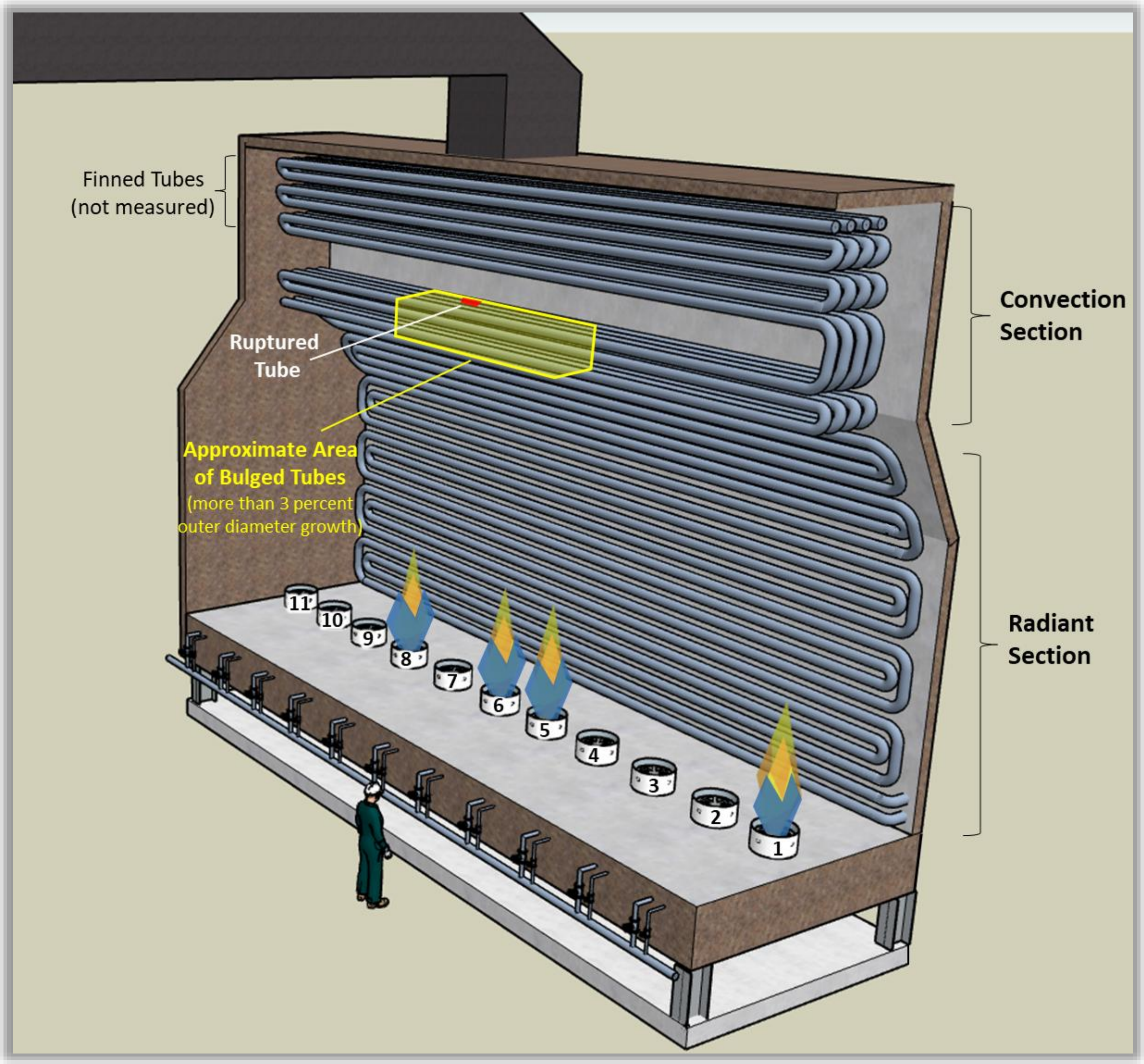


Figure 19. Heater illustration depicting tube damage found upon internal inspection post-incident. Note: The lit burners do not necessarily depict their actual state at the time of the incident. (Credit: CSB)

During the incident, tube metal temperatures exceeded their design temperature of 1,120 °F, rising to as high as 1,710 °F as measured by the thermocouples. The metallurgical analysis confirmed that the ruptured tube likely reached metal temperatures between 1,500 to 2,000 °F prior to the rupture. At these elevated temperatures well above the design temperature, the tubes were operating with significantly reduced strength.

The CSB concludes that the fired heater tube ruptured due to a damage mechanism called short-term overheating, which occurred when elevated temperatures much higher than the tube design temperature in the convection section of the heater caused the tube metal to lose strength and eventually fail at the process operating pressure.

Appendix E of this report includes links to seven other fired heater tube rupture incidents that have been reported to the CSB since 2020. At least five of these seven incidents were also caused by the same short-term overheat damage mechanism.

3.2 Flow Diversion Around the Heater

After the incident, Valve B was found in the open position when it should have been in the closed position. A post-incident hydraulic analysis found that with Valve B and the Diverter Valve in the open position, the flow path of least resistance was through the path shown in blue in **Figure 20**.[a] Process data also indicates that tube metal temperatures rapidly increased each time that the Diverter Valve was open, indicating that the flow path shown in **Figure 20** was available even when operators had closed Valve A (not shown in this figure).[b] The CSB concludes that leading up to the incident, process fluid diverted around the fired heater through a misaligned valve (open when it should have been closed), causing low flow through the fired heater tubes.

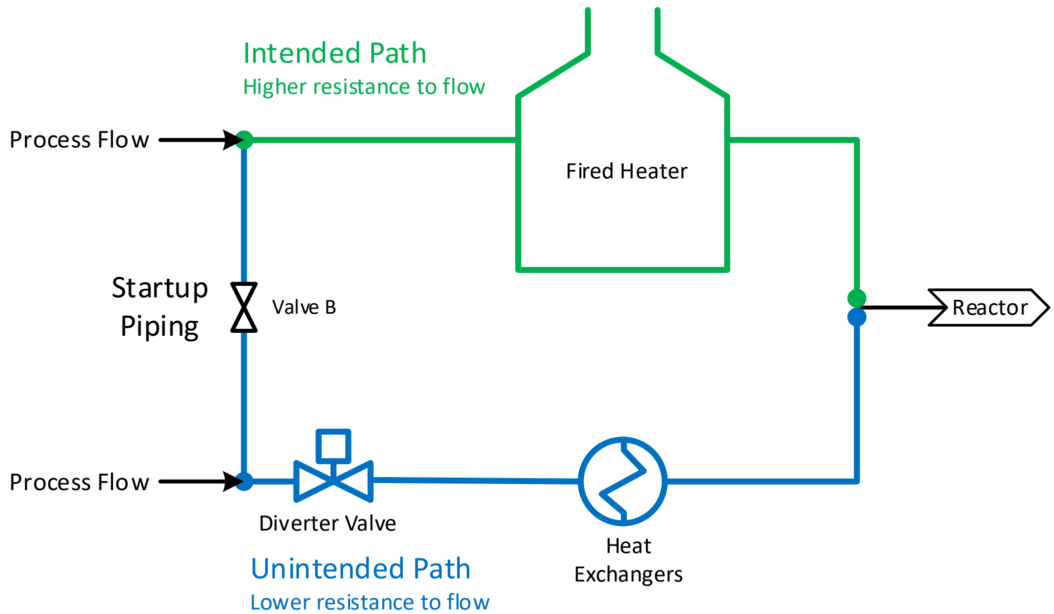


Figure 20. Simplified diagram of the two potential flow paths introduced by the open Valve B. (Credit: CSB)

[a] Marathon's initial simplified hydraulic model did not predict that most of the flow would bypass the heater. In its final investigation report, Marathon explained: "Simplified hydraulic models may not adequately predict the elevation changes in a system, only accounting for the total pressure drop" [34, p. 4]. To refine the hydraulic analysis, Marathon performed field walks and identified high points in the piping system between Valve B and the combined feed piping into the reactor. Marathon concluded that "the required pressure drop to overcome the elevation difference is 22 psig, compared to the backpressure available of the alternate path of 11.2 psig" [34, p. 4].

[b] The CSB determined that Valve B was likely open during the earlier startup attempt on November 11, 2023, based on measured hydrogen flow through the startup piping and tube metal temperature trends. However, there was less overheating observed in the convection section tube metal temperatures on November 11, likely in part due to differences in burner configuration and operation, and in makeup and recycle hydrogen rates and lineups.

3.3 AFTERBURNING IN THE HEATER'S CONVECTION SECTION

During normal fired heater operation, combustion should be completed before the flue gas exits the radiant section (the bridgewall, **Figure 2**).[a] Otherwise, combustion will continue to generate heat in the convection or stack sections and cause overheating and potential damage to equipment. The uncontrolled combustion past the fired heater's radiant section is called afterburning [29, pp. 343-345, 30, pp. 14, 28-29].

During the hour before the tube rupture, process data shows that tube metal temperatures were often higher at the convection section than at the top of the radiant section, indicating afterburning in the convection section. Post-incident, significant tube bulging and overheating damage confirmed that the highest-temperature locations were in the convection section.[b]

Post-incident, two of the four operating burners (burners 1 and 6) were found with their air intakes closed with cover plates (**Figure 11**), which likely prevented proper air-fuel mixing at the burners. Without proper air-fuel mixing at the burners, some unburnt fuel likely moved upward in the fired heater where it subsequently came into contact with available air at or near the convection section and ignited, causing afterburning and high tube temperatures.

The CSB concludes that the covered air intakes with fuel valves open on the fired heater burners in operation contributed to afterburning in the fired heater. A combination of afterburning and low flow through the fired heater tubes caused tubes located within the fired heater's convection section to overheat until a tube ruptured.

[a] The bridgewall, also known as the arch of the heater, is the sloped portion of the heater's radiant section opposite the floor [24, pp. 5-6].

[b] The newly installed tubes were all confirmed to be the same diameter and same metallurgy throughout the heater prior to start-up activities.

4 SAFETY ISSUES

Fired heaters are an essential and critical technology in the hydrocarbon and chemical processing industry [29, p. 31], yet fired heater tube rupture events occur too frequently.[a] In addition to the Marathon Martinez incident, at least seven other fired heater tube rupture incidents[b] have been reported to the CSB since the CSB promulgated its Accidental Release Reporting Rule in March 2020.[c,d] Two of these incidents, including the Marathon Martinez incident and a 2022 incident at the Valero Texas City Refinery, involved operators troubleshooting high tube temperatures while located near the fired heater at the time or shortly before a tube ruptured. These incidents illustrate that troubleshooting fired heaters can be hazardous for field operators who are tasked with inspecting tubes or adjusting burners when tubes are at elevated temperatures. Companies must designate tube metal temperatures at which all troubleshooting efforts must stop (see Section 4.1 *Safe Operating Limits*), approaching the heater should be avoided (see Section 4.2 *Worker Proximity to Fired Heater*), and other actions, such as shutting down a fired heater remotely, should be taken to avoid putting operators in these hazardous situations. Such precautions could have prevented the serious injury that occurred at the Marathon Martinez facility.

Additional safety issues that contributed to the tube rupture, flammable mixture release, and fire include:

- Marathon Martinez did not identify that process flow could divert around the fired heater in a manner that was undetectable to the safety instrumented system configured to prevent the heater from operating with low flow. (see Section 4.3 *Low Flow Through Fired Heater*);

- Marathon Martinez inadequately trained operators on fired heater operation and had procedures that did not detail the necessary steps to safely operate the heater, such as by ensuring cover plates were removed before lighting burners. Marathon Martinez also did not effectively monitor the combustion conditions inside the fired heater to identify when operational problems, such as high combustibles that could contribute to afterburning, were occurring. (see Section 4.4 *Burner Operation*);

- Marathon Martinez did not provide adequate operating procedures and training, equipment nomenclature and labeling, or other practices such as inherently safer systems analyses or "Walk the Line," to help ensure the piping was correctly aligned to route sufficient process flow to the fired heater. (see Section 4.5 *Valve Misalignment*); and

[a] One author, in describing the role of fired heaters in refineries and chemical plants, states that "combustion is the very lifeblood of the petroleum, petrochemical, and chemical sector" [29, pp. 31-32]. Another industry expert estimated that there are approximately 3,000 refinery fired heaters in the United States [88, p. 16]. A 2021 historical survey analyzed 189 fired heater and boiler accidents and found that the leading causes of the incidents were tube ruptures and errors in ignition/reignition sequences. The authors concluded that the accidents continue to occur frequently in part because "the number of existing units is quite high" [67].

[b] The seven other incidents, referenced in Appendix E, caused significant property damage totaling approximately $105 million.

[c] 40 CFR Part 1604

[d] The reporting rule requires the owner or operator of a stationary source to report any accidental release resulting in a fatality, serious injury, or substantial property damages. The CSB's Incident Reporting Rule website includes all accidental release incidents reported since March 23, 2020, the effective date of the Accidental Release Reporting Rule. The listing is revised quarterly and may include revisions or corrections to events previously reported and events that were not timely reported to the CSB in accordance with the regulation [68].

- Marathon Petroleum Corporation did not adequately ensure that its Martinez facility conformed to corporate standards, which included process safety requirements that could have helped to prevent this incident. (see Section 4.6 *Corporate Oversight*)

Appendix A contains the accident map (AcciMap), which provides a graphical analysis of this incident.

4.1 Safe Operating Limits

As described in this section, Marathon did not provide adequate guidance for workers to properly recognize and respond to the dangerously overheated tubes on the night of the incident. As a result, personnel continued to troubleshoot high tube metal temperatures until a tube ultimately ruptured.

Marathon Operating Limit Requirements and Resulting Actions Before the Incident

Marathon's corporate standards required "Normal Operating Limits" and "Not-to-Exceed" limits for various operating parameters, as defined in **Table 2** below. Marathon's corporate standards required alarms on Normal Operating Limits and Not-to-Exceed limits to trigger operator responses.

Table 2. Marathon's operating limit types that require prompt operator action.

Operating Limit Type	Description
Normal Operating Limit[a]	The upper or lower parameter bound (for example, temperature, pressure, flow rate) of normal operation. When this limit is reached, an Operator ***must troubleshoot*** and intervene to return the process to normal conditions, as continued operation beyond these boundaries will result in equipment degradation, unscheduled shutdown, or environmental exceedances.
Not-to-Exceed Limit[b]	The upper or lower parameter bound (for example, temperature, pressure, flow rate) where ***all troubleshooting ends*** and prescribed actions take place to immediately mitigate the potential problem. The Not-to-Exceed limit is set to avoid loss of containment.[c]

The Normal Operating Limits and Not-to-Exceed limits for tube metal and tube pass outlet temperatures, as well as the operator actions in response to these limits on the day of the incident, are shown in **Table 3** below. Marathon Martinez had not established Not-to-Exceed limits, or the limits at which all troubleshooting should end, for the fired heater tube metal temperatures, however. As a result, the troubleshooting efforts were not halted before the tube ruptured, and Marathon Martinez personnel did not shut down the fired heater remotely from the control room even though they had the capability to do so. In addition, the one type of temperature monitoring that Marathon Martinez *had* established a Not-to-Exceed limit for—the tube outlet pass temperature—was intended to be used to detect loss of flow through each individual heater pass and was never reached before the incident. Use of the tube outlet pass temperature as a Not-to-Exceed limit for detecting loss of flow through a fired heater pass is directly counter to guidance from API RP 556 that states: "A process outlet

[a] API refers to these limits as Integrity Operating Window (IOW) Standard Limits [31, p. 3]

[b] API refers to these limits as Integrity Operating Window (IOW) Critical Limits or Safe Operating Limits [31, p. 3].

[c] At the Marathon Martinez facility, all Not-to-Exceed limits were configured with emergency alarms that required predetermined operator responses in less than five minutes.

temperature measurement is not effective for detecting loss of charge flow," [30, p. 47] and advises against relying on process outlet temperature to detect and control flow through a fired heater.

Table 3. Operating limits for tube metal and tube pass outlet temperatures for the fired heater.

Parameter	Normal Operating Limit	Not-to-Exceed Limit	Actions on Day of Incident
Tube Metal Temperature (Convection Section, four locations)[a]	790 °F	None Established [Not required by Marathon standards]	Marathon procedures stated that when the tube metal temperature reached the Normal Operating Limit, operators should troubleshoot by readjusting flow through the tubes, increasing air to the heater, and adjusting or shutting off burners. Personnel conducted these prescribed actions for about an hour after the tube temperatures exceeded their Normal Operating Limits until the tube ruptured when tube metal temperatures reached up to 1,700 °F.[b] Personnel communicated to the CSB that they continued troubleshooting because no Not-to-Exceed alarm activated.
Tube Metal Temperature (Radiant Section, six locations)	1,100 °F [Note: this temperature was only 20 °F lower than the design temperature of 1,120 °F, the temperature at which the tubes could no longer withstand the process pressure at continued operation. A more appropriate limit would have been 880 °F (see Appendix D for analysis).]	None Established [Not required by Marathon standards]	
Tube Pass Outlet Temperature (One for each pass, four total)	730 °F	1,100 °F [Note: this temperature was set too high per Marathon's standards. A more appropriate temperature would have been 865 °F	According to API RP 556, "A process outlet temperature measurement is not effective for detecting loss of charge flow" [30, p. 47]. Counter to this guidance, Marathon's corporate fired heater standards required some heaters to have Not-to-Exceed limits on high process outlet temperatures to detect

[a] Both the convection and radiant section tubes had the same metallurgy, tube thickness, and design tube metal temperature.

[b] In its post-incident inspection, Cal/OSHA cited the facility for not developing and maintaining a compilation of written safety information for operators "to identify and understand the hazards and consequences of deviations from safe upper and lower limits of process variables of temperature, pressure and flows at the unit." In another citation, Cal/OSHA also cited the facility for not providing this information to affected employees "prior to allowing them to work in the unit." In addition, Cal/OSHA cited the facility for not "immediately remov[ing] exposed employees from imminent hazards created by [the heater]," leading to an operator being in an unsafe location next to the heater when the tube ruptured, seriously injuring the operator.

Parameter	Normal Operating Limit	Not-to-Exceed Limit	Actions on Day of Incident
		(see Appendix D for analysis)][a]	potential losses of flow through individual heater passes.[b] Marathon procedures required shutting down the fired heater when the Not-To-Exceed limit was reached. This Not-To-Exceed limit was never reached on the day of the incident.

The CSB concludes:

- Marathon did not set Not-to-Exceed limits for the fired heater tube metal temperatures, and as a result, personnel never stopped troubleshooting efforts—and did not shut down the fired heater remotely—before the tube ruptured. Troubleshooting efforts put the field operator directly next to the heater when the tube ruptured, and he was seriously injured during the incident.
- Marathon's corporate fired heater standards assert that Not-to-Exceed limits on high process outlet temperatures could prevent tube ruptures upon loss of flow to individual passes. This is inconsistent with current industry guidance advising not to rely on process outlet temperature to detect and control process flow through fired heater tubes. As a result, the fired heater did not have effective safe operating limits and alarms to alert personnel that the heater was in an unsafe state on the night of the incident.

After the incident, the Marathon Martinez facility configured new temperature operating limits and alarms according to Marathon's current fired heater standards. As discussed in this section, however, limits set based on Marathon's current guidance would likely not be effective in preventing a similar incident:

- Marathon lowered the fired heater's pass outlet temperature Not-to-Exceed limit from 1,100 to 850 °F, but this likely would not have prevented the November 19, 2023, incident. The alarm would have been triggered less than two minutes before the tube rupture—which is less time than the Martinez facility's expectation that a board operator should respond to an emergency alarm within five minutes.[c] This remains the only Not-to-Exceed temperature limit for the fired heater, even though the tube metal temperatures are a more direct indicator of tube overheating and a potential tube rupture.

[a] Marathon's operating limits standard required documenting the basis for setting operating limits. The Marathon Martinez facility had not documented the basis for its safe operating limits, and the CSB could not determine how Marathon selected the safe operating limits for the fired heater involved in the incident.

[b] Pass outlet temperature measurements could be coupled with other instruments to detect loss of flow. Appendix E includes a link to a LyondellBasell fired heater incident where flow bypassed the heater. Post-incident, the company began to monitor and alarm the difference between pass outlet temperatures and the combined heater outlet temperature to alert the operators to a potential loss of flow through the heater.

[c] At the Marathon Martinez facility, all Not-to-Exceed limits were configured with emergency alarms that required predetermined operator responses within less than five minutes.

- Currently, Marathon only requires one operating limit alarm for tube metal temperature, while at least two API sources (API RP 584, *Integrity Operating Windows* and API 530, *Calculation of Heater-tube Thickness in Petroleum Refineries*), recommend two levels of alarming—one to alert the operator to a potential longer-term problem, and another to alert the operator to immediately take predetermined actions such as shutting down the heater [31, p. 14, 32, pp. A-2]. Setting two levels of alarms could inform the operators when tube mechanical limits are in danger of being exceeded and when mechanical limits are actually exceeded, with each alarm requiring a different type of predetermined response.

The CSB recommends that Marathon update its corporate "Process Heater Not-to-Exceed (NTE) Limits and Alarms" standard with tube metal temperature alarming guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater. Once Marathon has completed this recommendation, the CSB recommends that the Martinez facility implement tube metal temperature alarming and predetermined operator responses consistent with corporate guidance for the fired heater involved in this incident.

KEY LESSON

Process equipment must be configured with safe operating limit (not-to-exceed limit) alarms that alert personnel that the equipment has reached an unsafe condition, troubleshooting efforts need to end, and predetermined actions must be taken swiftly to shut down or return the equipment to a safe state.

4.2 Worker Proximity to Fired Heater

The November 19, 2023, incident seriously injured the operator who was instructed to turn off individual burners at the heater moments before the tube ruptured. The only way the operator could turn off individual burners was to operate the valves in close proximity to the heater, which placed the operator in an unsafe location when the fired heater tube became dangerously hot and ruptured, releasing flammable hydrogen and diesel that subsequently ignited and escaped the fired heater.

Appendix E lists seven other fired heater tube incidents reported to the CSB from 2020 through 2024. Most of the incidents occurred during startup, abnormal operation, or emergency shutdown activities when field operators were often physically located near process equipment.[a] In one incident at the Valero Texas City Refinery, operators were troubleshooting, visually inspecting tubes, manipulating valves, and shutting off burners at a fired heater approximately one hour before a tube ruptured, releasing flammable materials and causing a fire.[b]

Fired heaters typically require field operators' presence while lighting, monitoring, and adjusting burners, but these activities must stop during hazardous conditions to ensure that operators are out of harm's way. API RP

[a] See incidents 1, 2, 3, 4, 5, and 7 in Appendix E.

[b] See the August 19, 2022, Valero incident in Appendix E.

KEY LESSON

Companies should ensure the safety of their workers by preventing workers from being in close proximity to a fired heater when tube temperatures are high or the fired heater is otherwise in an unsafe condition. Companies should create clear requirements for when troubleshooting in close proximity to fired heaters should be stopped and other actions, such as shutting down a fired heater remotely, should be taken. Enabling safe and remote adjustment of individual fired heater burners could also prevent workers from being in close proximity to fired heaters during troubleshooting efforts.

556, *Instrumentation, Control, and Protective Systems for Gas Fired Heaters*, recommends that facilities have safety instrumented systems that remotely and automatically close the main fuel supply valves to the heater when an unsafe condition is detected or when an operator initiates a shutdown [30].[a,b] As noted, the fired heater involved in the incident had this remote shutdown capability, and Marathon Martinez personnel could have shut down the fired heater remotely from the control room. Not all process conditions require an automated shutdown, however. For example, API RP 556 lists some typical operator responses to alarms that may require them to be physically present at the burners [30, pp. 56-60]. Similarly, Marathon's guidance at the time of the incident stated that operators could shut off individual burners while troubleshooting high tube metal temperatures. Further industry guidance is needed, however, for removing personnel from a fired heater's vicinity when conditions become unsafe for troubleshooting, such as when mechanical limits are exceeded.

The CSB concludes that the field operator was at risk when the heater fire began because Marathon did not prevent workers from being in close proximity to fired heaters while tube temperatures were high or the fired heater was otherwise in an unsafe condition, such as by requiring troubleshooting to stop and preventing personnel from approaching the area, as well as defining when other actions, such as shutting down the fired heater remotely, should be taken.

The CSB recommends that API revise API Recommended Practice 556 *Instrumentation, Control, and Protective Systems for Gas Fired Heaters* with requirements for proper response to high tube metal temperatures, including guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater.

[a] API RP 556 provides a standard for instrumentation and control system design and operation [30] and is a widely accepted RAGAGEP source for refinery fired heater safety instrumentation and controls. At the time of the incident, API RP 556 was a recommended practice intended to provide the industry with useful information rather than mandatory requirements. In 2024, API approved splitting API RP 556 into nine separate standards, many of which will contain mandatory requirements for gas-fired heaters [80]. This substantial update to API RP 556, which may take several years to implement, should improve minimum safety requirements for fired heaters in the refining and chemicals industries.

[b] Current API guidance does not explicitly recommend that facilities have the ability to remotely shut off individual burners, but the technology is available [30, p. 18].

4.3 LOW FLOW THROUGH FIRED HEATER

Low process flow through the fired heater tubes contributed to one of the tubes overheating and rupturing on the day of the incident. As will be discussed in this section, Marathon Martinez did not identify that process flow could divert around the fired heater in a manner that was undetectable by the safety instrumented system configured to prevent the heater from operating with low flow. Marathon did not identify the flow diversion during its process hazard analysis (PHA) or after a similar previous incident at another refinery where process flow was diverted around a fired heater.

4.3.1 PROCESS HAZARD ANALYSIS (PHA)

To protect against low flow through fired heater tubes, Marathon's internal fired heater standard (called the Heater Application Standard) required proper placement of flow meters and automatic functions called Safety Instrumented Systems (SIS) to bring the fired heater to a safe state when low flow was detected. Marathon's Heater Application Standard included the following requirement for flow meters associated with the safety instrumented system (emphasis added):

> The flow [meter] shall be located such that there are **no bypasses**, relief devices **or other flow diversions** located between the flow [meter] and the heater. This will ensure that the low flow SIS is **not accidentally bypassed**.
>
> **Note:** For existing installations, flow diversions are permissible where an engineering evaluation confirms that the flow to the heater will remain above the minimum heater flowrate […] upon a diverted flow scenario. These situations and the method for determining the minimum flowrate shall be reviewed with and approved by the [Marathon] Fired Equipment Specialist. […]

Marathon conducted a PHA for the new renewable diesel unit in June 2022 using the Hazard and Operability (HAZOP) methodology, a common method typically used for complex process units.[a,b] The HAZOP method primarily involves a multi-disciplinary team identifying hazards through systematic piping and instrumentation diagram (P&ID) reviews of equipment groupings [33, pp. 21-24]. At the time of the PHA, a hydraulic analysis of the piping system like the one Marathon performed after the November 19, 2023, incident to understand likely flow paths (see *Section 3.2*) did not exist. Such analysis is typically not required for HAZOP studies.

During the 2022 PHA, Marathon specifically evaluated "misdirected flow" to the fired heater, and determined that misdirected flow could be caused by "either [valve on the startup piping being] inadvertently open[ed],"[c] which was the event that occurred leading to the incident when Valve B was misaligned during startup activities.

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[a] The purpose of a PHA is to identify, evaluate, and control hazards associated with a process [47, p. 51]. A PHA was required by process safety regulations that covered the unit involved in the incident.

[b] Prior to the renewable fuels conversion project, the last PHA performed on the petroleum diesel unit was in 2017. During the renewable fuels conversion project, initiated in late 2021, Marathon repurposed equipment from the existing petroleum diesel unit, reconfigured process piping, and introduced new equipment. In the fired heater preheat section, changes included the number and physical placement of heat exchangers upstream of the reactor. Although portions of the unit's reactor preheat section were physically modified or rebuilt, the petroleum diesel unit's diesel and hydrogen flow control schemes, control valves, hydrogen startup line, and the fired heater's low-flow safety instrumented system remained largely the same in the renewable fuels unit.

[c] The team evaluated "either [valve on the startup piping being] inadvertently open" and did not differentiate between Valves A and B.

The PHA team determined that "[n]o hazardous consequences were identified associated with flowing recycle [hydrogen] gas into the [fired heater feed] stream. This is primarily an operational issue." Based on the PHA team's documentation of information available at the time, the CSB concludes that:

- The PHA team believed that with either of the valves on the startup piping open, additional material would flow *to* the heater. The team did not realize that material would reverse-flow through the piping, *away* from the fired heater, as shown in **Figure 21** below.

- The PHA team did not have sufficient hydraulic analysis information available during the PHA to understand the likely flow directions through the startup piping during all operating modes.

- The PHA team did not consider the startup piping to be potential "bypasses" or "flow diversions" (as so-named in Marathon's internal fired heater standard) between flow meters associated with the fired heater's safety instrumented system and the fired heater itself, as reverse flow was not expected.

- Had the PHA team identified the potential for reverse flow through the startup piping, they should have recommended corrective actions, such as the removal of one of the two branches in the startup piping or the implementation of engineering safeguards to prevent, or detect and automatically respond to, reverse flow and the resulting low flow through the fired heater tubes.

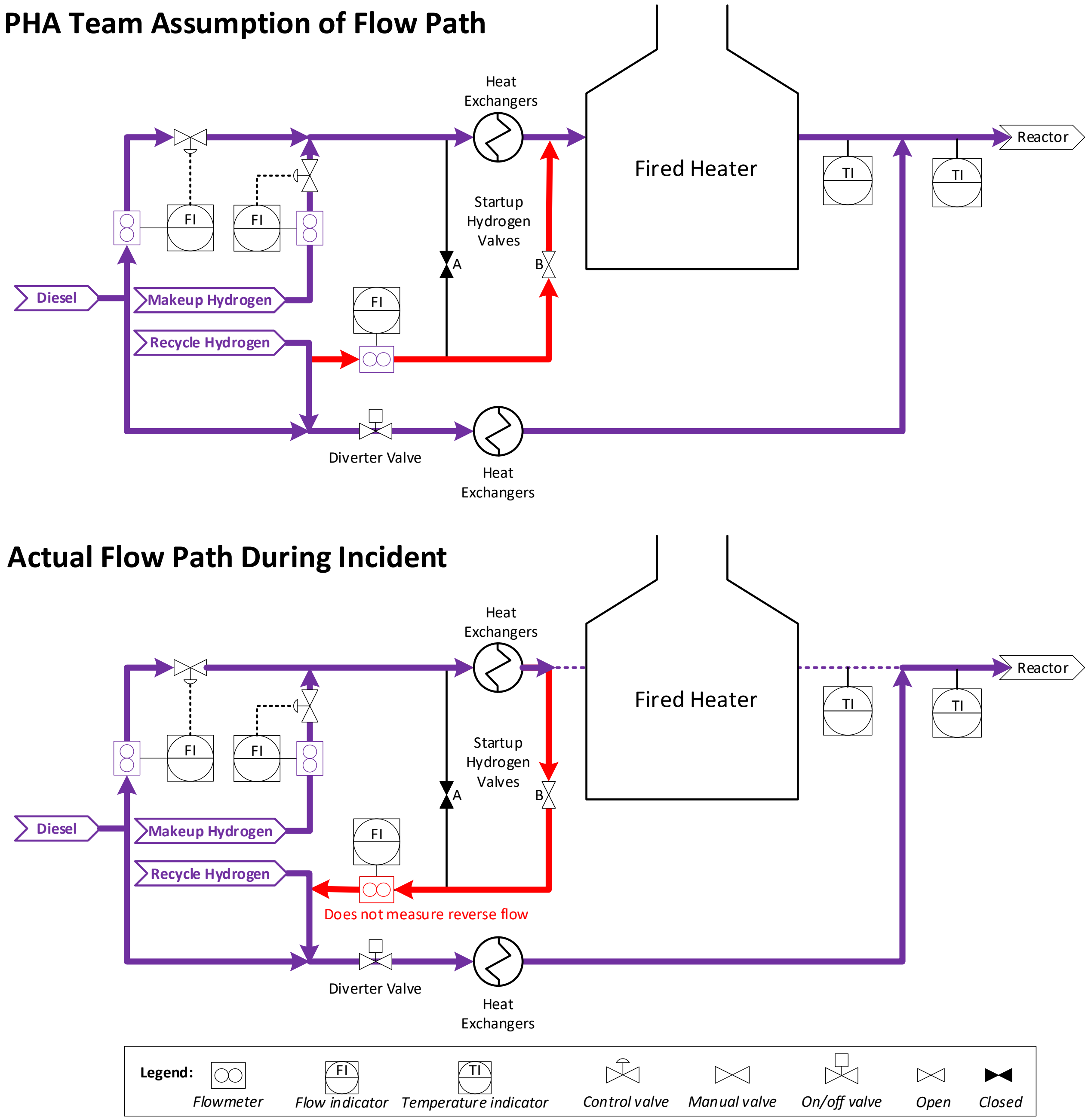

Figure 21. Flow path assumed by the PHA team compared with the actual flow path during the incident. (Credit: CSB)

4.3.2 LEARNING FROM PAST INCIDENTS

Marathon communicated process safety learnings across its refining organization through process safety advisories based on incidents it deemed Process Safety High Learning Value Events (HLVE). In 2019, Marathon created a process safety advisory following a fired heater low flow incident at another Marathon refinery in 2018. The CSB found that although Marathon took actions intended to prevent similar occurrences, these actions did not prevent the November 19, 2023, Martinez incident, as detailed below.

2018 Detroit Refinery Incident

In a process safety advisory sent to all Marathon refineries in 2019, Marathon discussed a 2018 incident at its Detroit refinery where a fired heater was damaged due to low process flow through its tubes.[a] Two valves, labeled in **Figure 22** as being normally closed (NC), were open during the 2018 incident, diverting flow away from the heater during the startup through the bypass piping. The advisory stated: "the low-flow condition was not detected because the bypass line was installed downstream of the SIS flow meter […], essentially defeating the safety system." Appendix C provides further details on this incident.

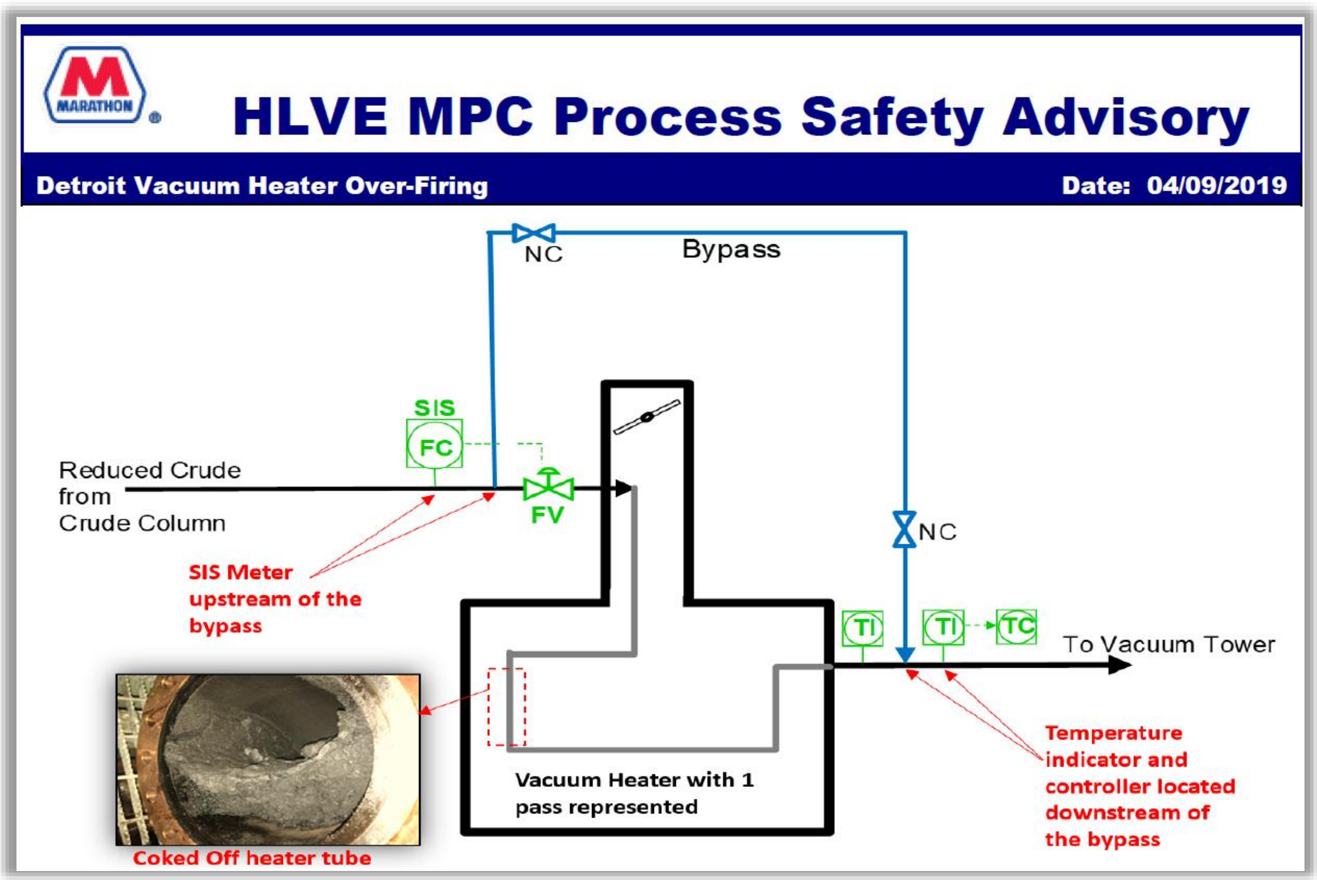

Figure 22. 2019 Marathon process safety advisory showing the defeated SIS flow meter. (Credit: Marathon)

[a] The unit eventually shut down when the process material inside the tubes overheated and plugged due to coke formation, and no tube rupture occurred.

The Detroit incident occurred while the unit was starting up from a project where a means to bypass the fired heater had been added. The PHA had not identified that the newly installed bypass piping could defeat the fired heater's low-flow safety instrumented system. As a result, Marathon failed to implement flow meter placement that would not defeat the safety instrumented system, or safeguards to prevent the valves on the bypass piping from being misaligned.

Marathon shared the process safety advisory with all of its refineries to communicate the learnings from the Detroit incident. In addition, Marathon implemented refinery surveys, updated its corporate PHA guidance documents, and updated its corporate safety instrumented system standards, as discussed below. None of these changes, however, prevented the Marathon Martinez incident in November 2023.

Refinery Surveys

In the 2019 process safety advisory, Marathon required all its refineries to do the following:

> Conduct a survey of all fired heaters at the site for bypass lines (equipment bypasses, startup bypasses, PSVs, etc.) that could:
>
> 1. defeat the low flow SIS shutdown
> 2. quench [lower] the outlet temperature controller reading for the heater.

The Marathon Martinez facility (then operating as a petroleum refinery) surveyed each of its fired heaters in 2019 using a checklist that asked, "Does the [heater] have bypass lines or PSVs that bypass the passes?" Of the 41 heaters that the Martinez refinery surveyed, 14 were identified to have bypasses around the heaters, but the heater involved in the November 19, 2023, incident was not one of the 14 identified. Nevertheless, Marathon Martinez concluded:

> Based on the survey results, […] in no instance do we have the potential to defeat the SIS low flow shutdown (i.e. flow indications feeding the SIS are downstream of the bypass take-off).

The Martinez incident differed from the Detroit incident in several ways:

- The Detroit bypass piping was intended by design to divert flow around the heater, while the Martinez startup piping was not;
- The Detroit bypass piping directed the process flow in the intended direction, while the Martinez startup piping directed the flow in the reverse direction, leading to the incident; and
- The Detroit fired heater was fed a single-phase (liquid) flow, while the Martinez fired heater was fed a two-phase (liquid and gas) flow that necessitated flow meters on the individual liquid and gas piping before they combined downstream of the respective flow meters.[a] During the Marathon Martinez

[a] Regarding fired heater protections for two-phase flow, such as in hydroprocessing units, API RP 556 states: "[t]wo phase flow cannot be measured reliably therefore the liquid and vapor phase flows should be individually controlled […]" [30, p. 20].

incident, the flow diversion occurred in gas feed piping downstream of the diesel and main hydrogen feed flow meters.

PHA Template and Company Standard Changes

Marathon determined that the potential flow diversion through the bypass piping involved in the 2018 Detroit incident could have been identified in a PHA, but it was not. Accordingly, the 2019 process safety advisory recommended the following for all Marathon refinery PHA teams to consider in future PHAs:

> **PHA Team:** During each 5-year PHA, evaluate whether (1) safety systems could be defeated or (2) the heater outlet temperature [could be lowered] due to open bypass lines, PSVs [(pressure safety valves)] lifting, etc. Where these safety systems can be defeated, the team shall make recommendations to modify the design and/or manage bypass lines during all modes of operation.

In 2019, Marathon updated its corporate PHA template to include the guide words "bypassing of safety systems due to inadvertently opened bypasses, PSVs, etc." and "shutdown system defeated by open bypass lines, PSV, etc." in two different sections of its PHA template, citing the 2019 process safety advisory as a source. Additionally, in 2020, Marathon updated its corporate SIS standard to require the following:

> For maintenance and startup purposes or for over pressure protection there may be cases where a piping bypass exists to divert flow around a piece of protected equipment, or a [pressure relief valve] may be located on the inlet side of a piece of protected equipment. Flow [meters] that provide low flow protection for the associated equipment shall be located such that there are no bypasses, relief devices or other flow diversions located between the flow [meters] and the protected equipment for new construction after [2020]. This will ensure that the low flow SIS is not accidentally bypassed.

The 2022 Martinez renewable diesel unit PHA team received general training on fired heater low-flow hazards; however, the PHA produced by the team did not document specifically reviewing the 2019 process safety advisory stemming from the Detroit incident. In addition, the PHA did not include the new guide words that Marathon added to its corporate template in 2019, suggesting that the Martinez PHA team used a different template for the 2022 PHA. The Martinez facility's conformance to Marathon's corporate standards is discussed further in *Section 4.6*.[a] The CSB notes, however, that even with the new PHA template prompt, the PHA team still might not have identified the Martinez fired heater flow diversion, because the team did not document any potential for reverse flow in the startup piping upstream of the fired heater.

The CSB concludes that Marathon's updated corporate guidance in 2019 and 2020 after a similar 2018 fired heater low flow incident prompted neither the 2019 Marathon Martinez fired heater survey team nor the 2022 Marathon Martinez PHA team to identify the potential for flow to bypass the heater involved in the November

[a] Post-incident, the Marathon Martinez facility reviewed PHAs for all three renewable diesel units at the facility to ensure conformance with Marathon's PHA and LOPA (layers of protection analysis) standards. The review resulted in an additional 51 PHA and 9 LOPA recommendations for two out of the three process units.

19, 2023, incident and defeat the safety instrumented system, likely because the review teams did not consider the startup piping to be a potential fired heater bypass or flow diversion.

The CSB recommends that Marathon update its "Heater Application Standard" with requirements for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system.

KEY LESSON

Companies should ensure that fired heaters are adequately protected from operating with low flow by evaluating all process connections between flow meters associated with the safety instrumented system and the heaters they are intended to protect, including considerations for reverse and misdirected flow.

API RP 556 recommends that fired heaters be equipped with safety instrumented systems that trigger an automatic safety shutdown when low flow is detected [30, pp. 28, 47]. Regarding two-phase flow, such as in hydroprocessing units, API RP 556 acknowledges: "[t]wo phase flow cannot be measured reliably therefore the liquid and vapor phase flows should be individually controlled […]" [30, p. 20]. Since fired heaters with two-phase feed often have flow meters on the individual liquid and gas piping before they combine downstream of the respective flow meters, there will be piping connections between the flow meters and the fired heater where reverse flow could occur during some operating modes. To prevent future incidents similar to the Marathon incident throughout the industry, the CSB recommends that API develop design requirements ("shall" rather than "should" language) for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter, in API Recommended Practice 556, *Instrumentation, Control, and Protective Systems for Gas Fired Heaters* or successor API products. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system.

4.3.3 Marathon Post-Incident Actions

Post-incident, the Marathon Martinez facility made physical changes to the startup piping to prevent a recurrence of this incident after revising its PHA to properly reflect the potential for flow diversion through the startup piping. Changes include the removal of the startup hydrogen Valve B, the addition of a valve position indicator on Valve A viewable from the control room,[a] installing dual diverse check valves in the startup hydrogen piping (**Figure 23**, circled in red), and updating operating procedures and operator training on the use of the startup piping [34, pp. 5-6].[b]

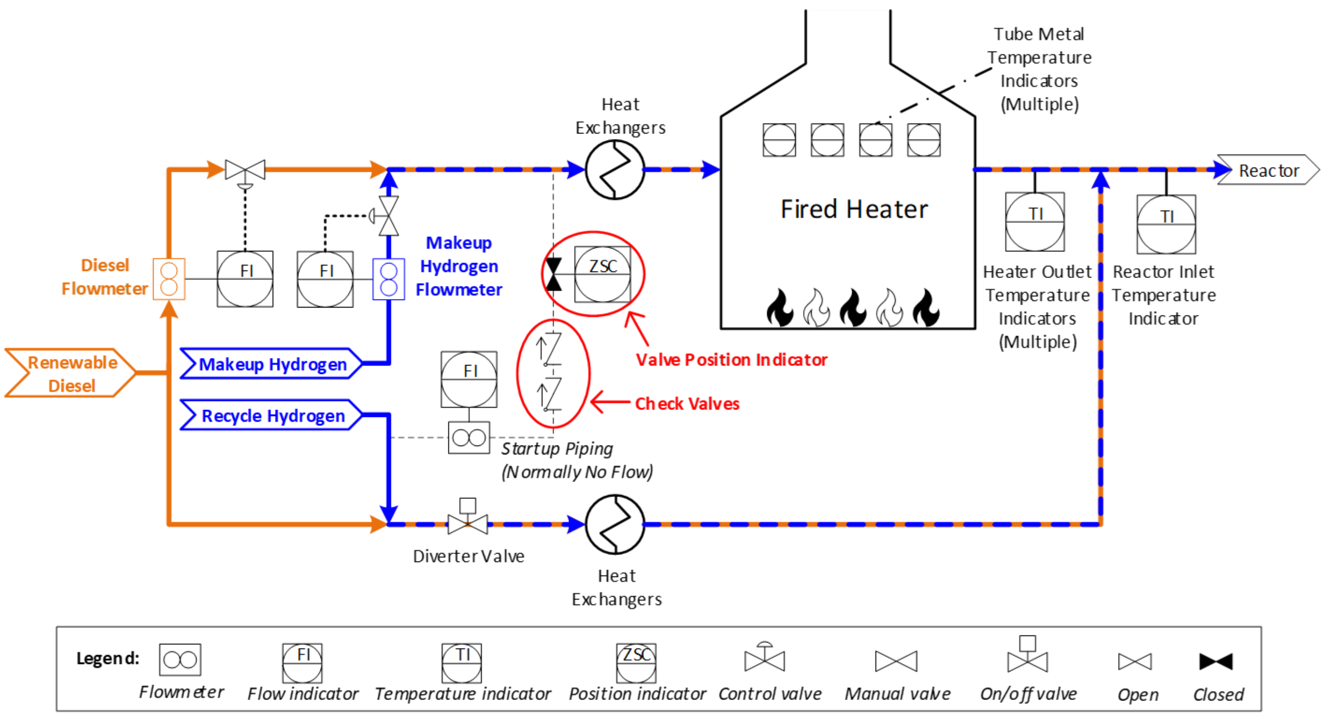

Figure 23. Marathon's post-incident modifications to the startup piping. (Credit: CSB)

[a] The Center for Chemical Process Safety (CCPS) publication *Inherently Safer Chemical Processes – A Life Cycle Approach* encourages "designing controls, indications, alarms and other man-machine interfaces so that there is no confusion, especially during accident conditions, of the status of plant equipment" [63, p. 77]. As discussed previously, the two valves on the startup hydrogen line were manually operated valves with no position indication feedback available for the board operators. The board operators could have noticed and corrected the valve misalignment, restoring flow to the heater well before the tube rupture, had the open-close status of these valves been visible to them. Another way to eliminate the potential for valve misalignment could have been to incorporate permissives (safety features that allow actions to occur only when certain conditions are met) into the control system so that the control system would not allow the opening of one valve until the other one was closed.

[b] The new startup procedure also requires shutting down the fired heater prior to opening the Diverter Valve and establishing the normal process routings, likely to minimize the impact of abrupt flow disruptions to the fired heater as routings are changed.

4.4 Burner Operation

As described in this section, the CSB found that improper operation of the fired heater burners, inadequate operator training and procedures, inadequate flame monitoring of the burners, and poor combustibles monitoring resulted in afterburning in the fired heater, which contributed to the tube rupture on the day of the incident.

4.4.1 Air Inlet Cover Plates

At the heater involved in the incident, each burner was equipped with air registers (or dampers) that could automatically open and close to control the air intake through the burner.[a] The air registers drew in some air even when they were closed. Because "tramp air" (air leakage into fired heaters through the air registers of out-of-service burners) can lead to excess oxygen in the heater and the formation of undesirable environmental emissions such as NOx [29, pp. 345-347], the burners could be covered by cover plates when not in use (**Figure 24**).[b] The Marathon Martinez facility's hydroprocessing unit training workbook explained:

> Each burner has a cover plate that will be used to cover the air inlet to that specific burner if the burner was offline. This is done to ensure that excess tramp air does not enter the box when the burner is [offline].

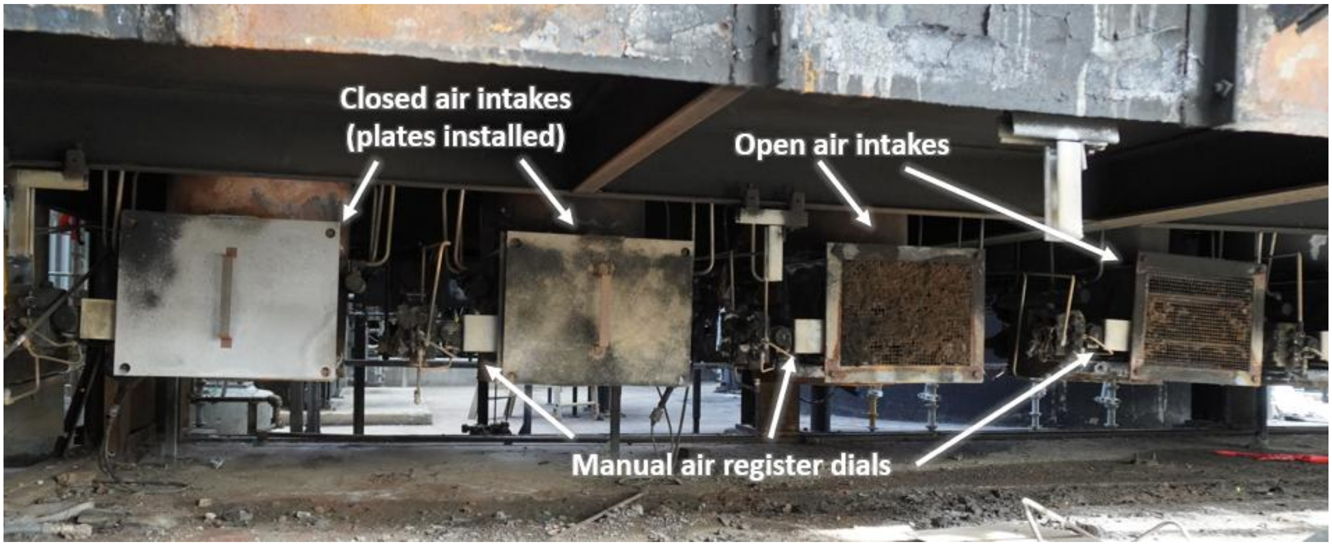

Figure 24. Burner air intakes, cover plates, and air register dials at each burner. (Credit: CSB)

As described in *Section 3.3*, the CSB found that two of the four operating burners' air intakes were blocked by cover plates, which led to afterburning in the fired heater and contributed to the tube rupture on the day of the incident. The CSB found that neither the operating procedures nor the operating training for the unit involved in the incident adequately instructed operators to remove these cover plates prior to lighting the burners:

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[a] Operators could adjust the air registers either locally via a manual dial on the burner or remotely from the control room.

[b] One Marathon employee told the CSB that offline burners would draw in too much air into the heater even with their air registers fully closed; therefore, they were supposed to be covered with plates.

- While the unit training workbook quoted above stated that cover plates are for offline burners, the operating procedures did not direct operators to remove cover plates before lighting burners. One procedure instructed field operators to "[t]urn the air register dials to 0% open on the burners which are not in service […]" with no mention of cover plates. Similarly, the operating procedure for starting the heater and lighting burners only instructed the board operator to remotely open the air registers[a] and did not instruct the field operator to remove the cover plates.

- Although the field operator training manual discussed cover plates, the operators were not specifically trained on the cover plates, which were not available for use until the day before the incident. Many of the field operators had only six months or so of operating experience at the Martinez facility, with some having no prior operations experience.[b] Marathon did not ensure that these operators, who may not have had fired heater safety training and experience prior to working at the Martinez facility, had sufficient knowledge about safe burner operation.

KEY LESSON

Operating procedures and operator training should include verification that air intake covers (where used) are removed prior to lighting a burner. Improper air-fuel mixing at the burners could lead to poor combustion control and high localized temperatures inside the heater.

The CSB concludes that Marathon did not ensure its operators had sufficient knowledge about safe burner operation. As a result, on the night of the incident, two of the four burners in service (burners 1 and 6) had their air intakes obstructed by cover plates, contributing to poor burner operation and afterburning inside the fired heater. Had Marathon incorporated administrative controls, operating procedures, and operator training to require that the air intake cover plates be removed prior to lighting the burners, the afterburning that contributed to the tube rupture could have been prevented.

Post-incident, Marathon implemented the following changes across multiple units at the Martinez facility:

- Developed a new two-day fired heater safety training class, which incorporated learnings from the November 19, 2023, incident, and trained all renewable fuel operators at the Martinez facility;

- Installed warning signs at each burner to remove air register plates prior to lighting the burner, at multiple fired heaters at the facility (**Figure 25**);

- Relocated the ignitor panel of the heater involved in the incident to be on the same side of the heater as the air register plates so that the plates can be visible; and

[a] API RP 556 recommends visually confirming that air registers are open prior to lighting a burner [30, p. 62].

[b] One of the three field operators lighting burners on the night of the incident had approximately six months of experience as a refinery operator. Another field operator had prior chemical plant operations experience and had approximately six months of experience at the Martinez facility. The third field operator had prior operating experience at the Martinez facility at a different unit and had not lit burners at this heater.

- Updated operating procedures with steps to remove air register cover plates prior to lighting burners and caution statements to warn operators of the hazards of blocked air registers.[a]

Figure 25. Signage installed at burner fuel gas valves at the Marathon Martinez facility post-incident. (Credit: Marathon)

4.4.2 Flame Monitoring

Flame detectors (also called flame scanners or fire eyes) are commonly used in heater safety instrumented systems for continual monitoring of a flame, and to automatically shut down the heater during dangerous combustion conditions such as a loss of flame [35, pp. 16-18]. The fired heater involved in the incident was equipped with flame detectors on 4 of the 11 burners, which were distributed evenly across the heater (**Figure 11**) and tied into the heater's safety instrumented system.[b] During startup activities, the process rarely needed more than four burners at a time, and the four burners equipped with flame detection were not always available

[a] Marathon Martinez also added a discussion on the importance of removing cover plates when burners are placed in service to the operator training manual.

[b] For fired heaters with more than 10 burners, Marathon required minimum flame detector coverage for 33% of the burners for existing applications and 50% of burners for new heaters. Marathon added the four flame detectors with an automated flameout shutdown to this heater's safety instrumented system as part of the 2023 renewables conversion project.

for use.[a] The operating procedures and operator training did not provide requirements for lighting specific burners, and Marathon personnel used various combinations of 10 of the 11 burners throughout the unit startup activities.

At the time of the incident, only one of four operating burners (burner 1) had a flame detector.[b] While burner 1's flame detector indicated that it remained lit leading up to the incident, the board operator had no information on the flames of the other three burners and had no way of knowing whether the burners remained lit.

The CSB concludes that the available flame detection capability was ineffective for protecting the fired heater on the night of the incident.

API RP 556 currently does not have flame detector requirements for fired heaters, stating that "flame monitoring may be used to detect loss of flame at one or more burners" [30, pp. 16-18].[c] Marathon's standards exceeded API RP 556 requirements in that they required a minimum percentage of burners to have flame detectors in both new and existing fired heaters. For existing fired heaters with more than 10 burners, such as the fired heater involved in the incident, Marathon recommended a minimum flame detector coverage of 33 percent.

Post-incident, Marathon installed a tunable diode laser (TDL) analyzer that continually monitors for methane, an indicator of unburnt fuel, at the bridgewall of the fired heater involved in the incident. The TDL could detect potential flameout without the need for a flame detector on each burner. Marathon configured a high methane alarm to alert the board operator of a "fuel rich firebox" that could result from potential loss of flame in the fired heater, with predetermined actions to reduce fuel gas or shut down the heater.[d]

4.4.3 Combustibles Measurement

Incomplete combustion can be detected by measuring combustibles such as carbon monoxide (CO), hydrogen, methane, and other fuel molecules.[e] API RP 556 states that "[c]ombustibles measurement may be used to detect the onset of incomplete combustion," and that "high levels of combustibles in the flue gas may be an indication

[a] Burners had to be taken out of service for maintenance at various points in the startup due to burner tip plugging, poor flame patterns, and other issues.

[b] When operations personnel restarted the fired heater, the heater was operating with the safety instrumented function associated with the flame detectors bypassed.

[c] The National Fire Protection Association (NFPA) publication NFPA 87, *Standard for Fluid Heaters*, is a standard for fired heaters in pressurized fluids service that excludes "fired heaters in petroleum and petrochemical facilities that are designed and installed in accordance with [API standards]" [81]. According to one source, the average heat input of a refinery natural draft fired heater in the United States is 72 million British thermal units per hour [88], while fired heaters that fall under NFPA 87 scope "suppl[y] a total input not exceeding 150,000 [British thermal units per hour]" [81, p. 1.1.3]. NFPA 87 requires that *each* burner has a flame detector tied into the safety instrumented system [81, p. 9.9.1].

[d] Marathon's post-incident investigation also determined that changes in the hydrogen content of the refinery's fuel gas composition contributed to flame stability issues in the heater. Post-incident, Marathon configured fuel gas composition alarms to alert the board operators to make adjustments to the refinery fuel gas to maintain the hydrogen concentration above a predetermined limit [34, p. 5]. In addition, for the fired heater involved in the incident, Marathon's internal investigation team recommended an evaluation of the burner's design to improve burner stability for a wider operating range in the future.

[e] Combustibles can be measured using analyzers that sample the combustion gas within the heater. API 556 recommends an infrared or laser-based CO measurement for a heater's air/fuel ratio for process control due to its faster response time; however, these sensors do not measure other combustibles [30, pp. 14-15, 82].

of […] improper burner operation or a change in fuel gas heating value." For fired heaters with combustibles detection, API recommends:

> Combustibles measurements should be taken as near as possible to the point where combustion should be completed, normally at the bridgewall. Combustibles should not be measured in the stack due to the potential for afterburning in the convection section [30, p. 14].[a]

Marathon's corporate "Process Heater Not-to-Exceed (NTE) Limits and Alarms" standard recommended that "the CO/combustibles reading should be made available to the Control Board Operator" and should be programmed with a high-priority alarm for when combustibles measurements at the bridgewall reach 1,500 parts per million (ppm). Despite this guidance, Marathon's Heater Application Standard also allowed the use of the stack analyzer to detect insufficient combustion if the heater was not already equipped with a combustibles analyzer.

The fired heater involved in the incident was equipped with a combustibles analyzer at the bridgewall,[b] but its readings were only available at a local panel next to the heater. Additionally, the combustibles data was not recorded and therefore was not available for review post-incident. Field operators reported checking this panel to ensure there were no combustibles before lighting pilots and burners; however, there was no continual combustibles monitoring available to the board operators at the control room, and, as noted, the data was not recorded.

On the night of the incident, stack CO and excess oxygen monitoring data did not indicate incomplete or a significant loss of combustion.[c] Because no combustibles measurement was available for continual monitoring inside the control room, the board operators could not detect incomplete combustion inside the radiant section of the heater that would have been indicative of afterburning leading up to the tube overheat and rupture.

The CSB concludes that the fired heater was not equipped with sufficient engineering controls to ensure safe operation, including burner flame detectors or combustibles measurement. Improved engineering controls could have notified the board operators of burner flameouts and afterburning, allowing them to take action to restore safe heater operation and prevent the incident.

Post-incident, Marathon made the following changes to the fired heater involved in the incident:

- Made existing combustibles analyzer readings viewable on the control room;

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[a] API RP 556 also allows for CO monitoring to help "keep the heater in a safe operating region" [30, p. 14], stating that the CO measurement "should be taken […] at the top of the radiant section" to "avoid complications associated with the potential for afterburning" [30, p. 14].

[b] The heater was configured with a low excess oxygen alarm at 2.5% and an automatic override controller that quickly reduced fuel gas to the burners when a low-low oxygen environment was detected at 2.0% or lower. Low oxygen was not detected either at the bridgewall or at the stack prior to the tube rupture.

[c] The heater stack was equipped with a CO analyzer, primarily for environmental monitoring of the flue gas leaving the stack to the atmosphere. Marathon's fired heater standards noted that "[Stack] CO analyzers are not typically ranged to allow for the High Alarm set point [of 1,500 ppm]." For most of the night shift of November 18, including the half hour leading to the tube rupture, CO measured at the stack was below the environmental alarm limit of 400 ppm, suggesting that combustion was completed inside the equipment before the flue gas left the stack.

- Installed a TDL analyzer that continually reports bridgewall combustible concentrations (CO and methane) with a faster response time than the existing analyzer;
- Configured alarms on high and high-high (Not to Exceed) CO and methane concentrations measured by the TDL analyzer to alert the board operators to insufficient combustion and potential afterburning in the heater, with predetermined actions to reduce fuel gas or shut down the heater;[a] and

Marathon also stated future plans to connect the TDL analyzer measurements into the fired heater's safety instrumented system for an automated shutdown of the heater when high combustibles are detected.

The CSB recommends that the Marathon Martinez facility implement engineering safeguards to detect and prevent afterburning in the fired heater involved in the November 19, 2023, incident. The safeguards may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The safeguards shall be capable of being monitored from the control room.

In addition, the CSB recommends that Marathon Petroleum Corporation update its Heater Application Standard with engineering safeguard requirements to detect and prevent afterburning in fired heaters. These requirements may address instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures that can be monitored from the control room.

As discussed previously, API RP 556 provides some industry guidance but does not prescribe minimum requirements for flame detection or combustibles monitoring to protect fired heaters from afterburning and equipment damage. The CSB concludes that while Marathon's internal standards exceeded API RP 556 guidance in requiring some flame detection protection, inadequate engineering safeguards to prevent afterburning, such as flame detection and the availability of combustibles monitoring, contributed to this incident. Had the API's guidance defined

KEY LESSON

Fired heaters should be equipped with continual combustibles monitoring at the bridgewall (transition area from the radiant section to the convection section) to detect the onset of incomplete combustion. The combustibles data (such as CO and methane) should be viewable by the board operators in the control room and should be equipped with alarms at appropriate setpoints. This will help ensure proper combustion control inside the heater and allow quick response to hazardous flameouts or afterburning.

[a] Marathon's post-incident investigation also determined that changes in the hydrogen content of the refinery's fuel gas composition contributed to flame stability issues in the heater. Because a refinery's fuel gas system typically incorporates offgas from multiple process units, the refinery's fuel gas composition at any given moment may change based on operating conditions of other process units [29, pp. 2,15]. Post-incident, Marathon configured fuel gas composition alarms to alert the board operators to make adjustments to the refinery fuel gas to maintain the hydrogen concentration above a predetermined limit [34, p. 5]. In addition, for the fired heater involved in the incident, Marathon's internal investigation team recommended an evaluation of the burner's design to improve burner stability for a wider operating range in the future. API Standard 535, *Burners for Fired Heaters in General Refinery Services*, provides guidelines for burner stable operating envelope requirements [86, pp. 13-14].

a minimum safety requirement for adequate flame detection or combustibles monitoring available to the control room, it could have driven Marathon to install a more robust combustion monitoring and protection system that could have protected the fired heater from the afterburning that contributed to the incident.

The CSB recommends that API update API RP 556 with engineering safeguard requirements ("shall" rather than "should" language) to detect and prevent afterburning in fired heaters. These requirements may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The requirements shall address monitoring capability from the control room.

4.5 Valve Misalignment

The process unit involved in the incident had two valves, Valves A and B, that both allowed hydrogen flow through the startup piping. Post-incident, Valve B was found to be misaligned, which allowed process material to bypass the fired heater and contribute to the tube overheating and rupturing. This section discusses how Marathon could have prevented the valve misalignment by using clear equipment labeling, inherently safer design, and improved "Walk the Line" practices.

4.5.1 Equipment Labeling

The startup piping that the Marathon Martinez unit's startup procedure referenced was colloquially referred to by both personnel and the procedure as the "Taylor Bypass." Valves A and B were identically sized manual valves labeled with this "Taylor Bypass" name (**Figure 26**). Valve A was located at grade, and Valve B was at an elevated platform, operated by a chain valve.

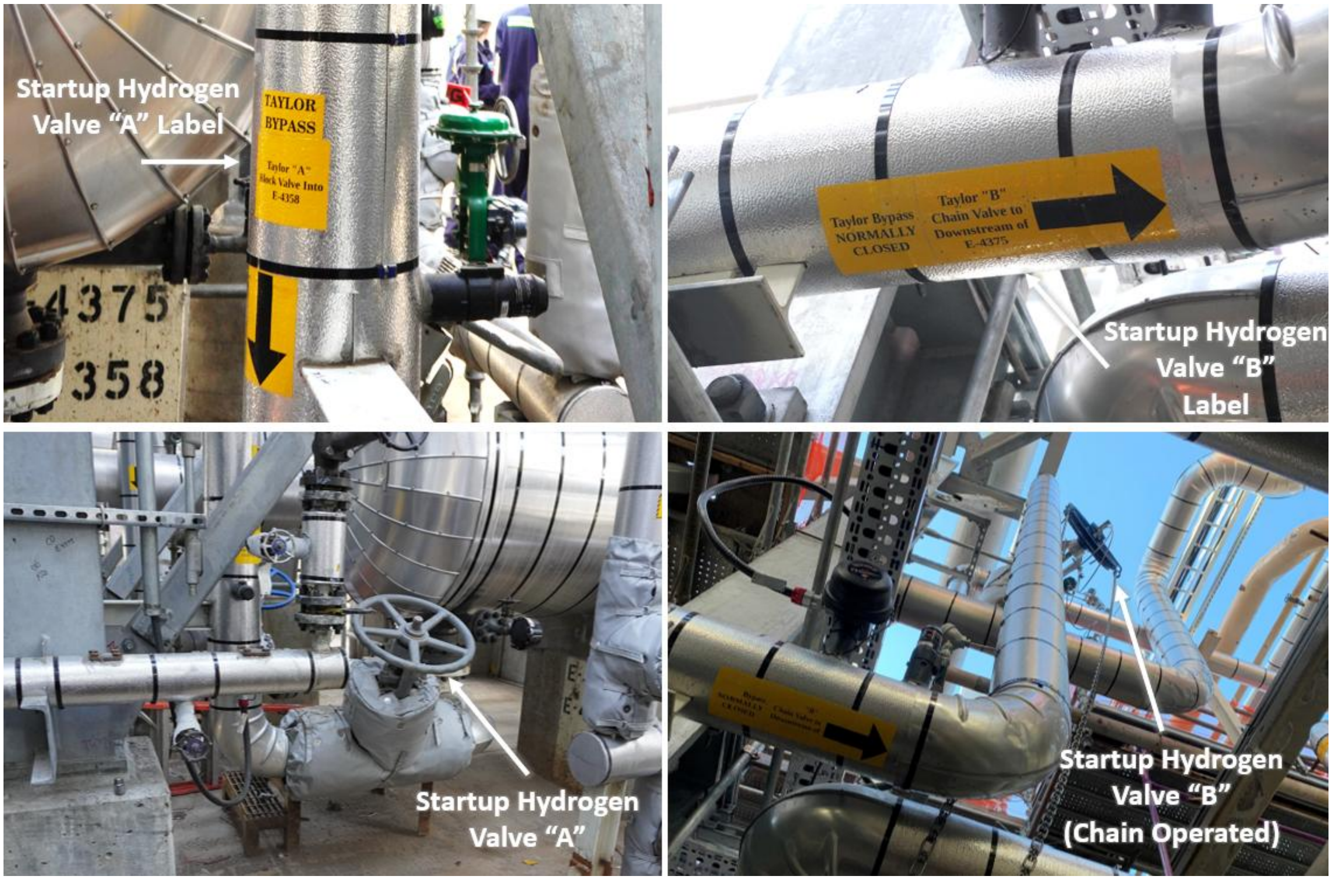

Figure 26. Location and labeling of startup Valves A (left) and B (right), photos taken post-incident. (Credit: CSB)

The original petroleum hydroprocessing unit’s startup piping included two block valves that could allow hydrogen flow into the fired heater. However, the operators who worked in the former petroleum unit told the CSB that in practice they only used one valve (the one at grade, which this report denotes as Valve A) during startup activities. The employees in the original unit had called the valve at grade the “Taylor Bypass Valve.” The Marathon Martinez facility’s old training material and operating procedures referred only to the “Taylor Bypass Valve” and did not mention the second startup valve. In addition, the second valve, which had previously been unnamed (the elevated valve, which this report denotes as Valve B), was not easily accessible. One employee who had worked in the original petroleum unit explained:

> [T]hat extra [elevated] valve up there on the deck, which if I remember correctly, was a valve you had to hang off the edge of the deck to access. So it was not a really easy-to-get-to-valve. […] So it was kind of like a…a valve that was there. But it was never given any title. And I don’t even recall that I even touched it my entire time I was at the [old unit].

Marathon included both valves in the new renewable hydroprocessing unit’s startup piping design and installed a chain wheel on the elevated valve to allow its operation from ground level. The new unit also employed new operators who had never worked in the old petroleum unit and who did not know the history of using only the valve at grade. To help distinguish between the two valves, in the weeks prior to the unit’s startup, the operators named the valves "Taylor A" and "Taylor B," believing both were associated with what was historically called the Taylor Bypass. A Marathon employee explained:

> [W]e named them A and B. Placeholders until we could find a better thing to call them and a way to communicate which valve was actually open, especially with some of the confusion that came about talking to the newly hired field operators […]. […] I spoke with several of them, and they had no idea what the [startup piping] did. They didn't know what the valves were for. Then some of them were shocked that there were two valves. Half of them thought the chain valve was the ["Taylor Bypass Valve" referenced in procedures]. Half of them thought the valve at grade was the ["Taylor Bypass Valve" referenced in procedures].
>
> I had supervisors that did not know what the ["Taylor Bypass Valve" referenced in procedures] did, and several of them told me that it was the chain valve. Several of them told me it was the valve at grade. So multiple operators got together, talked, and we essentially, unofficially, designated one the A and one the B and labeled them as normally closed because we were afraid of these valves being opened and forgotten because of the lack of training. […] The drawing that is depicted in the operator books does not include the [startup piping or these valves].

Marathon could have identified and resolved the discrepancy between the operating procedure and field labeling by conducting an effective human factors[a] analysis of the operating procedures as required by the Contra Costa County Industrial Safety Ordinance.[b,c] The Martinez facility's written human factors program included a "latent conditions checklist" that incorporated some of the questions that the County recommended in its example checklist [36, 37].[d]

The PHA team had completed a latent conditions checklist prior to January 2023, as required by the facility's human factors program requirement. At the time of the evaluation, the PHA team indicated that the operating procedures had not yet been written, committed to reviewing some of the items closer to the commissioning date, and did not develop additional recommendations for follow-up (**Table 4**). At the time, the PHA team did not document the two valves on the startup piping as a potential human factors issue.

[a] Human factors is a discipline that addresses adapting machines, operations, and work environments to human capabilities, limitations, and needs in a way that reduces the potential for human error [76, p. 3, 63, p. 125].

[b] Contra Costa County Code Title 4 § 450-8.016(b)

[c] The facility had also been required to develop human factors program pursuant to CA Title 8 §5189.1(s) and CA Title 19 § 5110.18 requirements when it operated as a California petroleum refinery. These regulations required the inclusion of a human factors assessment for each new and existing operating and maintenance procedure. At the time of the incident, this analysis was still required per the Contra Costa County Industrial Safety Ordinance 450-8 "Risk Management."

[d] The County's guidance document states that "[s]tationary Sources are not required by [the County] to use the checklist verbatim, but should ensure that their Human Factors program addresses the issues included in the checklist" [36, pp. B3-1].

Table 4. Excerpts from the latent conditions checklist filled out by the PHA team. (emphasis added by the CSB)

QUESTIONS	COMMENTS
3.13 Are all equipment labels (e.g. vessels, piping, valves, instrumentation, etc.) easy to read (clear and in good condition)?	All critical equipment is labeled sufficiently. No deficiencies were identified by the PHA Team. Any needed improvements **will be applied** during the commissioning phase.
3.14 Are all equipment labels correct and unambiguous?	All equipment labels **will be verified** as correct and unambiguous during the commissioning phase.
3.16 Do all equipment labels use standard terminology (e.g., acronyms, abbreviations, equipment tags, etc.)?	All equipment **will utilize standard terminology** for describing the vessel/equipment. The PHA Team made a concerted effort to converge on equipment/unit names and references during the PHA.
3.17 Are the equipment labels consistent with nomenclature used in procedures?	All equipment labels **will be consistent with procedures**.
3.18 Are all components that are mentioned in procedures (e.g., valves) labeled or otherwise identified?	All components are referred to consistently between procedures and labels in the field. If not labeled, equipment is adequately described to support the Operator's ability to easily find the correct reference to equipment.

Marathon did not document a similar human factors analysis while developing its operating procedures and did not document answers to checklist questions excerpted from the Contra Costa County latent conditions checklist as it had done during the PHA.[a] While personnel labeled the valves as "A" and "B" both in the field and on the operator control board, the new operating procedures still referred to only one "Taylor Bypass Valve."[b] While the CSB was unable to determine when Valve B was opened (due to lack of data), the CSB concludes that:

- The significant confusion about the names and purposes of the valves on the startup piping arising from discrepancies between the nomenclature used in the operating procedure and the corresponding field labeling likely contributed to the misalignment of one of the startup valves, which allowed process flow to bypass the fired heater.
- Marathon did not perform an effective human factors analysis of the renewable diesel unit's equipment or startup procedures. As a result, Marathon did not identify and resolve the discrepancies between the nomenclature used in the operating procedure and the corresponding field labeling of the two startup valves prior to the incident.

After the incident, Marathon removed Valve B from the startup hydrogen piping and assigned a distinct equipment number to Valve A to remove ambiguity from its operating procedures. The new operating procedures for the unit refer to Valve A by a specific equipment number. Marathon used its corporate operating

[a] The Marathon Martinez facility's human factors policy did not explicitly require retention of the checklists used in procedure development.

[b] The operating procedure described it as "the [six-inch] manual valve that flows the [normal routing] hydrogen to the […] flow path to [the heater]." Both startup hydrogen valves fit this description—both were six-inch manual valves, and opening either of them would have directed hydrogen to the heater.

procedure review checklist when updating the operating procedures, which included human factors checks such as verifying consistent equipment nomenclature and clear instructions.

4.5.2 Inherently Safer Systems Analysis

As a stationary source covered under Contra Costa County's Industrial Safety Ordinance, the Marathon Martinez facility was required to conduct inherently safer systems analyses (1) at least every five years during PHAs for existing processes, (2) as part of major changes, and (3) during the design of new processes.[a,b] The Marathon Martinez facility used an Inherently Safer Systems Checklist to identify inherently safer design opportunities at the project level and during each PHA. The checklist included 39 questions to guide the PHA team, including:

- Have unnecessary utility/process cross-connections been eliminated?
- Has equipment been designed so that it is difficult or impossible to create a potential hazardous situation due to an operating error (for example, by opening an improper combination of valves)?
- Have process controls been simplified?
  - Control one variable with one control valve.
  - Pair measurements/valves in simple single loops arranged to minimize process interaction.

The intent of inherently safer design is to prioritize eliminating hazards over relying on safeguards to manage risk, where feasible, as the checklist had intended to guide the PHA team. Contrary to this guidance, Marathon chose to keep Valve B and its associated piping even though it did not have a design purpose.[c] In the PHA, Marathon treated both startup valves as having the same impact on the process—but did not identify that having an additional, unnecessary startup piping routing created confusion and introduced hazards. The PHA team made a general comment in the inherently safety systems checklist to the effect that although operator actions could result in some process upsets, "it was verified [during the PHA] that sufficient safeguards exist"—a conclusion that is counter to the purpose of inherently safer design.

The CSB concludes that Marathon kept an unnecessary valve (Valve B) and its associated piping that had no design purpose, which introduced confusion and increased the potential for a valve misalignment during startup activities. Had Marathon implemented an effective inherently safer systems analysis on this unit, the company should have removed the unnecessary valve and piping. Eliminating this valve and piping could have prevented the flow diversion that contributed to the November 19, 2023, incident.

[a] Contra Costa County Code Title 4 § 450-8.016(i)

[b] The facility had been required to develop hierarchy of hazard controls analysis, which includes evaluating inherent safety, pursuant to CA Title 8 §5189.1(l) and CA Title 19 § 5110.16 requirements for California petroleum refineries. At the time of the incident, this analysis was still required per the Contra Costa County Industrial Safety Ordinance 450-8 "Risk Management."

[c] One employee involved in the renewables conversion project told the CSB: "I don't know that it was ever utilized. […] I have no one in Operations who's ever explained [Valve B] well enough to me. It's all…all stuff we inherited with the project […]." This person added, "We talked about the valves, […] whether we needed them in operations […]. They were preexisting and we kept them."

After the incident, Marathon updated the unit's inherently safer systems analysis prior to the restart of the unit, documenting both inherently safer design measures and safeguards implemented to prevent a similar incident. Changes included eliminating the unnecessary startup piping branch that included Valve B (an inherently safer design approach), adding position indicators and alarms to Valve A to prevent it from being left open when the equipment was aligned in the normal operating routings (added safeguards), and replacing the fired heater's tubes with metallurgy associated with a higher design temperature (an inherently safer design approach).

4.5.3 WALK THE LINE PRACTICES

"Walk the Line" is a framework developed by a chemicals manufacturing company that provides tools (such as work practices and checklists) that operators need to minimize valve alignment errors [38, p. 5, 39, 40].[a] In 2015, the American Fuel and Petrochemical Manufacturers (AFPM), an industry trade association, adopted Walk the Line as one of its safety programs and provided a resource library and industry-wide practice sharing information to its members [41]. Using industry process safety event data from its members, AFPM reported that line-up error events declined 90 percent from 2014 to 2018 [39]. As of 2024, over 50 companies across the world were estimated to have adopted some of the Walk the Line tools and philosophy [40], including Marathon.

Marathon Petroleum Corporation compiled its Walk the Line practices in a refinery reference document titled Operations Excellence. While Marathon adopted some of the Walk the Line tools, the CSB found that the implementation of those tools at the Martinez facility was poor in the following areas:

- The Marathon Martinez facility conducted an "Operational Readiness Review"—an action that is in alignment with the Walk the Line framework—before starting up the unit, which included walking the unit piping lines, verifying that valves were in the correct position, and documenting their positions on P&IDs. Marathon operations personnel verified that this verification was completed on October 29, 2023, and the supporting documentation indicates that Valve B was closed during the review. Assuming that the documentation was accurate, Valve B was opened at some point after this review but before the first effort to establish normal process routings on November 11.[b] During the startup activities and after Valve B was already open, a fire occurred that required shutting down the unit and repairing equipment. Despite the various valve and piping manipulations required for the equipment repair after the fire, Marathon never conducted another field verification to ensure that all unit valves were in the correct position before starting up again, and as a result Marathon did not identify the open Valve B.[c]

- The Walk the Line framework inherently requires operators to have a thorough understanding of the process so that they can know where process material will flow. Marathon had not trained its operators on the purpose and proper alignment of the startup piping, as described above in *Section 4.5.1*. As a result, some field operators did not understand why the board operators were asking them to manipulate

[a] Celanese Corporation, a chemicals manufacturing company, introduced the Walk the Line framework around 2010 and reported an 86 percent reduction in loss of primary containment incidents at the company within the first five years of adopting the program [77].

[b] The CSB determined that Valve B was likely also open during the earlier startup attempt on November 11, 2023.

[c] Marathon's corporate standard stated that "**at a minimum**, the [pre-startup or operational readiness review] checklist **shall** be completed for **all** unit startup activities from **standby**, turnaround, and major maintenance" (emphasis added). This checklist did not explicitly require a verification of all valve positions.

Valves A or B during startup activities, and there was significant operator confusion about their proper alignment.

- In interviews with the CSB, multiple employees reported that management personnel, who lacked the operator training and qualifications to operate the process units, often manipulated valves themselves during the unit startup activities. One employee described: "[t]he guys are willy-nilly out there opening the valves. And they're managers." Another employee described the pervasiveness of these practices: "We have managers that are coming in, making operational moves without communicating to operators themselves. There [have] been multiple instances of [managers] having caused [process] upsets […]."Marathon's failure to have operators participate in and understand valve alignment changes in their own units undermined the core principle of the Walk the Line framework.

The CSB concludes:

- Marathon did not effectively implement the "Walk the Line" philosophy and did not ensure that valves were correctly aligned before starting up the unit. Had Marathon ensured proper equipment alignment before restarting the unit after the unplanned shutdown, the flow diversion around the fired heater could have been prevented.

- Marathon did not ensure that operators were knowledgeable about the purpose and function of all of the unit equipment, and Marathon managers would manipulate valves themselves during startup activities, both of which prevented operators from achieving the core Walk the Line tenet of "know[ing] with certainty where a material will flow between any two points in a process."

The CSB recommends that the Marathon Martinez facility implement changes to improve Walk the Line performance at the Martinez facility by ensuring that the facility's practices are consistent with tools in the AFPM Safety Portal and guidance in Marathon's refining reference document titled Operations Excellence. At a minimum:

(a) Require that operator field walkdowns ensure that valves are correctly aligned before all unit startup activities from planned or unplanned shutdowns, such as those due to non-normal operations, emergencies, turnarounds, and major maintenance;

(b) Improve policies and practices for communications among and between shifts to ensure that operators understand abnormal line-ups in their units; and

(c) Reinforce Walk the Line concepts, including the expectation for only trained operators to control valve line-ups at their units, through training for all levels of management in the Operations department.

KEY LESSON

Companies should implement Walk the Line practices to minimize equipment lineup errors. Walk the Line activities include verifying valve positions before starting up a unit, understanding operating procedures and equipment routings, and properly communicating and documenting shift turnover information.

Additionally, the CSB recommends that Marathon Petroleum Corporation conduct an Operations Excellence assessment on the Martinez facility, and develop and implement action items to effectively address findings from the assessment.

4.6 Corporate Oversight

> **KEY LESSON**
>
> Companies should have effective oversight to ensure that processes are safe, equipment meets or exceeds local, state, federal, industry, and internal company safety standards, and workers are adequately trained and prepared before startup of a new or revamped process.

As discussed in previous sections of this report, the Marathon Martinez facility did not conform to all of Marathon's corporate requirements at the time of the November 19, 2023, incident. After it was acquired by Marathon in 2018, the Martinez facility lagged behind in integrating Marathon's corporate standards for refining technology and operations as discussed below.

Fired Heater Application Standard

Marathon's Heater Application Standard, first issued in 2000, had already been adopted by Marathon's original six refineries. When Marathon acquired 10 additional refineries in 2018, including the Martinez facility, the company set a deadline of 2034 for these facilities to adhere to all Heater Application Standard requirements.[a,b] In the meantime, Marathon considered all gas-fired heaters at the Martinez facility to conform to API RP 556, the industry-accepted external RAGAGEP for fired heater protection. As discussed in previous sections, the current version of API RP 556 has few mandatory requirements compared to Marathon's internal standard, and the fired heater involved in the incident did not have many of the industry-recommended safety features.

In 2020, Marathon started an Automation Modernization Program (AMP) project to bring all fired heaters in the 10 newly acquired facilities to Marathon standards by 2034. At the time of the incident, Marathon had planned to fully conform the fired heater at the Marathon Martinez facility that was involved in the incident to company standards by 2028.

The Martinez renewables conversion project took place between 2021 and 2023. Marathon completed a partial review of the heater against the corporate standard and documented that the AMP project would close the remaining gaps at a later date. For example, a 2021 evaluation by the AMP project had identified the need to bring the fired heater's existing combustibles analyzer readings into the control room, either during the renewables conversion project or at a later date. The 2022 PHA team did not recommend remote monitoring of the combustibles analyzer, however, and this work was ultimately not implemented during the renewables conversion project. As a result, at the time of the November 2023 incident, the combustibles monitoring was not brought into the control room, even though Marathon's Heater Application Standard said that the readings should be used for fired heater protection systems and alarms.

[a] Prior to the Marathon acquisition, Tesoro had identified hardware and software deficiencies in their distributed control systems and safety instrumented systems and were developing a plan to upgrade them. A former Tesoro employee stated: "There [was] a significant amount of work being done in Tesoro to modernize [its] heater safety systems. […] Marathon had been doing it, they'd been doing it for a long time. […] [Tesoro] did not have as well-developed safety requirements."

[b] The 2034 deadline was based on the goal of implementing all changes within two turnaround cycles across all facilities.

Gap Assessments

In early 2020, Marathon initiated a Standards Gap Assessment project to identify gaps and recommendations for bringing the 10 acquired refineries into full conformance with Marathon's standards. Several months later, the Martinez facility stopped operating as a petroleum refinery and transitioned to terminal operation. In late 2020, Marathon updated the Martinez facility's gap assessment requirements to only cover equipment in service for terminal operation, which did not include fired heaters.

In 2021, when the Marathon Martinez facility began project work to resume operation as a refinery, Marathon did not reinstate the refinery-specific gap assessment project for the facility.[a] As a result, at the time of the 2023 incident, the Marathon Martinez facility had not yet performed a full gap assessment against a number of standards, including the Heater Application Standard.

After the incident, in August of 2024, the Marathon Martinez facility reported that it reviewed 273 company standards and determined that 71 (21%) of them still "need to have a gap assessment conducted or gaps uploaded to the system" to bring the facility into conformance with Marathon corporate standards.

Corporate Audits

Marathon required various types of auditing of its facilities to assess their conformance to company standards, typically once every three to five years for refineries. In 2019, Marathon conducted an integration assessment of the Martinez facility and identified nine high-priority, 59 medium-priority, and 41 low-priority gaps.[b] At the time, the assessment report noted that the Martinez facility "had made a good start on revising local site standards to be aligned to the [Marathon standards]." Shortly after, the Martinez facility stopped operations as a refinery in 2020. Around 2021, personnel from Marathon conducted an audit and a health check on the Martinez facility's terminal operations' conformance to Marathon standards. At the time, the Marathon audit teams identified that some of the Martinez facility's policies did not conform to Marathon's standards and made recommendations to resolve them. After starting operations as a renewable fuels refinery, the Martinez facility was due for a comprehensive refinery corporate audit in 2024.

At the time of the incident on November 19, 2023, some of the Martinez site policies had not been updated since the facility ceased operations as a petroleum refinery,[c] and some still referenced Tesoro corporate standards that were no longer in effect. Furthermore, by around 2020, Marathon had updated many of its corporate standards that had not yet been integrated into local Martinez policies, including Process Hazard Analysis, Operating Procedures, and standards referenced in the document Operations Excellence. As a result, portions of the site policies at the Marathon Martinez facility were not being followed because personnel believed the existing policies to be outdated. For example, the Marathon Martinez human factors policy had not yet been updated as

[a] Marathon performed a Management of Organizational Change (MOOC) for transitioning the Marathon Martinez facility from refinery to terminal operations. Marathon did not perform an MOOC for transitioning the facility from terminal operations to renewable fuels refinery operations.

[b] The assessment team evaluated operating procedures and training, operating practices, and the application of process safety advisories, and interviewed operators.

[c] For example, some policies still referred to operations positions, such as "Operator-in-Charge," "The #1 Operator," or "Head Operator," that no longer existed in the Martinez organization after it restarted as a renewables facility.

the facility had transitioned to Marathon's corporate standard for operating procedures, and it was not used in developing the operating procedures for the unit involved in the incident.

The CSB concludes that Marathon Petroleum Corporation's ineffective oversight of the Martinez facility's conformance to internal corporate standards after 2019, such as in the areas of operating limits (see *Section 4.1*), process hazard analysis (see *Section 4.3*), and operating procedures, training, and practices (see *Sections 0* and *4.5*), led to deficiencies in the facility's management of technology upgrades and local policies that contributed to the November 19, 2023, incident.

After the incident, a corporate audit team from Marathon Petroleum Corporation audited the Martinez facility in early 2024 and found many deficiencies with the outdated status of the site policies and gaps from its corporate standard, such as in the areas of process hazard analysis, operating procedures, and operational practices discussed previously in this report. Marathon Petroleum Corporation also made organizational changes to its corporate refining team and the Martinez facility's leadership team to improve the company's process safety management oversight of its refineries.

In addition to the comprehensive gap assessment and corporate audits performed by Marathon audit teams after the incident, the Martinez facility is also participating in third-party audits.[a] At the time of this report:

- The Marathon Martinez facility is addressing process safety management system findings from a Contra Costa Health Hazardous Materials Programs (CCHHMP) comprehensive audit conducted in 2024;[b,c]
- The Marathon Martinez facility is participating in a third-party Safety Culture and Management Systems evaluation, commissioned by CCHHMP, that began in January 2025 [42];[d] and
- Marathon has engaged with API to participate in its voluntary Process Safety Site Assessment Program [43] and has plans to complete an assessment for the Martinez facility in 2027.

Third-party audits are typically designed to review a facility against regulatory requirements and industry practices. These audits may not include a comprehensive review of a company's own policies where they include elements that exceed regulatory requirements.

[a] After the November 2023 incident, the Marathon Martinez facility underwent seven audits in 2024, including audits of its process safety management programs. Five of the audits were conducted by Marathon's corporate refining organization and two were third-party audits.

[b] In the summer of 2024, Contra Costa Health Hazardous Materials Programs performed a CalARP/ISO program audit of the Marathon Martinez facility and identified one deficiency and 23 partial deficiencies in existing process safety management programs at the facility. The report concluded, "This system was found to be deficient in terms of implementing process safety programs completely and tracking action items for the different programs." At the time of writing this report, the Marathon Martinez facility is working with Contra Costa County to address the audit findings and proposed recommendations [89, pp. 3-4].

[c] Prior to the November 19, 2023, incident, the last comprehensive audit performed by CCHHMP was in 2019 when it was operating as a petroleum refinery. Around August 2023, CCHHMP performed a limited inspection of the facility in reaction to concerns related to flaring raised by the community. Based on its initial findings, CCHHMP expanded the scope of the limited inspection to include management of organizational change, fatigue management, and review of emergency operations and made recommendations to the Marathon Martinez facility on these topics approximately one year before the November 19, 2023, incident [90].

[d] Contra Costa Health reported that a third-party Safety Culture and Management Systems evaluation of the Marathon Martinez facility began on January 30, 2025, and created a website to provide ongoing updates related to the November 19, 2023, incident [42].

The CSB recommends that the Marathon Martinez facility complete a comprehensive gap assessment of the Martinez facility against Marathon Petroleum Corporation policies, addressing the following at a minimum:

(a) Operating Limits;

(b) Process Hazard Analysis; and

(c) PSM/RMP Refining Operating Procedures.

After the facility conducts the comprehensive gap assessment, the CSB recommends that Marathon Petroleum Corporation confirm the results of the assessment and conduct an Operations Excellence assessment on the facility. The CSB recommends that Marathon develop and implement action items to effectively address findings from the assessments.

5 Conclusions

5.1 Findings

Technical Analysis

1. The fired heater tube ruptured due to a damage mechanism called short-term overheating, which occurred when elevated temperatures much higher than the tube design temperature in the convection section of the heater caused the tube metal to lose strength and eventually fail at the process operating pressure.

2. Leading up to the incident, process fluid diverted around the fired heater through a misaligned valve (open when it should have been closed), causing low flow through the fired heater tubes.

3. The covered air intakes with fuel valves open on the fired heater burners in operation contributed to afterburning in the fired heater. A combination of afterburning and low flow through the fired heater tubes caused tubes located within the fired heater's convection section to overheat until a tube ruptured.

Safe Operating Limits

4. Marathon did not set Not-to-Exceed limits for the fired heater tube metal temperatures, and as a result, personnel never stopped troubleshooting efforts—and did not shut down the fired heater remotely—before the incident occurred. Troubleshooting efforts put the field operator directly next to the heater when the tube ruptured, and he was seriously injured during the incident.

5. Marathon's corporate fired heater standards assert that Not-to-Exceed limits on high process outlet temperatures could prevent tube ruptures upon loss of flow to individual passes. This is inconsistent with current industry guidance advising not to rely on process outlet temperature to detect and control process flow through fired heater tubes. As a result, the fired heater did not have effective safe operating limits and alarms to alert personnel that the heater was in an unsafe state on the night of the incident.

Worker Proximity to Fired Heater

6. The field operator was at risk when the heater fire began because Marathon did not prevent workers from being in close proximity to fired heaters while tube temperatures were high or the fired heater was otherwise in an unsafe condition, such as by requiring troubleshooting to stop and preventing personnel from approaching the area, as well as defining when other actions, such as shutting down the fired heater remotely, should be taken.

Low Flow Through Fired Heater

7. The PHA team believed that with either of the valves on the startup piping open, additional material would flow to the heater. The team did not realize that material would reverse-flow through the piping, away from the fired heater.

8. The PHA team did not have sufficient hydraulic analysis information available during the PHA to understand the likely flow directions through the startup piping during all operating modes.

9. The PHA team did not consider the startup piping to be potential "bypasses" or "flow diversions" (as so-named in Marathon's internal fired heater standard) between flow meters associated with the fired heater's safety instrumented system and the fired heater itself, as reverse flow was not expected.

10. Had the PHA team identified the potential for reverse flow through the startup piping, they should have recommended corrective actions, such as the removal of one of the two branches in the startup piping or the implementation of engineering safeguards to prevent, or detect and automatically respond to, reverse flow and the resulting low flow through the fired heater tubes.

11. Marathon's updated corporate guidance in 2019 and 2020 after a similar 2018 fired heater low flow incident prompted neither the 2019 Marathon Martinez fired heater survey team nor the 2022 Marathon Martinez PHA team to identify the potential for flow to bypass the heater involved in the November 19, 2023, incident and defeat the safety instrumented system, likely because the review teams did not consider the startup piping to be a potential fired heater bypass or flow diversion.

Burner Operation

12. Marathon did not ensure its operators had sufficient knowledge about safe burner operation. As a result, on the night of the incident, two of the four burners in service had their air intakes obstructed by cover plates, contributing to poor burner operation and afterburning inside the fired heater. Had Marathon incorporated administrative controls, operating procedures, and operator training to require that the air intake cover plates be removed prior to lighting the burners, the afterburning that contributed to the tube rupture could have been prevented.

13. The available flame detection capability was ineffective for protecting the fired heater on the night of the incident.

14. The fired heater was not equipped with sufficient engineering controls to ensure safe operation, including burner flame detectors or combustibles measurement. Improved engineering controls could have notified the board operators of burner flameouts and afterburning, allowing them to take action to restore safe heater operation and prevent the incident.

15. While Marathon's internal standards exceeded API RP 556 guidance in requiring some flame detection protection, inadequate engineering safeguards to prevent afterburning, such as flame detection and the availability of combustibles monitoring, contributed to this incident. Had the API's guidance defined a minimum safety requirement for adequate flame detection or combustibles monitoring available to the control room, it could have driven Marathon to install a more robust combustion monitoring and protection system that could have protected the fired heater from the afterburning that contributed to the incident.

Valve Misalignment

16. The significant confusion about the names and purposes of the valves on the startup piping arising from discrepancies between the nomenclature used in the operating procedure and the corresponding field

labeling likely contributed to the misalignment of one of the startup valves, which allowed process flow to bypass the fired heater.

17. Marathon did not perform an effective human factors analysis of the renewable diesel unit's equipment or startup procedures. As a result, Marathon did not identify and resolve the discrepancies between the nomenclature used in the operating procedure and the corresponding field labeling of the two startup valves prior to the incident.

18. Marathon kept an unnecessary valve and its associated piping that had no design purpose, which introduced confusion and increased the potential for a valve misalignment during startup activities. Had Marathon implemented an effective inherently safer systems analysis on this unit, the company should have removed the unnecessary valve and piping. Eliminating this valve and piping could have prevented the flow diversion that contributed to the November 19, 2023, incident.

19. Marathon did not effectively implement the "Walk the Line" philosophy and did not ensure that valves were correctly aligned before starting up the unit. Had Marathon ensured proper equipment alignment before restarting the unit after the unplanned shutdown, the flow diversion around the fired heater could have been prevented.

20. Marathon did not ensure that operators were knowledgeable about the purpose and function of all of the unit equipment, and Marathon managers would manipulate valves themselves during startup activities, both of which prevented operators from achieving the core Walk the Line tenet of "know[ing] with certainty where a material will flow between any two points in a process."

Corporate Oversight

21. Marathon Petroleum Corporation's ineffective oversight of the Martinez facility's conformance to internal corporate standards after 2019, such as in the areas of operating limits, process hazard analysis, and operating procedures, training, and practices, led to deficiencies in the facility's management of technology upgrades and local policies that contributed to the November 19, 2023, incident.

5.2 Cause

The CSB determined that the cause of the incident was overheating of the fired heater's tubes because (1) a misaligned (open) valve diverted a significant amount of process flow away from the fired heater; and (2) two of the four burners were operating with cover plates blocking their air inlets, leading to afterburning in the convection section.

Contributing to the severity of the incident was the presence of a field operator next to the fired heater when the tube ruptured because (1) personnel directed the field operator to conduct troubleshooting actions in close proximity to the fired heater while the heater was in an unsafe condition (had high tube temperatures); and (2) Marathon had not established Not-to-Exceed limits (safe operating limits) for the fired heater tube temperatures to indicate when the fired heater was in an unsafe condition, which resulted in personnel continuing to troubleshoot high tube metal temperatures until the tube ruptured instead of shutting down the fired heater remotely from the control room.

Marathon Martinez's failure to identify the potential for the flow diversion that defeated the heater's safety interlock system and inadequate engineering and administrative controls to prevent the valve misalignment contributed to the incident. Marathon Martinez's inadequate operating procedures and operator training for safe burner operation and inadequate engineering controls for operators to identify combustion issues inside the fired heater also contributed to the incident. Marathon Petroleum Corporation's inadequate oversight of the Martinez facility's conformance to company standards allowed these deficiencies that contributed to this incident.

6 RECOMMENDATIONS

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 MARATHON MARTINEZ RENEWABLES

2024-01-I-CA-R1

Implement engineering safeguards to detect and prevent afterburning in the fired heater involved in the November 19, 2023, incident. The safeguards may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The safeguards shall be capable of being monitored from the control room.

2024-01-I-CA-R2

For the fired heater involved in the incident, after Marathon Petroleum Corporation's "Process Heater Not-to-Exceed (NTE) Limits and Alarms" standard is updated according to 2024-01-I-CA-R5, implement tube metal temperature alarming consistent with corporate guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater

2024-01-I-CA-R3

Implement changes to improve Walk the Line performance at the Martinez facility by ensuring that the facility's practices are consistent with tools in the AFPM Safety Portal and guidance in Marathon Petroleum Corporation's refining reference document titled "Operations Excellence." At a minimum:

(a) Require that operator field walkdowns ensure that valves are correctly aligned before all unit startup activities from planned or unplanned shutdowns, such as those due to non-normal operations, emergencies, turnarounds, and major maintenance;

(b) Improve policies and practices for communications among and between shifts to ensure that operators understand abnormal line-ups in their units; and

(c) Reinforce Walk the Line concepts, including the expectation for only trained operators to control valve line-ups at their units, through training for all levels of management in the Operations department.

2024-01-I-CA-R4

Complete a comprehensive gap assessment of the Martinez facility against Marathon Petroleum Corporation policies. At a minimum, address the following policies:

(a) Operating Limits;

(b) Process Hazard Analysis; and

(c) PSM/RMP Refining Operating Procedures.

Develop and implement action items to effectively address findings from the assessment.

6.2 Marathon Petroleum Corporation

2024-01-I-CA-R5

Update the corporate "Process Heater Not-to-Exceed (NTE) Limits and Alarms" standard with tube metal temperature alarming guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater.

2024-01-I-CA-R6

Update the corporate "Heater Application Standard" with the following requirements:

(a) Requirements for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system; and

(b) Engineering safeguard requirements to detect and prevent afterburning in fired heaters. The safeguards may include the use of instrumentation such as combustibles measurements, flame detectors, and/or thermocouples that measure tube metal, flue gas, and process fluid temperatures. The safeguards shall be capable of being monitored from the control room.

2024-01-I-CA-R7

Confirm the results of the Martinez facility's comprehensive gap assessment required in 2024-01-I-CA-R4. Upon completion, conduct an Operations Excellence full assessment on the Martinez facility. Develop and implement action items to effectively address findings from the assessment.

6.3 AMERICAN PETROLEUM INSTITUTE (API)

2024-01-I-CA-R8

Revise API RP 556 *Instrumentation, Control, and Protective Systems for Gas Fired Heaters,* or successor API products, with the following:

(a) Requirements for proper response to high tube metal temperatures, including guidance to alert operators when safe operating limits are exceeded and to specify predetermined response actions, such as shutting down the fired heater remotely. The predetermined response actions must include actions that specify when to stop troubleshooting and remove personnel from the vicinity of the fired heater;

(b) Design requirements ("shall" rather than "should" language) for protecting fired heaters from low process flow where process piping diverges downstream of a flow meter. Requirements may include achieving proof of flow to the heater through valve position indicators and interlocks on branch connections downstream of flow meters to prevent backflow, reverse flow, or other diverted flow scenarios that could defeat the safety instrumented system; and

(c) Engineering safeguard requirements ("shall" rather than "should" language) to detect and prevent afterburning in fired heaters. These requirements may include the use of combustibles measurements, flame detectors, and/or thermocouples such as tube metal, flue gas, and process fluid thermocouples. The requirements shall address monitoring capability from the control room.

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Process equipment must be configured with safe operating limit (not-to-exceed limit) alarms that alert personnel that the equipment has reached an unsafe condition, troubleshooting efforts need to end, and predetermined actions must be taken swiftly to shut down or return the equipment to a safe state.

2. Companies should ensure the safety of their workers by preventing workers from being in close proximity to a fired heater when tube temperatures are high or the fired heater is otherwise in an unsafe condition. Companies should create clear requirements for when troubleshooting in close proximity to fired heaters should be stopped and other actions, such as shutting down a fired heater remotely, should be taken. Enabling safe and remote adjustment of individual fired heater burners could also prevent workers from being in close proximity to fired heaters during troubleshooting efforts.

3. Companies should ensure that fired heaters are adequately protected from operating with low flow by evaluating all process connections between flow meters associated with the safety instrumented system and the heaters they are intended to protect, including considerations for reverse and misdirected flow.

4. Operating procedures and operator training should include verification that air intake covers (where used) are removed prior to lighting a burner. Improper air-fuel mixing at the burners could lead to poor combustion control and high localized temperatures inside the heater.

5. Fired heaters should be equipped with continual combustibles monitoring at the bridgewall (transition area from the radiant section to the convection section) to detect the onset of incomplete combustion. The combustibles data should be viewable by the board operators in the control room and should be equipped with alarms at appropriate setpoints. This will help ensure proper combustion control inside the heater and allow quick response to hazardous flameouts and afterburning.

6. Companies should implement Walk the Line practices to minimize equipment lineup errors. Walk the Line activities include verifying valve positions before starting up a unit, understanding operating procedures and equipment routings, and properly communicating and documenting shift turnover information.

7. Companies should have effective oversight to ensure that processes are safe, equipment meets or exceeds local, state, federal, industry, and internal company safety standards, and workers are adequately trained and prepared before startup of a new or revamped process.

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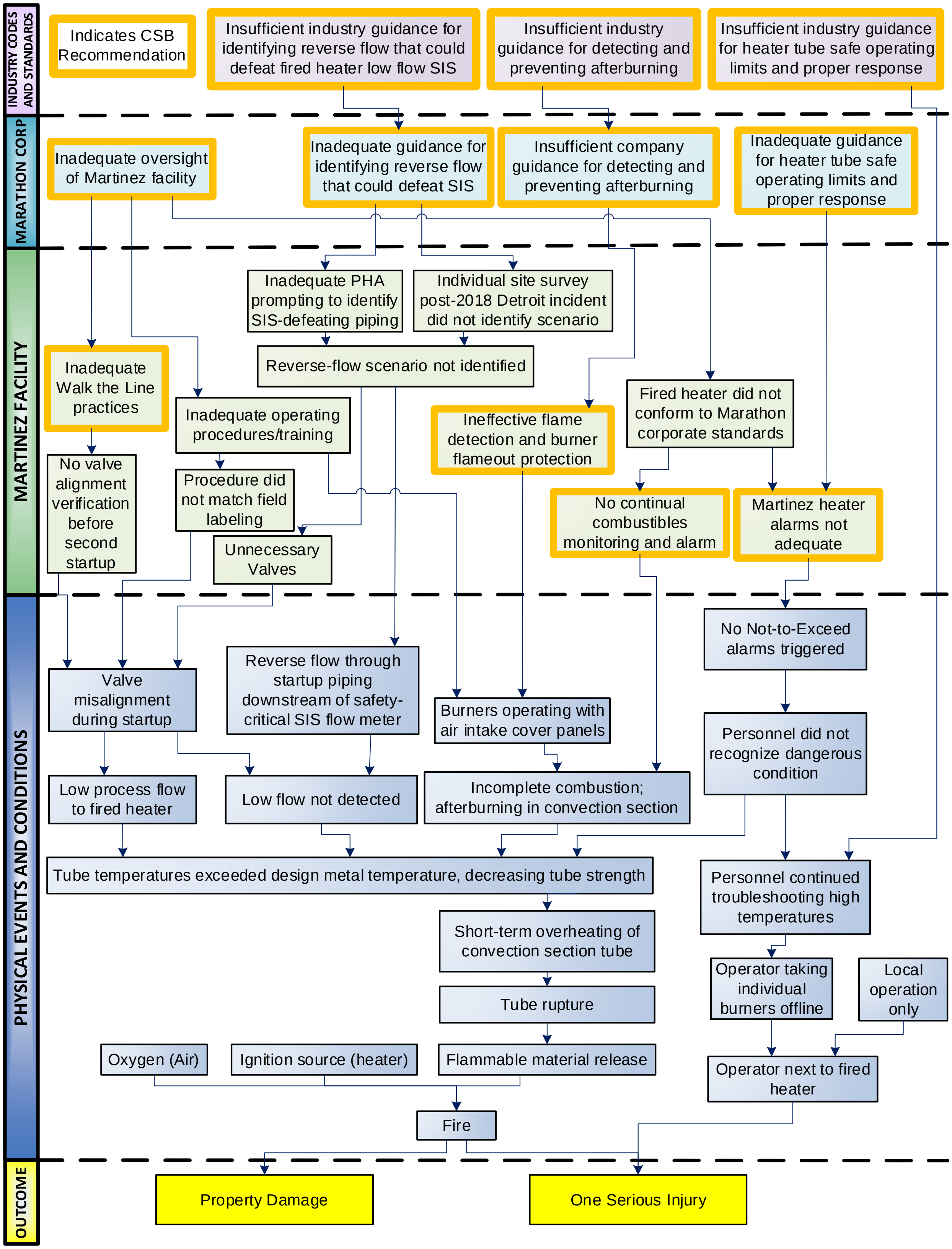
APPENDIX A—SIMPLIFIED CAUSAL ANALYSIS (ACCIMAP)



APPENDIX B—DESCRIPTION OF SURROUNDING AREA

There are two census tracts located within approximately one mile of the Martinez Renewable Fuels facility (**Figure 27**). The demographic information of the population residing within the one-mile radius of the Martinez Renewable Fuels facility is summarized in **Table 5**.

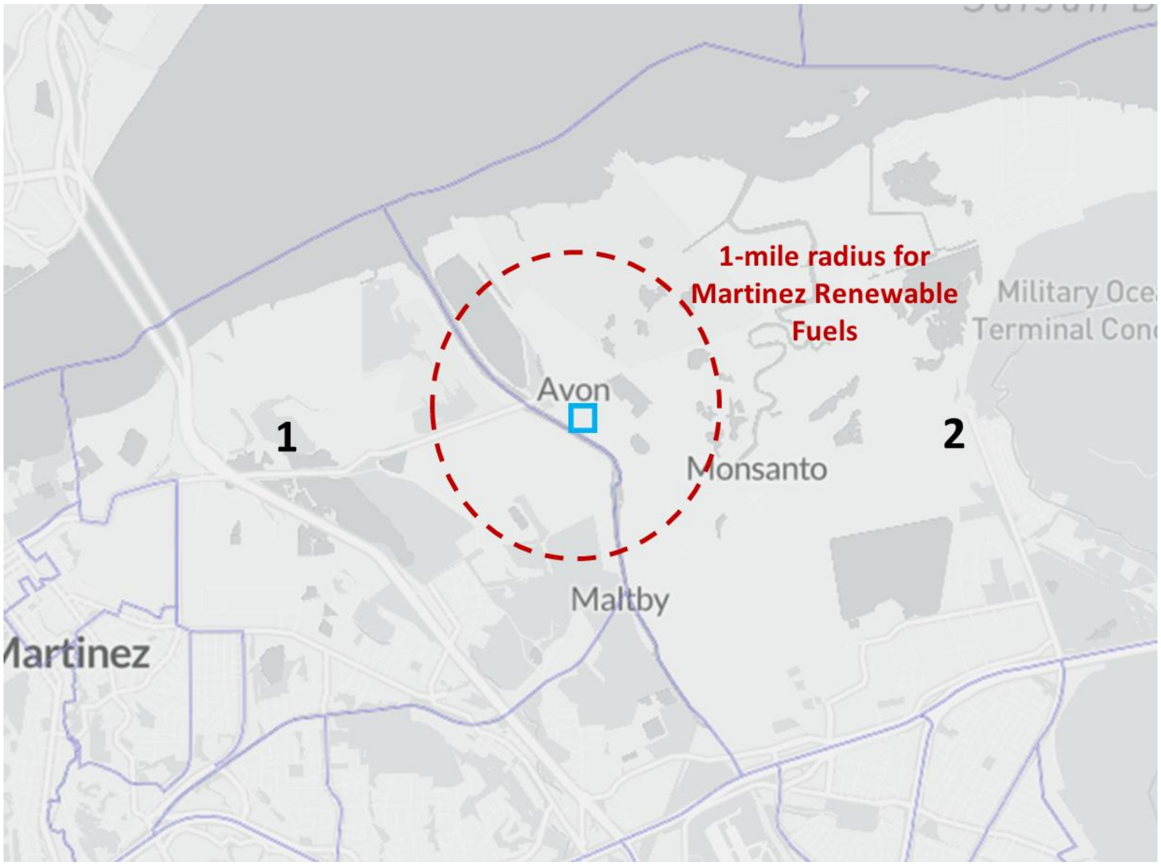


Figure 27. Census blocks within the approximately one-mile distance from the Martinez Renewable Fuels facility. (Credit: Census Reporter, annotations by CSB).

Table 5. Tabulation of demographic data for the populations within the census blocks shown in **Figure 27**. (Credit: Census Reporter, compiled by CSB)

Tract Number	Population	Median Age	Race and Ethnicity		Per Capita Income	% Persons Below Poverty Line	Number of Housing Units	Types of Structures	
1	3,100	39.2	58%	White	$42,529	620.0%	1,024	88%	Single Unit
			0%	Black				11%	Multi-Unit
			0%	Native				1%	Mobile Home
			7%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			1%	Other					
			6%	Two+					
			29%	Hispanic					
2	3,772	35.4	29%	White	$43,815	670.0%	1,199	98%	Single Unit
			15%	Black				2%	Multi-Unit
			0%	Native				0%	Mobile Home
			15%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			1%	Two+					
			39%	Hispanic					

Appendix C—Marathon Detroit 2018 Incident

The following is an excerpt from Marathon's process safety advisory describing a 2018 fired heater incident at its Detroit refinery:

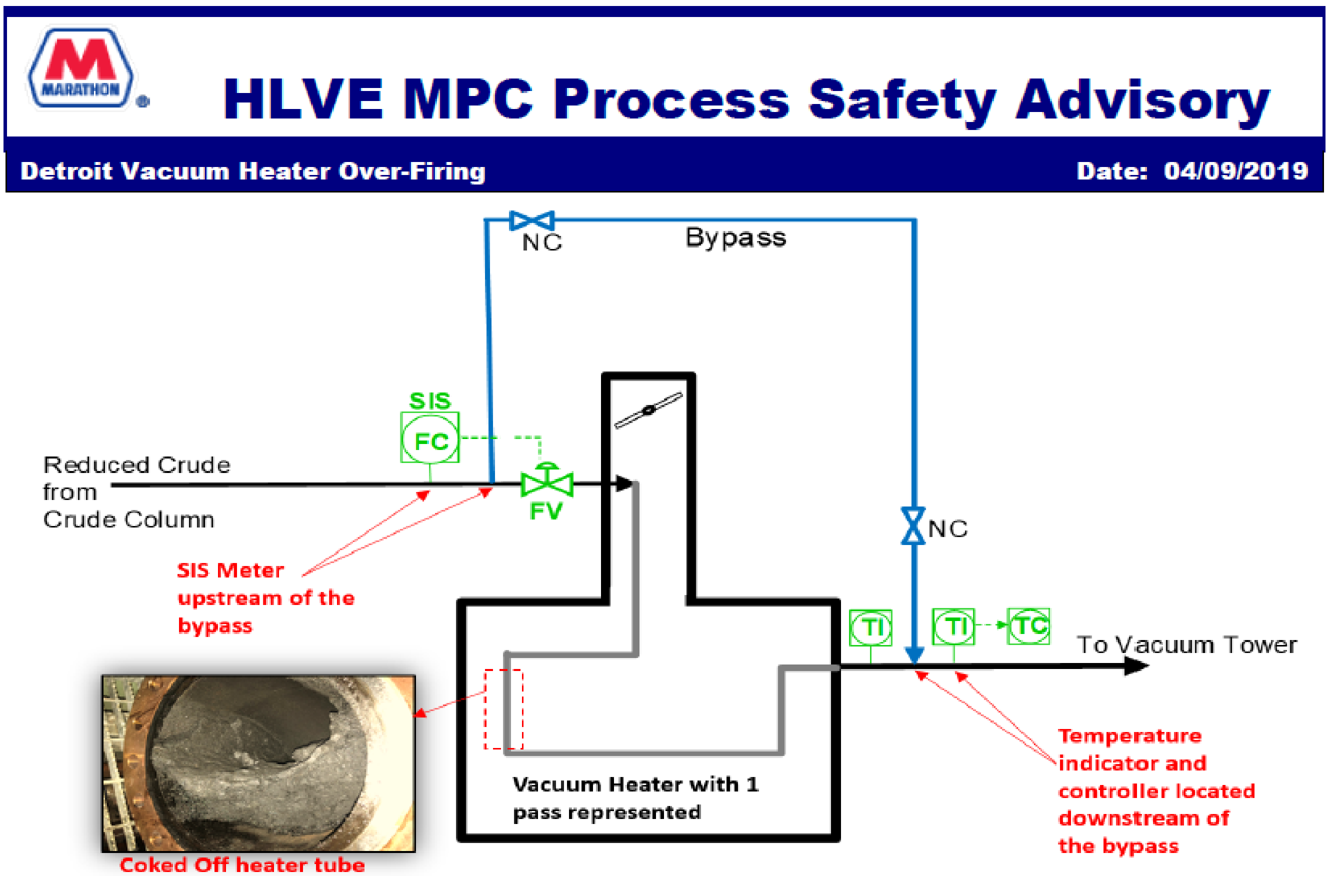


Figure 1: Simplified Schematic of Vacuum Heater Showing SIS and TI location relative to the bypass

Incident Summary

During start-up from the Detroit 2018 Plantwide Turnaround, the crude unit vacuum heater, 4H2, experienced a low-flow situation resulting in damage […] with the potential for a loss of containment and fire to have occurred. **Note: This incident has been deemed a Process Safety High Learning Value Event (HLVE) and has been selected for discussion in the Refining organization through this Process Safety Advisory.**

Background

As part of the Detroit Heavy Oil Upgrade Project (DHOUP), bypasses were installed to allow for one of the two parallel crude vacuum heaters to be taken offline. During startup from the 2018 Turnaround these vacuum heater bypasses were initially opened per procedure to air free and remove water from the lines. However, the startup procedure did not contain steps to close the bypasses and a significant portion of the flow bypassed 4H2 rather than flowing through the heater tubes.

The heater was equipped with a safety instrumented system (SIS) to protect against low flow through the heater tubes, however the low-flow condition was not detected because the bypass line was installed downstream of the SIS flow meter (Figure 1), essentially defeating the safety system. Ideally, this condition would have been identified during the unit Process Hazard Analysis, but it was not.

As startup progressed, the true heater outlet temperature was higher than intended. Because the inputs to the temperature controller are located downstream of where the bypass line ties in to the heater outlet (Figure 1), the temperature being controlled was much lower than the true heater outlet temperature. The result was over-firing of the heater. A high heater outlet temperature alarm on the temperature indicators upstream of the bypass was not received, as this alarm point had not been loaded after the alarm rationalization effort.

Tube skin [metal] temperatures increased in the vacuum heater due to part of the flow being bypassed and the over-firing of the heater. Multiple high skin-temperature alarms were not identified as a critical situation by the console operator due to alarm flood, an incorrect alarm description, inadequate control screens, and alarm priority.

Vacuum could not be maintained on the vacuum column due to an excess of vacuum column overhead vapor. Troubleshooting efforts did not identify that the high heater tube temperature was causing thermal cracking of the reduced crude, producing a large amount of vapor and depositing coke in the heater tubes. (Figure 1).

Ultimately, 4H2 tripped on low flow due to the severe coking in the tubes further restricting flow. The vacuum column pressure immediately began decreasing and operations identified the open bypass lines.

Root Cause Investigation

The following root causes and recommendations were identified during the Detroit Root Cause Analysis:

Root Causes:

- Bypass lines are located downstream of flow indication associated with SIS low-flow shutdown.
- High skin [tube metal] temperature alarms not identified as critical situation by console operator.
- Startup procedure does not contain a step for closing the [heater] bypasses.

Recommendations:

- Implement a project that prevents the heater bypass lines from defeating the […] SIS shutdowns.
- Add a permissive to the SIS startup logic […] to require confirmation that the bypasses are closed.
- Update all vacuum side startup procedures to ensure that bypasses around [the heaters] are closed prior to lighting heaters. Add a warning statement on the consequences of not closing the bypasses.

- Update vacuum heater combined HMI screen to display max tube skin temperatures for [the heaters] and correct the description for the 4H2 max tube skin temperature to reference 4H2.

- Set all the tube [metal] temperature alarms as high priority across the site.

What can YOU do?

Review this process safety advisory with your workgroup and watch the video. Specifically consider the following:

- Are there bypass lines, pressure safety valves, etc. that could defeat an SIS system due to their location? If so, inform your supervisor.

- Do temperature controllers on process heaters measure the true heater outlet temperature? Inform supervision of any instances where the temperature controller readings can be quenched by bypass lines, etc.

- Are there steps in your operating procedures that do not have a necessary subsequent follow up step?

APPENDIX D—CSB INTERPRETATION OF MARATHON FIRED HEATER NOT-TO-EXCEED LIMIT AND ALARM SETTINGS

High Pass Outlet Temperature Not-to-Exceed (NTE) Limit

Marathon Standard Language:

This NTE shall be set at either:

(a) The Heater design process exit temperature (from the heater data sheets) plus 150 °F, or

(b) the process exit temperature that results in a heater tube failure in 10,000 hrs.

Available Data from Documents Provided for Martinez Heater:

Parameter	Value	Source
Heater design process exit temperature	714.8 °F at end of run	Heater Data Sheet
Process exit temperature that results in a heater tube failure in 10,000 hours	Not available	N/A

CSB Analysis:

Note that these temperature instruments measure the process temperature (the fluid inside the piping), not the piping metal temperature.

NTE limit: With the available data, the calculation from item (a) becomes: 715 °F + 150 °F = **865 °F**

Parameter	CSB Interpretation	Actual Marathon Setting
NTE limit	865 °F	1,100 °F

High Tube Metal Temperature Alarm

Marathon Standard Language:

Set this alarm at the ***lowest*** of the following:

- Temperature corresponding to a remaining tube life of 100,000 hours (11.4 years),
- Maximum temperature corresponding to the elastic allowable stress limit, […] or
- Tube temperature that is 100 °F above the anticipated [end-of-run] tube temperature from the heater data sheets for new heaters.

Available Data from Documents Provided for Martinez Heater:

Parameter	Value	Source
Temperature corresponding to a remaining tube life of 100,000 hours	1,108 °F	Marathon calculations (post-incident)[a]
Maximum temperature corresponding to the elastic allowable stress limit	1,120 °F	Heater Data Sheet, "Design tube metal temperature (Elastic)"
Anticipated end-of-run tube temperature	Radiant Section: 780 °F Convection Section (Lower): 715 °F Convection Section (Upper): 650 °F[b]	Heater Data Sheet, "Maximum tube metal temperature – fouled"

CSB Analysis:

With the available data, the calculation from the third bullet becomes: 715 °F + 100 °F = **815 °F** for the convection section and 780 °F + 100 °F = **880 °F** for the radiant section.

Both these values are ***lower*** than the elastic allowable stress limit temperature of **1,120 °F**.

Parameter	CSB Interpretation[c]	Actual Marathon Setting
High tube metal temperature alarm	Convection Section: 815 °F Radiant Section: **880 °F**	Convection Section: 790 °F[d] Radiant Section: **1,100 °F**

[a] The heater data sheet documented that the design is based on 200,000 hours of tube life and calculations in API Standard 530 [32].

[b] The upper convection section (finned tubes) did not have tube metal thermocouples.

[c] The interpretation is based on Marathon's corporate standards at the time of the incident. API recommends setting tube metal temperature limits at the 20,000-hour creep temperature for safety and at the 100,000-hour creep temperature for reliability [32, pp. A-1, 31, pp. 14-15]. This information was not available for the Martinez heater.

[d] Marathon likely set the convection tube metal temperature alarms to limit long-term coking. The pre-2020 operating manual for the petroleum diesel unit recommended keeping heater pass temperatures below 800 °F to prevent coking in the tubes.

APPENDIX E—OTHER INDUSTRY INCIDENTS OF RELEVANCE

The following additional fired heater tube rupture incidents were reported to the CSB from 2020 through 2024.

	Incident Date	Company	City, State	Link to Incident Report
1	2/15/2021	Chevron Phillips Chemical	Port Arthur, TX	Link to report
2	2/15/2021	Chevron Phillips Chemical	Sweeny, TX	Link to report
3	8/19/2022	Valero	Texas City, TX	Link to report
4	12/23/2022	Delek	El Dorado, AR	Link to report
5	1/21/2023	PBF Energy	Chalmette, LA	Link to report
6	3/17/2024	ExxonMobil	Baytown, TX	Link to report
7	7/12/2024	LyondellBasell	Channelview, TX	Link to report

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