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Potential Vulnerability of US Petroleum Refineries to Increasing Water Temperature and/or Reduced Water Availability

Executive Summary of Final Report

Prepared for

US Department of Energy

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Prepared For

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For Jacobs Consultancy

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Executive Summary

Introduction

The US Department of Energy (DOE) engaged Jacobs Consultancy Inc. (Jacobs Consultancy) to study the potential vulnerability of US petroleum refineries to increasing water temperature and/or reduced water availability.

The DOE is exploring questions such as:

- How do water temperature or water volume reductions affect refinery capacity? How is this handled at the operational level by refinery operators? Have any cutbacks affected regional and national supply of refined products?
- How do refinery operators plan for water temperature variability at operational (short-term) and tactical/strategic (long-term) time scales? Are contingency plans required to deal with water temperature increases due to drought or longer-term climate trends? How do refining companies deal with water temperature and water reductions in their risk analysis, including siting for new refineries?
- Are refineries in certain regions more or less vulnerable to water temperature issues? Is refined product supply in certain regions more or less vulnerable to refinery outages or reductions caused by water temperature increases or volume decreases?
- How does potential water temperature / volume vulnerability interact with other systems-level vulnerabilities that refineries may face (e.g., electrical outage, planned and unplanned refinery maintenance, strikes)?

The Refinery Water and Energy Balance

A modern oil refinery is a complex, multi-technology, multi-process manufacturing facility which utilizes a significant amount of energy to process crude oil into finished products. As much as 10% of the energy content of crude oil is consumed in the processing steps, and a significant amount of this energy is shed to the atmosphere via thermal losses, fired heater stack gas heat loss, air coolers, and removed in water coolers. The heat absorbed in the closed loop water coolers then has to be released to the atmosphere via contact with air and through water evaporation from the cooling water system's cooling towers. This evaporation is one of the primary loss points for water within a plant.

A typical refinery will use about 1.5 barrels of water to process 1 barrel of crude oil. However, water use can vary significantly, depending on the design of the facility. A primary differentiator is whether the plant utilizes any once-through cooling water systems (systems which pump water from an external body of water through cooling exchangers and then directly back into the water body), or a recirculating closed-loop water cooling system. (About 10% of the industry, on a barrels of oil processed-basis, uses once-through cooling water). As an industrial consumer of water, the refining industry ranks well behind that of the electric power industry and agricultural consumers within the United States and on par with other industrial users such as the chemical industry, but individual plants can be significant local consumers.

Study Objectives

In this Study, we model and discuss the uses of water within the US petroleum refining industry. We also look at the impact of a reduction in availability of the volume of water in each of the cases. Finally, as part of this work we contacted refiners directly in different regions of the United States to assess the validity of our findings.

The makeup water (MUW) source, consumption, and location of the final disposition from the refinery's internal Waste Water Treating Plant (WWTP) for any specific refinery can vary significantly; consequently, we developed some "typical" refineries to model and then based our discussion upon the expected effects of changes for these facilities.

The effect of rising MUW temperature is not biased by refinery configuration, but may be somewhat biased by geographic location. Most US refineries currently can handle a 20˚F to 50˚F or greater swing in their MUW temperature due to variations between day/night and summer/winter ambient temperature differences.

Refinery Water Use Discussion

Water is utilized in oil refineries in a number of different ways. The primary uses are:

- Cooling water (CW) cooling tower (closed loop cooling water, CLCW) makeup
- Process water
- Boiler feed water (BFW) production for steam
- Fire mains
- Utility water
- Once-through seawater or freshwater for cooling
- Potable water and sanitary water system

A certain amount of water is lost or consumed in each use. We discuss MUW in more detail below. The primary loss points from these users are (in relative order of decreasing volume):

1. WWTP effluent to a regulated outfall
2. Water vapor to atmosphere from the top of cooling water towers
3. Water vapor from steam traps, steam vents, open sewers, and open-roofed waste water treating plant equipment
4. Leakage from fire mains to the ground

There are two basic water sources for refineries: surface water (seas, lakes, rivers, ponds) and ground water (aquifers). Water from aquifers normally is accessed by drilling wells. The source of the MUW to the refinery can be any one of the following, or, more typically, a combination of:

- City or municipal water district fresh water (~60%[1] of refineries)
- Ground water (~15%)
- Once-through sea water (~5%)
- Once-through river water (~10%)
- River water (~50%)
- Lake water (<5%)[2]

Most refiners reuse or recycle various water streams within the refinery in an effort to either:

- comply with regulatory limitations
- reduce the volume (and cost) of purchased water
- save MUW processing energy costs, and/or
- reduce the volume of effluent water.

Primary Water Systems in the Refinery

Refinery Cooling Water Systems

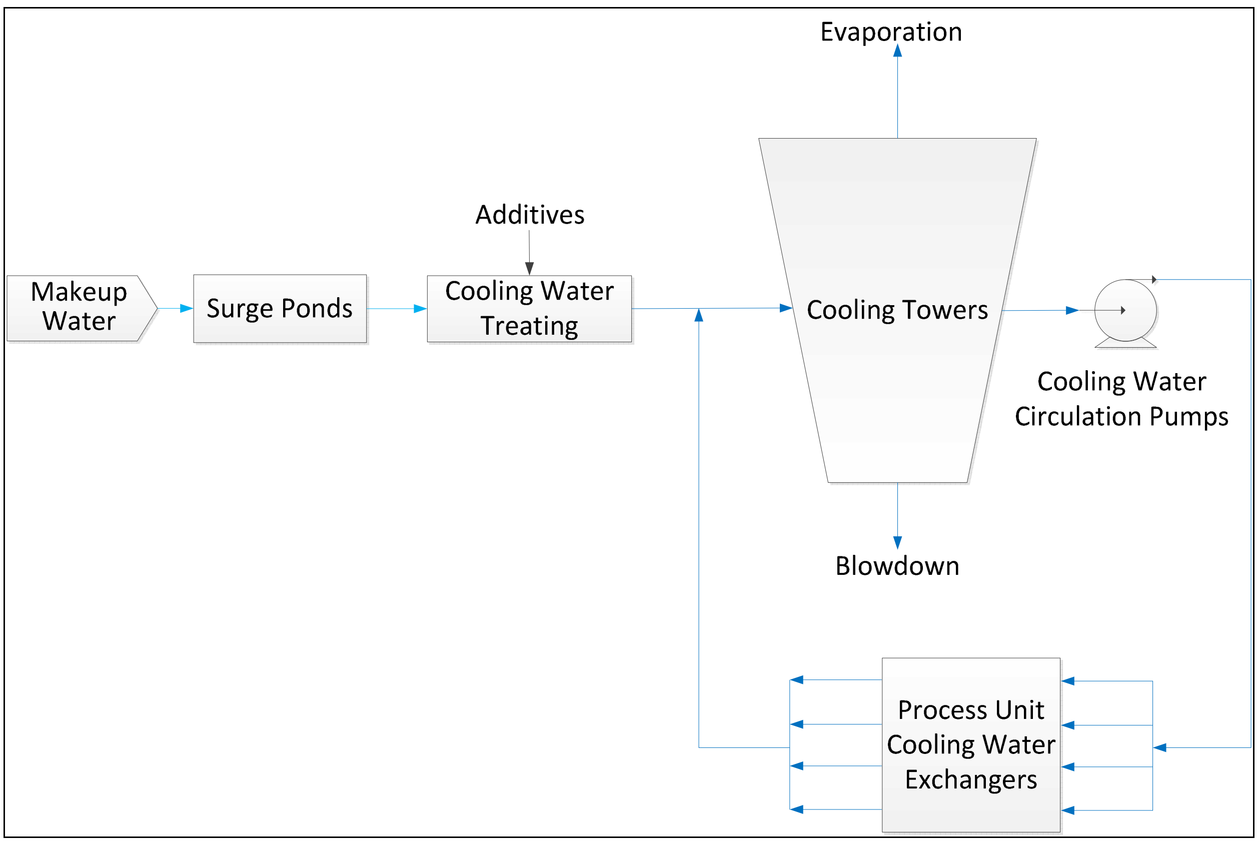
Most oil refineries use large cooling water (CW) recirculation systems for various process cooling services. These cooling water systems are made up of multiple-cell cooling towers above surge basin(s), an MUW system (including treatment), circulating pumps, chemical additive pumps, and a distribution and gathering header. A generic diagram is included below.

1 as a percentage of the top 135 US oil refineries, not on a barrel capacity basis
2 the numbers add up to >100% due to many refiners having more than one source of MUW

Normally, these systems are treated as a utility and are not considered a “profit center,” thus they may not be proactively updated except when their performance results in a significant economic problem for the facility. The MUW source, design, and capacity of these systems will have been specified during the initial design of the refinery. Since then, little will have changed besides augmentation and expansion throughout the years as the size and complexity of the refinery increases.

Cooling requirements for process fluids are typically met by first rejecting some process heat to the atmosphere using an air cooler, followed by a water-cooled heat exchanger. The balance between the use of air-cooled heat exchangers and cooling water exchangers will have been set during the initial design of a facility, and any desire to retrofit the system to shift the duty balance between cooling water and air will be expensive and, usually, only done incrementally as new units are added to the refinery.

Figure 1.
Typical Refinery Cooling Water Loop



The performance of the cooling water system is mostly determined by the amount and size of the cooling water towers and the ambient air conditions (temperature and dew point). The effect of an increase in the MUW temperature on the cooling water system would be minor, since the volume of water circulated is typically 20 to 100 times larger than the MUW volume. *A larger effect would be expected from higher ambient temperatures which will cause the cooling water in circulation to be warmer,* as the temperature of the cooling-tower-effluent water is highly dependent on ambient temperature. Higher ambient temperature and dew point will reduce the effectiveness of the cooling water system and reduce the heat removal capability of every single cooling water exchanger in the facility by increasing the cooling water tower outlet temperature. Since the flowrate of cooling water to any one exchanger is set by the capacity and head of the cooling water circulating pumps and the pressure dynamics of the cooling water header, there is typically no way to adjust the flowrate of water to an exchanger. Throughout the rest of the report, the performance of the cooling towers and their associated process cooling exchangers is the primary concern as we discuss the effect of higher ambient temperatures.

Boiler Feed Water Systems

To minimize fouling and scaling, steam systems require very clean boiler feed water, low in hardness and total dissolved solids. A number of different technologies are available to treat MUW for the boiler system. The technology chosen will determine the volume and quality of the reject water from the treating system. The boilers themselves are large producers of wastewater as they need to be “blown down” on a frequent schedule (purged to the sewer to minimize the buildup of solids and ions within the water) to help minimize the amount of harmful impurities which build up in them. This “blowdown” water is at boiler temperature and may need to be cooled prior to entering the wastewater feed system to avoid overheating the micro-organisms (the “bugs”) utilized within the WWTP for treatment.

Process Water Systems

In a refinery, most process water has come in contact with hydrocarbons in process equipment and must be separated and recovered from the hydrocarbons. Most refineries do not maintain a separate process water header. The volumes needed for process water are typically sourced from a cooled, clean steam condensate header or from BFW to minimize the impurities contained within the water to avoid fouling and/or corrosion of the process equipment.

Once-Through Seawater System for Cooling

Some coastal refineries can utilize once-through sea water for process cooling. After passing through the various process coolers, the warmed sea water is routed back to the source via some type of thermal dispersion header. Over time, refiners have reduced the use of sea water to lessen the risk of hydrocarbons leaking directly into a seawater ecosystem. An advantage once-through seawater may have over a closed-loop system is that the inlet water temperature can be significantly below ambient air temperature, thus allowing the process coolers to remove more heat and/or be smaller in size.

Once-Through Freshwater System for Cooling

Some refineries can utilize once-through fresh water for process cooling from a large lake or river. Fresh water does not pose the corrosion threat of sea water, but as with sea water, once-through freshwater systems present the risk of freshwater ecosystem contamination from hydrocarbon leaks. As with sea water, once-through freshwater systems may provide cooling water at a lower temperature than closed-loop systems.

Refinery MUW Sources

In this section we discuss the most common sources of MUW to US oil refineries and review the prevalence, pros and cons, and issues associated with each source. All potential sources of water for a refinery may be classified as either surface water (seas, lakes, ponds, lagoons, canals, rivers, streams) or ground water (aquifers). Water from aquifers usually is accessed by drilling wells into the aquifer.

City/Municipal Water

- May be sourced from surface water or ground water.
- The most common, cleanest, and typically most expensive of MUW sources, since city water undergoes extensive treatment to be potable.
- Quality: Can be used as cooling water system MUW directly and/or processed into BFW.
- Temperature: The temperature of this MUW can vary significantly with the seasons as it will be coming from a fresh water source via an open air municipal water processing facility. The temperature would be expected to vary between a low near freezing and a high temperature approaching 10˚F below the maximum ambient temperature reached on a typical day.
- Availability: This source may be expected to have supply constraints and/or would be expected to become more expensive over time.
- Disposal: Nearby surface water typically will be required for disposal of WWTP effluent. Allowable disposal water quality and possibly temperature will be monitored and will require local, state, and possibly federal permits.

River / Canal / Agricultural Water

- A major source of MUW, especially for cooling water systems. This surface water may not have any user fees associated with it, but the total volume allowed is usually regulated by state or local authorities to ensure adequate supplies are available for all users.

- Quality: This relatively clean water typically will only need to go through settling ponds and flocculation prior to usage as MUW for cooling water systems. This water source can also be used to feed BFW feed pretreatment systems, but significant purification efforts will be required to bring it up to BFW quality.
- Temperature: The temperature of this MUW can vary significantly with the seasons, varying between a low near freezing and a high temperature approaching 10°F below the maximum ambient temperature reached on a typical day. Water temperature affects the use of water by refineries. Some refineries that use water from rivers for once-through cooling have auxiliary groundwater supplies for use in summer when the river temperatures are too high for effective cooling. Other refineries continue using the river supply, but increase the withdrawal for cooling as the river temperature increases.
- Availability: This source possibly could be expected to have supply constraints and/or would be expected to become more expensive over time. In extreme circumstances, rivers can actually dry up and/or have water usage rationed, which would cause significant difficulties for a refinery.
- Disposal: WWTP effluent disposal is back into the source where it came from. Allowable disposal water quality and possibly temperature will be monitored.

Lake Water

- Primarily only available to be used as a significant source of MUW for refineries directly on the Great Lakes. This water may not have any user fees associated with it, but the total volume allowed is usually regulated by state or local authorities to ensure that adequate supplies are available for all users.
- Quality: The quality of the water is fairly constant and good. Can be fed to both cooling water systems and BFW pretreatment systems.
- Temperature: The expected seasonal temperature variation will be less than that seen for river water and could be significantly cooler than other water sources.
- Availability: Availability may be limited for regulatory reasons, rather than actual supply limitations.
- Disposal: WWTP effluent disposal should be back into the source. Allowable disposal water quality and possibly temperature will be monitored.

Ground Water

- Typically utilized in landlocked or more arid areas. This water may not have any user fees associated with it, but the total volume allowed is usually regulated by state or local authorities to ensure adequate supplies are available for all users and to avoid depletion of the resource.
- Quality: The quality of this water can vary depending on the source. Typically, the water can be very hard with a high mineral content, thus making it more expensive to treat to BFW quality.
- Temperature: An advantage of using water from an aquifer is that the temperature is not expected to fluctuate at all with surface ambient conditions.
- Availability: A significant disadvantage could be the finite volumes which may be available and the desire of society to conserve this fresh water resource for other uses.
- Disposal: A nearby surface water resource will be required for disposal of WWTP effluent. Allowable disposal water quality and possibly temperature will be monitored.

Sea Water

- Used for once-through cooling in some coastal refineries, but requires expensive high-metallurgy equipment for pumping, transfer, and heat exchangers due to the corrosive nature of salt water.
- Quality: The quality of this water should not vary much.
- Temperature: The temperature will vary seasonally. Typically, the temperature of sea water will be lower than that found in freshwater river sources, but higher than what would be found in the open ocean as sea water for cooling is sourced from a shallow bay or estuary.
- Availability: Unlimited, but the potential environmental exposure of sending hydrocarbon directly into the ocean has led refiners to seek to reduce their usage of once-through sea water and only refiners on the coasts can utilize this option.
- Disposal: The water is not treated and needs to be returned uncontaminated to the location from which it came and at no more than a prescribed temperature above the water into which it is being discharged. Holding tanks with oil skimming capability may be utilized.

Underground Saline Water Sources

Underground saline water resources are available as both a water source and a location for deep well injection disposal of refinery-effluent water, but the high cost of treating the water to achieve useable quality limits its use by most refineries for MUW. In contrast, saline aquifers are a major source of water for oil sands production in Alberta, Canada.

Model Refinery

For this Study, we developed a simple, non-linear model of a typical medium-sized (120-mbpd FCC-based) refinery configuration running a benchmark crude oil, light, sweet West Texas Intermediate (WTI). We used the model to better understand the MUW balances and to determine the effects of changes in MUW quality, temperature, and/or availability. We qualitatively reviewed each of the process units and estimated what effects a very significant (+20˚F) increase in ambient temperature would have on the refineries during the heat of the summer. This highly unrealistic climatic temperature change was chosen to amplify the effects of higher ambient temperatures on the industry. If a smaller and much more typically discussed temperature increase of, for instance, 2˚C (3.6˚F), were utilized, very little effect would be seen with our analysis.

Our model results show:

- The blowdown flowrate from the cooling water tower system is a significant proportion of the WWTP's feed.
- The quality of the MUW will have a significant effect on how much closed-loop cooling tower blowdown water is required to reduce the solids content of the circulating water. Lower-quality river and agricultural water will require higher purge volumes.
- Increasing the size of a refinery will proportionally (i.e., 20% more throughput requires 20% more water usage) increase the volume of MUW required.
- Increasing the complexity of a refinery by adding more process units will proportionally increase the volume of MUW required.
- Increasing the sulfur content of the crude oil to a refinery will proportionally increase the volume of MUW required.
- Increasing the heaviness of the crude oil to a refinery will proportionally increase the volume of MUW required.
- Water evaporation from the cooling towers is the primary loss point inside a plant.
- An increase in ambient air temperature will increase the cooling water temperature.

Refinery Size and Complexity

In reviewing the process units that would be most affected by ambient temperature increases, we observe that the relative vulnerability of a refinery would not be affected by its size, complexity, or crude slate. Water usage will increase roughly in proportion to an increase in overall crude processing capacity, in proportion to a refinery's relative complexity [as indicated by its Nelson index (a common industry index used to indicate the complexity of a refinery)], and in proportion to the volume of heavier, more sour crude processed (as indicated by the crude oil's API gravity).

MUW Temperature and Availability

Makeup water is only a small portion of the total closed-loop cooling water circulation system. Thus, a higher MUW temperature will not significantly affect the temperature of the refinery's cooling water. However, the higher ambient temperatures (and probable associated higher humidity) which caused the MUW to be warmer will have a significant effect on the performance of the process units during the hottest days of the summer as the circulating cooling water temperature increases. With enough warning (months and years), some of these effects can be remedied by increased maintenance costs, operating costs, or capital spend to modify the cooling water system or to change the process units.

Refineries which rely upon dwindling sources of ground or surface water may be required to increase their capital investment to reduce their consumption of water, or find alternate sources. These investments to minimize net water usage could become increasingly expensive and have diminishing, or negative, economic returns as the easiest and most profitable ones are executed first.

Refiners which currently rely upon once-through sea/freshwater cooling water (~15 of the medium/large refineries) are particularly susceptible to public pressure and/or environmental regulation which may require that they switch to a closed-loop Cooling Tower system. This would be an extremely costly change. Costs for our medium-sized refinery would accrue in three main areas:

1. the capital cost of adding a closed-loop cooling tower system (>$100m),
2. the capital cost of enlarging and/or modifying a large number of existing cooling water exchangers for their new service (>$50m), and
3. the process debits associated with lower exchanger performance since, typically, the once-through cooling water temperature is lower than what can be economically attainable by the new closed-loop cooling water system (>$100m).

Refinery Water Case Studies

In this section we summarize recent conversations with refinery personnel and other refining subject matter experts. All discussions and usage of this information were on the condition of confidentiality.

- **Refinery A—**This West Coast refinery (PADD 5) uses city water for most of its MUW, except for about 30% of the process units which utilize once-through seawater for cooling. Ten years ago, they studied the cost and logistics of switching this OTCW system to use cooling towers, but the lack of available land and extremely high cost made this economically infeasible. They have no long-term concerns about the temperature, quality, or availability of their MUW, but the cost per gallon has doubled in the past three years and local drought has brought additional surcharges.

  The refinery has developed a list of possible projects to reduce their use of water. They do co-process sanitary sewer water in their WWTP and they discharge the WWTP effluent into the ocean via a strictly regulated diffuser system. They have never had to cut back production due to loss of MUW and are never fuel gas long.

- **Refinery B—**This PADD 4 refinery uses city water for all of its MUW. They have no concerns regarding the availability, quality, or temperature of this water source in the long term. In fact, they currently have a feedwater surge tank which they are going to take out of service since it has reached the end of its useful life. Their water price has been rising, but not enough to warrant any significant investments to minimize water consumption beyond their current recycle and reuse strategy. They discharge to a local creek and do not have a maximum allowable temperature limit for effluent. They have never had to cut back production due to loss of MUW.

- **Refinery C—**This Midwest refinery (PADD 2) uses canal water for all of their MUW. There are no concerns about the availability, quality, or temperature of this water source in the long term. They have a recycle and reuse strategy in place. They discharge back into the canal and do not have a maximum allowable temperature limit. During the wintertime, when a significant amount of salt runoff from the roads occurs, the salt levels in the canal are actually higher than that of the plant’s discharge. They have never had to cut back production due to loss of MUW.

- **Refinery D—**This large Gulf Coast refinery (PADD 3) uses river water for all of their MUW as supplied by a local water authority. Recently a significant curtailment of this water availability has been threatened due to drought, but they remain as a senior water right holder and have only seen an actual decrease in volumes of 10%, which they were able to replace by purchasing water from local farmers. (In addition, refiners can usually handle temporary reductions of this magnitude by minimizing CLCW tower blowdowns and some other short-term measures.) Proposed curtailments of water availability have provided incentive for the site to consider numerous options to reduce baseline water usage. This exercise has yielded a comprehensive plan for incrementally shedding consumption in the short and medium term, if it became required.

The refinery discharges to the sea and the effluent's temperature is monitored, but their permit allows them to be within a certain range above the water body's temperature, so if the ambient temperature (and the water body's temperature) rises, then their effluent temperature is also allowed to rise by a similar amount.

- **Refinery E—**This Midwest refinery (PADD 2) uses ground water and untreated city water for their MUW. They have no concerns about the temperature, quality, or availability of their MUW source. They have problems with discharge of their WWTP effluent to a small river, and thus are going to add a zero-discharge system to re-process the effluent for recycle and then will inject the remaining concentrate into a deep well.
- **Refinery F—**This East Coast refinery (PADD 1) uses city water for MUW and sea water for OTCW. They have no concerns about the temperature, quality, or availability of their city water supply.
- **Refinery G—**This large Midwest refinery (PADD 2) uses lake water for their MUW, including OTCW for most of their process cooling. They have no concerns about the temperature or quality of their MUW, but are exploring the cost of going to a CLCW system for all of their units which currently are on OTCW. Initial estimates show this to be extremely costly (>$400MM), especially because the lake water temperature is significantly lower than what a CLCW system would be able to achieve, so large process unit debits would be expected without significant capital upgrades.
- **Refinery H—**This East Coast refinery (PADD 1) uses city water for their MUW. They have no concerns about the temperature, quality, or availability of their MUW.
- **Refinery I—**This Gulf Coast refinery (PADD 3) uses river water for their MUW. They have no concerns about the temperature, quality, or availability of their MUW. Their corporate parent has a water team which is exploring long-term issues related to water, but they did not share with us their specific focus.
- **Refinery J—**This West Coast refinery (PADD 5) uses river water for their MUW, supplied by the local municipal district. They have a recycle and reuse strategy in place. Historically water recycle has been done to save money. They have no current concerns about the temperature, quality, or availability of their MUW. They discharge to the sea.
- **Refinery K—**This Midwest refinery (PADD 2) uses river water for their MUW as permitted by state authorities. They discharge back into the same river. They have no concerns about the temperature or quality of their MUW, but in the past there have been drought conditions which caused them to have to monitor the quality and flowrate of river water closely as their effluent became a large portion of the river's total flow. They have a recycle and reuse strategy in place.

- **Refinery L—**This large Gulf Coast refinery (PADD 3) uses river water for all of their MUW as supplied by a local water authority. They have been threatened with significant curtailment of water availability recently due to a drought, but remain as a senior water right holder. Over the past ten years they have reviewed their water usage frequently and have engineered and constructed a number of projects to reduce their use of MUW for economic, operational, and energy saving reasons. With completion of these projects, they now utilize a significant number of different recycle streams.

  They have an aggressive recycle and reuse strategy in place due to local supply limitations.

Case Study Discussion

Overall we were able to directly review and/or discuss the performance and concerns of over ten refineries across all of the PADDs with a total processing capacity of more than 2.5mbpd. The breadth and depth of the discussion varied with each facility representative, but the specific issues and challenges which were communicated to us supported the Study's findings and have helped us to more fully develop our final conclusions below. None of the refiners have reported any difficulties with meeting their effluent discharge temperature limits (if they have this type of limit).

Overall Conclusions

1. Oil refineries in the United States utilize MUW from a variety of different sources, depending on their history and geographic location. This reduces the vulnerability of the industry to any one type of event which could reduce the quality or quantity of any one particular type, or source, of MUW.
2. Higher ambient temperatures will increase the temperature of most forms of fresh MUW to oil refineries (except for groundwater), but this increased temperature will not necessarily be directly problematic.
3. Higher ambient temperatures affect the performance of the Closed Loop Cooling Tower systems and will lead to directionally lower yields, throughput, and performance of most refineries during summertime peak temperatures. Lost profits during peak summertime temperatures for a medium-sized temperature-limited refinery can currently be in the range of $10k to $100k per day, but no regional shortages due to this issue are known to have occurred within recent memory.
4. Higher ambient temperatures will increase the temperature of Once-Through Cooling Water (OTCW) from fresh and salt water bodies, and this may directionally lower the yields, throughput, and performance of a refinery which utilizes this type of resource.

5. Some refiners are looking to eliminate their usage of OTCW from fresh or salt water bodies, but this appears to be prohibitively expensive and may, in some cases, force a facility to be shut down if ultimately required by regulatory bodies.

6. Some refiners expressed concerns about the cost of complying with possible future regulatory requirements for discharging of waste water effluent, but that was outside of this Study's scope.

7. Maintenance, operational, and capital solutions exist for any of the problems that can arise from an increase in the temperature or salinity of MUW, or a physical or regulatory reduction in MUW availability. These solutions will require economic justification and take time and capital money to complete. Additional maintenance/operating costs to minimize this type of effect in the short to medium term could range from $50k to $300k per month, and capital expenditures could be in the range of $5MM to $100MM for a medium-sized refinery which utilizes closed-loop cooling towers, depending on the plant configuration and the severity of the issue.

8. Some individual refineries currently have, to varying degrees, water availability or price concerns, but these appear to be at just a few locations and manageable nation-wide and region-wide from an industry standpoint. Of the three primary risks analyzed within this Study (MUW temperature, quality, or availability), availability was deemed to be the highest risk at this time.

9. A few refiners have already been faced with varying levels of water supply restrictions. Refiners can usually handle temporary reductions of this magnitude by minimizing closed-loop cooling water tower blowdowns and some other short-term measures.

10. Few refineries consider the availability, quality, or temperature of MUW to be a significant threat to their future profitability, capability, reliability, or existence.

11. Based upon our analysis of the current status of the industry—the size, type, number of, current water-usage status, and geographic distribution of US refineries—we estimate that industry investments driven directly by rising ambient temperatures and water shortages could exceed $10 billion (in current dollars) over a 50-year period. Given that the expected climatic changes will be gradual and that this amount of money is relatively small to the amount of money that the industry has to spend as part of their regular capital replacement program, we opine that this should not be a significant concern for the future national and regional availability of transportation fuels compared to other potentially disruptive issues which refining companies worry about and prepare for, such as electrical outage, planned and unplanned refinery maintenance, labor strikes, mechanical failures, pipeline outages, hurricanes, and other weather events.