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Analysis of Alternative Uses for the Red Hill Bulk Fuel Storage Facility

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About This Report

Since the 1940s, the U.S. Department of the Navy (DoN) has owned and operated one of the largest bulk fuel storage sites in the world, located at the Red Hill ridgeline on the island of Oahu, Hawaii. The site, which was designated a historic civil engineering landmark by the American Society of Civil Engineers in 1995, has been the source of public attention since three fuel releases occurred between 2014 and 2021. In 2021, the Secretary of Defense authorized the permanent closure of the facility, and Congress tasked the Secretary of Defense and the U.S. Department of Defense (DoD) to commission an independent study examining potential beneficial reuse alternatives for the Red Hill Bulk Fuel Storage Facility site. DoD and, more directly, DoN tasked the RAND Corporation, a federally funded research and development center (FFRDC) to conduct the study. This report is the direct result of, and fulfills, that requirement. It considers five alternatives for the Red Hill Bulk Fuel Storage Facility (no beneficial reuse, energy storage using pumped hydropower, energy generation using renewable sources, water storage, and a museum) and evaluates each alternative against four criteria (executability, economics, nonfinancial considerations, and robustness to uncertainty). Our overall recommendation is that the best available data and evidence suggest that policymakers should delay any decision on alternative reuses of the Red Hill Bulk Fuel Storage Facility for the foreseeable future.

The report is intended for Congress, and the public more generally, and does not require extensive background knowledge (although understanding parts of the methodology might be beneficial). We anticipate that the report will be of interest to stakeholders in the debate around the future of Red Hill Bulk Fuel Storage Facility.

The research reported here was completed in January 2024 and underwent security review with the sponsor before public release.

RAND National Security Research Division

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Summary

Since the 1940s, the U.S. Department of the Navy (DoN) has owned and operated the Red Hill Bulk Fuel Storage Facility (RHBFSF), one of the largest bulk fuel storage sites in the world, located at the Red Hill ridgeline on the island of Oahu, Hawaii. The site, which was designated a historic civil engineering landmark by the American Society of Civil Engineers in 1995, has been the source of public attention since three fuel releases occurred between 2014 and 2021. In 2021, the Secretary of Defense authorized the permanent closure of the facility, and Congress tasked the Secretary of Defense and the U.S. Department of Defense (DoD) to commission an independent study examining potential beneficial reuse alternatives for the RHBFSF site. DoD and, more directly, DoN tasked the RAND Corporation, a federally funded research and development center (FFRDC) to conduct the study. This report is the direct result of, and fulfills, that requirement. The study was to include the following steps:

- engagement with stakeholders
- a review of historical alternative uses of facilities with similar characteristics
- other modalities necessary to appropriately identify alternative-use options, including data and information collected from various stakeholders and thorough site visits to physically inspect the facility
- a cost-benefit analysis of any of the feasible alternatives.

Section 336 of the fiscal year 2023 National Defense Authorization Act directed the Secretary of Defense to oversee a study “to determine the range of feasible alternative Department of Defense uses for the Red Hill Bulk Fuel Storage Facility.”¹ In response to the National Defense Authorization Act’s directive, the Assistant Deputy Chief of Naval Operations for Installations and Logistics (OPNAV N4B) tasked the RAND Corporation with the following:

- Perform a thorough site visit and inspection of RHBFSF to identify potential alternative uses and collect data and information from on-site stakeholders.
- Solicit ideas for potential reuse alternatives by DoD.
- Develop criteria to assess potential reuse alternatives provided by DoN to determine which alternatives would be acceptable for the next step: a detailed cost-benefit analysis.
- For reuse alternatives identified in task 3, perform a cost-benefit analysis of feasible DoD alternative uses, consisting of estimated design and construction costs, estimated life-cycle costs and disposal costs, military costs, benefits to the local economy, environment impacts, and any other relevant factors.
- Publish an unclassified, detailed report of the findings and recommendations.

¹ Public Law 117-263, James M. Inhofe National Defense Authorization Act for Fiscal Year 2023, December 23, 2022.

Approach

The RAND team was unable to identify suitable analogs to RHBFSF from which to derive meaningful comparisons. Aside from general research, we primarily drew on three third-party sources of data and analysis provided by the sponsor specifically for this report:

1. publicly available reports furnished by DoN on the status of, and plans for, the RHBFSF site
2. Makai Ocean Engineering's *Navy Red Hill Energy Storage Feasibility Study* report provided courtesy of the Hawaii Natural Energy Institute, an affiliate of the University of Hawaii's School of Ocean and Earth Science and Technology²
3. Nakupuna Consulting's series of reports on the local community's views and preferences regarding reuse of RHBFSF.³

In consultation with the sponsor, the RAND team assessed the five most-feasible alternatives derived from the numerous alternatives proposed by above sources:

1. no beneficial reuse
2. energy storage using pumped hydropower
3. energy generation using renewable sources
4. water storage
5. museum.

Importantly, these alternatives are not the sole intellectual provenance of the RAND team. The following constraints and considerations helped guide the selection of the above alternatives:

- The Secretary of the Navy would entertain options to transfer ownership of the RHBFSF site and facility after closure; alternatively, non-DoN organizations could operate reuse alternatives.
- Alternatives need to avoid further contaminating the land or aquifer.
- Alternatives must be able to be practically implementable at the RHBFSF site.
- Sufficient information was necessary to evaluate the selected alternatives; alternatives were rejected that were not clearly described in the source material or lacked sufficient details to enable the RAND team to perform an assessment.
- Alternatives were preferred that were likely to receive support from the community, as determined by Nakupuna Consulting's study results.

² Makai Ocean Engineering, Inc., *Navy Red Hill Energy Storage Feasibility Study Final Report: Infrastructure Review and Preliminary Energy Comparison*, October 13, 2023b.

³ Nakupuna Consulting LLC, *Final Qualitative Survey Report: Survey Results Regarding Potential Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, August 2023a; Nakupuna Consulting LLC, *Soft Sounds Interviews Report: Input and Feedback from Key Stakeholders and Community Influencers Regarding Potential Beneficial Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, August 2023b; Nakupuna Consulting LLC, *Final Quantitative Survey Report: Survey Results Regarding Potential Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, November 2023c.

To keep the analysis manageable and follow, broadly, a cost-benefit methodology, we identified four key evaluation criteria:

1. executability
2. economics
3. nonfinancial considerations
4. robustness to uncertainty.

The congressional language mandating this study included a requirement to assess the environmental impact. Different aspects of this environmental assessment are in both the executability and nonfinancial consideration sections. We evaluated each alternative according to each criterion and assigned a score for each criterion using a four-point (1–4) scale: 1 was the lowest rating an alternative could receive, and 4 was the highest. The scoring methodology and meanings of each score varied for each criterion. We created a matrix to compare the scores of each alternative by criteria. We did not assign weights to any of the criteria, opting to treat them all equally; however, policymakers may value one criterion more than others.

Key Findings

Table S.1 shows the final matrix with the five alternatives and RAND’s scores for each according to the four assessment criteria.

Table S.1. Scoring Assessment of Analyzed Alternatives

Alternative	Score (by Criterion)			
	Executability	Economics	Non-Financial Considerations	Robustness to Uncertainty
No beneficial reuse	4	3	3	4
Energy storage using pumped hydropower	3	1	1	3
Energy generation using renewable sources	4	1	2	3
Water storage	2	1	1	3
Museum	4	1	2	3

NOTE: Red boxes indicate the lowest possible score; green boxes indicate the highest possible score.

We found that a course of action to not develop the facility for beneficial reuse, while not technically a reuse alternative, scores well for all four criteria, which indicates that this alternative is highly executable from a technical, regulatory, and environmental perspective; is able to be effectively evaluated from an economic perspective; has potential environmental, cultural, and social benefits; and is robust to uncertainty. Policymakers wishing to minimize the overall risk associated with reusing the RHBFSF site would be best served by this alternative.

Using RHBFSF for pumped hydropower energy storage scores high in terms of executability and robustness against uncertainty but low against economics and nonfinancial considerations. Given that the economics of this alternative cannot be evaluated precisely enough to warrant any financial-based decisionmaking and that it would likely have negative environmental, cultural, and social impact, policymakers who would like to minimize financial, environmental, or social risk would likely not choose this alternative.

Renewable energy generation scores very high for executability and robustness to uncertainty but low for economics and nonfinancial considerations. Therefore, policymakers who desire to limit the technical, regulatory, or environmental hurdles involved in implementing an alternative, as well as an alternative's vulnerability to future changes in policy, technology, or the environment, may view this alternative favorably. However, policymakers who give greater consideration to avoiding potential financial risk, environmental risk (a perception that may or may not be real—more-detailed analysis would be needed), or social risk would likely seek other alternatives than reusing RHBFSF for renewable energy generation.

Using RHBFSF for water storage scores high for our robustness to uncertainty criterion but low against the other three criteria. Therefore, unless policymakers consider robustness against future policy, technological, or environmental changes to be especially important, this alternative is unlikely to be beneficial, because significant uncertainty surrounds executability and economics, and there are potentially negative environmental and social impacts.

Turning RHBFSF into a museum performs well in the executability and robustness to uncertainty categories but low for economics and nonfinancial considerations. Therefore, as with renewable energy generation, this alternative is likely undesirable for policymakers who place greater emphasis on minimizing potential financial, environmental perception, or social risk than on risks associated with implementation or future policy, technological, or environmental changes.

Conclusions and Recommendation

Through our research, we have come to the following conclusions about RHBFSF and the alternatives that were presented to us:

- **Key conclusion 1:** The bespoke nature of RHBFSF makes reconfiguration and reuse for almost anything other than liquid storage difficult to contemplate.
- **Key conclusion 2:** There is uncertainty surrounding the timing of the availability of RHBFSF after closure, which would meaningfully affect the timeline for a reuse option. Although most defueling operations are completed, closure and remediation efforts are not scheduled to conclude until 2027, at the earliest. This implies that no reuse options can be fully planned or undertaken until at least 2027.
- **Key conclusion 3:** There are currently insufficient data to meaningfully compare the alternatives on equal terms without making significant assumptions about some of the alternatives.

Given these conclusions, the evidence we have gathered and the analysis we have done support one key recommendation:

- **Recommendation:** The best available data and evidence suggest that policymakers should delay any decision on alternative reuses of the Red Hill Bulk Fuel Storage Facility for the foreseeable future.

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Chapter 1. Introduction

Since the 1940s, the U.S. Department of the Navy (DoN) has owned and operated one of the largest bulk fuel storage sites in the world, located at the Red Hill ridgeline on the island of Oahu, Hawaii. The Red Hill Bulk Fuel Storage Facility (RHBFSF), which was designated a historic civil engineering landmark by the American Society of Civil Engineers in 1995,⁴ has been the source of public attention since three fuel releases occurred between 2014 and 2021. In 2021, the Secretary of Defense (SECDEF) authorized the permanent closure of the facility, and Congress tasked the SECDEF and the U.S. Department of Defense (DoD) to commission an independent study examining beneficial reuse alternatives for RHBFSF. DoD and, more directly, DoN tasked the RAND Corporation, a federally funded research and development center (FFRDC) to conduct the study. This report is the direct result of, and fulfills, that requirement.

Section 336 of the fiscal year (FY) 2023 National Defense Authorization Act directed the SECDEF to oversee a study “to determine the range of feasible alternative Department of Defense uses for the Red Hill Bulk Fuel Storage Facility.”⁵ The National Defense Authorization Act further required that the study include a cost-benefit analysis to evaluate the alternative uses examined, which would consider⁶

- design and construction costs
- life-cycle costs, including the operation and maintenance costs for running the facility and any disposal costs at the end of the useful life of the facility
- potential military benefits
- potential benefits for the local economy
- environmental impact analysis requirements
- effects of the alternative use on future mitigation efforts.

The Assistant Deputy Chief of Naval Operations for Installations and Logistics (OPNAV N4B) assigned RAND the following tasks:

- Perform a thorough site visit and inspection of RHBFSF to identify potential alternative uses and collect data and information from on-site stakeholders.
- Solicit ideas for potential reuse options by DoD.
- Develop criteria to assess potential reuse alternatives provided by DoN to determine which reuse alternatives would be acceptable candidates for the next step: a detailed cost-benefit analysis.

⁴ American Society of Civil Engineers, “Red Hill Underground Fuel Storage Facility,” webpage, undated.

⁵ Public Law 117-263, James M. Inhofe National Defense Authorization Act for Fiscal Year 2023, December 23, 2022.

⁶ Public Law 117-263, 2022.

- For reuse alternatives identified in task 3, perform a cost-benefit analysis of feasible DoD alternative uses, consisting of estimated design and construction costs, estimated life-cycle costs and disposal costs, military costs, benefits to the local economy, environment impacts, and any other relevant factors.
- Publish an unclassified detailed report of the findings and recommendations.

The bulk of the research and analysis of this report was done between August and November 2023. To conform with statutory and contract requirements, members of the team conducted a site visit of RHBFSF on August 14, 2023. With assistance from the sponsor and RAND’s other DoD-affiliated FFRDCs—RAND Project Air Force (for the U.S. Air Force), RAND Arroyo Center (for the U.S. Army), and the National Defense Research Institute (for the Office of the Secretary of Defense)—we attempted to solicit reuse alternatives from other stakeholders within DoD. This report documents our research, analysis, and conclusions regarding the reuse options.

Organization of This Report

This report is organized as follows: Chapter 2 describes RHBFSF and outlines the incidents that led to the decision to close the facility. Chapter 3 discusses the methodology we used to conduct our analysis, presents the five alternatives for analysis, and details how the alternatives were selected. Chapters 4 through 8 present a detailed assessment of each of the alternatives. Chapter 9 holistically assesses and compares the results of each analysis of the alternatives and presents the conclusions and recommendations from this study. The appendix describes the rationale for, and methodology used to conduct, the robustness-to-uncertainty analysis.

Chapter 2. Overview of the Red Hill Bulk Fuel Storage Facility

This chapter details the construction and layout of RHBFSF and outlines the various legislative acts and orders that govern the defueling and closure of the facility.

Historical Background and Facility Description

In 1940, amid concerns about the vulnerability of aboveground fuel storage, DoN began to build RHBFSF at Kapukaki, near Honolulu, Hawaii (see Figure 2.1). More than 3,900 people worked to construct the facility, which was completed in September 1943.⁷

Figure 2.1. Map of Oahu Showing the Location of the Red Hill Bulk Fuel Storage Facility



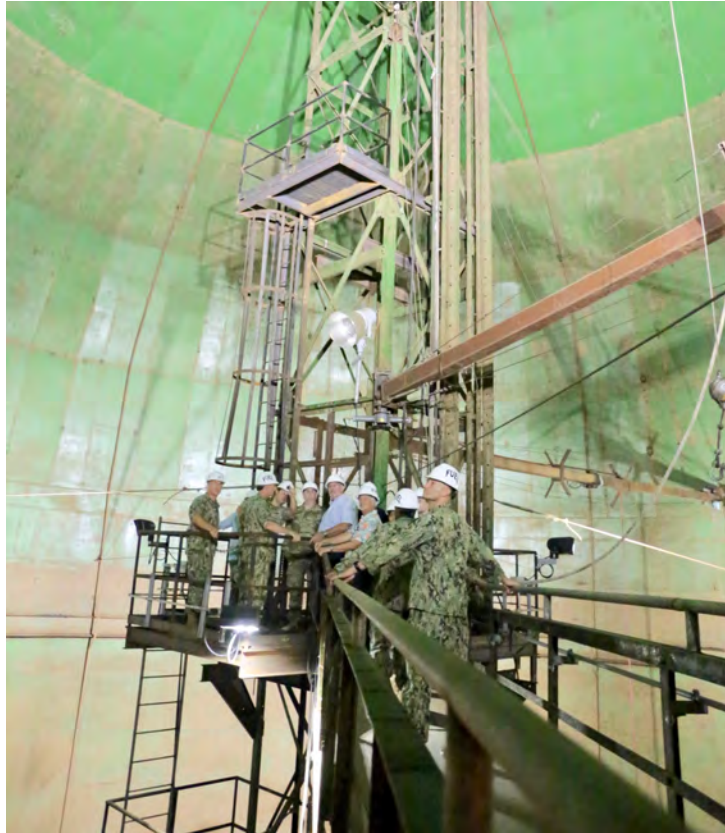
SOURCE: Google Maps.

At the time, 20 feet of rock cover was considered sufficient protection from bomb damage, but to increase the factor of safety, the engineers decided that the facility should have 100 feet of

⁷ American Society of Civil Engineers, “Red Hill Underground Fuel Storage Facility,” webpage, undated.

rock cover.⁸ Construction involved drilling and mining through the rock at Kapukaki to allow for the installation of 20 underground vertical tanks arranged in two rows (see Figures 2.2 and 2.3); horizontal tunnels known as *adits* provide access to the tanks.⁹

Figure 2.2. Tour Conducted Inside a Red Hill Bulk Fuel Storage Facility Tank, 2019



SOURCE: U.S. Navy photo by Shannon Haney, August 26, 2019.

⁸ David O. Woodbury, *Builders for Battle: How the Pacific Naval Air Bases Were Constructed*, E. P. Dutton and Company Inc., 1946.

⁹ Woodbury, 1946.

Figure 2.3. Array of Tanks at the Red Hill Bulk Fuel Storage Facility

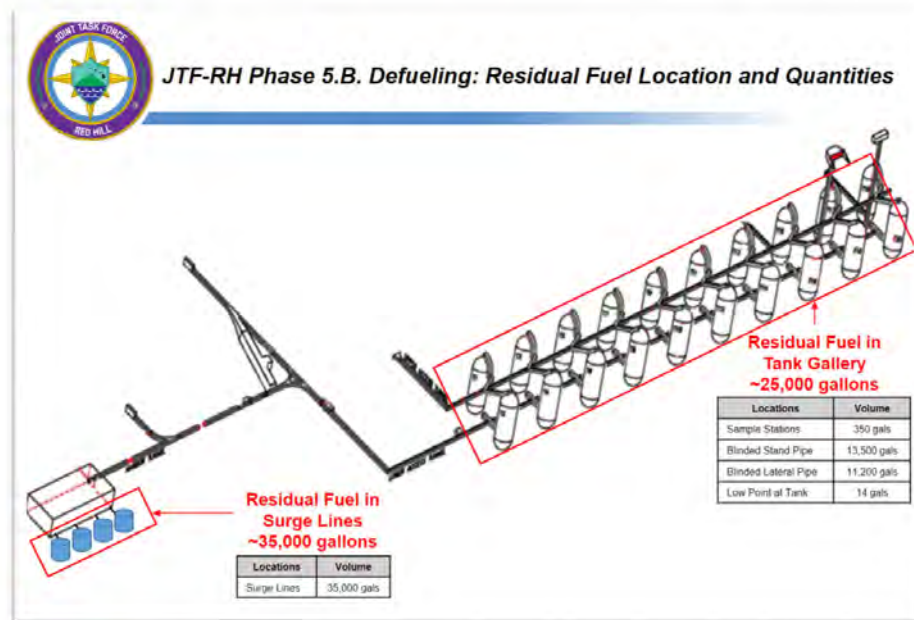


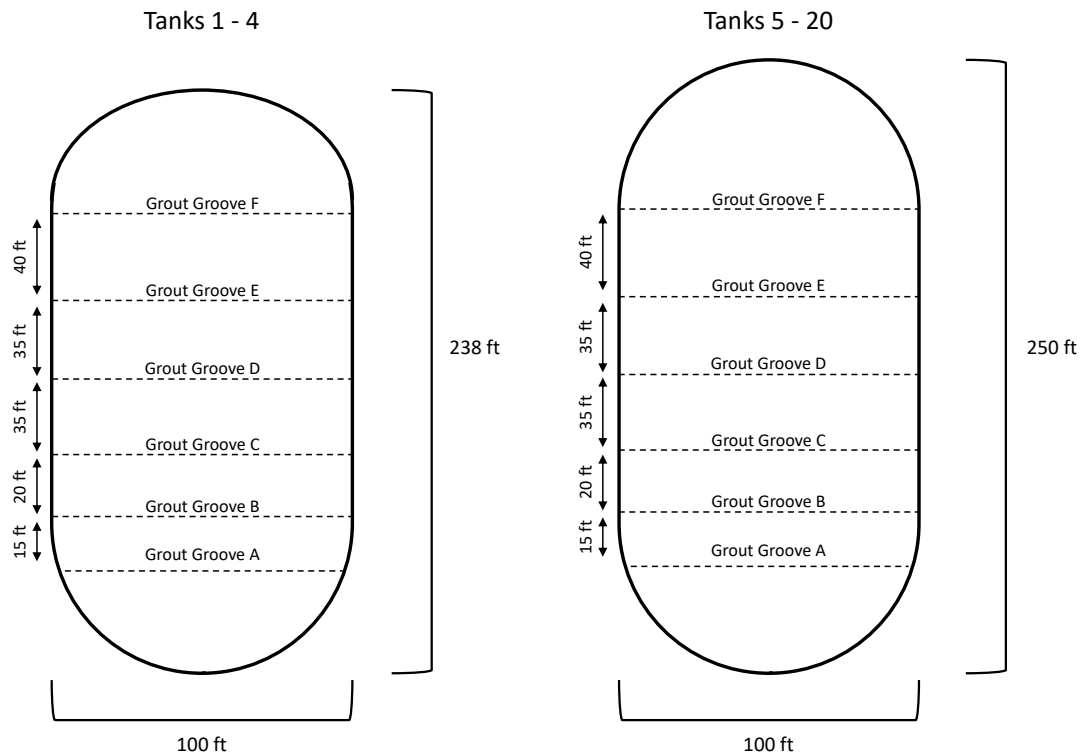
Figure 3 – JTF-RH Phase 5.B. Defueling: Residual Fuel Locations and Quantities

SOURCE: DoN, Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii: Defueling Plan Supplement 3—November 14, 2023, November 14, 2023, p. 8.

Each tank is shaped like a capsule and is 100 feet in diameter. Tank heights vary from 238 to 250 feet, providing a fuel capacity of 12.0 million to 12.7 million gallons per tank, or between 240 million and 254 million gallons total.¹⁰ Each tank is lined with one-quarter inch of steel that was grouted to further seal the tank. Figure 2.4 shows the structure and dimensions for the different tank sizes at RHBFSF.

¹⁰ U.S. Department of the Interior, *U.S. Naval Base, Pearl Harbor, Red Hill Underground Fuel Storage System (Joint Base Pearl Harbor-Hickam, Naval Supply Systems Command Fleet Logistics Center Pearl Harbor) (Red Hill Pump House, Tanks, Tunnels, Adits, and Ventilation Structures)*, HAER No. HI-123, 2015; Makai Ocean Engineering, Inc., *Navy Red Hill Energy Storage Feasibility Study Final Report: Infrastructure Review and Preliminary Energy Comparison*, October 13, 2023b.

Figure 2.4. Tank Structure and Dimensions



SOURCE: Adapted from Simpson Gumpertz & Heger Inc., *Long-Term Structural Integrity Assessment of the Red Hill Underground Storage Tanks*, May 26, 2023, p. 10.

As of early 2024, DoN had almost completed defueling, such that 14 tanks have only minor amounts of fuel remaining, and six are completely empty. DoN has one tank set up as a demonstration tank that allows visitors to see the tank interior. The active tanks are monitored by control systems. Three types of fuel were stored in these tanks: JP-5 jet fuel, F-24 jet fuel, and F-76 marine diesel.¹¹ Fuel flowed from these tanks through piping systems run between RHBFSF along a tunnel and an underground pump house at Joint Base Pearl Harbor-Hickam, approximately 2.3 miles away.¹²

Closure of the Red Hill Bulk Fuel Storage Facility

In response to the releases at RHBFSF, the Hawaii State Legislature, Hawaii Department of Health (DOH), and the Environmental Protection Agency (EPA) have issued a series of

¹¹ DoD, *Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii: Defueling Plan*, June 30, 2022.

¹² U.S. Department of the Interior, 2015.

legislative acts and orders to reduce the risk to the local community and prevent future incidents.¹³

Emergency Orders

On December 6, 2021, in response to the November incident, the Hawaii DOH issued an emergency order requiring DoN to cease all activities related to fuel transfer at RHBFSF and to install a system to treat drinking water at the facility. Additional requirements of the order relevant to fuel operations were the implementation of an independent third-party assessment of operations and systems needed for the safe defueling of the bulk fuel storage tanks, the defueling of said tanks on completion of any required corrective actions, and the assessment of systems and operations to determine any deficiencies that may affect the environment.¹⁴

On May 6, 2022, DOH issued a second emergency order. In addition to the fuel transfer from the 20 tanks at RHBFSF and maintenance of a groundwater treatment system, the order called for DoN to submit a phased plan for the defueling and permanent closure of RHBFSF. In determining whether to approve said defueling and closure plan upon its submission, DOH said that it would consider the inclusion of the following elements:

- specific procedures for the 20 tanks, four surge tanks, and relevant pipelines, including the sequence of defueling, the defueling process, and the fuel transfer destination
- a description of work completed to assess RHBFSF's structural integrity as it relates to procedures outlined in the defueling and closure plan
- a description and incorporation of recommendations needed for safe defueling
- oil spill or release prevention, containment, and response and contingency plans
- an implementation schedule for defueling within 30 calendar days or as soon as possible while allowing for the protection of the environment and public health.¹⁵

Meanwhile, on June 2, 2023, the EPA entered into a consent order with DoN and the Defense Logistics Agency (DLA). In addition to carrying out defueling and closure procedures, the consent order also requires the provision of a resilient supply of drinking water to the DoN - owned JBPHH drinking water system. The consent order's contents are pursuant to the following conclusions of law:

- the Resource Conservation and Recovery Act, codified as 42 U.S.C. § 6973, because DoN's and DLA's handling of solid waste may represent a threat to public health and the environment¹⁶

¹³ EPA, "Defueling Plan and Closure of the Red Hill Bulk Fuel Storage Facility," webpage, last updated October 23, 2023b; DOH, "Red Hill Water Information," webpage, last updated August 24, 2023.

¹⁴ DOH, "Emergency Order: Emergency Change-in-Service and Defueling of 20 Underground Storage Tanks, Red Hill Bulk Fuel Storage Facility," December 6, 2021.

¹⁵ DOH, "Emergency Order: Emergency Change-in-Service, Defueling, and Closure of 20 Underground Storage Tanks, Surge Tanks, and Associated Piping, Red Hill Bulk Fuel Storage Facility," May 6, 2022.

¹⁶ U.S. Code, Title 42, Section 6973, Imminent Hazard.

- the Safe Drinking Water Act, codified as 42 U.S.C. § 300(i), because the leakage of fuel into underground sources of drinking water may present a threat to the health of individuals who source their drinking water close to RHBFSF.¹⁷

Department of the Navy and Third-Party Assessments

As a response to the 2021 incidents, DoN launched an initial investigation on January 14, 2022, which was supplemented by a second investigation on June 13, into the cause of the leakage. The investigations concluded that the contamination of the Red Hill Shaft drinking water was ultimately due to “the Navy’s ineffective immediate responses to the 6 May and 20 November 2021 fuel releases at the Red Hill Bulk Fuel Storage Facility (Red Hill), and failure to resolve with urgency deficiencies in system design and construction, system knowledge, and incident response training.”¹⁸

On April 29, 2022, the engineering firm Simpson Gumpertz & Heger—in accordance with the DOH’s 2021 emergency order—released its hazard and operability study on the operational risks of defueling RHBFSF.¹⁹ Recommended actions to be carried out in the lower access tunnel prior to defueling included the following:

- performing a surge analysis of the three main fuel pipes to determine the likelihood of a larger load than predicted occurring while defueling
- ensuring that the cross-tunnel lateral piping is connected at tanks to protect dresser couplings
- installing lateral restraints for all three main pipelines
- permanently connecting lateral piping between odd-numbered tanks and main pipelines.

General recommendations of the Simpson Gumpertz & Heger report that are not as critical for defueling include pursuing the coordinated engineering of modifications that affect the tanks’ structural responses, having third parties verify design changes, instituting a more robust facility-specific management and anomaly tracking system, and adopting a risk-based process safety management system.²⁰

Meanwhile, to assess the integrity of RHBFSF’s fuel transfer system, the firm Austin Brockenbrough and Associates conducted an investigation, the results for which were released on August 30, 2022. In addition to identifying locations requiring system repairs and parts replacements because of cracking or erosion or corrosion, the inspection identified locations in

¹⁷ U.S. Code, Title 42, Section 300(i), Emergency Powers; EPA, “Red Hill Bulk Fuel Storage Facility Defueling, Closure, and Joint Base Pearl Harbor-Hickam Drinking Water System 2023 Consent Order,” webpage, last updated October 16, 2023a.

¹⁸ Vice Chief of Naval Operations, “Command Investigation into the 6 May 2021 and 20 November 2021 Incidents at the Red Hill Bulk Fuel Storage Facility,” U.S. Department of the Navy, June 13, 2022, p. 22.

¹⁹ Simpson Gumpertz & Heger Inc., *Final Assessment Report: Assessment of Red Hill Underground Fuel Storage Facility*, April 29, 2022.

²⁰ Simpson Gumpertz & Heger Inc., 2022.

which access to pipelines was not physically possible.²¹ On October 3, DoN released an additional fuel transfer system assessment report, which identified piping locations between Hotel Pier and the underground pump house that required boot seal replacements.²²

On December 20, 2022, the DoN contractor Jacobs released its analysis of the cost, scheduling, and engineering feasibility of four closure alternatives: (1) closure in place, (2) closure in place and preparation for nonfuel reuse, (3) closure and fill (with inert material), and (4) removal of tank liner and fill (with inert material).²³ The analysis yielded the following conclusions for each closure alternative:

- Alternative 1 was identified as the safest option, with the least impact on the environment and the local community and the most engineering feasibility, as it simply requires ventilation to the outside for cleaning and maintenance that can then be closed off, disconnection from unneeded electrical systems, and ongoing assessment of structural integrity.
- Alternative 2 contains more uncertainty than the first, as the nonfuel reuse at the time of RHBFSF's defueling and closure would be speculative. Although the assumption is that the tanks would be used to store a product other than fuel and would therefore need a protective coating, if that assumption proves wrong, it will significantly increase the time and cost of implementing this option.
- Alternative 3, while eliminating all tank maintenance and potentially providing long-term structural stability, would negatively affect the environment, as it requires heavy traffic to transport an enormous amount of fill material that would give off dust and vehicular exhaust. This option also eliminates the possibility of nonfuel reuse.
- Alternative 4 includes all of the drawbacks of alternative 3 and adds safety concerns related to the removal of the steel lining, such as the potential destabilization of the surrounding geology. This alternative also involves the longest schedule and highest cost.

On May 26, 2023, Simpson Gumpertz & Heger released a second assessment report on RHBFSF, which evaluated the long-term structural integrity of the facility in support of the closure-in-place plan.²⁴ The study examined the bulk fuel storage tanks' earthquake resistance and the durability of the steel liners and concrete walls, simulating both a "design earthquake" based on Honolulu building code requirements and an "extreme earthquake event," which is typically considered only for critical infrastructure. The results were as follows:

- The "design earthquake" caused no damage to the tanks, with or without the steel liner.
- The "extreme earthquake event" caused localized cracking in the concrete without the steel liner but no significant damage.

²¹ Austin Brockenbrough and Associates, LLC, *Fuel Transfer System Inspection Report*, August 2022.

²² Naval Facilities Engineering Command, *Hotel Pier to UGPH Fuel Transfer Infrastructure Assessment Report*, U.S. Department of the Navy, October 3, 2022.

²³ Jacobs, *Red Hill Tank Closure Plan Analysis of Alternatives & Concept Design to Close in-Place*, December 20, 2022.

²⁴ Simpson Gumpertz & Heger Inc., 2023.

- No significant deterioration is expected in the next 50 years.
- The tanks' internal atmosphere will corrode the thickness of the steel liners by about half their thickness in 100 years, but no significant external corrosion should occur.
- Localized deterioration of the concrete may occur after 300 years because of corrosion of the embedded reinforcing steel.

On August 28, 2023, DoN and DLA completed their “finding of no significant impact” report regarding the RHBFSF defueling and fuel relocation processes in accordance with the National Environmental Policy Act review process. DoN and DLA determined that their proposed action, relocating the fuel to other DoD fuel supply locations in the Pacific, would have no significant, direct, or cumulative environmental impact. Elements analyzed in the report include the impact on public health and safety, water resources, marine biological resources, hazardous materials and waste, and air quality.²⁵

²⁵ Joint Task Force Red Hill and Defense Logistics Agency, *Finding of No Significant Impact (FONSI) for Red Hill Defueling and Fuel Relocation from Joint Base Pearl Harbor-Hickam, Honolulu, Hawaii*, U.S. Department of Defense, August 28, 2023.

Chapter 3. Reuse Alternatives and Assessment Methodology

This chapter describes how we selected the alternatives for the reuse of RHBFSF and details the methodology we used to assess each alternative.

Selection of Alternatives for Analysis

In any effort of this kind, the selection of alternatives to analyze in-depth is critical, as it fundamentally bounds the contours of the discussion. The RAND team, in discussion with the sponsor, selected what it deemed to be the most-feasible alternatives from a combination of its own assessments and the third-party data and analysis that were provided to the team by the sponsor. As directed by Congress, the RAND team conducted research exploring potential historical alternatives with similar characteristics but was unable to identify suitable analogs to RHBFSF from which to derive meaningful comparisons, because it is a “one-of-a-kind” facility.²⁶ This section details the data sources from which the alternatives were culled, discusses how the alternatives were selected (including why other options in the same class were excluded), and briefly describes the other alternatives considered. One important fact to keep in mind when looking at the alternatives presented in this report is that these options are not the sole intellectual provenance of the RAND team and were chosen with input from the sponsor.

As mentioned, the sponsor provided us with several data sources from which some of the initial options were taken. Because of a lack of sufficient data sources for all of the options, we were required to make some technical assumptions in order to analyze a plausible way the option could be executed in accordance with how it was described in the source document. Therefore, we endeavor to be as clear as possible regarding what assumptions we made to execute our analysis. Although the language authorizing this study did not preclude an examination of using RHBFSF for future fuel storage, since the SECDEF issued the order to permanently close the facility, all communications from DoN have relayed that any reuse would be strictly non–fuel related.²⁷

Major Sources of Data and Alternatives

Aside from general research, the bulk of the data compiled for this report came from three primary sources specifically provided for this study. We will briefly describe each of them, and

²⁶ Commander, Navy Region Hawaii, “About Red Hill,” webpage, U.S. Department of the Navy, undated.

²⁷ Commander, Navy Region Hawaii, “Department of the Navy’s Tank Closure Plan, Red Hill Bulk Fuel Storage Facility,” webpage, U.S. Department of the Navy, December 28, 2023b. See also Lloyd J. Austin III, “Statement by Secretary of Defense Lloyd J. Austin III on the Closure of the Red Hill Bulk Fuel Storage Facility,” U.S. Department of Defense, March 7, 2022.

identify important caveats, before discussing the method by which the alternatives for analysis were generated. The first source of data used for this report was publicly available reports furnished by DoN on the status of, and plans for, the RHBFSF site. DoN maintains a public-facing website from which many of the documents cited for this report were drawn,²⁸ including the *Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii: Defueling Plan*, which, along with its supplements, informed much of our analysis of DoN’s proposed alternative (no beneficial reuse).²⁹ We supplemented these publicly available data with a site visit to the facility and frequent communications with the team overseeing the RHBFSF site to address any follow-up questions.

Another major source of data was a report provided courtesy of the Hawaii Natural Energy Institute (HNEI), an affiliate of the University of Hawaii’s School of Ocean and Earth Science and Technology. The *Navy Red Hill Energy Storage Feasibility Study*, prepared for HNEI by Makai Ocean Engineering, helped supplement our knowledge of the engineering details of the facility and formed the basis for our understanding and analysis of potential energy storage options.³⁰ Finally, DoN commissioned Nakupuna Consulting to conduct three studies that surveyed the attitudes of the local population toward reuse of RHBFSF and solicited potential reuse ideas to meet the congressional requirement for stakeholder engagement. Nakupuna Consulting generated three reports; we were furnished both the drafts and the final versions of the *Qualitative Survey Report* and the *Quantitative Survey Report* and the final version of the *Soft Sounds Interviews Report*.³¹

Although these sources formed the nucleus of data provided to the study team by DoN, we supplemented the data with a review of publicly available information about RHBFSF, some of the results of which can be seen in Chapter 2. Because many of the ideas proposed for reuse alternatives were conceptual in nature, our team members had to use their subject-matter expertise, in coordination with and concurrence of the sponsor, to help determine which reuse alternatives to bring forward.

²⁸ Commander, Navy Region Hawaii, “The Red Hill Bulk Storage Facility,” webpage, U.S. Department of the Navy, December 21, 2023a.

²⁹ DoD, 2022; DoN, *Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii: Defueling Plan Supplement 3*, November 14, 2023.

³⁰ Makai Ocean Engineering, Inc., 2023b.

³¹ Nakupuna Consulting LLC, *Soft Sounds Interviews Report: Input and Feedback from Key Stakeholders and Community Influencers Regarding Potential Beneficial Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, August 2023b; Nakupuna Consulting LLC, *Final Quantitative Survey Report: Survey Results Regarding Potential Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, November 2023c; Nakupuna Consulting LLC, *Final Qualitative Survey Report: Survey Results Regarding Potential Repurposing of the Red Hill Bulk Fuel Storage Facility (RHBFSF)*, August 2023a.

Alternatives Considered and Selected Alternatives for Evaluation

This section provides a brief overview of the major conceptual alternatives and presents the selection logic for the five alternatives that were ultimately chosen for analysis. Table 3.1 lists the options for the reuse alternatives presented in each of the data sources discussed in the previous section.

Table 3.1. Alternatives Considered and Sources of Each

Sources	Suggested Alternatives
DoD's <i>Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii: Defueling Plan</i> and the Office of the Secretary of DoN's <i>Red Hill Bulk Fuel Storage Facility: Tank Closure Plan</i>	• No beneficial reuse
Makai Ocean Engineering's <i>Navy Red Hill Energy Storage Feasibility Study</i> (draft and final), prepared for HNEI	• Pumped hydropower storage – Freshwater hydropower storage – Saltwater hydropower storage – Saltwater hydropower storage with desalination plant • Compressed-air energy storage • Compressed carbon dioxide energy storage • Cryogenic Energy Storage or Liquid Air Energy Storage (available only in the final version of the report) • Lifted weight energy storage • Buoyance energy storage technology • Hydrogen storage • Thermal storage • Chemical batteries
Nakupuna Consulting's draft <i>Qualitative Survey Report</i> , draft <i>Quantitative Survey Report</i> , and final <i>Soft Sounds Interviews Report</i>	• Housing • Homeless shelter • Renewable energy – Solar – Battery storage – Hydroelectricity and gravity-fed energy – Compressed-air energy storage • Water storage and/or treatment – Desalination plant – Water storage—potable, nonpotable, rainwater catchment – Wastewater reclamation • Research and development – University of Hawaii laboratory – Technology development – Artificial intelligence development • Vault or storage for archival records • Data center • Museum, visitor attraction, or educational use – Could be part of the Pearl Harbor historic attractions – Museum could highlight the history of the facility and engineering aspects – Museum could highlight military malfeasance on Hawaii • Agriculture and food production – Vertical farming – Aquaculture – Mushrooms

Sources	Suggested Alternatives
	– Traditional crops (on the land above the facility) – Seed bank for native and endangered plants and crops – Coral polyps grown to replenish reefs – ‘Opae’ula (Hawaiian red shrimp), hīhīwai (freshwater snails), or any kind of organism or plant that is beneficial to Hawaii and its ecosystems • Emergency preparedness – Storage of emergency supplies – Storage of Spam, rice, and toilet paper for a potential dock workers’ strike – Emergency shelter • Landfill for dry, nonhazardous material waste – Construction waste – Excavated material • Office space • Secure facility for DoD – Training – Command center – Research facility • Homeland security purpose • World’s biggest brewery • Regenerative tourism • Entertainment and recreation – Underground nightclub – Theater – Video and gaming production – Casino – Amusement rides or roller coasters – Wall climbing – Diving – Scuba training • Nonreuse – Return to the state or Native Hawaiians and let the people decide what to use it for – Dismantle and return to its natural state – Environmental sanctuary or park area – Fill with inert material – Give back to the state or Board of Water Supply to decide on the next best use

SOURCES: DoD, 2022; Office of the Secretary of the Navy, *Red Hill Bulk Fuel Storage Facility: Tank Closure Plan*, U.S. Department of the Navy, November 1, 2022; Makai Ocean Engineering, Inc., 2023b; Nakupuna Consulting LLC, 2023a, p. 5; Nakupuna Consulting LLC, 2023b; Nakupuna Consulting LLC, 2023c.

With assistance from the sponsor and RAND’s other DoD-affiliated FFRDCs, we attempted to solicit reuse alternatives from other stakeholders within DoD, including the Air Force, Army, and the Office of the Secretary of Defense. We received limited interest or follow-up, which left us unable to derive meaningful reuse alternatives from these stakeholders. We attribute the lack of response to the following: (1) RHBFSF is extremely bespoke, and military reuse alternatives are relatively scarce, and (2) reuse of the facility by a non-Navy entity might require extensive negotiation or assurances. Therefore, there are few if any apparent alternative DoD uses for the RHBFSF once the facility is permanently decommissioned.

We reviewed the available alternatives with assistance from the sponsor to identify alternatives for further analysis. The RAND team and sponsor selected alternatives for analysis in light of the following constraints and considerations:

- Either the Secretary of the Navy will entertain options to transfer ownership of the RHBFSF site and facility or non-Navy organizations will operate reuse alternatives; alternatives that require a change in ownership are out of scope.
- Alternatives need to avoid further contaminating the land or aquifer.
- Alternatives must be able to be practically implementable at the RHBFSF site.
- Sufficient information was necessary to evaluate the selected alternatives; alternatives were rejected that were not clearly described in the source material or lacked sufficient details to enable our assessment.³²
- Alternatives were preferred that were likely to receive support from the community, as identified in Nakupuna Consulting's studies.³³

Given the above guidance, some options were immediately discarded because they were contrary to this guidance, deemed too difficult to assess, or duplicative of other options. For example, despite the guidance DoN would consider transferring ownership, any option that would necessitate private ownership (e.g., all of the entertainment and recreation options) or that suggested turning over RHBFSF (e.g., return it to the State of Hawaii) would likely require substantial negotiations and other concerns that would make assessing the options prohibitively difficult and thus were not selected. Other options that were discarded were those that suggested technologies for which there were currently no at-scale examples (e.g., compressed [gas], mechanical, or thermal energy storage). Anything that risked health and safety—especially because of the previous use of the tanks—was eliminated (e.g., agricultural options, brewery). Other options were considered problematic or implausible without the widespread reengineering of the facility (e.g., data center), or we assessed that there was no amount of engineering that would make the facility fit for the long-term use proposed (e.g., housing or homeless shelter).

One option that initially appeared attractive—using the facility to host lithium-ion batteries—was not chosen because of the danger of thermal runaway and the difficulties with fire suppression and the associated risk of explosions.³⁴ In our discussions of the selected alternatives in the following chapters, we might refer to other options within the macro-level category that were *not* chosen and provide supporting detail and reasons for why not (e.g., options for energy storage that were highly likely to entail potential risk to the aquifer) were discarded. Once these

³² Supporting data availability was one criterion among many, and many options lacked sophisticated technical studies to back them. No option was rejected solely on the grounds of lack of data.

³³ Some of the most-favored options cited in Nakupuna Consulting's *Quantitative Survey Report* were defueling and closing the facility, reuse to generate renewable energy, and reuse for water storage. See Nakupuna Consulting LLC, 2023c.

³⁴ See Naval Sea Systems Command, *Navy Lithium Battery Safety Program: Responsibilities and Procedures*, S9310-AQ-SAF-010, November 3, 2020.

filter criteria were applied, a small subset of options remained, and we (with input from the sponsor) identified the following five alternatives for further analysis:

1. no beneficial reuse
2. energy storage using pumped hydropower
3. energy generation using renewable sources
4. water storage
5. museum.

The selected alternatives and their specifics are reviewed in more detail in Chapters 4–8.

Assessment Methodology

To keep the analysis tractable and adhere to a cost-benefit analysis methodology, broadly construed, we identified four key evaluation criteria to perform our analysis:

1. executability
2. economics
3. nonfinancial considerations
4. robustness to uncertainty.

We evaluated each alternative according to each criterion and assigned a score for each criterion using a four-point scale, in which 1 was the lowest rating an alternative could receive, and 4 was the highest. The scoring methodology and meaning of each score varied for each criterion. We used this scoring to create a matrix to compare the scores of each alternative by criteria.

Evaluation Criteria

The four evaluation criteria used in this assessment are described in detail in the following sections.

Executability

Executability was measured using a four-point scale, as described in Table 3.2.

Table 3.2. Executability Rating Scale

Category	Score Value	Description
Very high	4	Uncertainty is very low, the likelihood of an unexpected interruption or significant delay is very low, and the level of technical maturity is very high (the technology is very widely used, and no further development is required for this particular use).
High	3	Uncertainty is low, the likelihood of an unexpected interruption or significant delay is low, and the level of technical maturity is high (the technology is widely used, and little if any development may be needed to adapt it for this particular use).
Moderate	2	There is some uncertainty in general, the likelihood of an unexpected interruption or significant delay is moderate, and the level of technical maturity is moderate (the technology is in use in some areas but not broadly, and some development is likely to be needed to adapt it for this particular use).
Low	1	There is considerable uncertainty in general, the likelihood of unexpected interruption or significant delay is high, and the technical maturity is low (the technology is not in widespread use, and significant development may be needed to adapt it for this particular use).

Executability was then evaluated along five axes, each using the scale provided in Table 3.2. The five axes are described in Table 3.3.

Table 3.3. Executability Evaluation Axes

Axis	Description
Technical executability	This axis focuses on how mature the technology is, as illustrated by how widespread its use is, especially at scale in large facilities.
Schedule executability	This axis focuses on how easily and with what certainty and predictability the technology can be installed or constructed. This axis differs from technical executability—for example, building a large-scale solar energy facility may be very technically executable (there are thousands in existence today), but the confidence that it can be done to a specific schedule is likely lower, simply owing to the complexity, the number of component parts, and uncertainty over weather conditions that can interrupt construction (hurricanes, etc.).
Regulatory executability	This axis focuses on the requirements—and hurdles—the technology faces to obtain government (federal, state, and local) approval to proceed. The axis therefore also confronts local conditions and circumstances that will differ in an island environment, such as Hawaii's, compared with those in the continental United States.
Environmental executability	Unlike regulatory executability, this axis focuses on the impact that the technology may have on the environment and whether that impact is likely to confront political or legal obstacles regardless of whether a regulator is willing to permit the use of the technology.
Maintenance executability	This axis focuses on how easy or difficult it is to maintain the technology to ensure its proper function through the lifetime of its use. Maintenance executability therefore covers the ability to check system status, replace defective or broken parts (including the likely availability of those parts over time), and generally maintain system operations within approved regulatory limits.

Economics

Each alternative has research and development, engineering, production or procurement, and operational support costs associated with implementation and maintenance. In some cases, the

alternative may have revenue streams that will potentially affect the local community and the state government.

We did not estimate specific cost requirements or potential revenue for the alternatives. However, we used existing cost estimates where feasible, applying the criteria of reliability, realism, and completeness. When estimates were not provided, we qualitatively assessed our ability to make such estimates and their likely rough order of magnitude (ROM).

We analyzed the alternatives for economic impact according to the following attributes:

- nonrecurring cost
- recurring cost
- cost realism and completeness
- revenue projections (if any) and realism
- present or net present value, as appropriate.

The economic assessments were scored on a 1–4 scale, as shown in Table 3.4.

Table 3.4. Framework for the Cost Assessment of the Alternatives

Descriptor	Description	Score Value
Poor	Details are lacking or appear to be speculative	1
Marginal	Design or technology is not well developed or defined	2
Adequate	Technology is known but design details are not completely defined	3
Good	Amounts are nominal or are based on detailed estimates	4

We neither analyzed nor estimated for each alternative the costs to demilitarize and decommission the RHBFSF tanks, because those costs are required for each alternative and provide no value in differentiating between alternatives.

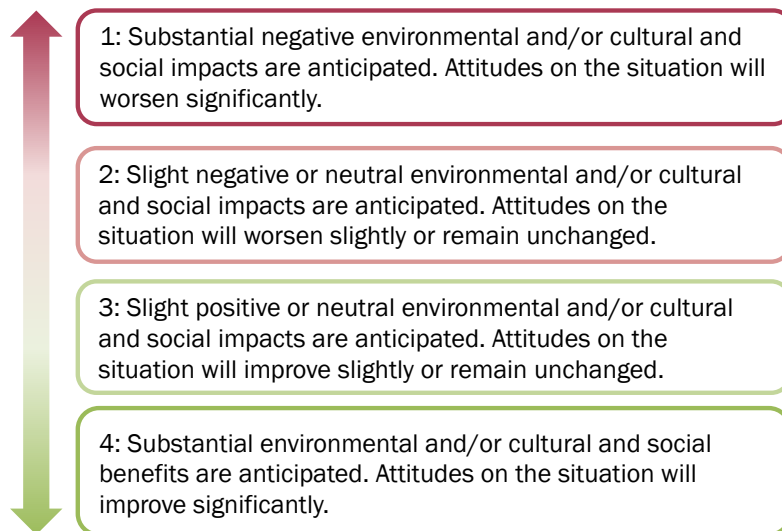
Nonfinancial Considerations

Nonfinancial considerations comprise two categories: (1) potential environmental impact and (2) potential cultural and social impact. The environmental impact category focuses on how the Hawaiian public might perceive the impact an alternative will have on Hawaii’s natural resources because of the option’s environmental sustainability and the level of risk it poses to the surrounding environment.³⁵ The cultural and social impact category assesses how an alternative might affect the Hawaiian community and includes such factors as public perception of RHBFSF and the Navy, educational opportunities provided, and the impact on the Native Hawaiian culture. We considered each alternative according to these categories and gave each alternative a

³⁵ Note that this category is distinct from the environmental impact assessment in the executability criterion, which assesses actual environmental risk rather than perceived risk.

score from 1 (most-negative impact) to 4 (most-positive impact). The scores are further defined in Figure 3.1.

Figure 3.1. Scoring Scale for Nonfinancial Considerations



NOTE: The shading indicates the level of environmental or cultural and social impact an option may have on a continuum, ranging from very negative (the upward arrow) to very positive (the downward arrow), with dark red meaning very negative and dark green meaning very positive.

Robustness to Uncertainty

RHBFSF has been in service since the 1940s. Although it will no longer be used to store fuel, the facility will endure for a long time to come, and any reuse option could reasonably be expected to last for several decades. Therefore, any assessment of a reuse option should take into account how well that option can withstand changes in the fundamental assumptions used to justify it. This section considers how well the various alternatives fare under circumstances that look different from today. We considered three types of change (policy changes, technological changes, and environmental changes) at four levels of difference from today (incremental, punctuated equilibrium, transformative, and radical departure). These scenarios are not exhaustive, and we cannot know which (if any) may occur; the objective is to conduct a “what if” thought experiment and decide whether choosing that option was likely to cause buyer’s remorse if that future came about. The greater the number of scenarios in which policymakers were likely to experience buyer’s remorse, the lower the score assigned to this variable, with 1 being experiencing regret in 12 to ten scenarios, 2 being experiencing regret in nine to six scenarios, 3 in five to three scenarios, and 4 in two to zero scenarios. Table 3.5 provides the scenarios chosen for analysis, and Table 3.6 shows an example analyzed.

Table 3.5. List of Plausible Alternative Futures for Analysis

	Policy	Technology	Environmental
Incremental	<i>Continuing “continuing resolutions”</i> Federal budgetary legislation uncertainty continues, leaving programs and offices facing the possibility of cuts.	<i>Green evolution, not revolution</i> The adoption of green technologies and associated advances fails to continue at a rapid pace, leading to only marginal gains in efficiency over today.	<i>Climate continues to change</i> Ongoing climate change leads to greater demand for resources, such as developable land and clean drinking water.
Punctuated equilibrium	<i>Rigid environmental regulation</i> Environmental regulation, including freshwater conservation efforts, increases to protect local habitats.	<i>Rarer rare-earth metals</i> A global shortage in critical minerals affects the U.S. industrial capacity to satisfy domestic demand for advanced technology.	<i>More remediation than expected</i> During environmental remediation and cleanup, remediation requirements are more extensive or complex than expected, causing costs to increase and delays in turnover.^a
Transformative	<i>Meet the new boss</i> The political beliefs and positions of state and local leaders shift to deprioritize the conservation of natural resources in favor of economic growth.	<i>Energy storage solved</i> Breakthroughs in energy storage systems continue and increase such that more power can be stored safely, smoothing the load on the grid during peak times.	<i>Climate change accelerates</i> Climate change's most dramatic effects, including worsening weather and sea-level rise, occur faster than anticipated.
Radical departure	<i>Handing over the reins</i> DoN decides to close a majority of its facilities in the state of Hawaii.	<i>Cheap, limitless energy, at long last</i> Breakthroughs in fusion research continue and accelerate such that cheap, (almost) limitless energy becomes foreseeable within a near-term time horizon.	<i>The very ground beneath our feet</i> An unforeseen event (e.g., an earthquake) causes the deterioration of the tanks to quicken, rendering them unusable.

^a Although many stakeholders already anticipate that remediation requirements will be more extensive or complex than expected (see, for instance, Red Hill Water Alliance Initiative, *Red Hill Water Alliance Initiative [WAI] Report*, November 2023, p. 3), whether that is true is a matter of debate. Therefore, we feel that it is important to include both possibilities. Most of our analysis assumes that remediation requirements are as reported and expected; this option specifically assumes that it is worse than expected.

It is important to note that this is a first-order assessment; we did not attempt to assign weights to any of the futures or make any value judgments regarding which (if any) futures merit special interest. Should a policymaker deem guarding against regret in a particular future, or group of futures, to be more important than the entire set, then the results of the analysis or the attractiveness of a given option might change. Different policymakers and different stakeholders will have different preferences, and it is precisely these discussions and prioritizations that this criterion is attempting to surface. Readers interested in the intellectual lineage and a more detailed discussion of this methodology are encouraged to read the appendix.

Table 3.6. Example Table of the Robustness of a Notional Reuse Alternative

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing "continuing resolutions"	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare- earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Notional alternative	Not robust	Robust	Not robust	Robust	Not robust	Robust	Robust	Robust	Robust	?	Robust	Not robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer's remorse in this scenario, red (not robust) indicates that buyer's remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty.

Description of Aggregated Assessment and Alternatives by Criteria Matrix

As discussed, the result of each individual criterion analysis yields a score between 1 (low) and 4 (high). We used these scores to populate a table summarizing the results of each analysis to give the reader a high-level overview of how the proposed reuse alternative scores across the range of factors. Table 3.7 provides an example of the table.

Table 3.7. Notional Scoring Assessment by Criterion

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
Notional reuse alternative				

For each criterion, the summary table is complemented by a brief discussion of factors that we assessed as critically relevant to the analysis. For example, if a given alternative would require substantial, indefinite government (or other entity) expenditure, this would be noted both in the economics section and reinforced as a primary concern in the summary assessment. The tables for each criterion are aggregated in Chapter 9 to compare the results, as shown in Table 3.8. It is important for readers to remember that although each criterion is set on the same scale (i.e., 1 to 4), the factors that make up the various criteria are different, and thus comparisons are valid only between columns, not between rows.

Table 3.8. Assessment Matrix to Compare Alternatives

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
No beneficial reuse				
Energy storage using pumped hydropower				
Energy generation using renewable sources				
Water storage				
Museum				

Chapter 4. No Beneficial Reuse

This chapter evaluates the “no action” option to refrain from converting RHBFSF to any beneficial new uses post-closure. Therefore, it is not a reuse option per se, but it provides a baseline against which to compare other alternatives.

Overview

This alternative will carry out the processes outlined in DoD’s defueling plan and DoN’s closure plan.³⁶ The defueling process began on October 16, 2023,³⁷ and encompasses several steps:

- working with DOH and the EPA to iteratively plan the defueling process
- removing fuel from pipelines to allow pipeline repairs to proceed
- repairing pipelines and installing bypass lines at fuel tanks
- safety planning and training for personnel to minimize the risk of further incidents
- defueling tanks and relocating fuel products.³⁸

DoN has almost entirely completed defueling as of January 2024. Once the defueling process is complete, DoN will begin executing the closure process. Although DoN’s closure plan outlined several potential closure options, it identified *closure in place* as DoN’s preferred alternative.³⁹

Under closure in place, DoN would remove and dispose of all pipelines, eliminate each tank from service, and take steps to prevent tanks from being reused for fuel-related purposes; the tanks would not be filled with inert material.⁴⁰ Closure in place would also address the following elements:⁴¹

- **Ventilation:** Isolate tanks from the ventilation system, with the tanks’ individual vents being opened to the outside during cleaning and closure.
- **Secured access:** Prevent unauthorized entry to the tanks.
- **Water accumulation:** Monitor and periodically drain water from the bottom of the tanks.
- **Electrical system:** Disconnect tanks from all electrical systems.

³⁶ DoD, 2022; Office of the Secretary of the Navy, 2022.

³⁷ Michelle Broder Van Dyke, “Red Hill Defueling Begins Oct. 16,” *Spectrum News*, September 27, 2023.

³⁸ DoD, 2022, pp. 1–4.

³⁹ Office of the Secretary of the Navy, 2022, p. 37; Office of the Secretary of the Navy, *Red Hill Bulk Fuel Storage Facility: Tank Closure Plan—Supplement 2*, U.S. Department of the Navy, May 31, 2023, p. 5.

⁴⁰ Office of the Secretary of the Navy, 2022, pp. 37–38.

⁴¹ Office of the Secretary of the Navy, 2022.

- **Access tunnels:** Maintain access to upper and lower tunnels for ongoing maintenance and environmental monitoring.

DoN estimates that closure in place will be completed by August 2027.⁴² Observation-based analyses of the tanks indicate a low likelihood of the tanks deteriorating over the next 100 years once empty, thereby increasing the feasibility of allowing the tanks to remain idle for an extended period.⁴³

Assessment by Criteria

The following sections present our assessment of the alternative according to the four criteria discussed in Chapter 3 (executability, economics, nonfinancial considerations, and robustness to uncertainty).

Executability

This alternative is DoN’s proposed action, as described in its environmental assessment under the National Environmental Policy Act.⁴⁴ The proposal is thoroughly described and evaluated under the environmental assessment and does not need repeating here. The only important nuance is cost over time, which is assessed elsewhere in this report. From the standpoint of executability, it ranks very high (a score of 4) along all axes.

Economics

Under contract to DoN, Jacobs prepared a ROM estimate for this alternative dated November 22, 2022.⁴⁵ As Jacobs stated, “ROM cost estimates are to be used only for consideration and comparison of the relative magnitude of alternative effort, and are not intended for purposes of planning, programing, budgeting and execution, or establishment of milestone schedules for the work to be performed.”⁴⁶ The Jacobs ROM estimate additionally contains closure costs, which cannot be disaggregated (as they are common to all options), and covers just nonrecurring costs. The ROM cost estimates could be considered legacy estimates; moreover, the estimates do not provide an indication of the escalation rate applied to the values. Therefore, we evaluated the estimates for face value and did not normalize them to current-year FY 2023 dollars, and we did not apply inflationary factors to the estimates in this analysis. However, recurring costs will occur: “Given the properties of water and the nature of its movement underground, it is expected

⁴² Office of the Secretary of the Navy, 2023, p. 11.

⁴³ Jacobs, 2022, p. 11.

⁴⁴ Office of the Secretary of the Navy, 2022; Public Law 91-190, National Environmental Policy Act of 1969, January 1, 1970.

⁴⁵ Jacobs, 2022.

⁴⁶ Jacobs, 2022, p. 5.

that water and/or condensation will eventually intrude into the tank cavities. This liquid should be monitored and removed periodically from the bottom of each tank.”⁴⁷ Moreover, Jacobs notes,

Some level of ongoing inspections will be required to ensure the long-term integrity of the tank structure and steel liner. A cursory visual inspection of the tanks should be performed every 2 years from the catwalk and from the piping in the lower tunnel. Based on current clean, inspect, and repair process schedules, a structural assessment should be performed every 20 years.⁴⁸

These recurring costs are not estimated but appear to be nominal, apart from a structural inspection every 20 years.

Our assessment of the economic impact of this alternative is shown in Table 4.1.

Table 4.1. Economics: Scoring of No Beneficial Reuse

Category	Score
Nonrecurring cost	Score value 3: The Jacobs estimate is a ROM, not a detailed estimate.
Recurring cost	Score value 3: The cost is not included in the Jacobs ROM but is qualitatively described.
Cost realism and completeness	Score value 3: Jacobs used industry-standard estimating techniques on a well-defined scope of work. The estimate is a ROM because of the level of detail.
Revenue projections and realism	Score value 4: No future revenue will result from this course of action.
Present value	Score value 1: Cannot calculate this score because of lack of recurring cost estimate.
Summary assessment	Score value 3: The ROM estimate is based on a scope of work and ROM that is sufficient for decisionmaking but not detailed enough to use for budgeting or pricing a contract.

Nonfinancial Considerations

This alternative is expected to have a neutral impact on the surrounding environment. By refraining from storing any new substances in RHBFSF post-closure, the option does not present any added sources of contamination that could affect surrounding bodies of water. Long-term structural maintenance required to prevent the facility from becoming destabilized (e.g., tunnel ventilation, fire protection, tunnel dewatering) will likely cause little to no additional risk to the environment, making this option relatively sustainable.⁴⁹

Community stakeholders surveyed by Nakupuna Consulting resolutely opposed any fuel-related reuse of the facility, implying that a decision to not develop the facility for future reuse

⁴⁷ Jacobs, 2022, p. 10.

⁴⁸ Jacobs, 2022, p. 11.

⁴⁹ Jacobs, 2022, pp. 10–12.

would likely be seen favorably by the local community.⁵⁰ Should the situation change in the future, closure in place leaves open the opportunity to reuse the facility in such a way that protects the surrounding aquifer without posing a risk to the environment or public safety, which was viewed as the most preferred defueling action by 58 percent of surveyed Red Hill community members and 53 percent of those surveyed in the wider Oahu community.⁵¹ However, more than one-third of those surveyed in Oahu expressed desire for the land on which the facility sits to be given back to native Hawaiians, and another one-third wished for it to be given to the State of Hawaii. This indicates that DoN's continued presence in maintaining the facility after closure would likely not be viewed favorably.⁵²

Since it is likely to have a neutral to positive environmental and cultural and social impact on the local community, this alternative receives an overall score of 3 in the nonfinancial considerations category. The plan presents little to no risk of any potential future remnants mobilizing and generally aligns with the preferences indicated by the Nakupuna data.

Robustness to Uncertainty

The alternative to not develop RHBFSF for beneficial reuse post-closure is quite robust against many potential changes in future circumstance. The reason for this is that, by shutting down the site and essentially leaving it to go fallow (save for monitoring and other basic needs) renders most changes in technology or policy related to the site either extraneous or easy to deal with. Likewise, many other environmental changes, such as those anticipated to occur because of climate change or under an even more aggressive climate change scenario, would likely pose minimal risks to a closed facility. Finally, even if environmental remediation requirements are more extensive than anticipated, any delays in handing over the site are moot (as there is no reuse), and environmental cleanup efforts have unfettered access to as much of the facility as required.

One potential scenario that is difficult to properly analyze is “handing over the reins,” in which DoD decides to close a majority of facilities in the state of Hawaii. This scenario is problematic because the details of a future negotiated arrangement between DoN and the government of Hawaii are extremely difficult to predict. Therefore, an “uncertain” coding is given to this alternative future.

DoN's proposed alternative appears robust against 11 of the 12 plausible alternative futures we generated, and so we awarded it a score of 4 (or high) on robustness to uncertainty (see Table 4.2). Deciding to not reuse the facility at all is likely the most conservative option one can take, as it reduces costs to the minimum required to remediate the facility, allows unfettered access should unexpected events occur, and essentially removes the need for any new investments or

⁵⁰ Nakupuna Consulting LLC, 2023b, pp. 19–23.

⁵¹ Nakupuna Consulting LLC, 2023c, p. 5.

⁵² Nakupuna Consulting LLC, 2023c, p. 8.

technological changes. Given this, if policymakers are seeking a “safe” option that appears to be largely immune to changes of all sizes, simply closing and remediating the facility, as proposed by DoN, appears to fall into this category.

Table 4.2. Robustness to Uncertainty Scoring Matrix for No Beneficial Reuse

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing “continuing resolutions”	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare-earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
No beneficial reuse	Robust	Robust	Robust	Robust	Robust	Robust	Robust	Robust	Robust	?	Robust	Robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer’s remorse in this scenario, red (not robust) indicates that buyer’s remorse is likely should the scenario manifest (not applicable for this alternative), and gray (question mark) indicates uncertainty.

Conclusion

Table 4.3 summarizes the scoring assessment of this alternative. No beneficial reuse features a high degree of technical and regulatory executability, sufficiently estimable economic costs, potentially positive cultural and social and environmental benefits, and a high degree of robustness against future uncertainty. We estimate that by carrying out this option, DoN would face little to no risk in the short term, although there is a degree of uncertainty in the long term regarding structural maintenance. However, as noted above, risk of significant deterioration within the next century appears unlikely.⁵³ These circumstances would likely make no beneficial reuse a favorable option in the eyes of risk-averse policymakers.

Table 4.3. Scoring Assessment of No Beneficial Reuse Alternative

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
No beneficial reuse	4	3	3	4

⁵³ Jacobs, 2022, p. 11.

Chapter 5. Energy Storage Using Pumped Hydropower

This chapter evaluates the conversion of RHBFSF into a facility that stores energy by using pumped hydropower.

Overview

Pumped hydropower storage is a form of energy storage that generally involves converting the potential energy of water stored in an upper reservoir into kinetic energy by allowing it to flow downward into a lower reservoir. Excess energy is used to pump water up to the top reservoir, and when energy is needed, the water is then released downward through a turbine, which generates electrical energy that can then be returned to the grid.⁵⁴

Traditional hydropower systems are *one way* (unidirectional), meaning that water flows from an upper reservoir to a lower one, traversing turbine electric generators that convert the potential energy in the falling water into electrical energy. Generally, the power produced by the hydropower system is a function of (1) the height difference between the upper reservoir and the turbine generators, which are usually located proximate to (and at about the same level as) the lower reservoir; (2) the mass (volumetric) flow rate of the water (i.e., how many liters per second); and (3) the design and capacity of the turbine generators. Dams usually provide the demarcation of the upper reservoir (Hoover Dam and Lake Mead in Nevada are examples). Separately, the energy stored in the hydropower system (and thus available to be converted into power) is a function of the volume of water in the upper reservoir and the height difference between the upper reservoir and the turbine generators (again proximate to the lower reservoir). These two elements—power and energy—are both important to a hydropower system because they dictate how much total stored energy the system possesses and how quickly the stored energy can be withdrawn (which is energy over time, also known as *power*).

In a pumped storage hydropower system (which can be open or closed loop), the flow of water is bi-directional. That is, such a system produces power like a traditional one-way hydropower system, but the pumped storage hydropower system stores energy by reversing the flow of the water from the lower back to the upper reservoir. Normally, pumping water uphill occurs when an energy source is available that is excess to other needs. For example, if a solar farm or wind farm is producing energy that is not needed for immediate consumption by the electric grid, that energy can be diverted into pumping water uphill, which thus stores as energy the gravitational potential energy in the water that has been pumped. At a later time, such as during the evening or on a windless day, the water that was pumped and is residing in the upper

⁵⁴ Makai Ocean Engineering, Inc., 2023b, pp. 10–11.

reservoir can then be allowed to flow downhill to the lower reservoir, producing electrical power as it flows through the turbine generators.

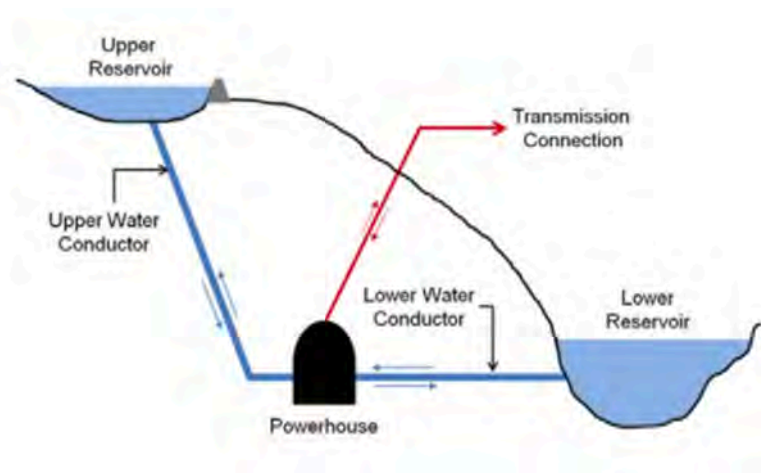
According to the U.S. Department of Energy,

[Pumped storage hydropower (PSH)] facilities can be found all around the world! According to the 2023 edition of the Hydropower Market Report, PSH currently accounts for 96% of all utility-scale energy storage in the United States. America currently has 43 PSH plants and has the potential to add enough new PSH plants to more than double its current PSH capacity. . . . Vital to grid reliability, today, the U.S. pumped storage hydropower fleet includes about 22 gigawatts of electricity-generating capacity and 550 gigawatt-hours of energy storage with facilities in every region of the country.⁵⁵

Figure 5.1 shows an example of a pumped hydropower system. Makai Ocean Engineering’s study for the HNEI proposed multiple options for reusing RHBFSF as a pumped hydropower storage facility:⁵⁶

- Use the RHBFSF fuel tanks as the upper reservoir and construct a lower freshwater reservoir.
- Use the RHBFSF fuel tanks as the upper reservoir and use Pearl Harbor as a lower reservoir. The facility would use salt water from Pearl Harbor.
- Develop a combined pumped hydropower storage and desalination facility, again using the RHBFSF fuel tanks as the upper reservoir and Pearl Harbor as the lower reservoir. The facility would provide potable water in addition to stored energy.

Figure 5.1. Pumped Hydropower Storage Example



SOURCE: U.S. Department of Energy, *Hydropower Vision: A New Chapter for America's 1st Renewable Electricity Source*, July 2016, p. 186.

⁵⁵ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Water Power Technologies Office, “Pumped Storage Hydropower,” webpage, undated.

⁵⁶ Makai Ocean Engineering, Inc., 2023b, pp. 13–14.

The option explored in this chapter is specifically a closed-loop, freshwater, pumped hydropower storage option. The rationale for excluding other options in the hydropower storage category (i.e., open loop, non-fresh water) can be found in the executability section, below.

Assessment by Criteria

The following sections assess this alternative according to the four criteria discussed in Chapter 3 (executability, economics, nonfinancial considerations, and robustness to uncertainty).

Executability

This section considers the various technical parameters and constraints relevant to implementing this reuse alternative and evaluates the alternative's executability. The energy used to pump the water uphill can come from two sources: (1) Hawaii's electric grid (i.e., Hawaiian Electric) or (2) a system that would have to be located at RHBFSF, such as a wind farm or an array of solar panels. This report does not posit which source is to be used, just that a source will supply the energy.

Assuming that the upper reservoir could be represented by the location and volume of the empty storage tanks (i.e., the water for the upper reservoir is placed into the tanks, so the tanks become the upper reservoir), then the height of the tanks would be approximately 74 meters (since the height of the facility above sea level is 104 meters, but the tanks are approximately 30 meters underground). However, the tanks themselves are about 86 meters tall, which would place their bottoms $74 - 86 = 12$ meters below sea level, which would be a problem and is very unlikely to be how they were engineered or built. Developing a more precise estimate of the upper reservoir water *head* (the technical term for how high the water in the upper reservoir is relative to the turbine generators and lower reservoir) would require additional effort, but for sake of argument, it is reasonable to assume that the bottom of the tanks is probably around 20 meters above sea level. This would make the best water head height (when the tanks are full) $20 + 86 = 106$ meters. As the tanks drain, the head height of the water diminishes, as does the ability to generate power as the water runs through the turbines. As the tanks reach empty, the head height diminishes to 20 meters. For good facility management, generally one would want to keep the tanks as full as possible, so an average head height of around $20 + 0.75 * 86 =$ around 75 meters, representing keeping the tanks around 75 percent full on average, is the most reasonable assumption.⁵⁷

An important question is: What should be used for the lower reservoir? If the working fluid is water, of course there are two types of water the fluid could be: fresh water or ocean (salt) water. Thus, having the lower reservoir be the ocean and simply draining water to it and pumping water

⁵⁷ An analogy would be ensuring that, when using an electric vehicle, the driver would endeavor to keep the battery charge level above 75 percent, so the car is always available for use without first needing further recharging.

uphill from the ocean to the upper reservoir (the storage tanks) is the most efficient system and conforms to the calculations above. This is an open-loop system. However, as DoN is well aware from the significant effort required to maintain ship hulls and systems, salt water is corrosive, and the internals of the tanks could contain some level of trace chemicals or other residue (e.g., trace amounts left behind from the cleaning process), which, when salt water is pumped through them, might dissolve or mobilize. Further, discharging water that has been in the tanks into the ocean is likely to pose environmental and regulatory challenges that require monitoring and mitigation efforts, as well as potentially running the risk of serious public perception issues.

The alternative is to create a lower reservoir that does not connect to the ocean but instead is similar to a water treatment facility's retention pond, with an appropriate impervious layer and sufficient volume to hold the entire contents of the tanks. This is a closed-loop system. Although this is certainly doable from an engineering perspective, the details would need to be worked out (such as location, retention pond dimensions, piping to move water from the tanks to the retention pond and vice versa, and locating the turbine generators proximate to the retention pond). Additionally, protections would have to be in place to ensure that any residue from the tanks or the retention pond does not get into the ocean or groundwater as a consequence of, for example, rainfall during storms that might cause the pond to overflow. Evaluating the best location of the pond and working out its engineering details would require further study beyond the scope of this report, but suffice it to say that considerable expense could be incurred doing so, especially engineering the pond to ensure no accidental release of contents.

Using fresh water has the advantage of reducing the corrosion and deterioration of the tanks, piping, and turbines, but, of course, fresh water itself is a precious commodity. Having an open-air lower reservoir (the retention basin) means incurring evaporative losses, which would need to be replenished. A rough estimate of annual evaporative loss can be derived from a comprehensive study of the topic done at Texas A&M University by Professors Gang Zhao and Huilin Gao.⁵⁸ Assume that the lower reservoir measures around 200 meters in radius, is circular, measures 10 meters in depth (which is sufficient to hold the full contents of the storage tanks). The Zhao and Gao model posits an approximate average loss of 2 millimeters per day across more than 700 lakes and ponds in the United States; given the surface area of the retention pond (around 100,000 square meters), that equates to an annual evaporative loss of at least 500,000 liters per day that would have to be made up from Oahu's freshwater supplies, which come from underground aquifers. According to reports from the Oahu Board of Water Supply,⁵⁹ aquifer supply to Oahu is around 150 million gallons (or 1 billion liters) daily. This is more than 2,000 times the expected evaporative losses, but the losses would remain a continuous drain on freshwater supplies. Separately, filling the tanks with fresh water to enable them to be used for

⁵⁸ Gang Zhao and Huilin Gao, "Estimating Reservoir Evaporation Losses for the United States: Fusing Remote Sensing and Modeling Approaches," *Remote Sensing of Environment*, Vol. 226, June 1, 2019.

⁵⁹ Board of Water Supply, Oahu, "Data & Statistics," webpage, last updated October 9, 2023.

this project would consume approximately a full day's supply, so it would have to be done gradually to avoid disrupting supplies to residents.

It is important to establish how much energy the pumped storage hydropower facility might be able to store and then compare that amount with useful metrics. The total volume of the 20 storage tanks is approximately 1 billion liters of water; for water, that equates to 1 billion kilograms of mass. The formula for gravitational potential energy is mass times gravity times height (which would be average height = $20 + 0.5 * 86 = 63$ meters), producing approximately 170 megawatt-hours of energy storage when the tanks are full of water.

Even if all of this energy could be converted to electric power (it cannot—typical maximum efficiency is 80 percent, so only 136 megawatt-hours are available for use), this is not an enormous amount of energy for a large population. A typical modern electric vehicle has a battery containing almost 100 kilowatt-hours of energy, so 170 megawatt-hours is equivalent to the energy stored in around 1,700 electric vehicles. As of June 2023, there were 26,001 electric vehicles of all types registered in Hawaii.⁶⁰

Another useful comparison is to juxtapose 170 megawatt-hours against electrical energy consumption in Oahu in general and Honolulu in particular. Honolulu is the largest city in Hawaii and the one closest to RHBFSF. Per Hawaiian government reports,⁶¹ Oahu overall consumes around 10 terawatt-hours annually, which equates to around 27 gigawatt-hours per day. Honolulu has around 70 percent of the population on Oahu, so its electrical energy consumption is around 19 gigawatt-hours per day. Thus, 170 megawatt-hours of storage capability in the hypothetical pumped storage hydropower facility is less than 1 percent of the electrical energy consumed daily by the residents of Honolulu.

Additionally, we emphasize that, as the water level in the upper reservoir (the tanks) decreases during use, the ability to produce power diminishes considerably, because the water head also decreases. Thus, although 170 megawatt-hours is the total energy storage capacity, on average much less than that would actually be available to tap as power. For example, when the upper reservoir is half empty, the water head diminishes from 106 meters to 63 meters, which reduces the available power proportionately. Thus, if the facility can produce 10 megawatts of power when full, it can produce only around 6 megawatts when half full. (Note that power production capability is also a function of turbine generator design, but the law of diminishing returns as the water level declines applies regardless.) To summarize, the power-production profile of the facility would be nonlinear with time, making it a diminishingly reliable source of power for grid augmentation during the power-production cycle (reservoir draining), coupled with offline unavailability during the reservoir replenishment pumping cycle.

⁶⁰ Max Rodriguez, "More Electric Car Chargers Needed to Meet Demand," KHON2 News, July 31, 2023.

⁶¹ Binsheng Li, *Hawaii's Electricity Industry: 2020–2021 Analysis and Recent Trends*, Hawaii Department of Business, Economic Development and Tourism, Research and Economic Analysis Division, August 2022.

As calculated above, the maximum available energy is 170 megawatt-hours. The maximum power that the facility can produce is a function of several elements: (1) the maximum energy in the system (as noted), (2) the design and capacity of the turbine generators (e.g., one could use large generators with a capacity of 340 megawatts, but that would drain the entire upper reservoir in under an hour), and (3) the design and size of the pipes or conduits that bring the water from the upper reservoir (the existing tanks) to the turbine generators. On the receiving end, the electric utility (Hawaiian Electric) dictates how much power it wants to receive, at what price, and for what duration. Thus, matching power produced to power demanded is a key factor that cannot be established without detailed discussions with Hawaiian Electric.

As noted, other mechanisms for non-battery energy storage—such as compressed air, the production and storage of hydrogen (usually through water hydrolysis), and flywheels—require more-complex technology, produce higher risks (explosion of compressed gas or hydrogen, or destabilization of high rotational velocity flywheels), or lack the gross energy storage capacity of pumped storage hydropower. Additionally, some technologies (e.g., flywheels) are well suited for providing higher amounts of power but obviously drain their energy more quickly when in use. These reasons explain why pumped storage hydropower is in such widespread use compared with those other non-battery energy storage technologies.

Table 5.1 shows how we evaluated this alternative with respect to executability using the five axes described in Chapter 3: technical, schedule, regulatory, environmental, and maintenance. Overall, this alternative received a score of 3 for executability.

Economics

No cost estimate exists for turning RHBFSF into a pumped storage hydropower facility, as no design exists from which an estimate could be made. These costs would have to include land acquisition, reservoir construction, tunnel construction, generator and pumphouse equipment procurement, and construction. Additionally, the costs not included in the below discussion would be needed for transmission lines to the grid from the generator and pumphouse and possibly a new substation.

In the absence of any details for the RHBFSF site, a parametric estimate will have to be used to get a ballpark figure of what a pumped storage hydropower installation at RHBFSF would cost to construct and operate. The Department of Energy's National Renewable Energy Laboratory recently produced a table of minimum and maximum values for various renewable energy technologies, including pumped storage hydropower.⁶² The relevant data are shown in Table 5.2.

⁶² National Renewable Energy Laboratory, "2023 Electricity ATB Technologies and Data Overview," webpage, undated.

Table 5.1. Executability: Scoring of Energy Storage Using Pumped Hydropower

Axis	Score	Rationale
Technical executability	4 (very high)	The technology is mature and widely used.
Schedule executability	3 (high)	Building a pumped storage hydropower facility does not require any technical breakthroughs or complicated engineering; it requires relatively straightforward components (piping, pumps, turbines) that are well understood and not difficult to assemble into a system. But such a facility is a significant undertaking of substantial scale; hence, there will always be some degree of schedule risk owing to the possibility of such factors as inclement weather delaying construction or uncertainties in ensuring a firm foundation for key components. Several substantive questions also would need to be answered about the nature and siting of the lower reservoir.
Regulatory executability	2 (moderate)	Building and operating a pumped storage hydropower facility would require multiple environmental permits and development of measures to mitigate any impact under, at a minimum, the Clean Water Act, since pumping surface water up to the upper reservoir (the tanks) and allowing it to flow back down to the lower reservoir inevitably risks trace levels of remnants potentially entering into the water stream and hence into the lower reservoir. And, as noted, the lower reservoir likely would need to be an engineered retention pond, which could be a considerable undertaking owing to its necessary size to hold up to 1 billion liters of water.
Environmental executability	2 (moderate)	A pumped stored hydropower facility normally has little environmental impact, since, unlike dammed traditional hydropower, it does not restrict the flow of a river, does not flood a large area surrounding the upper reservoir, and does not stop fish migratory patterns (such as salmon). However, with the RHBFSF tanks containing fresh water functioning as the upper reservoir, any theoretical remnants from those tanks may find their way into the lower reservoir, posing environmental risks for which mitigation plans would be required, assuming that the traces pose any risk in the first place. As noted, the lower reservoir would likely also need to be an engineered retention pond, which could be a considerable undertaking.
Maintenance executability	3 (high)	Maintaining a pumped storage hydropower facility should be straightforward, entailing only the monitoring of equipment, such as turbines and pumps, and the replacement of components, such as electrical control circuitry, valves, and pumps, at the end of their service lives.

Table 5.2. National Renewable Energy Laboratory's Cost Ranges for Pumped Hydropower Storage

National Renewable Energy Laboratory Data	Factor
Capital expenditures range	\$2,227–\$4,434/kilowatt
Midpoint capital expenditures range	\$3,330/kilowatt
Variable cost	\$0.54/megawatt-hours
Fixed cost	\$19.00/kilowatt-year

NOTE: Figures are in FY 2023 dollars.

SOURCE: National Renewable Energy Laboratory, undated.

Sizing the pumped hydropower storage plant for the maximum total energy storage capacity of 170 megawatts, discussed elsewhere in this report, would require an unrealistic discharge rate of water in an hour. Moreover, power-peaking needs for the Oahu electrical grid could well last

for more than an hour. If a more realistic discharge time of five hours is used, the plant could be sized to 34 megawatts, costing \$75,718,000 to \$155,075,600. At a midrange value of \$3,330 per kilowatt, a 34-megawatt plant could cost about \$115,397,000 to build. While the National Renewable Energy Laboratory capital expenditures factor includes costs for an upper reservoir, RHBFSF tanks will obviate the need to acquire land and construct an upper reservoir. However, constructing a lower reservoir will still be necessary and acquiring land at or near sea level in Oahu will likely be very expensive, if even possible. This is the reason for not adjusting the capital expenditures factor.

Assuming that peaking power is needed for the Oahu electrical grid Monday through Friday for five hours a day (250 days per year), a 34-megawatt plant would generate electricity for 1,250 hours per year. If the plant could operate at an 80 percent efficiency factor, it would produce 34,000 megawatt-hours per year. Using data from Table 5.2, the variable cost is calculated as follows:

$$\text{Variable Cost} = \frac{\$0.54}{\text{MWh}} \times 34,000 \frac{\text{MWh}}{\text{year}} = \$18,360 \text{ per year}$$

The fixed cost is calculated as follows:

$$\text{Fixed Cost} = \frac{\$19.00}{\text{kWyear}} \times 1,000 \frac{\text{kWyear}}{\text{MWyear}} = \frac{\$19,000}{\text{MWyear}}$$

$$\left(\frac{\$19,000}{\text{MWyear}} \right) \times \left(\frac{1}{8,760 \frac{\text{hours}}{\text{year}}} \right) = \frac{\$2.17}{\text{MWh}}$$

$$\frac{\$2.17}{\text{MWh}} \times 34,000 \frac{\text{MWh}}{\text{year}} = \$73,780 \text{ per year}$$

Additionally, generally accepted accounting principles require the facility depreciation cost to be included in the cost of electricity produced. If 30 years of straight-line depreciation is used on a \$115,397,000 facility, annual depreciation would be \$3,846,566.

Electricity is typically billed in dollars per kilowatt-hour. The 34,000 megawatt-hours of electricity this hypothetical plant could produce in a year equate to 34,000,000 kilowatt-hours. The total cost of electricity that could be produced by this hypothetical pumped storage hydropower facility in dollars per kilowatt-hour is shown in Table 5.3.

Table 5.3. Projected Cost of Electricity Produced by the Pumped Hydropower Alternative

Cost Type	Annual Cost	Cost in Dollars per Kilowatt-Hour
Variable	\$18,360	\$0.0005
Fixed	\$73,780	\$0.002
Depreciation	\$3,846,566	\$0.113
Total	\$3,938,706	\$0.12

The \$0.12 per kilowatt-hour compares favorably to the June 2023 electricity retail price (net revenue per kilowatt-hour sold) for Oahu of \$0.3656 per kilowatt-hour,⁶³ if the power needed to pump the water back up to the upper reservoir can be obtained inexpensively. Pumped storage hydropower is most economical when the power required to pump the water back to the upper reservoir costs substantially less than the revenue it generates flowing back to the lower reservoir. Only 25 percent of Hawaii’s electric power was generated by wind and solar in 2022, with 60 percent of the state’s electric power generated by petroleum.⁶⁴ This imbalance could result in considerable cost to pump stored water back to the upper reservoir.⁶⁵

Regarding revenue, it is not likely that Hawaiian Electric would buy electricity at its net revenue value. A significant discount would be necessary to provide for overhead and transmission costs in addition to profit. Moreover, the electricity produced by an RHBFSF pumped storage hydropower facility would have to be tightly integrated into Oahu’s grid, necessitating operation by the local utility. Further research and discussions with Hawaiian Electric would be necessary to determine

- the utility’s willingness to operate such a pumped storage hydropower facility integrated into its grid
- the economic feasibility of such a model.

Without such discussions, all the parametric estimates above are purely speculative. For all these reasons, we assess the economic impact of the pumped storage hydropower alternative as shown in Table 5.4.

⁶³ David Shuai, *Monthly Energy Trend Highlights—September 2023 Highlights*, Hawaii Department of Business, Economic Development and Tourism, October 6, 2023.

⁶⁴ Hawaii State Energy Office, Open Data Portal, datasets, undated-b.

⁶⁵ For perspective, in 2019, only 0.5 percent of the electricity generated in the United States overall came from petroleum products. See Hawaii State Energy Office, *Hawai‘i’s Energy Facts & Figures*, 2020, p. 6.

Table 5.4. Economics: Scoring of Pumped Hydropower Storage

Category	Score
Nonrecurring cost	Score value 1: Parametric estimate applied to hypothetical facility operating to speculative conditions.
Recurring cost	Score value 1: Parametric estimate applied to hypothetical facility operating to speculative conditions.
Cost realism and completeness	Score value 1: No details to estimate or assess revenue projections and realism.
Revenue projections and realism	Score value 2: Any revenue would be based on Hawaiian Electric billing rates.
Net present value	Score value 1: Cannot calculate.
Summary assessment	Score value 1: Without a facility design and discussions with Hawaiian Electric, this course of action cannot be properly evaluated.

Nonfinancial Considerations

Freshwater, closed-loop pumped hydropower risks having a negative impact on the surrounding environment for multiple reasons. Although DoN will be cleaning the tanks in accordance with the American Petroleum Institute’s recommended procedure 1604 (“Closure of Underground Petroleum Storage Tanks”), as stated in the closure plan,⁶⁶ our opinion is that sufficiently cleaning the fuel storage tanks might not be feasible, such that one can say with absolute certainty that water stored in them might not contain trace amounts of residual fuel or other residual particulates. On the other hand, it is also not known whether the amount of such particulates would exceed regulatory and safety guidelines.⁶⁷ Therefore, it would be prudent to assume that any fresh water that is stored within the tanks will at least no longer be considered potable absent robust mitigation efforts and could theoretically pose a risk to surrounding bodies of fresh water unless carefully monitored. Additionally, turning RHBFSF into a pumped hydropower facility would require the construction of a lower reservoir somewhere, which would require land to be dedicated to that purpose (see this chapter’s earlier discussion on executability for related details).

⁶⁶ DoN, 2022.

⁶⁷ Although multiple organizations, including the World Health Organization and the U.S. Navy, outline procedures for cleaning and repurposing nonwater storage containers to store and deliver water in emergency situations, these organizations explicitly state that containers that previously held fuel should never be used for potable water storage. A pumped hydropower storage facility does not necessitate potable water for viability, but it is likely that the level of residuals will be a source of scrutiny. For sources, and more information, see Centers for Disease Control and Prevention, “History of Drinking Water Regulations,” webpage, updated April 25, 2019; Janet O. Hall, *Investigation of Cleaning Procedures for Converting Petroleum Tankers to Potable Water Service*, U.S. Army Mobility Equipment Research and Development Command, May 1981; Sam Godfrey and Bob Reed, “Cleaning and Disinfecting Water Storage Tanks and Tankers,” World Health Organization, July 2013; DoN, Bureau of Medicine and Surgery, “Water Quality Afloat,” in *Manual of Naval Preventive Medicine*, NAVMED P-5010-6 (Rev. 1-2022), January 2022, p. 6-43.

Oahu faced water shortages following the 2021 releases at RHBFSF, which led to the precautionary closure of three primary water wells; this coincided with a drought.⁶⁸ Hawaii also is reportedly currently facing a potential freshwater crisis because of a combination of rainfall decline, loss of watershed forests, and high levels of tourism.⁶⁹ Diverting any amount of fresh water to electricity generation could theoretically exacerbate these issues. Additionally, although green energy can help mitigate pollution caused by fossil fuels, Hawaii's pollution issues seem to center on sewage management, making the net environmental benefit of pumped hydropower uncertain.⁷⁰ Although contributing to the construction of Hawaii's green energy infrastructure could mitigate pollution attributed to the energy sector, this benefit would likely be outweighed by the added risk of water contamination and water shortages.

Freshwater pumped storage hydropower could reasonably be expected to not enjoy a positive reception. Although renewable energy, including hydropower, and water storage were the most popular reuse options among those surveyed in the Red Hill and the wider Oahu community, respondents were concerned that storing water for hydropower could threaten the aquifer if there were a leak from the facility.⁷¹ Moreover, in November 2023, the Red Hill Water Alliance Initiative, a working group composed of key stakeholders from the state and local governments of Hawaii and the University of Hawaii, released a report that stipulated:

[T]he facility cannot be used for any purpose that will store or use substances harmful to the water, air, or natural environment, or accelerate the level of contamination of the subsurface or water table. This prohibition includes any use that introduces substantial amounts of water intentionally or accidentally as this would accelerate the migration of fuel contaminants.⁷²

Thus, it is likely that this alternative would not enjoy a warm reception from many key stakeholders in the community, particularly those members of the Red Hill Water Alliance Initiative working group. Because of the potential for negative environmental and cultural and social impacts on Hawaii, pumped storage hydropower receives an overall score of 1 in nonfinancial considerations.

Robustness to Uncertainty

When evaluating the energy storage via pumped hydropower option, of the 12 potential futures, four appear especially problematic. Two of them, “more remediation than expected” and “the very ground beneath our feet,” threaten the very viability of the project by raising existential

⁶⁸ Kristen Consillio, “Oahu Facing Critical Water Shortage as Residents Urged to Conserve,” KITV Island News, updated March 25, 2022.

⁶⁹ Hawaii Community Foundation, “Fresh Water Security for Hawai‘i,” webpage, undated.

⁷⁰ Surfrider Foundation, “BWTF Publishes 2022 Annual Report,” webpage, undated.

⁷¹ Nakupuna Consulting LLC, 2023c, p. 6; Nakupuna Consulting LLC, 2023b, p. 11.

⁷² Red Hill Water Alliance Initiative, 2023, p. 6.

questions about the viability of the site for this purpose. The other two, “energy storage solved” and “cheap, limitless energy, at long last,” could fundamentally change the economic calculus or *raison d’être* of the project in the first place. For all other alternative futures under consideration, the changes posited by those scenarios do not appear to meaningfully affect or alter the desirability of this option.

In a future in which “more remediation than expected” manifests, the use of RHBFSF for energy storage via pumped hydropower appears problematic unless certain criteria are met. The creation of a large reservoir (necessitated by the closed-loop design), as well as the additional excavation required to ensure the adequacy and efficiency of the facility, runs the risk of transporting nonbiodegraded residue to a new, previously unaffected location, depending on how early on the residuals are detected. This risk could be mitigated by necessitating that the lower reservoir is not placed above the aquifer. Likewise, any future in which the tanks’ viability for storage is in question threatens the efficiency of the system. Given the geology, it is unlikely that the water in the upper reservoir (i.e., the tanks) would catastrophically fail, some or all of the tanks becoming unusable would reduce the efficiency of the system or necessitate very costly, long-term repairs.

In futures in which energy storage systems become less of a challenge (e.g., safer, more-effective lithium-ion battery storage), the need for a power system that stores a relatively small amount of power for its size becomes questionable. Furthermore, futures positing breakthroughs in energy-generation technology that decrease the environmental and economic costs of generating energy also call into question the need to store energy in such an antiquated way. It is the long lineage of this technology that provides the benefits in executability but leaves the technology vulnerable to more-modern innovations.

In summary, the pumped hydropower energy storage option is likely safe against regret in eight of the 12 alternative futures while being likely subject to regret to four of them, most of which reside in futures that are marked by a greater divergence from today (see Table 5.5). For this reason, we give the alternative a score of 3 out of 4 on robustness to uncertainty. Notable, however, is the fact that if more remediation requirements than expected are discovered, this option begins to appear very brittle, as the chances of expanding the area in which remnants are present may go up, absent careful mitigation plans. Therefore, policymakers who prioritize minimizing environmental risks might consider this potentiality unacceptable.

Table 5.5. Robustness to Uncertainty Scoring Matrix for Energy Storage Using Pumped Hydropower

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing “continuing resolutions”	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare- earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Energy storage using pumped hydro- power	Robust	Robust	Robust	Robust	Robust	Not robust	Robust	Not robust	Robust	Robust	Not robust	Not robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer’s remorse in this scenario, red (not robust) indicates that buyer’s remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty (not applicable for this alternative).

Conclusion

Table 5.6 summarizes the scoring assessment of the pumped hydropower alternative. The results of our assessment indicate that turning RHBFSF into a pumped hydropower facility features a reasonable degree of executability and robustness to uncertainty. However, the risk of residuals affects three of the four assessment criteria, as the risk decreases regulatory executability, could negatively affect the environment and public perception, and increases the fragility of the alternative in a future in which “more remediation than expected” is found. Additionally, we were unable to fully evaluate the economic feasibility of this alternative because of the lack of site surveys and robust facility design that would be required to estimate associated costs. Therefore, policymakers averse to environmental or economic risk would likely not select this option.

Table 5.6. Scoring Assessment of Energy Storage Using Pumped Hydropower Alternative

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
Energy storage using pumped hydropower	3	1	1	3

Chapter 6. Energy Generation Using Renewable Sources

This chapter evaluates the conversion of RHBFSF into a facility to produce renewable energy.⁷³

Overview

Multiple types of renewable energy sources exist, including wind power, solar (photovoltaic or solar thermal), hydroelectric, and geothermal or tidal forces. On Oahu, however, only solar photovoltaics or wind energy are plausible and available renewable energy sources, given the island's geography.⁷⁴ The fundamental challenge is that both technologies are above ground by nature. They do not deal with reusing or repurposing the existing RHBFSF infrastructure, which is primarily below ground. Nor do they address the overall geography of the RHBFSF site, which is mostly hilly and not flat and hence not very conducive to solar photovoltaics. Therefore, the only practical renewable energy source that might be feasibly implemented is wind power.

Assessment by Criteria

The following sections assess the alternative according to the four criteria discussed in Chapter 3 (executability, economics, nonfinancial considerations, and robustness to uncertainty).

Executability

Determining whether wind power is suitable as a renewable energy source would require a survey of wind power in the Red Hill area to determine the velocity and persistence of wind and hence its economic viability. Assuming that such a study did determine suitability, then technical executability becomes relatively straightforward, owing to the ubiquity of land-based wind turbines and their well-understood technology. Table 6.1 shows how we scored this alternative, which received an overall executability score of 4.

⁷³ Note that energy storage and energy generation uses are sometimes confused because electric power can be obtained from both energy storage and energy production facilities (although from the former only if energy has already been stored there). Additionally, sometimes energy storage and energy production facilities can be colocated. An example of that is placing solar photovoltaic panels at a pumped hydropower facility and using the former to supply power to pump water from the lower reservoir to the upper reservoir. Since this report evaluates both storage and production, the effects of combining the two can be inferred from the separate analyses, but they are not treated as a single alternative.

⁷⁴ This island has no meaningful geothermal sources; tidal power has to be at or below ocean surface and thus is unsuitable for RHBFSF, and there are no rivers to supply once-through hydroelectric power.

Table 6.1. Executability: Scoring of Energy Generation Using Renewable Sources

Axis	Score	Rationale
Technical executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Schedule executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Regulatory executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Environmental executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Maintenance executability	4 (very high)	There are no cutting-edge or unusual technologies involved.

Economics

As noted above, the only practicable renewable energy option for RHBFSF is wind power. Even this option requires a comprehensive wind survey at the site to determine feasibility. If such a survey determined feasibility, a detailed engineering study would then be needed to determine the number, size, and location of the wind turbines at the RHBFSF site. No such surveys or studies have been performed. Moreover, discussions with Hawaiian Electric would be necessary to determine the need for substations and transmission lines and actions for grid integration. Without these surveys, studies, and discussions, any cost estimate for wind power at RHBFSF will be hypothetical and based on parametric estimates.

The National Renewable Energy Laboratory issued a review of the cost of wind energy for 2021 in December 2022.⁷⁵ The report identified that the average wind turbine in 2021 was rated at 3.0 megawatts and that the total capital expenditure for a wind turbine, balance of site costs (e.g., engineering, foundation, site access, assembly, and electrical infrastructure) and financial costs, to be \$1,501 per kilowatt.⁷⁶ If these costs are valid for Hawaii today, each 3.0-megawatt wind turbine would cost about \$4.5 million to install. According to the U.S. Bureau of Labor Statistics inflation calculator, \$4.5 million in June 2021 U.S. dollars had the same buying power as \$5.1 million in October 2023.⁷⁷

The same National Renewable Energy Laboratory report estimated the levelized cost of energy (LCOE) for a representative land-based wind energy project installed in a moderate wind resource in the United States as \$34 per megawatt-hour: “LCOE is a metric used to assess the cost of electricity generation . . . and can be used to compare costs of all types of generation.”⁷⁸ This estimate considers capital expenditures, financing costs, operating expenditures, and net average annual energy production. The LCOE of \$34 per megawatt-hour equates to \$0.034 per kilowatt-hour, which is substantially below the \$0.3656 per kilowatt-hour for which Hawaiian

⁷⁵ Tyler Stehly and Patrick Duffy, *2021 Cost of Wind Energy Review*, National Renewable Energy Laboratory, December 2022.

⁷⁶ All costs cited in this chapter are in 2021 U.S. dollars.

⁷⁷ U.S. Bureau of Labor Statistics, “CPI Inflation Calculator,” webpage, undated.

⁷⁸ Stehly and Duffy, 2022, p. 14.

Electric sells electricity on Oahu.⁷⁹ This favorable difference could make it worthwhile to perform a wind survey at the RHBFSF site, conduct preliminary engineering design studies, and begin discussions with Hawaiian Electric. Table 6.2 summarizes the scoring of the renewable energy alternative for the economics criterion.

Table 6.2. Economics: Scoring of Energy Generation Using Renewable Sources

Category	Score
Nonrecurring cost	Score value 1: Parametric estimate applied to hypothetical facility operating to speculative conditions.
Recurring cost	Score value 1: Parametric estimate applied to hypothetical facility operating to speculative conditions.
Cost realism and completeness	Score value 2: Some estimates can be made according to NREL estimates, but without site surveys and a facility design, cost cannot be fully estimated.
Revenue projections and realism	Score value 2: Any revenue would be based on Hawaiian Electric billing rates.
Net present value	Score value 1: Cannot calculate.
Summary assessment	Score value 1: Without site surveys, a facility design, and discussions with Hawaiian Electric, this course of action cannot be properly evaluated.

Nonfinancial Considerations

Both solar and wind power could ostensibly offer a sustainable source of energy on Oahu and do not require the use of high-demand resources, such as fresh water.⁸⁰ The key components of both solar and wind power would need to be installed above ground, and, as noted, only wind power appears plausible in this case due to Red Hill’s geography. The construction necessary to create a viable wind farm at Red Hill would need to be carefully planned and executed to preserve the environment as much as possible, with detailed mitigation plans that are currently unavailable. Although many of the effects are likely transitory, we cannot assess or speculate on the level of permanent versus temporary effects.

The installation and generation of renewable energy would likely have a positive impact on public perception surrounding RHBFSF and the Navy but would also likely generate some negative externalities in the immediate vicinity. Renewable energy was identified as the most popular reuse option among local community members surveyed in Red Hill and Oahu. Additionally, given that the State of Hawaii has committed to achieving a net-negative emissions target by 2045, this option will mostly likely be seen as aligning with Hawaii’s climate goals, which could potentially help community attitudes toward the Navy and RHBFSF.⁸¹ However,

⁷⁹ Shuai, 2023.

⁸⁰ Hawaii Community Foundation, “Fresh Water Security for Hawai‘i,” undated.

⁸¹ Hawaii State Energy Office, “Decarbonization,” webpage, undated-a.

given the unknowns associated with environmental impacts, there is a potential that any unmitigated impacts could sway public opinion more negatively toward the reuse of RHBFSF for renewable energy. Thus, the environmental and cultural and social impacts of this option would most likely range from neutral to negative, resulting in an overall score of 2. The option offers long-term environmental net benefits to Hawaii and is shown to be viewed as highly favorable among the surveyed local population.

Robustness to Uncertainty

Looking outside the facility to use the surrounding mountainside as a site for renewable power generation appears to be a relatively robust option against multiple plausible futures. The two scenarios of special concern in which the alternative appears likely to encounter regret are directly related to potential technological breakthroughs in power-generation capabilities or to the potential unavailability of critical inputs (in the form of rare-earth metals) to the manufacturing and maintenance process. One case in which the details of the scenario matter a great deal is in “the very ground beneath of our feet,” which posits a failure of the tanks inside the interior of the facility.

Of the three scenarios, the “rarer rare-earth metals” alternative future appears to be most salient, as one can already observe concern about the availability of these inputs. Should relationships with major suppliers of rare-earth metals continue to sour, or should countries determine that exporting the metals is no longer in their interest, major disruptions in supply chains are likely to manifest. This could cause higher prices for materials, delays in maintenance, and other production disruptions that could fundamentally alter the economic calculus or viability of the project. In the long term, it is possible that a reduction in the supply of rare-earth metals currently used to power green technology would cause alternative materials to be pursued, but the time horizon is unclear. Given that this future would fundamentally alter the cost-benefit equation in a substantial way, we judge it brittle against this potential future.

In the case of a breakthrough in energy production, such as that posited by the “cheap, limitless energy, at long last” alternative future, the fundamental alteration of the cost-benefit calculus drives the determination of likely regret. Inherent in the substantial financial cost required to construct the necessary infrastructure to support green energy generation on a mountainside is an expectation of when the project might reach a break-even point. Any development that pushes the cost of energy generation down, or even dramatically reduces demand, changes the fundamental economic logic of the alternative. Although this alternative is in the radical departure category—meaning that it posits substantial divergence from today and thus requires more-optimistic assumptions about numerous crucial inflection points—it cannot be ruled out.

Finally, it is difficult to assess whether the installation of wind energy generation facilities on the mountainside would be brittle to a scenario such as the one posited in “the very ground beneath our feet.” If the tanks’ linings simply wear out sooner than the expected life, no threat is

posed to the viability of wind turbines located on the exterior of the mountain. On the one hand, it can be argued that any event of sufficient magnitude to degrade the tanks would likely be significant in size and scope. This would imply that objects located on the exterior of the mountain, and in the surrounding environs, would likewise be damaged. On the other hand, it is possible that the wind turbines could be engineered to withstand such hazards as rockslides or wildfires. Because the data provided to us about the alternative were largely conceptual in nature, and we had to make a large number of assumptions, we are unable to adequately assess with confidence both whether this option sufficiently hedges against such a future and whether this option truly deserves to be deemed as likely to encounter regret. Therefore, we feel that an “uncertain” ranking is warranted. This leaves the scenario with a score of nine scenarios that are judged safe from regret, two likely regrets, and one uncertain, for a combined score of 3 in robustness to uncertainty (see Table 6.3).

Table 6.3. Robustness to Uncertainty Scoring Matrix for Energy Generation Using Renewable Sources

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing “continuing resolutions”	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare-earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Energy generation using renewable sources	Robust	Robust	Robust	Robust	Not robust	Robust	Robust	Robust	Robust	Robust	Not robust	?

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer’s remorse in this scenario, red (not robust) indicates that buyer’s remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty.

Conclusion

Table 6.4 summarizes the scoring assessment of the renewable energy alternative. Our assessment indicates that converting RHBFSF into a renewable-energy-generation facility, while technically executable and robust to many of the aforementioned uncertain futures, could have a negative impact on the surrounding environment and public opinion. Of renewable energy technologies, wind power is the only one that could plausibly be implemented at the RHBFSF site. But this alternative would not use the internal structure of the facility, and construction of any type of renewable energy infrastructure on the mountainside would require detailed mitigation plans, which are not currently available. Additionally, the economic parameters of this option cannot be estimated because of a lack of specificity (e.g., site surveys and analysis) regarding the design of such a facility. Policymakers wishing to hedge against environmental or economic risks would likely not select this option.

Table 6.4. Scoring Assessment of Energy Generation Using Renewable Sources

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
Energy generation using renewable sources	4	1	2	3

Chapter 7. Water Storage

This chapter evaluates converting all of the fuel tanks at RHBFSF into water storage reservoirs.

Overview

This alternative, suggested by various Nakupuna Consulting studies, posits repurposing the 20 RHBFSF fuel tanks to store potable water for use by residents of Oahu.⁸² There are three types of water that could be stored: salt water from the ocean, nonpotable fresh water, and potable fresh water. Although DoN has committed to cleaning the tanks as part of its closure activities, this alternative requires that the large storage tanks be cleaned and rinsed sufficiently or otherwise converted to hold water without introducing residuals from (for example) the cleaning process to that water. At the direction of the sponsor, we considered a water storage option, and after analysis the specific alternative we chose to consider was potable freshwater storage.

Assessment by Criteria

The following sections assess the alternative according to the four criteria discussed in Chapter 3 (executability, economics, nonfinancial considerations, and robustness to uncertainty).

Executability

The first possible water type noted above, holding a reservoir of salt water from the ocean, makes little sense because it risks contaminating the aquifer and because the Pacific Ocean around to Oahu is a vast reservoir of salt water. The second possible water type, holding nonpotable fresh water, was deemed undesirable because without either purification or sufficient testing and remediation, it is not possible to guarantee that the water would not be corrosive to the tank interiors or likely to mobilize any residual materials on the surface. This would require the additional research and analysis to conclude what forms of nonpotable water would be considered safe and the construction of special facility features to convert such water into either safe nonpotable or simply potable form before it could be used. Although DoN is currently planning a water treatment facility at RHBFSF, any additional facilities required would need to be built and would necessitate multiple environmental reviews and permits, a large source of

⁸² Nakupuna Consulting LLC, 2023a; Nakupuna Consulting LLC, 2023b; Nakupuna Consulting LLC, 2023c.

energy to run the facilities, and professional staff to operate and maintain them, all of which add up to a substantial undertaking.

One alternative might be to use the facility to store stormwater runoff to prevent flooding. While a possibility, this does not appear feasible to analyze at present because of the extensive culverts and stormwater management systems that would need to be created off-site and linked up to an input mechanism of sufficient size to allow entrance to the tanks, plans for which currently do not exist to our knowledge, nor do we believe that the details are readily estimable. Or it might be prudent to store nonpotable fresh water in the tanks for future conversion into potable water at the existing 13 Oahu municipal water treatment facilities in an emergency situation. This itself raises the question: How does the volume of the tanks compare with the volume of fresh water in the aquifer beneath the tanks? There is considerable literature published by the U.S. Geological Survey on this subject.⁸³ The data indicate that the aquifer below Oahu has multiple regions, with an average recharge rate (from rainfall) of almost 800 million gallons per day (representing around 40 percent of the rainfall—the rest is consumed by surface foliage or lost due to runoff or evaporation). An average of less than 200 million gallons per day is withdrawn through wells for human consumption, with another 300 million for agriculture and other uses, making the total average daily withdrawal fewer than 500 million gallons. Thus, at least at present, the balance of additions minus withdrawals is highly favorable.

For a variety of reasons, it is difficult to measure the total available inventory of fresh water in the aquifer; such an estimate would depend on the detailed configuration of the aquifer, which is not known. As a result, it is useful to compare RHBFSF tank volume just with the average recharge rate cited above of 800 million gallons per day. As described earlier in this report, total tank volume is around 1 billion liters, or approximately 264 million gallons. Thus, the entire volume of the tanks represents, on average, much less than one day's worth of aquifer recharge.

A related concern has to do with using the RHBFSF storage tanks to store fresh water after it has been converted into potable form and maintain it in that potable form for later use. Owing to the potential for trace amounts of residuals on the interior surfaces of the tanks after DoN has cleaned them, plus any metal corrosion that the previous contents have induced over the years, any water placed into the tanks in their current condition could become contaminated at levels that exceed safety guidelines and thus no longer be potable.

There are three options to deal with this situation if the goal is to place potable water into the tanks and preserve the water in its potable form while in the tanks:

- 1. Chemically clean the interior of the tanks to remove all contaminants and restore the inner surfaces of the tanks to a condition suitable for potable water storage.**

Typically, however, water storage tanks have an interior membrane to protect the water from the outer container of the tank. Nevertheless, chemically cleaning remains an option

⁸³ See William D. Nichols, Patricia J. Shade, and Charles D. Hunt, Jr., *Summary of the Oahu, Hawaii, Regional Aquifer-System Analysis*, U.S. Geological Survey, January 1, 1996.

depending on the use case. This would require the use of extremely caustic and toxic chemical agents, with multiple flushes to remove debris in both ionic and nonionic (solid) form and then the disposal of the debris and the contaminated fluid in an environmentally safe form. Although this approach is technically possible, it would be very costly, owing to the large volumes of the tanks, require the use of toxic chemicals, produce considerable toxic waste, and incur substantial environmental risks that would need to be carefully mitigated. Further, testing to prove that all the interior surfaces of the tanks have been cleaned to a satisfactory level would be a difficult task, and DoN is currently (as of the writing of this report) in talks with regulators over exactly how to do this. As discussed in Chapter 5, many organizations have explicit warnings against reusing containers that once held fuel.⁸⁴ For these reasons, this possibility is not considered further.

2. **Line the interior surfaces of the tanks with an impervious material that would insulate the tank from the potable water to be placed into it.** Since the tank interior surfaces are enclosed, the impervious material could theoretically be metallic, but this effort would likely be extensive or prohibitive, and other materials are generally preferred for interior liners. Similarly, materials often used to line water basins to prevent water from infiltrating into the ground, such as asphalt and concrete, are not suitable, since there is no way to ensure that they fully coat the interior surfaces of the tanks and form an impervious layer. Other methods, such as the vapor deposition of ceramics or metals or electrochemical deposition of such materials, are also problematic because those techniques typically require the use of large volumes of toxic chemical agents or require that a near vacuum be drawn in the tanks during deposition; typically, these techniques create only thin deposition films that might not be of sufficient depth to ensure the impermeability to water infiltration over time.⁸⁵ Ensuring that the material being deposited covers all the interior surfaces and is in sufficient depth to be impermeable would require considerable development and testing. Creating multiple water towers of the size of even one of the tanks at RHBFSF, or using these techniques for the very large-volume tanks, which have uncertain and uneven interior surface conditions, would be a “first of a kind” effort, with commensurate technical and environmental risks and substantial uncertainty of regulatory approval.
3. **Line the interior surfaces of the tank with some form of synthetic rubber, such as a large bladder that could be inflated to conform to the shape of the interior surfaces of the tanks.** The largest commercially available bladders for holding potable water are 210,000 gallons⁸⁶—less than 2 percent of the size of a typical RHBFSF tank (20 tanks holding 264,000,000 gallons = around 13,000,000 gallons per tank). Thus, covering an entire tank’s interior surface would require a custom-made bladder and may require altering the bladder’s design, materials, and construction to avoid rupturing the bladder walls during installation and use.

⁸⁴ For a detailed discussion of reusing water containers, please see the “Nonfinancial Considerations” section in Chapter 5.

⁸⁵ David L. Chandler, “Explained: Chemical Vapor Deposition,” *MIT News*, June 19, 2015.

⁸⁶ Ready Containment LLC, “Military Bladder Tanks,” webpage, undated.

Although a custom-designed bladder appears to be the only plausible approach that preserves potable water integrity while not entailing significant effort or raising serious environmental risks or the likelihood of regulatory opposition, there are several challenges associated with this approach, if it is indeed feasible at all. First, ensuring that the bladder conforms to the interior surfaces when full of water could be complicated. Ensuring that any trace residuals on the interior surfaces of the tanks, and the roughness of those surfaces, do not deteriorate the bladder material or puncture the bladder walls would also likely require some engineering examination and testing. It is doubtful whether there are any long-term data on how well such a bladder would preserve its integrity under these conditions, so that too would have to be evaluated. Periodic testing of any potable water stored in the bladders would have to be performed. Finally, the piping necessary to insert potable water into the bladder and remove it from the bladder would need to be engineered as part of the customized bladder design and construction.

Table 7.1 shows the scoring breakdown for this alternative, which receives an overall executability score of 2.

Table 7.1. Executability: Scoring of Water Storage

Axis	Score	Rationale
Technical executability	2 (moderate)	This alternative would require a custom-designed bladder system to insert into the tanks and may be a “first of a kind” situation, owing to the very large size of the bladder compared with what is commercially available. The alternative would require additional examination and testing to verify that the interior surfaces would not damage the bladder during insertion and inflation and would require additional monitoring to ensure bladder integrity over time.
Schedule executability	2 (moderate)	Same reasoning as for technical executability.
Regulatory executability	2 (moderate)	Same reasoning as for technical executability.
Environmental executability	2 (moderate)	Same reasoning as for technical executability.
Maintenance executability	3 (high)	Same reasoning as for technical executability. How to test and maintain the bladders would be established as part of their design and installation.

Economics

As discussed in the executability section, potable water would likely be the best water product to store in tanks at RHBFSF. To prevent the risk of trace residuals, the tanks must be chemically cleaned, which poses serious environmental risks because of the toxic and caustic nature of the cleaning agent and would be unlikely to receive regulatory approval. Alternatively, an internal sealant would need to be placed on the inner tank walls, possibly using vapor deposition or electrochemical deposition. Because we do not know the detailed nature of the internal wall surfaces, the process would require substantial development to ensure that it would work and would also likely incur regulatory opposition. Another approach would entail installing

a bladder (or bladders) in the tanks to preclude water contacting the internal walls of the tanks. As noted, the largest bladder that is commercially available holds 210,000 gallons, which is a small fraction of the volume of each of the 20 tanks in RHBFSF.

To avoid the high likelihood of regulatory opposition to cleaning or deposition, the most plausible approach is to use bladders to hold potable water in the RHBFSF tanks. Hence, the following actions would be required:

- Structural elements in the tanks would have to be removed to facilitate installation and inflation of any bladders.
- Appropriately sized bladders would have to be designed, produced, installed, managed, and tested periodically.
- A new piping system would have to be designed and installed to place water into the bladders and remove water from the bladders for testing and use.

To avoid major structural work in the mountain, the bladders would have to be of a size that, when deflated, would fit through existing access ports to the tanks. No estimates have been prepared for any of these actions, as they would require engineering studies to arrive at specifications.

The economic impact of using RHBFSF for water storage is assessed as shown in Table 7.2.

Table 7.2. Economics: Scoring of Water Storage

Category	Score
Nonrecurring cost	Score value 1: There is no basis on which an estimate can be made.
Recurring cost	Score value 1: There is no basis on which an estimate can be made.
Cost realism and completeness	Score value 1: There is no basis on which an estimate can be made.
Revenue projections and realism	Score value 1: There is no basis on which an estimate can be made.
Net present value	Score value 1: There is no basis on which an estimate can be made.
Summary assessment	Score value 1: There is no basis on which estimates can be made and economic impact assessed.

Nonfinancial Considerations

The potential environmental and cultural and social impacts of reusing RHBFSF as a freshwater storage facility depend heavily on whether the tanks can be cleaned or modified so that they do not risk contaminating the potable water they are storing. From an environmental perspective, significant testing and mitigation efforts would be required. Measures that simply clean but do not replace the lining of the tanks would very likely result in the stored water becoming contaminated, which presents additional risks. By contaminating the potable water that is stored in the tanks, this option could theoretically exacerbate the freshwater shortages that

Hawaii has faced (and is prone to).⁸⁷ Replacing the tanks' linings, while lowering the risk of residuals, would present other environmental risks associated with the intensive construction process that would need to be mitigated. These risks include dust and vehicular exhaust associated with heavy traffic leading to and from the facility, which, while transitory, would need to be accounted for and mitigated to the extent possible.⁸⁸

The public perceptions of converting RHBFSF into a freshwater storage facility are unlikely to be favorable. As noted in Chapter 5, the November 2023 report released by the Red Hill Watershed and Aquifer Initiative, a working group composed of key stakeholders from the state and local governments of Hawaii and the University of Hawaii, argued that introducing water to the facility poses a significant risk.⁸⁹

We note that water storage was ranked as the second and third most popular reuse option by those surveyed in the Red Hill community and Oahu, respectively.⁹⁰ Among the separately surveyed individual community stakeholders who opted for reuse, water storage was the top choice, although some individuals expressed concerns about whether the tanks could be cleaned enough to allow for the safe storage of drinking water. Other individuals expressed the concern that any nonpotable water stored in the tanks entails risk of leakage into the aquifer.⁹¹ In consideration of the Red Hill Watershed and Aquifer Initiative working group's report, we conclude that this alternative runs the risk of being viewed very poorly by many key stakeholders in the community.

Given the potential for environmental impact absent significant mitigation efforts and the risks of worsening public perception as a result of this alternative, water storage receives an overall score of 1 for nonfinancial considerations.

Robustness to Uncertainty

Turning the tanks into freshwater storage is the closest benign liquid-storage option one can reasonably conceive of that uses RHBFSF for a purpose close to that of its original intent. Therefore, the scope and scale of the *unknown unknowns* surrounding this option should be relatively small. A quick overview of the potential futures suggests that only those related to meaningful changes to the tanks' structural integrity ("the very ground beneath our feet"), environmental stewardship ("rigid environmental regulation"), or state of the facility ("more remediation than expected") would appear to meaningfully affect the desirability of this option.

⁸⁷ Hawaii Community Foundation, undated.

⁸⁸ Jacobs, 2022, pp. 10–12.

⁸⁹ Red Hill Water Alliance Initiative, 2023, p. 6.

⁹⁰ Nakupuna Consulting LLC, 2023c, p. 7.

⁹¹ Nakupuna Consulting LLC, 2023b, p. 11.

We focused our analysis on these options and explored the reasons a water storage option appears to be undesirable.

Of all three scenarios listed above, the futures posited by the “rigid environmental regulation” and “more remediation than expected” appear to be the most concerning following the issuance of the Red Hill Water Alliance Initiative report on RHBFSF.⁹² For instance, under a “rigid environmental regulation” scenario, substantial issues remain even if the state’s concerns regarding the placement of water in the tanks is ameliorated.

Likewise, if either “more remediation than expected” or “the very ground beneath of our feet” comes to pass, the concerns expressed by the Red Hill Water Alliance Initiative could theoretically become exacerbated, given the large amount of water that would be in the tanks. Therefore, policymakers who are interested in options that are in harmony with the recommendations laid out by the State of Hawaii would likely do well to steer away from this option. This option also does not appear robust to anything that would negatively affect the tanks’ integrity, for many of the same reasons discussed in previous chapters. Even scoring these three scenarios as likely to cause regret still leaves us with a score of 9 out of 12—a score of 3 on robustness to uncertainty—as demonstrated in Table 7.3.

Table 7.3. Robustness to Uncertainty Scoring Matrix for Water Storage

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing “continuing resolutions”	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare- earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Water storage	Robust	Robust	Robust	Not robust	Robust	Not robust	Robust	Robust	Robust	Robust	Robust	Not robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer’s remorse in this scenario, red (not robust) indicates that buyer’s remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty (not applicable for this alternative).

Conclusion

Table 7.4 summarizes the scoring assessment of the water storage alternative. Although the functional similarity between using RHBFSF for freshwater storage and fuel storage increases this option’s robustness to our proposed futures, uncertainty surrounding the process needed to safely carry out this option yields a relatively low level of executability, economic viability, and environmental and cultural and social benefit. There is little precedent for the type of structural adjustments in the tanks that would be needed to make them safe for potable water, which complicates determining the schedule and cost of implementing this option. Additionally,

⁹² Red Hill Water Alliance Initiative, 2023.

structural adjustments to alleviate the possibility that the stored water could become contain residuals appear problematic.

Table 7.4. Scoring Assessment of Water Storage

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
Water storage	2	1	1	3

Chapter 8. Museum

This chapter evaluates the option of converting RHBFSF into a museum open to the general public.

Overview

RHBFSF was declared a historic civil engineering landmark by the American Society of Civil Engineers in 1995 because of the facility's innovative design and construction.⁹³ One survey suggestion was to turn the facility into a museum to display the engineering of the site; some surveyed community stakeholders also suggested that the facility could be incorporated with the Pearl Harbor Historic Sites and showcased as both an engineering marvel and a tribute to the local residents who took part in its construction.⁹⁴ DoN has conducted limited tours of the site and has one drained fuel tank set up to allow visitors to view the interior of the tank. Visitors are currently issued hard hats and required to carry flashlights in case of emergency. The tunnels are relatively dimly lit, and upgrades (e.g., brighter lights, replacing the scaffolding with a more permanent structure or guardrails) would be necessary to ensure visitor safety. Site upgrades might also be necessary to ensure that visitors could access and park at the facility, not to mention any additional upgrades required to make the entirety of the facility compliant with regulations under the Americans with Disabilities Act.⁹⁵ The site is very remote, challenging to access, and does not have designated visitor parking or drop-off and pickup sites, which would be necessary to enable and maximize tourism at the site.

Assessment by Criteria

The following sections assess the alternative according to the four criteria discussed in Chapter 3 (executability, economics, nonfinancial considerations, and robustness to uncertainty).

Executability

This alternative contemplates converting RHBFSF into a museum that would accept visits by members of the public who would be willing to pay. The executability of this alternative is affected by several factors:

⁹³ American Society of Civil Engineers, undated; Commander, Navy Region Hawaii, 2023a.

⁹⁴ Nakupuna Consulting LLC, 2023b, p. 12; Nakupuna Consulting LLC, 2023a, p. 5.

⁹⁵ Public Law 101-336, Americans with Disabilities Act of 1990, July 26, 1990.

- Before allowing visitors to enter RHBFSF, any path that the visitors would be permitted to traverse would need to be precisely defined, and mechanisms would need to be put in place to ensure that visitors were not physically able to deviate. Creating those paths (and the barriers to deviation) would require construction within RHBFSF proximate to existing systems, such as tanks and pipes.
- Although RHBFSF must meet Occupational Safety and Health Administration (OSHA) requirements imposed by the U.S. Department of Labor and state regulators covering employees, the requirements imposed for access by the public will be far more stringent and would need to be negotiated with state environmental and other regulators. Additionally, requirements to protect museum visitors are much broader than OSHA requirements (which focus on noise abatement and protection against airborne and surface toxic materials) and include guidelines set by the Centers for Disease Control and Prevention (to protect against airborne and surface pathogens) and guidelines set by the U.S. Department of Homeland Security (to protect against terror attacks). Meeting all these requirements does make executability more complex and unpredictable—and increases overall project costs.
- In the event of an incident (a terror attack, a visitor experiencing a heart attack or other medical problem, etc.), any affected visitor would need to have aid rendered quickly and possibly be evacuated. The facility is carved out of the mountain, and detailed plans for routes that might necessitate additional mining could be required. This effort not only incurs costs but also affects executability, since placing aid stations (automatic electronic defibrillators, for example) along the visitor paths would be necessary, as would having trained museum personnel available to use the equipment.

There is one additional element: It is possible that the facility could be sold to a private party to convert and run as a museum, and the private party would either share or take all of any profits from visitor fees. This does not affect executability (for converting the facility into a visitor museum) but may affect the economics, which are addressed in the next section of this chapter. Table 8.1 shows how executability was evaluated for this alternative. The alternative receives an overall score of 4.

Table 8.1. Executability: Scoring of the Museum

Axis	Score	Rationale
Technical executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Schedule executability	4 (very high)	There are no cutting-edge or unusual technologies involved.
Regulatory executability	3 (high)	There would need to be additional engagement with regulators covering topics that have not been heretofore evaluated (e.g., visitor safety).
Environmental executability	4 (very high)	The facility would remain self-contained while in use as a museum.
Maintenance executability	4 (very high)	There are no cutting-edge or unusual technologies involved.

Economics

No studies have been performed to estimate what it would take to convert RHBFSF into a museum. The nonrecurring costs would likely be easy to estimate realistically, as they would likely be mostly for items to enhance the safety of the site, such as guardrails, lighting, and signage. Recurring costs for museum operations would likewise be nominal and easy to estimate realistically, as they would involve, for example, guides, utilities, and marketing expenses. The recurring expenses of water removal and periodic inspections addressed in Chapter 4's discussion of no beneficial reuse would also apply but have not been estimated. Revenues from sales of admission tickets cannot be reliably estimated, as

- the museum would be in a remote location well away from Oahu's normal tourist attractions
- the general population is unlikely to have substantial interest in the museum.

For all these reasons, we assessed the economic impact of this alternative as shown in Table 8.2.

Table 8.2. Economics: Scoring of the Museum

Category	Score
Nonrecurring cost	Score value 3: Museum operation costs are nominal and easy to estimate, but long-term water removal and periodic inspection costs are not estimated.
Recurring cost	Score value 4: Nominal amount easy to estimate.
Cost realism and completeness	Score value 1: No details to estimate or assess.
Revenue projections and realism	Score value 1: Any revenue is highly speculative.
Net present value	Score value 1: Cannot calculate.
Summary assessment	Score value 1: Without a scope of work and revenue projections from a substantive marketing survey, a museum option for RHBFSF cannot be properly evaluated.

Nonfinancial Considerations

The environmental impact of turning RHBFSF into a museum would most likely be neutral or slightly negative, as compared with the status quo. Although this option does not pose any immediate risks to the aquifer, as it does not involve the storage of any potential hazards within the facility, opening the facility to tourism presents potential stresses to the surrounding environment, and any unmitigated risks carry the potential for negative public perception.⁹⁶

The cultural and social impact of a museum on the local community could potentially range from neutral to slightly positive. Among those surveyed in the Red Hill and wider Oahu

⁹⁶ United Nations Environment Programme, "Environmental Impacts of Tourism," 2001; Jacobs, 2022, p. 17.

communities, turning RHBFSF into a museum was the fifth most popular reuse option.⁹⁷ Those in favor of this option highlighted the educational potential of incorporating the facility into the Pearl Harbor Historic Sites, using it as an opportunity to both honor the local residents who took part in the construction and showcase the facility's unique engineering characteristics.⁹⁸ Several stakeholders interviewed also emphasized the value of tourism to the Hawaiian economy, making it possible that this option would be viewed favorably by a portion of the local community and improve attitudes toward the Navy.⁹⁹ However, as the owner of the facility, DoN would have to take measures ensure the safety of visitors, as it would likely be liable for any injuries that occur at the facility. Moreover, this option would likely fall out of favor in the local community if it were viewed as a risk to public safety.¹⁰⁰

Overall, the museum alternative receives an overall score of 2 for this criterion. Although the option offers demonstrable educational and tourism benefits, it would also result in a higher concentration of long-term human activity at close proximity to the aquifer. Moreover, any negative environmental impacts will certainly negatively affect public perception of the option.

Robustness to Uncertainty

Turning the facility into a museum appears to have downsides in two classes of future: ones in which human safety is a concern and ones in which economic viability is a concern (see Table 8.3). The most obvious set of human safety concerns occurs in a scenario such as that posited by “the very ground beneath our feet”: An event occurs in which the tanks degrade faster than anticipated. At best, this would involve minor debris from the tanks' ceilings being at risk of falling, which might necessitate putting netting over the catwalks or forbidding access to the interior of certain tanks. At worst, this would be an event, such as a facility fire that strikes the museum at peak occupancy, leaving museum goers at great risk from collapsing debris and being stuck in a tunnel system with limited means of egress. Although the number of people affected by such a scenario would depend on the projected ticket sales (which other parts of this analysis have reported as unavailable), it may be the case that guarding against even more-prosaic versions of this scenario are deemed of paramount importance.

One interesting scenario to consider is that posed by the “more remediation than expected” scenario, as this future has both economic and safety concerns. Depending on the scope, scale, and type of environmental cleanup efforts, it may be the case that either (1) it takes a long time to remediate the facility or (2) the facility is deemed to never be suitable to host a general audience for any number of reasons. The implications of both of these have a direct impact on

⁹⁷ Nakupuna Consulting LLC, 2023c, p. 6.

⁹⁸ Nakupuna Consulting LLC, 2023b, p. 12.

⁹⁹ Nakupuna Consulting LLC, 2023b, p. 52.

¹⁰⁰ Nakupuna Consulting LLC, 2023c, p. 5.

the economic viability of the project, as well as the safety of the general public, which falls under much higher safety regulations than those of paid contractors or uniformed military personnel. Therefore, this option seems exceedingly brittle to this potential future.

In futures that care about fiscal certainty, or desire robust economic benefit—such as those posited by “continuing ‘continuing resolutions,’” “meet the new boss,” and “handing over the reins”—this museum option appears likely to cause regret, as it entails substantial recurring costs, with an (at best) uncertain chance of generating sufficient revenue to offset costs. Depending on the specific scenario in question, any future that imposes a requirement for even a cost-neutral option will likely preclude this option for selection. Although this should come as no surprise, given that museums are often maintained as public goods without the expectation of substantial profitability, it does raise the question of whether the proverbial juice is “worth the squeeze.” Unless and until future analyses show substantial interest in viewing the facility, the factors that made it attractive as a fuel storage site (e.g., seclusion) may ultimately doom any museum to very sparse attendance. This leads us to conclude that choosing to use RHBFSF as a museum hedges against seven of the 12 alternative futures we generated, for a score of 3 out of 4 (see Table 8.3).

Table 8.3. Robustness to Uncertainty Scoring Matrix for the Museum

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing “continuing resolutions”	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare- earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Museum	Not robust	Robust	Robust	Robust	Robust	Not robust	Not robust	Robust	Robust	Not robust	Robust	Not robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer’s remorse in this scenario, red (not robust) indicates that buyer’s remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty (not applicable for this alternative).

Conclusion

Table 8.4 summarizes the scoring assessment of the museum alternative. Although our assessment shows that this alternative is highly executable and reasonably robust to uncertainty, the economic costs of turning RHBFSF into a museum are challenging to estimate. Moreover, the alternative poses potentially negative impacts on the surrounding environment and public perception. Specific risks to consider regarding the museum alternative include costs that exceed revenue, tourism-related pollution, and DoN liability for public injury. Policymakers who prioritize economic, environmental, or safety concerns over cultural and educational impact may shy away from this option.

Table 8.4. Scoring Assessment of the Museum

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
Museum	4	1	2	3

Chapter 9. Overall Findings, Conclusions, and Recommendations

This chapter reviews the five alternatives evaluated, summarizes our assessment of each alternative, and compares the scores across alternatives. It then summarizes our key findings, conclusions, and recommendations.

Brief Overview of Each Alternative Assessed

No Beneficial Reuse

Although not a reuse option per se, this alternative represents the closest available alternative to a status quo case, whereby DoN decides not to develop a reuse option for the facility post-closure. Beyond the maintenance tasks needed to ensure the facility's long-term structural integrity, no further action would be required.

No beneficial reuse scores highly across all assessment criteria. Given that this alternative relies on technology and procedures that are well established, it is very executable, and its costs can be estimated to a degree sufficient for relevant decisionmaking. Additionally, the alternative minimizes the risk of the facility causing additional environmental harm and is highly robust to a series of potential policy, technological, and environmental changes as it simply sits dormant.

Energy Storage Using Pumped Hydropower

This alternative proposes converting RHBFSF into a pumped hydropower storage facility. Of potential designs, a closed-loop, freshwater design is the only feasible option to minimize environmental risk. In this design, excess energy provided by either Hawaiian Electric or renewable energy sources would be used to pump water into the upper reservoir (i.e., the tanks), which is then used to drive turbines during times of peak demand. A closed-loop system would necessitate the construction of a lower reservoir, given that one is not naturally provided by the surrounding environment.

This alternative scores moderately well in technical executability and robustness to uncertainty because of the maturity of the technology required to implement the alternative and its resistance to potential policy changes, respectively. However, because it involves pumping water that could potentially contain residuals from any number of sources, this option scores poorly in terms of regulatory and environmental executability and nonfinancial considerations. Meanwhile, because specific details are lacking (e.g., site surveys) surrounding the design of a pumped hydropower facility at RHBFSF, we were unable to properly evaluate the economics of this option.

Energy Generation Using Renewable Sources

This alternative proposes converting RHBFSF into a facility for renewable energy generation. Because of the geographic characteristics of Oahu and the hilly terrain surrounding RHBFSF, wind power is the only plausible option of currently available renewable energy technologies. Since wind power is an above-ground technology, this alternative would not repurpose the tanks and facility but rather would use the mountainside at the RHBFSF site.

Using RHBFSF for renewable energy generation scores very well in executability and robustness to uncertainty. This option would employ well-developed technologies and would most likely not be affected by any of the previously mentioned futures (aside from disruptions in supply of rare-earth metals and radical breakthroughs in energy production). However, the construction required to install renewable energy infrastructure on the mountainside could have potentially negative environmental impacts absent mitigation efforts and would then run the risk of public opinion souring. Finally, uncertainties regarding the construction process and operation of a renewable energy facility at RHBFSF make it impractical to properly evaluate the economics of this option.

Water Storage

This alternative proposes using RHBFSF's tanks as a large-scale water reservoir that could be used as needed for a variety of purposes. This option has the benefit of being superficially the most like RHBFSF's current mission of fuel storage while harnessing it toward a beneficial end without having to dramatically reinvent or reengineer the facility. However, to execute this option safely, the tanks and all supporting equipment would need to be adjusted (e.g., fitted with interior liners or a bladder) to their new purpose and in such a way that precludes the water stored within them from being potentially contaminated by trace cleaning residue or fuel residuals.

Water storage scores well in robustness to uncertainty due to the functional similarity between fuel storage and water storage. However, the structural adjustments that the tanks and supporting equipment would have to undergo to prevent the water stored within them from risk are far from being well established. This risk negatively affects the executability and economic evaluation of this alternative. The difficulty of mitigating this risk, absent an internal coating or other liner, greatly increases the likelihood of this option having a negative environmental and cultural and social impact.

Museum

This alternative proposes using RHBFSF as a museum that would be open to the public, perhaps as part of the Pearl Harbor Historic Sites, to showcase the facility as both an engineering

marvel and a tribute to the local residents who took part in its construction.¹⁰¹ Stakeholders would need to consider how the facility would be made readily accessible and safe for a large number of tourists, given that the facility is bored into the earth.

This alternative scores well in both executability and robustness to uncertainty due to a lack of technological complexity. However, introducing tourism raises several challenges (e.g., accessibility) for which sufficient answers do not yet exist. Additionally, it is difficult to predict how much revenue such an attraction would generate, particularly given the facility's remote location, making it impractical to evaluate the economics of this option.

Cross-Alternative Assessment

Table 9.1 shows the final matrix with the five alternatives and our scores for each according to the four assessment criteria. As discussed in Chapter 3, each alternative received a score from 1 (least preferred) to 4 (most preferred) for each of the four assessment criteria.

Table 9.1. Scoring Assessment of Analyzed Alternatives

Alternative	Score (by Criterion)			
	Executability	Economics	Nonfinancial Considerations	Robustness to Uncertainty
No beneficial reuse	4	3	3	4
Energy storage using pumped hydropower	3	1	1	3
Energy generation using renewable sources	4	1	2	3
Water storage	2	1	1	3
Museum	4	1	2	3

NOTE: Green denotes cells with the highest possible score (i.e., 4), and red denotes cells with the lowest possible score (i.e., 1).

No beneficial reuse scores well against all four criteria, which indicates that the alternative is highly executable from a technical, regulatory, and environmental perspective; can be effectively evaluated from an economic perspective; has potential environmental and cultural and social benefits; and is robust against future uncertainty. Policymakers wishing to minimize overall risk associated with RHBFSF would be best served by this option.

Using RHBFSF for pumped hydropower energy storage scores high in terms of executability and robustness against uncertainty but low against economics and nonfinancial considerations. Given that the economics of this option cannot be evaluated precisely enough to warrant any financial-based decisionmaking and that it would likely have negative environmental and

¹⁰¹ Nakupuna Consulting LLC, 2023b, p. 12.

cultural and social impact, policymakers wishing to hedge against financial, environmental, or social risk would likely not choose this option.

Renewable energy generation also scores very high against executability and robustness to future uncertainty but low for economics and nonfinancial considerations. Therefore, policymakers who desire to limit the technical, regulatory, or environmental hurdles involved in implementing an alternative—as well as an alternative’s vulnerability to future changes in policy, technology, or the environment—may view this option favorably. However, those who give greater consideration to hedging against financial, environmental perception, or social risks would likely shy away from using RHBFSF for renewable energy generation.

Using RHBFSF for water storage scores high against robustness to future uncertainty but low against the other three criteria. This being the case, unless policymakers consider robustness against future policy, technological, or environmental changes to be of paramount importance, this option is unlikely to be beneficial because of the significant uncertainty surrounding executability and economics, as well as negative environmental and social impacts.

Turning RHBFSF into a museum performs well in the executability and robustness to uncertainty categories but low against economics and nonfinancial considerations. Therefore, as with renewable energy generation, this option is unlikely to be chosen by policymakers who place greater emphasis on avoiding financial, environmental perception, or social risk than on risks associated with implementation or future policy, technological, or environmental changes.

Findings, Conclusions, and Recommendations

The disposition of the RHBFSF site comes with immense public scrutiny, which necessitates a careful and considered analysis of any potential reuse options. This report has attempted to synthesize the best data that are currently available about any potential reuse options. We conducted a first-order cost-benefit analysis in accordance with generally accepted best practices. In this analysis, we considered five distinct options for the future of the facility:

- no beneficial reuse
- energy storage
- energy generation
- water storage
- museum.

Our first finding is that **the bespoke nature of RHBFSF makes reconfiguration and reuse for almost anything other than liquid storage difficult to contemplate.** RHBFSF was mined out of a mountain and situated above Oahu’s aquifer. Thus, many of the reasons people would want to visit RHBFSF as a museum (e.g., it is a civil engineering marvel) preclude reconfigurations or additions to the facility without immense engineering efforts. Any options that require additional facilities that need to be constructed would need to be built outside the facility (which may make maintenance unwieldy or cause costs to increase) or necessitate

additional mining, which would increase cost and risk. Given the wide variety of reuse options suggested by the public, it appears likely that substantial misconceptions exist about the types of reuse options that can likely be achieved at relatively acceptable costs. The facility has long been either classified or under protection as both an active military facility and critical infrastructure, so this is unsurprising.

Our second finding from this study is that, despite DoN's rapid defueling of the facility, **there is still uncertainty surrounding the timing of the availability of RHBFSF for reuse development.** What became apparent during the course of this analysis is that each option is at a different stage of maturity. Defueling is scheduled for completion in early 2024, but closure-in-place efforts are not concluding until 2027 at the earliest. This implies that no reuse options can be fully planned or undertaken until *at least* 2027. Given the high-profile nature of the facility and the complex engineering required to undertake even the most well-understood reuse efforts considered here, it is almost certain that the relative attractiveness of options will change over time.

As more information and details about the facility and what will be required to implement a given alternative become available, the executability and economic viability of the options could change in ways not contemplated here. Given the bespoke nature of the facility, its location inside a mountain, and the lack of direct and routine access to the facility by planners, only first-order, conceptual assessments of reuse options could be undertaken by some stakeholders. Because of this, the third finding from our analysis is that **there are currently insufficient data to meaningfully compare the options on equal terms without making significant assumptions about some of them.**

For instance, because of the straightforward task of closing the facility and the (generally) well-understood nature of turning it into a closed-loop freshwater storage facility for pumped hydropower energy, there exists a high volume of decision-quality data for that option. There are less data on how to use RHBFSF to safely store water in the tanks for use. There are three general categories the options fall into:

1. Substantial decision-quality data exist or are readily obtainable for *all* categories of this analysis.
2. Substantial decision-quality data exist or are readily obtainable for *most* categories of this analysis.
3. Substantial decision-quality data *do not exist nor appear to be readily obtainable* for most categories of this analysis.

Given the data presented to us, as well as the supplementary research and analysis we conducted for the purposes of this report, it is our conclusion that the options generally fall into the above categories, as shown in Table 9.2.

Table 9.2. Characterization of Options

Category	Option(s)
Substantial decision-quality data exist or are readily obtainable for all categories of this analysis	• No beneficial reuse
Substantial decision-quality data exist or are readily obtainable for most categories of this analysis	• Energy storage • Energy generation
Substantial decision-quality data do not exist nor appear to be readily obtainable for most categories of this analysis	• Water storage • Museum

Stark evidence of this assessment is that much of the data presented to us over the course of our analysis were in draft form or being finished concurrently with our research and analysis. This is not a criticism of the quality, timeliness, or professionalism of any entity involved in providing data or assisting with this report; indeed, all involved were timely in their response and provided as much information in as much detail as they currently had available to them.

Our overall recommendation, drawing on the best available data and evidence, is that the **best option is to delay any decision on alternative reuses of RHBFSF for the foreseeable future**. DoN will not be ready to do anything meaningful with RHBFSF beyond defueling and closure until 2027 at the earliest. Once environmental remediation begins, certain potential future scenarios (e.g., remediation requirements are more extensive or complex than expected) can be ruled in or out. This will provide greater clarity for stakeholders about the status of the facility moving forward and determine whether or not 2027 is a realistic target.

Allowing the defueling and closure to advance toward their completion before deciding the disposition of RHBFSF has several benefits. First, the approach will allow time for additional studies to be conducted and allow all proposed reuse options to be further refined beyond the conceptual-paper stage. For instance, an economic-benefit study for a museum that measures anticipated viewership could be completed in this time. Second, the environmental site assessment and remediation planning can mature, which will allow both for unfettered access for remediation crews and for certain options (e.g., whether water can be safely stored in the tanks or not) to be ruled in or out. There appear to be time and space to wait for events to unfold and decide once all (or most) of the necessary facts have come in.

Appendix. Futures Analysis Methodology Deep Dive

This appendix describes the rationale for, and methodology used to conduct, the robustness-to-uncertainty analysis in depth. Because any reuse of RHBFSF would be a long-term endeavor, the facts that currently obtain may not in the future. Therefore, our analysis should consider whether a reuse option is sensitive to changes to various conditions. This entails an examination and assessment of plausible alternative futures in policy, technology, and environmental conditions that RHBFSF might encounter in the medium to long term. The project team relied on a method adapted from Robust Decision Making (RDM), a RAND analytical approach discussed in greater detail below, to guide this aspect of the analysis. Because of the inherent uncertainty involved in future forecasting, this analysis is fundamentally different from the other criteria used in this report. The core idea is simple: The future is inherently uncertain, and policymakers very frequently (all other things being equal) want to minimize regret by choosing options that are attractive against a host of variations in the future.

This appendix walks readers through the intellectual lineage of this approach, a discussion of how and why we chose the scenarios we did, and the scoring methodology. The team strove to assess the futures along a similar 1–4 scale, as was used in other areas of the analysis. But readers should note that creating this scale involved more steps than the other scales and relied on a different filtering approach.

Robustness to Uncertainty

When deciding between alternatives, it is important to weigh the *risk* that a given decision entails. In the abstract, *risk* can mean many different things—it could be financial risk (i.e., the risk of a stranded or lost investment) or environmental risk (i.e., the risk a given choice might harm the environment), and so some systematic way to both define and narrow down the types of risk considered becomes necessary. Indeed, embedded in the assessments of each of the criteria (economic, executability, and nonfinancial considerations) is a discussion of the risks associated with that particular factor, as well as decisions about where the uncertainty bounds lie. In the terms made famous by former SECDEF Donald Rumsfeld, these represent the known risks and the known unknown risks associated with each category. But, because both the economic and executability analyses cover a 30-year time frame, there are a lot of other potential risks that might befall a project that are unforeseen by those criteria; in other words, there exists some set of *unknown unknown* risks that might fundamentally alter the attractiveness of one or more of the alternatives. The question that follows from this is: How can we understand (some of) the uncertainty and attempt to make our decisions as robust as possible against the inherent uncertainty of the future?

Robust Decision Making

In the early 2000s, RAND analysts pioneered the development of RDM, a subset of the Decision Making Under Deep Uncertainty literature, to help policymakers come to better decisions by considering a wider range of factors, rather than attempting to make better point predictions about the future.¹⁰² In its ideal form, RDM follows a prespecified, well-defined process and iterative modeling to generate insights into how given policies might perform under different assumptions.¹⁰³

It is impractical for us to execute a full RDM analysis, given that the data requirements are prohibitive in this case. Although we were not tasked to conduct a full RDM analysis, we could apply many of the same core concepts in a first-order assessment of how different options might perform against a range of plausible futures by considering whether a given option “hedges” against that future.¹⁰⁴ Furthermore, should more-detailed follow-on studies be required to choose between alternatives, this report lays out the foundations for a more fulsome RDM analysis, providing a shorter runway for future researchers interested in continuing from where we left off.

One cornerstone of the RDM process is the consideration of a multitude of plausible futures in an attempt to “characterize and communicate deep uncertainty.”¹⁰⁵ By considering whether or not a given policy option or choice hedges against that future and by exploring a wide range of potential futures, policymakers can get a more detailed sense of the uncertainty space and the unexpected ways in which the future might change. Different policymakers may prefer options that hedge against particular kinds of futures, a preference that is surfaced by the exercise and unavailable if one relies solely on single-point predictions. As Robert Lempert urges regarding two of the four key elements of RDM:

- Consider a multiplicity of plausible futures. The ensemble of futures should be as diverse as possible to adequately stress test proposed policies. The ensemble can also facilitate group processes by including futures that correspond to different groups’ worldviews.
- Seek robust, rather than optimal strategies. Robust strategies perform well, compared to the alternatives, over a wide range of plausible futures.¹⁰⁶

¹⁰² Robert J. Lempert, “Robust Decision Making (RDM),” in Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, eds., *Decision Making Under Deep Uncertainty*, Springer, 2019, p. 25.

¹⁰³ Robert J. Lempert, Steven W. Popper, and Steven C. Bankes, *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*, RAND Corporation, MR-1626-RPC, 2003.

¹⁰⁴ This method was developed by Joel Predd and Stephen M. Worman, in collaboration with one of the founders of RDM, Steven Popper, and has been used before in a defense analysis context.

¹⁰⁵ Lempert, 2019, p. 28.

¹⁰⁶ Lempert, 2019, p. 30.

Magnitudes and Types of Change

In this spirit, our analysis looked at 12 plausible futures in an attempt to provide a first-order assessment of which options appear robust over the range of those futures.

This raised several questions. How do we generate these futures? How can we be sure that we adequately covered the uncertainty space? Why 12 futures and not more (or fewer)? To ensure that we were approaching the problem efficiently and effectively and that we had sampled appropriately, it made sense to start with some guidelines on how we can think about the future.

One potential starting point was to conceptualize *how different* any given future might be from today—that is, how much does a given future diverge from today? Generally speaking, the future can be said to diverge from the present in one of four discrete magnitudes, which are presented in order from most like today to least like today:

- Incremental change: An **incremental change** can be conceived of as analogous to the phrase *the best predictor of tomorrow is today*. Changes in this class are different from today in significant ways but generally in ways we understand and that will take time to fully manifest. An example of this from defense would be countries' deepening relationships with Australia that eventually led to new cooperation in the AUKUS framework between Australia, the United Kingdom, and the United States.
- Punctuated equilibrium: A **punctuated equilibrium** is characterized by the future experiencing a sharp disruption in which the system rapidly transitions from one state to another—but then is relatively stable after the change has occurred. Two examples of this would be the fall of the Soviet Union and the post-9/11 security environment.
- Transformative: **Transformative** futures are those that experience significant events or developments akin to those in a punctuated equilibrium, but the pace of change continues for the foreseeable future. Examples of this class of future might be the growth in semiconductor capability via Moore's law or the rapid advances in large language models, which currently show no signs of slowing.
- Radical departure: **Radical departures** are game-changing breakthroughs that occur very rarely but have the potential to fundamentally alter the operating environment. An example might be the wide-scale deployment of quantum computers.

Now that we had a concept of just how different a potential future might be from today, we needed to consider relevant types of changes that could occur, because they relate to the choices in front of us and help distinguish the futures from one another.¹⁰⁷ For this analysis, we focused on three categories relevant to the options under consideration, presented in no particular order:

- Policy changes: These could be fiscal, regulatory, or other changes that are subject to fluctuations in (for example) policymaker preferences, lawmaker directives, or public voting. Changes in law would fit in this category.

¹⁰⁷ We could have chosen many other ways in which the future might diverge from the present (e.g., demographic changes), but different categories will have different levels of salience; therefore, it was important to choose several domains that directly applied to the problem we were studying.

- Technological changes: These could be changes in any type of technology that might affect the viability of the reuse alternative.
- Environmental changes: These could be changes in the physical environment or the human environment surrounding the reuse alternatives. This category is distinct from policy insofar as changes in public perception but not changes in law would apply.

By combining the four magnitudes of divergence with the three categories of change, we got 12 potential categories of futures to consider. As a general rule, we attempted to make the changes exogenous to the policy options under consideration—that is, we avoided positing breakthroughs in technology that would directly make one option more attractive than another (e.g., positing advances in the efficiency of pumped hydraulic energy storage). We also avoided scenarios that featured major combat operations against peer or near-peer adversaries, as those options risked brushing up against our scope conditions and thus were not considered germane to our analysis.¹⁰⁸

Scoring the Futures

To ensure that the alternatives represented a multitude of perspectives and plausible futures, a blank matrix representing each of the 12 possible combinations was circulated to each team member, who had the option of filling in as many of the grid squares as desired before sending it back. The results were then integrated, and one scenario from the group was selected for each square by the project leaders and given a brief title to encapsulate the core idea the future was seeking to explore. The draft matrix was then recirculated for approval and provided to the sponsor for feedback, which resulted in the final futures selected for analysis, which are detailed in Table A.1 (reproducing Table 3.5).

Finally, for the purposes of this analysis, each reuse alternative was analyzed against each possible future by considering whether a given option would be adversely affected by such a future. If a given alternative was considered to not be adversely affected, it was deemed to have hedged against that future, which is to say that policymakers would not appear likely to experience regret in this particular instance. Alternatively, if an alternative was adversely affected, it was deemed to be brittle to that future—that is, policymakers would likely experience buyer’s remorse.

There may be some cases in which the specifics of a scenario may vary greatly, and minor variations in the assumptions behind the scenario could yield different results. Consider scenarios that involve cases in which the funding source for whatever reuse alternative is chosen may be in doubt (e.g., the facility is transferred to a new owner, whether public or private). The specifics of the negotiated terms matter a great deal; there are many potential scenarios, and the details matter greatly. In these cases, the alternative is deemed to be uncertain.

¹⁰⁸ For the reason for this, see “Selection of Alternatives for Analysis” section in Chapter 3.

Our analysis has detailed the potential inflection points and scenario assumptions that drove this uncertainty. Our rationale for assigning a negative score was that because the specific issues and factors matter greatly—and may be endogenously influenced by the reuse alternative and thus cannot be held constant across scenarios—it was more prudent to guard against the downside risk than to hope that the future conforms to the best-case scenario for that particular option.

Table A.1. List of Plausible Alternative Futures for Analysis

	Policy	Technology	Environmental
Incremental	<i>Continuing “continuing resolutions”</i> Federal budgetary legislation uncertainty continues, leaving programs and offices facing the possibility of cuts.	<i>Green evolution, not revolution</i> The adoption of green technologies and associated advances fails to continue at a rapid pace, leading to only marginal gains in efficiency over today.	<i>Climate continues to change</i> Ongoing climate change leads to greater demand for resources, such as developable land and clean drinking water.
Punctuated equilibrium	<i>Rigid environmental regulation</i> Environmental regulation, including freshwater conservation efforts, increases to protect local habitats.	<i>Rarer rare-earth metals</i> A global shortage in critical minerals affects the U.S. industrial capacity to satisfy domestic demand for advanced technology.	<i>More remediation than expected</i> During environmental remediation and cleanup, remediation requirements are more extensive or complex than expected, causing costs to increase and delays in turnover. ^a
Transformative	<i>Meet the new boss</i> The political beliefs and positions of state and local leaders shift to deprioritize the conservation of natural resources in favor of economic growth.	<i>Energy storage solved</i> Breakthroughs in energy storage systems continue and increase such that more power can be stored safely, smoothing the load on the grid during peak times.	<i>Climate change accelerates</i> Climate change’s most dramatic effects, including worsening weather and sea-level rise, occur faster than anticipated.
Radical departure	<i>Handing over the reins</i> DoN decides to close a majority of its facilities in the state of Hawaii.	<i>Cheap, limitless energy, at long last</i> Breakthroughs in fusion research continue and accelerate such that cheap, (almost) limitless energy becomes foreseeable within a near-term time horizon.	<i>The very ground beneath our feet</i> An unforeseen event (e.g., an earthquake) causes the deterioration of the tanks to quicken, rendering them unusable.

^a Although many stakeholders already anticipate that remediation requirements will be more extensive or complex than expected (see, for instance, Red Hill Water Alliance Initiative, 2023, p. 3), whether that is true is a matter of debate. Therefore, we feel that it is important to include both possibilities. Most of our analysis assumes that remediation requirements are as reported and expected; this option specifically assumes that it is worse than expected.

The final product of this analysis is a single table listing all the scenarios, color coded green (for likely safe from regret), red (for likely to experience regret), and gray (for uncertain). Table A.2 (reproducing Table 3.6) is a summary of the notional evaluations to give readers an overview of how an alternative performs against the whole range of scenarios considered. All things being equal, more hedges are considered better than fewer, and so the total number of hedges over the total number of scenarios considered is used to assign a score between 1 (low) and 4 (high). With 1 being between zero and two hedges, 2 being between three and six hedges, 3 between seven and nine hedges, and 4 between ten and 12 hedges.

It is important to note that this is a first-order assessment; we did not attempt to assign weights to any of the futures or make any value judgments regarding which futures should be hedged against vice others. Should a policymaker deem hedging against a particular future, or class of futures, to be more important than the entire set, then the results of the analysis or the attractiveness of a given option might change. Different policymakers and different stakeholders will have different preferences, and it is precisely these discussions and prioritizations that this category is attempting to surface.

Table A.2. Example Table of the Robustness of a Notional Reuse Alternative

	Incremental			Punctuated Equilibrium			Transformative			Radical Departure		
	Continuing "continuing resolutions"	Green evolution, not revolution	Climate change continues	Rigid environmental regulation	Rarer rare- earth metals	More remediation than expected	Meet the new boss	Energy storage solved	Climate change accelerates	Handing over the reins	Cheap, limitless energy, at long last	The very ground beneath our feet
Notional alternative	Not robust	Robust	Not robust	Robust	Not robust	Robust	Robust	Robust	Robust	?	Robust	Not robust

NOTE: Green (robust) indicates that policymakers are unlikely to face buyer's remorse in this scenario, red (not robust) indicates that buyer's remorse is likely should the scenario manifest, and gray (question mark) indicates uncertainty.

Abbreviations

DLA	Defense Logistics Agency
DoD	U.S. Department of Defense
DOH	Hawaii Department of Health
DoN	U.S. Department of the Navy
EPA	Environmental Protection Agency
FFRDC	federally funded research and development center
FY	fiscal year
HNEI	Hawaii Natural Energy Institute
RDM	Robust Decision Making
RHBFSF	Red Hill Bulk Fuel Storage Facility
ROM	rough order of magnitude
SECDEF	Secretary of Defense

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