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School of Energy Resources
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& Policy Analysis

NUCLEAR SERIES PART 5

WYOMING'S NUCLEAR SUPPLY CHAIN OPPORTUNITIES AND CHALLENGES: SPENT FUEL

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SER collaborates with stakeholders at the state, national and international levels to advance energy technologies and policies to grow and support Wyoming's robust energy sector. SER's mission is to promote energy-driven economic development for the state, and it leads the University of Wyoming's talent and resources for interdisciplinary research and outreach, fulfilling Wyoming's promise to be a global leader in a thriving and sustainable energy future.

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Abbreviations

CISF	Consolidated interim storage facility
DOE	Department of Energy
EPA	Environmental protection agency
FR	Fast reactor
GAO	Government accountability office
HALEU	High-Assay Low-Enriched Uranium
IFR	Integral Fast Reactor
IPTW	Inverse propensity weighting method
LWR	Light weight reactor
MOX	Mixed oxide fuel
NRC	Nuclear regulatory commission
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act of 1982
PUREX	Plutonium uranium reduction extraction
SRS	Savannah River Site
SMR	Small modular reactor
SNF	Spent nuclear fuel
CERPA	The University of Wyoming, School of Energy Resources Center for Energy Regulation and Policy Analysis
VSL	Value of statistical life
WTP	Willingness to accept
WTA	Willingness to pay

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EXECUTIVE SUMMARY

This report quantifies the economic opportunities and outcomes of forming a spent nuclear fuel (SNF) management industry in Wyoming. The unique opportunities and challenges of expanding the industry are identified. Additionally, empirical analysis is conducted to estimate the various benefits and costs associated with developing a consolidated interim storage facility (CISF) in the State.

The analysis concludes that spent nuclear fuel storage would be feasible in Wyoming, if federal and State legal requirements are changed. Such a facility would provide economic benefits to the State including tax revenue and employment increases. Spent fuel recycling industry growth is limited by technological and economic constraints preventing immediate Wyoming development.

This report is one of a series evaluating the feasibility of developing an integrated nuclear sector in Wyoming. From uranium recovery to spent fuel processing, each step in the nuclear supply chain has unique economic challenges. To compare the opportunities for Wyoming across the nuclear supply chain, a qualitative scoring system of advantages and obstacles is applied (*Gebben & Peck, 2023*). The summary of these *scoring criteria* for spent fuel management is provided in *Table 1.*

For both industries studied, federal and State legal obligations are a key obstacle restricting development. Wyoming has yet to approve a CISF project, and by State law a project cannot be approved until progress is made to find a permanent U.S. storage location. Further, a federal court ruling has vacated all NRC licenses for private spent fuel storage. At the time of writing both legal obstacles could be lessened by ongoing proceedings. A proposal before the Wyoming Legislature would allow the State to approve a CISF prior to a permanent disposal location being identified[1]; the U.S. Supreme Court will hear arguments pertaining to the authority of the NRC to license private SNF storage facilities. If these legal obstacles are lessened, a federal or private CISF project could become feasible in the State. However, spent fuel recycling in Wyoming would still be subeconomic under current market conditions. To overcome this challenge technological enhancements could lower operating costs, or uranium prices could rise, making recycling more attractive.

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[1] HB0016 would require substantial assurance to the State that the facility would be temporary. The term substantial assurance is not defined in the proposal, and would require legislature discretion to asses if the standard is met by a given plan. A second bill SF0186 would create financial punishment for keeping the SNF in Wyoming longer than was originally planned.

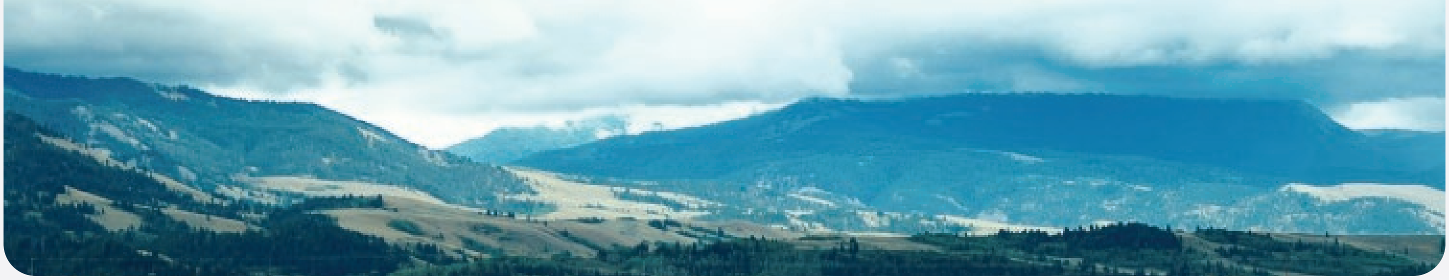


Table 1:
Economic Factors Related to Wyoming Spent Nuclear Fuel Industry Development

	Intermediate Storage		Recycling	
	Level	Summary	Level	Summary
Economic	Moderate Advantage	Current demand for U.S. storage	Major Obstacle	Costs are too high to be profitable
Existing Industries	Minor Obstacle	Two other facilities already have a NRC license, but are delayed.	Minor Advantage	Current development of fast reactors in Wyoming.
Tax Structure	Moderate Advantage	Wyoming has the lowest effective tax rate for similar industries.	Major Obstacle	Tax exemptions for reactors using U.S. sourced uranium promotes the use of fresh fuel, but not recycled fuel.
Location	Minor Advantage	Locations with low seismic disturbance and water contamination risk exist in the State.	Minor Advantage	Some advantages for fast reactor operation.
State Legal	Severe Obstacle	Wyoming approval has not been granted.	Major Obstacle	Limitations on importing spent fuel for recycling
Federal Legal	Severe Obstacle	Court ruling excludes NRC licensing of private storage. On appeal at the Supreme Court.	Major Obstacle	No NRC guidelines for reprocessing.
Technology	Neutral	No obstacles to deployment.	Minor Obstacle	The technology to recycle spent nuclear fuel exists but is still maturing.

The benefits and costs of developing a CISF are estimated using a series of quantitative analysis procedures. The direct benefits assessed include an increase in State taxes, job creation, and potential benefits to Wyoming from the Department of Energy for hosting a facility. The cost estimate includes a facility risk analysis[2], and social costs assigned to Wyoming residents based on a preference to avoid a SNF storage facility.

Three scenarios were considered where the CISF storage capacity ranges from 20,000 tons to 120,000 tons. Three direct payment levels are applied, which are feasible under DOE cost considerations. Finally social costs are calculated that account for the money citizens would pay to avoid hosting a CISF. The social cost estimates include the median cost, average cost, and a variation of survey phrasing. Job additions are provided in *Table 2* and monetary returns are estimated in *Table 3*.

[2] *The risk of radiation exposure to residents during operation is considered but found to be negligible.*

Table 2: Job Additions from a Wyoming Spent Nuclear Fuel Storage Facility

Scenario	Low	Middle	High
Jobs During Construction (Yearly[3])	1,900	4,300	8,200
Jobs During Operation (Yearly)	900	2,500	4,000

Table 3: Monetary Benefits and Costs of a Wyoming Spent Nuclear Fuel Storage Facility

Scenario	Low	Middle	High
Social Costs (Mill. USD)	-70.6	-15.4	-11.2
Tax Revenue (Mill. USD)	52.6	67.8	108.5
DOE Payment (Mill. USD)	28	243	515
Net Value (Mill. USD)	10	295.4	612.3

A Wyoming CISF would generate new jobs and tax income for the State. All project scenarios are expected to provide a net benefit to the State, when revenues are compared to social costs.

Based on a range of personal preferences individuals report that they dislike the idea of storing U.S. spent fuel in the State. The average value placed on avoiding the facility is $41 per person[4], so if the government can provide more than $41 of value to each citizen from the taxes acquired from the CISF most Wyoming citizens will be made better off. The benefits from the project can be applied directly through tax reductions, or indirectly through other State programs. For example, the most common concern reported by survey takers was changes to environmental quality. If the facility is built the tax revenue could be spent on environmental quality programs at State parks. Meaning that by allowing the facility to be built overall environmental quality could be improved, once accounting for the economic tradeoffs of lost funding for other programs. The net total benefit[5] estimates for Wyoming range from 10 million dollars up to 612 million, depending on the storage facility size, and the expected federal payments.

3 Assuming a three-year construction period.

4 With an upper bound estimate of $103 per person

5 This is a net present value estimate which discounts future benefits and costs at 6% annual percent yield.

INTRODUCTION

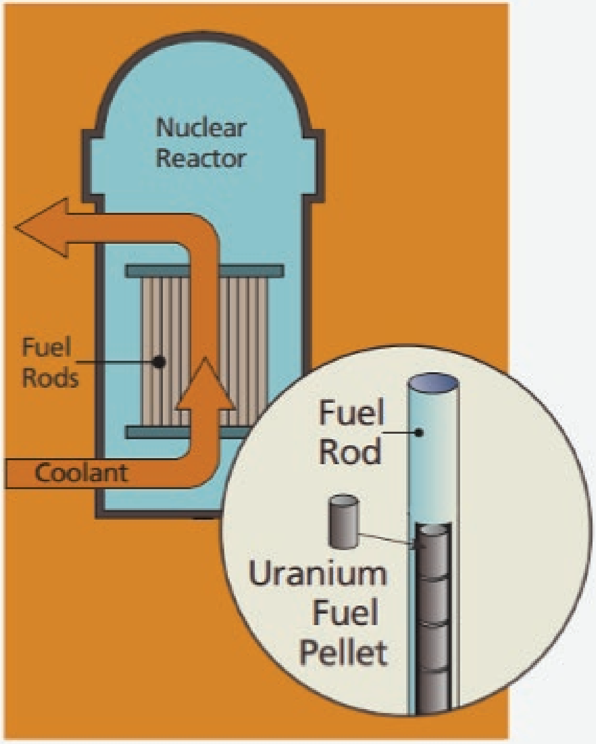
The University of Wyoming, School of Energy Resources Center for Energy Regulation and Policy Analysis (CERPA) completed a series of interdisciplinary economic analyses evaluating the opportunities and challenges for Wyoming economic development in the nuclear sector. The series successively evaluates the economic conditions of each segment of the nuclear supply chain, from uranium mining, all the way to spent fuel storage. This report is the fifth in the series focused on the management of spent nuclear fuels. These economic analyses were produced to provide the Wyoming Legislature, other policy makers, stakeholders, and the general public with objective evaluations of new investment opportunities within the State.

This white paper begins by providing an overview of spent nuclear fuel management methods, and history. The paper identifies advantages and challenges for managing the countries spent nuclear fuel inventories in Wyoming. Then, an economic impact analysis is created for the spent nuclear fuel storage sector. Changes in employment, tax revenue, and non-monetary considerations are provided under different project plans.

BACKGROUND

Nuclear energy generation is the largest source of carbon-free electricity in the United States and generates approximately 2,000 metric tons of spent fuel annually (DOE, 2022c). Spent nuclear fuel (SNF) is a byproduct of the electricity generation process at nuclear power plants. The electricity produced by a nuclear generator is from a steam turbine with water heated by nuclear fuel. Once the fuel has reached the end of its efficient lifespan, it is removed and placed in wet storage, a pool of water located near the reactor, for several years to cool down. Once the SNF has cooled, it is transferred to a dry storage cask and placed in on-site storage (see Figure 1). Most of the energy available from the source of uranium remains in the SNF if it is only passed through a reactor once (a once through cycle). An alternative to disposal is reprocessing the SNF for a twice through cycle. Currently, the overwhelming majority of U.S. SNF is created with a once through cycle and is stored at the power plant where it was utilized.

Figure 1:
Spent Fuel Generation Process (NRC, 2017)



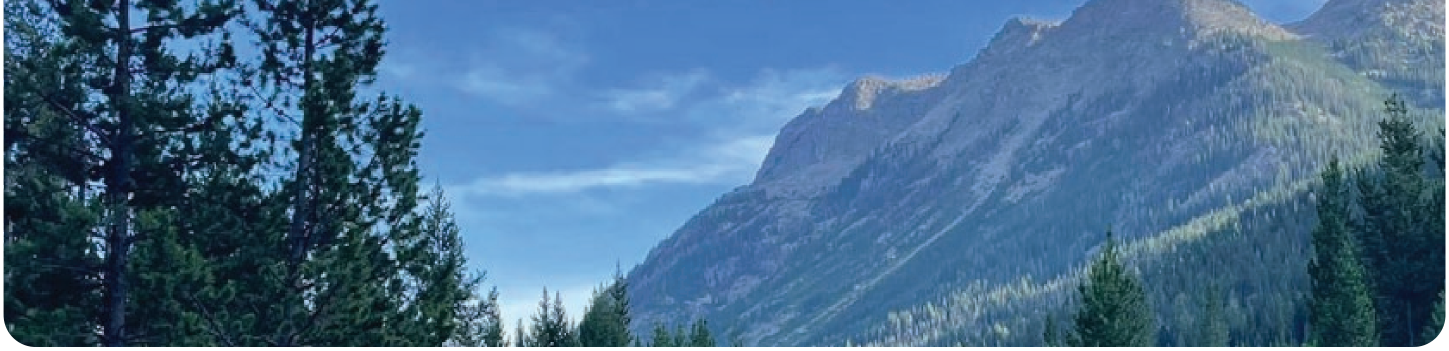
There are two general classifications of nuclear or radioactive waste: low-level waste which is typically generated from medical or commercial uses and high-level waste. High-level waste includes any radioactive material left over after spent fuel is reprocessed. SNF may be classified as high-level waste, but is sometimes excluded from this definition because it can be recycled making it a by-product rather than a waste stream. (NRC, 2020a)

The Nuclear Waste Policy Act (NWPA) of 1982[6] assigned responsibility for the siting, construction, and operation of a permanent repository for SNF to the Department of Energy (DOE). The NWPA directed the Environmental Protection Agency (EPA) to create standards for offsetting the environmental impact of radioactive waste and granted licensing power for a DOE repository that meets the requirements of the Nuclear Regulatory Commission (NRC). As a result of the NWPA, the DOE developed the Nuclear Waste Fund (NWF) which collects fees from nuclear power generators with the intention to pay for the construction and operation costs associated with a centralized permanent disposal facility. In 1987 congress directed the DOE to characterize the Nevada, Yucca Mountain site as the only potential was proposed as the permanent disposal site. (EPA, 2024b)

The SNF storage facility was designed to be built 1,000 feet below the mountain and able to store up to 70,000 metric tons of SNF with the opportunity for additional storage in the future (EPA, 2024b). However, the Yucca Mountain project has been indefinitely delayed due to a lack of acceptance from Nevada. Other attempts to construct an interim storage facility for SNF have also failed up to this point with the same reason being cited (GAO, 2011).

One of the temporary storage sites that was considered by the DOE was in Fremont County, Wyoming. In 1992, the State began a feasibility study of the DOE Project, but it was vetoed by Governor Mike Sullivan. In his statement, Governor Sullivan primarily cited a lack of control that the State would have for a project as the basis for his veto (Sullivan, 1992). In addition, he acknowledged potential long-term consequences for the environment, public health, and safety, along with the perception of Wyoming and concerns regarding the timeline of storage and the DOE's record of failure with securing a permanent repository at Yucca Mountain (Sullivan, 1992). The potential benefits of hosting a temporary repository remain economically attractive, and the issue is often discussed by the Wyoming Legislature.

[6] Which was amended in 1987.



In 2020, the NRC initiated proceedings to license two private consolidated interim storage facilities (CISFs) in New Mexico and Texas, but the U.S. Court of Appeals for the 5th Circuit ruled that the NRC lacked the authority to do so as the NWPA only grants licensing authority to the NRC for DOE repositories (*Appeal from the Nuclear Regulatory Commission Agency No.* 72-1050, 2023; Pearl, 2023). While this may be overturned on appeal, the ruling places uncertainty about the future of private CISF options.

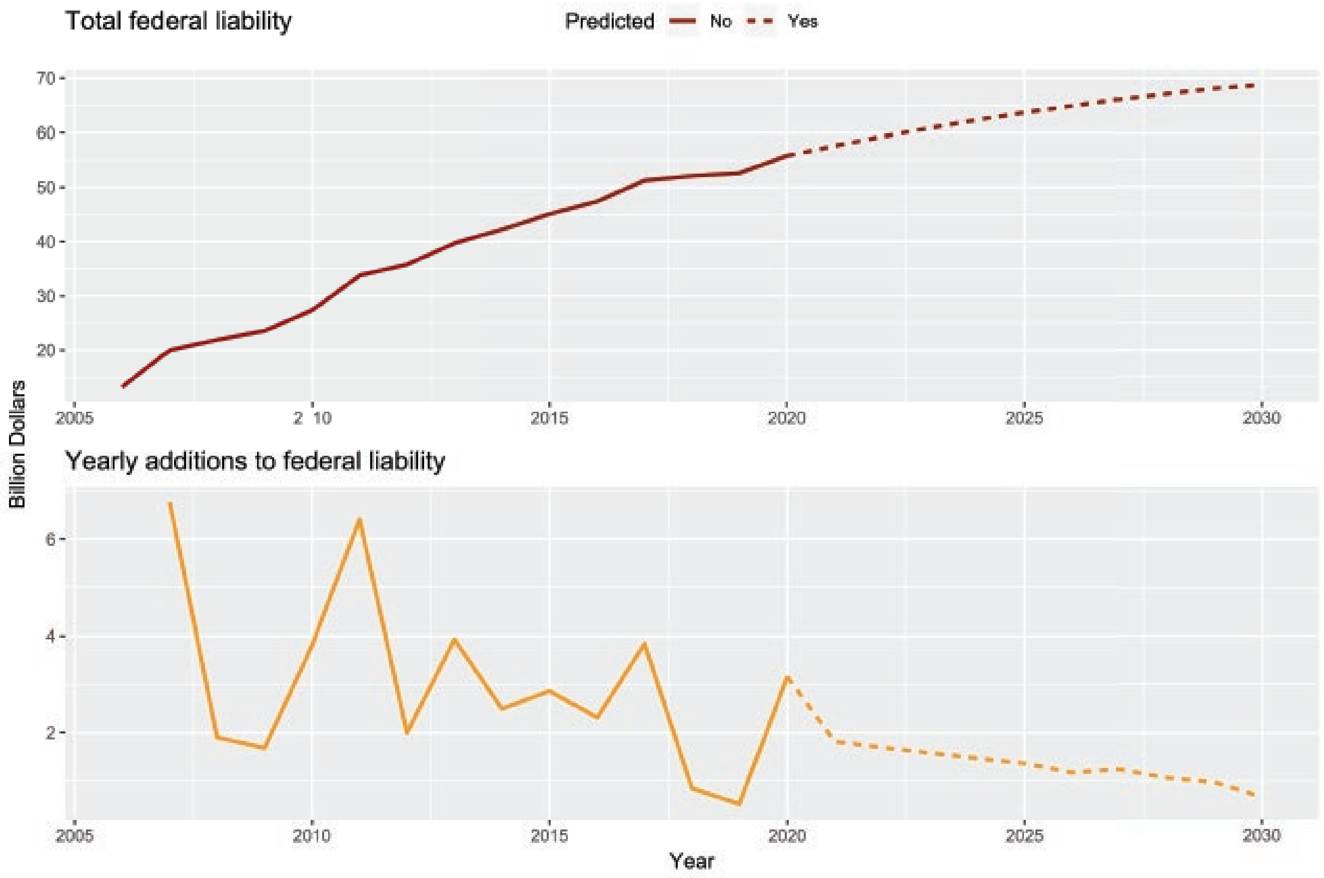
As a result of the halted progress of the Yucca Mountain project, lack of acceptance by states for an interim storage facility, and the inability of private companies to be licensed by the NRC, the DOE has shifted to a consent-based siting approach for an SNF storage facility. This method seeks to prioritize the participation and needs of communities and obtain their informed consent. However, there remains uncertainty about the potential timeline for either a consolidated interim storage facility or permanent disposal facility (DOE, 2024).

This has left the DOE with legal obligations to manage spent nuclear fuel, providing an imperative to manage a growing cost base of spent nuclear fuel. The expected total cost of SNF management for the DOE overtime is provided in Figure 2.

While overall costs have been climbing, reduced nuclear electric generation, higher burnup rates, and inflation adjustment have decreased the growth rate. Nevertheless, the DOE is faced with managing the spent nuclear fuel of an ever-aging U.S. nuclear fleet, at significant cost.

Another option exists in lieu of simply storing SNF: recycling. Nuclear fuel reaches the end of its lifespan at the first reactor in which it was utilized after expending about 5% of its total potential for energy production(Adkisson, 2021). This is largely to maintain peak efficiency for the generator. It stands to reason that more of this potential energy production could be utilized, but the difficulty comes in the form of how complex it is to recycle SNF on an industrial scale. Not only is separating the usable fuel from the unusable fuel a difficult process, but the alternatives, such as Argonne National Laboratory's Integral Fast Reactor (IFR), are technologies still in their infancy in the U.S., so commercial-scale operations may yet be several years into the future (Nelson et al., 2021).

Figure 2:
Federal Liabilities for Spent Nuclear Fuel Storage[7]



[7] Data was collected from the most recent Government Accountability Office report on spent nuclear fuel (GAO, 2021). This report did not adjust for inflation. To correct for this, we first discount all values in the report to 2020 dollars, which is the most recent date of the reported liability records. Since the GAO used nominal dollars, the expected future trends in liability include the effect of inflation. We apply an average inflation rate of 2.48% for all values in which the GAO forecasts liabilities from 2021-2030, and the true inflation rate for all values from 2006-2020. While the true inflation for 2021-2024 in known, the GAO forecast would have to base their estimates on past averages, so we likewise use the average inflation rate from 2006 to 2020 to discount the liabilities from 2021-2030. Once all liability values are transformed into 2020 dollars they are then shifted 2024 dollars with increase of 21% (U.S. Bureau of Labor Statistics, 2024a).

Other countries have also begun to explore options for the management of SNF. The International Atomic Energy Agency released a technical report detailing the status and trends of SNF among member nations in 2022, and Table 1 shows the SNF management by country. Globally, SNF management commonly includes reprocessing which reduces the volume of spent fuel. However, interest in constructing large scale SNF repositories is growing. France, India, and Russia all currently operate reprocessing facilities which recover fissile material from the SNF for follow-on use in other applications. The United Kingdom maintained a reprocessing facility that recently shut down after international contracts expired (Sellafield Ltd, 2022). China is preparing for a commercial-scale facility, and Japan has commissioned the construction of a reprocessing facility which began in 2021.

Table 4:
Spent Fuel Management Strategies by Nation (IAEA, 2022)

	Commercial Scale Reprocessing Facility					
County	**Existing**	**Planned**	**Formerly Maintained**	**SNF Shipped Internationally**	**Planning SNF Repository**	**Keeping Options Open**
Argentina						✓
Belgium			✓		✓	✓
Brazil						✓
Bulgaria				✓		
Canada					✓	
China		✓			✓	
Czech Republic			✓		✓	
Finland			✓		✓	
France	✓					
Germany			✓		✓	
Hungary			✓		✓	
India	✓	✓				
Italy				✓		
Japan		✓		✓		
South Korea						✓
Lithuania					✓	
Mexico						✓
Netherlands				✓		
Romania					✓	
Russia	✓	✓				
Slovakia			✓		✓	
Slovenia					✓	
Spain			✓		✓	
Sweden			✓		✓	
Switzerland			✓		✓	
Turkey					✓	
UK	✓		✓		✓	
Ukraine			✓	✓		✓
USA			✓		✓	

ADVANTAGES AND BARRIERS IN WYOMING

A set of empirical and qualitative analyses are applied to contextualize the opportunities and challenges related to fostering SNF management investments in Wyoming. A scoring system ranging from *severe obstacle* (red) to *major advantage* (green) is given to each category of development (see Gebben & Peck, 2023). Two scores are provided, one for intermediate storage solutions and another for advantages and challenges unique to recycling SNF.

At the beginning of each section, the *Scoring Criteria* subsection provides the score and rationale. For those seeking a more thorough explanation, a discussion of the steps used to identify the score is provided in the *Analysis* sub-section.

3.1 ECONOMICS

Intermediate Storage	Recycling
Moderate Advantage	Major Obstacle

Economic Barriers: Scoring Criteria

Economic considerations allow for a CISF to feasibly be built in Wyoming. A model of the market demand for centralized storage is created using engineering estimates of project costs. This is compared to the avoided costs of temporarily storing SNF at each operating power plant. These results demonstrate that the value of constructing a CISF increases as the nuclear fleet ages. The current age distribution of nuclear power plants in the U.S. is enough to make a 60,000-ton centralized storage facility economically viable. The total benefits of such a facility are estimated to be around $1 billion and will grow overtime. This places the economic *scoring criteria* for intermediate storage in Wyoming as a *moderate advantage*. The economic considerations do not uniquely advantage the State when compared to alternatives in New Mexico and Texas but do lay the groundwork for a potential project in Wyoming.

Recycling SNF is found to be constrained by uranium prices and cheap disposal alternatives. The added cost of creating mixed oxide (MOX) fuel from SNF exceeds expected returns. Best estimates suggest that if uranium price increase to $239 per pound, recycling will become economically viable in the U.S. (Rothwell et al., 2014). At a market price of $80 per pound, the economic considerations are scored as a major disadvantage to recycling SNF generally and in Wyoming (Cameco Corporation, 2024).

Economic Barriers: Analysis

There are multiple economic considerations that determine which SNF strategy is viable in the U.S. Broadly, three methods of storage can be used that are paired with two categories of SNF recycling.

1) Storage
    a) On site storage
    b) Centralized intermediate storage
    c) Long-term disposal
2) Spent fuel recycling
    a) Mixed oxide generation for repeat cycles
    b) Fast reactors

The final strategies used in Wyoming depend on economic conditions and each option must be compared to the expected cost of the other alternatives. We begin by evaluating the costs associated with each SNF storage strategy. Later, the relative cost of applying recycling methods is assessed.

Demand for Centralized Storage

Under the status quo, most SNF is housed at reactor sites. Therefore, the value of developing a storage site is the difference in management costs between keeping the material on site and the total cost of developing a centralized site.

The avoided costs of on-site storage are the social benefit of building an alternative storage site. The social "profit" of developing the project is this reduction in cost. Even though both centralized and dispersed SNF storage facilities are a cost paid to operate a nuclear power plant from an accounting perspective, a reduction in cost is identical to an increase in profits in an economic net benefit analysis. Therefore, to determine the benefits of a centralized storage facility, the cost of onsite storage is first modeled.

The cost of onsite storage is modeled based on four cost categories: 1) upfront construction costs; 2) cost of SNF canisters and concrete; 3) operating costs; and 4) closure costs. The baseline comes from a 2021 journal article that analyzed costs associated with upfront capital investment, operations, and decommissioning (Rothwell, 2021). Upfront capital investment was calculated to be $28 million, with expenses from local facility extensions and SNF canisters costing $131,300 per ton of capacity, and decommissioning expenses at $29.4 million (IAEA, 2009; Rothwell, 2021). Canister costs are treated as being proportional to the amount of SNF produced each year.

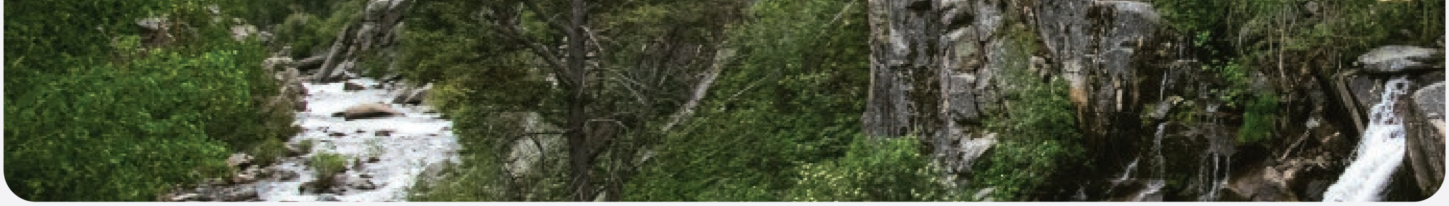
The cost of storing SNF at an operating nuclear power plant is less than the cost for a closed facility (Alvarez, 2017; Jarrell et al., 2016; Rothwell, 2021). When a nuclear power plant is in operation, the facility maintains security, handling licenses, and monitoring equipment necessary for the operation of a storage facility. By housing the SNF on site, these sunk costs can be applied to operation expenses. However, once the nuclear power plant is decommissioned, these costs could be avoided if SNF was vacated from the facility. As a result, the cost to store the SNF at an operating facility is $1.23 million compared to $6.2 million for a shuttered powerplant (Rothwell, 2021).

Costs are escalated to present dollars, based on the expense category. Initial building costs are escalated based on the average producer price indexes of building material costs and nuclear radiation detection and monitoring instruments (U.S. Bureau of Labor Statistics, 2024e, 2024b). The facility requires a mixture of nuclear specific technology and generic building materials, so the average of these indexes is preferred over either metric individually. Nuclear canister costs are escalated based on the nuclear radiation detection and monitoring instruments index. All other values are inflation adjusted to 2024 dollars based on the consumer price index (U.S. Bureau of Labor Statistics, 2024a).

While these costs are assigned based on a single facility with a maximum storage capacity of 2000 tons, we upscale these values for 10, 20, and 30 facilities. This changes some fixed costs into variable costs, since replicating the fixed capital adds additional storage. For example, NRC licensing costs do not significantly change based on the capacity of the nuclear power plant. However, these costs become variable with capacity when duplicating an existing facility. Therefore, unlike in (Rothwell, 2021) all upfront costs are treated as scalable with capacity.

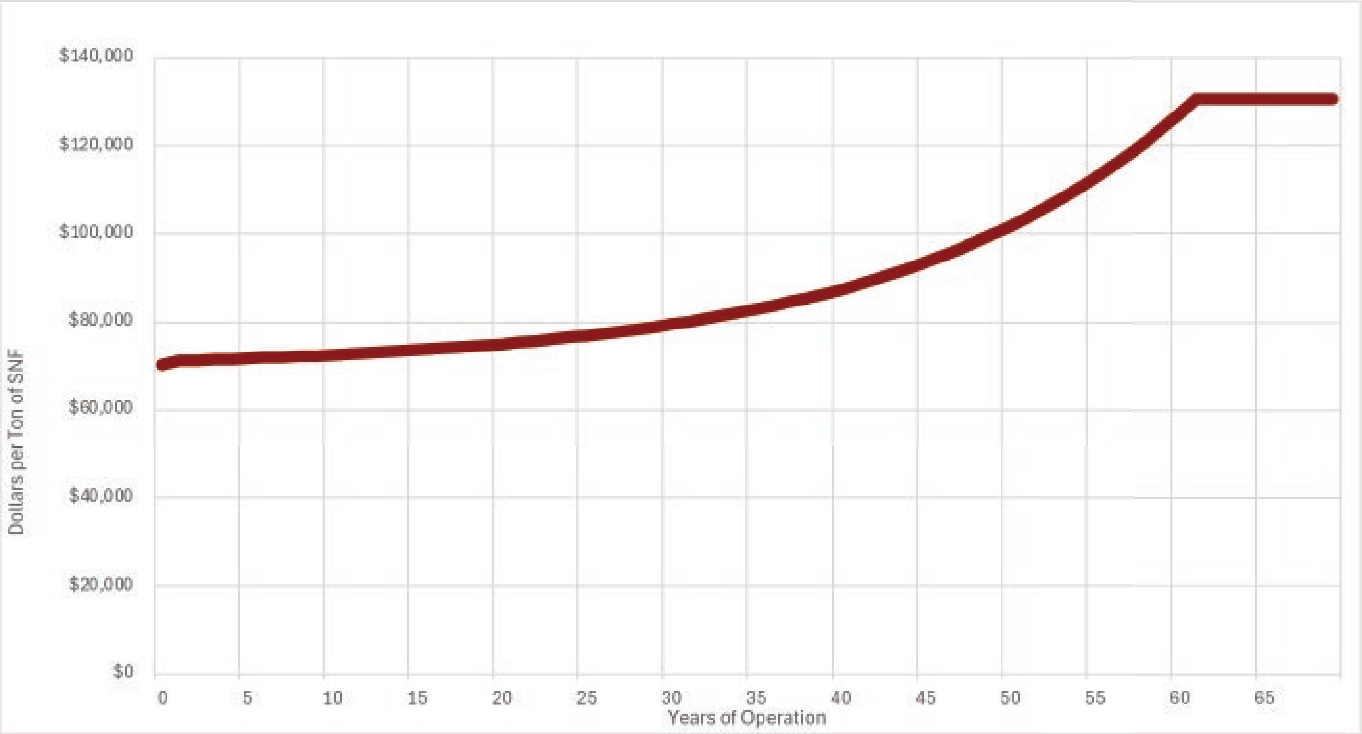
Based on a typical NRC license's length, the baseline operating life of the nuclear power plant is set to 60 years. The power plant is assumed to operate at a constant capacity, so total canister costs are averaged over this lifespan. After electricity generation stops, the annual operating costs increase. These costs are discounted with a base rate of 6% although alternative rates are considered. Operating costs after closure are discounted back from year 61 using an infinite number of periods, assessing the cost of permanent disposal at the facility.

The total benefits of building a centralized storage are calculated every year of the power plant's operation. Each year, the total net present costs of permanent disposal are subtracted by the closure cost. Adding a centralized storage facility removes all future storage related costs at the power plant but adds a new closure cost that would not occur if the SNF remained on-site at the nuclear power plant.



The benefits of adding a centralized storage facility changes over time. When the nuclear power plant is first built, the larger operating costs of storage are more than 60 years in the future. As the facility approaches retirement, the avoided costs provided by the operating facility increase. This effect is shown in Figure 3. The figure estimates the benefits of adding a CISF for a nuclear power plant that has operated for the number of years indicated on the x-axis. The total benefits are averaged by the tonnage of SNF sent to the CISF facility.

Figure 3:
Benefit of centralized storage to a nuclear power plant across time.



The total value of avoiding future storage costs is lowest when the powerplant begins operation, at approximately $70,000 per ton of SNF. By the time the facility is retired, the value increases to $130,000 per ton. The actual storage cost remains constant over the life of the power plant, but the expected higher operating costs are closer to fruition as time progresses. It should also be noted that these costs will escalate if the discount rate is lowered from 6%.

Importantly, the power plant avoids the most cost by opening the CISF exactly at the time of closure. In an ideal world, the timing of the CISF opening would align perfectly with the retirement of the nuclear power plants served. In actuality, a CISF would be constructed to accommodate the storage needs of multiple sites all with different ages, so this timing cannot be met at every nuclear power plant.

For example, assume two power plants will be served by a CISF facility. The first power plant has operated for 60 years and the second has operated for 50 years. The total amount of money the 60-year-old powerplant owners would be willing to pay to offload the SNF is $130,000 per ton. The 50-year-old powerplant would be willing to pay up to $100,000 per ton. By building the facility today, the average value would be $115,000 per ton[8].

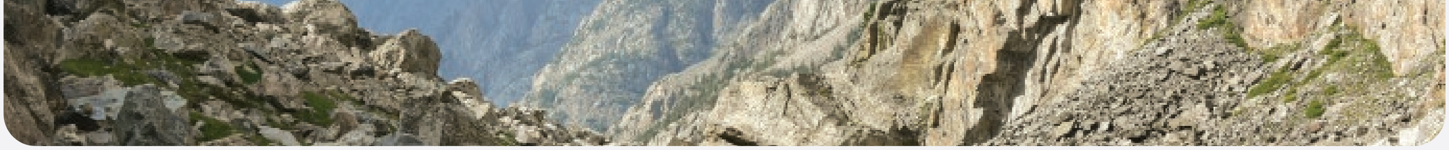
The CISF can wait to open for ten years in which case both power plants would pay $130,000 for the SNF, an increase from the average payment of $115,0000 per ton. However, at a 6% discount rate, this is only worth $64,000 per ton in net present value. Despite being suboptimal from a pure engineering logistics perspective, it is more profitable to open the CISF today rather than wait for each served nuclear power plant to retire. This leads to the conclusion that a large CISF will collect SNF from a range of power plants, and each powerplant places a different value on central storage of the SNF.

These results are used to estimate the current value of constructing a CISF. Because the value of storage depends on the time until a nuclear power plant is closed, the volume of SNF and time until closure is predicted at each US power plant. The start date, summer nameplate capacity, expected closure date, and actual closing date of U.S. nuclear reactors was collected from EIA Form 860 data (EIA, 2024b). The GC-859 survey provides the annually volume of SNF stored at commercial facilities (EIA, 2023).

For each year since 1968, the generated SNF by each nuclear reactor is estimated. The total SNF produced in the U.S. during a given year is allocated to each power plant based on the ratio the power plant's nameplate capacity relative to the total nuclear nameplate capacity[9]. This is then summed to find a final predicted volume of SNF at each site in 2024. It is assumed that each reactor applies the U.S. average burnup rate in each year. This is balanced to match the last observed spent nuclear fuel at retired facilities of just under 10,000 metric tons in 2018, providing a closer approximation of the unobserved historic burnup rate (Banerjee et al., 2024; CURIE, 2024).

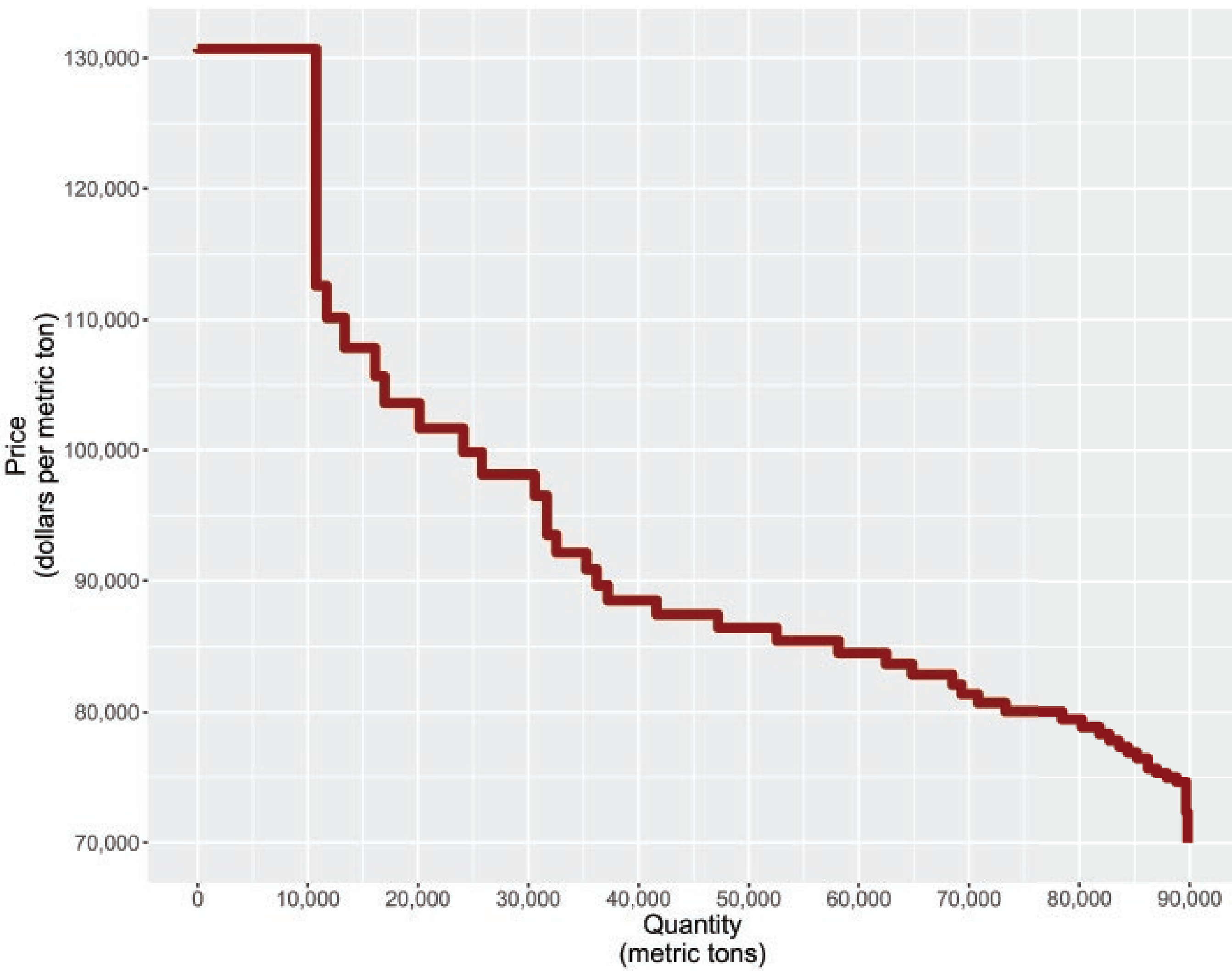
[8] Assuming a 50% split of SNF between the two

[9] For example, if a nuclear reactor has 20 giga-watts of summer nameplate capacity and 200 giga-watts of nuclear nameplate capacity was active in the U.S. for 2007, then this power plan is assigned 10% of all SNF produced in 2007. The start date of each power plant is used to determine which powerplants were active each year. If this power plant opened in 2007 than 0% is assigned in 2006.



Finally, the value of offloading all SNF at these facilities is calculated using the results from Figure 3. Each power plant is assigned a retirement date, and the total value is assessed based on the number of years until closure. All power plants are assumed to be active for 60 years, unless they have filed for an extension with the NRC to operate for 80 years[10]. This procedure creates a demand curve for CISF storage in the U.S., the results shown graphicly in Figure 4.

Figure 4:
Demand Curve for Centralized Storage



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[10] Turkey Point units 3 & 4, Nine Mile Point unit 1, Peach Botton units 1-4, H.B Robinson units 2, Oconee units 1-3, Brunswick units 1-2, Catawba units 1-2, McGuire units 1-2, St. Lucie units 1-2, Edwin I Hatch units 1-2, R.E Ginna unit 1, North Anna units 1-2, and Cooper Nuclear Station unit 1 are assumed to operate for 80 years (Duke Energy, 2019; NRC, 2024). While some of these applications have been reversed, we assume that they will either eventually be approved or that an equivalently sized powerplant will also request an extension (Larson, 2023).

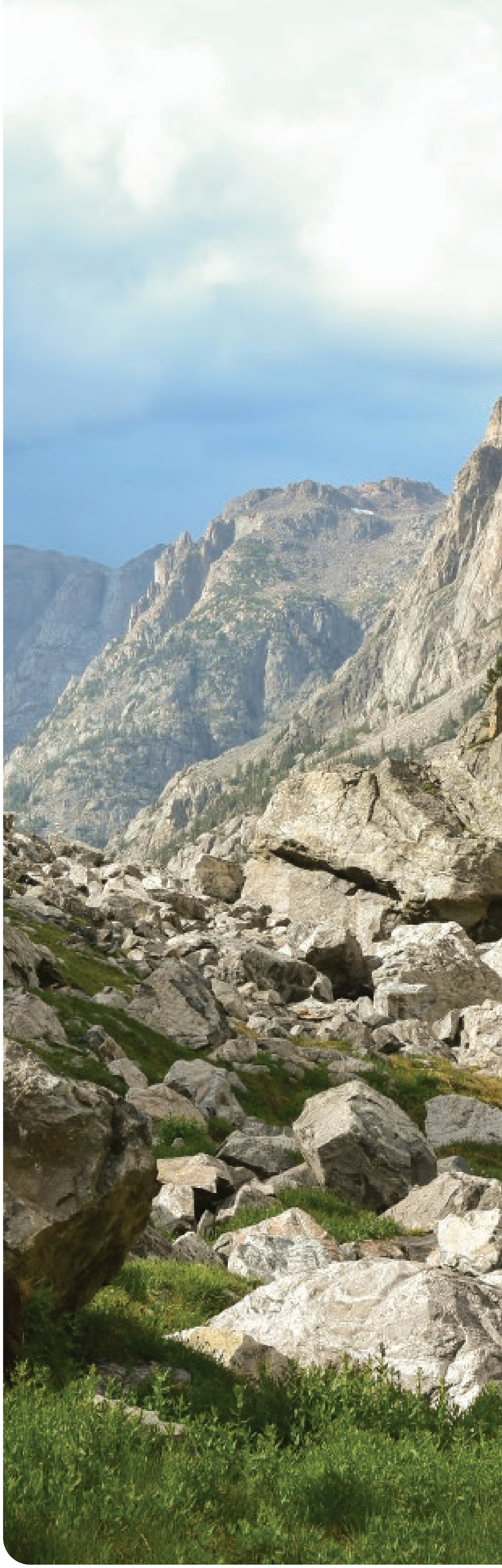
The value of adding a CISF declines with total storage capacity. The retired reactors in the U.S have the highest value for added intermediate storage. A small facility would acquire the SNF from the nuclear reactors closest to retirement. Eventually, a large facility would serve relatively new reactors that have a lower avoided cost. The distribution of nuclear power plant ages leads to a declining marginal value of storage as capacity increases.

Supply of Centralized Storage

We next develop a model of the supply function of CISF to pair with these demand estimates. Since there are no commercial CISF projects operating in the U.S., there is limited cost data to apply. We utilize a generalized project plan for CISF, using estimates of various capacities (Energy Resources International, Inc. et al., 2009). We update the model by accounting for the time value of money in project profits, as well as performing cost escalation to 2024 dollars. We also extend the usability of the model by creating two benchmark projects. In the first project, SNF is housed in the facility for a total of 40 years, while in the second project, an NRC 20-year extension is granted with a total operating life of 60 years.

The model assumes that it takes 20 years to either load or unload the SNF from the facility. In the 60-year project, the average operating costs decline while the SNF is being stored but not transported. The full details of the model parameters are provided in Appendix (A).

The results of six versions of the model are presented in Figure 5. These include total present costs of 20,000; 40,000; and 60,000 metric ton capacity facilities, each with either a 60 year or 40 year operating life. For each of these six projects, the total cost is found using discount rates that range from 0% to 15%.



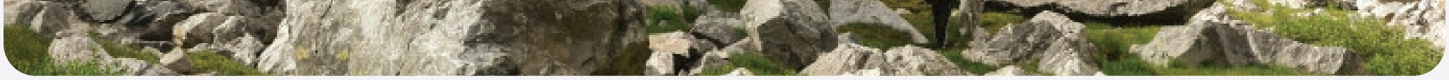
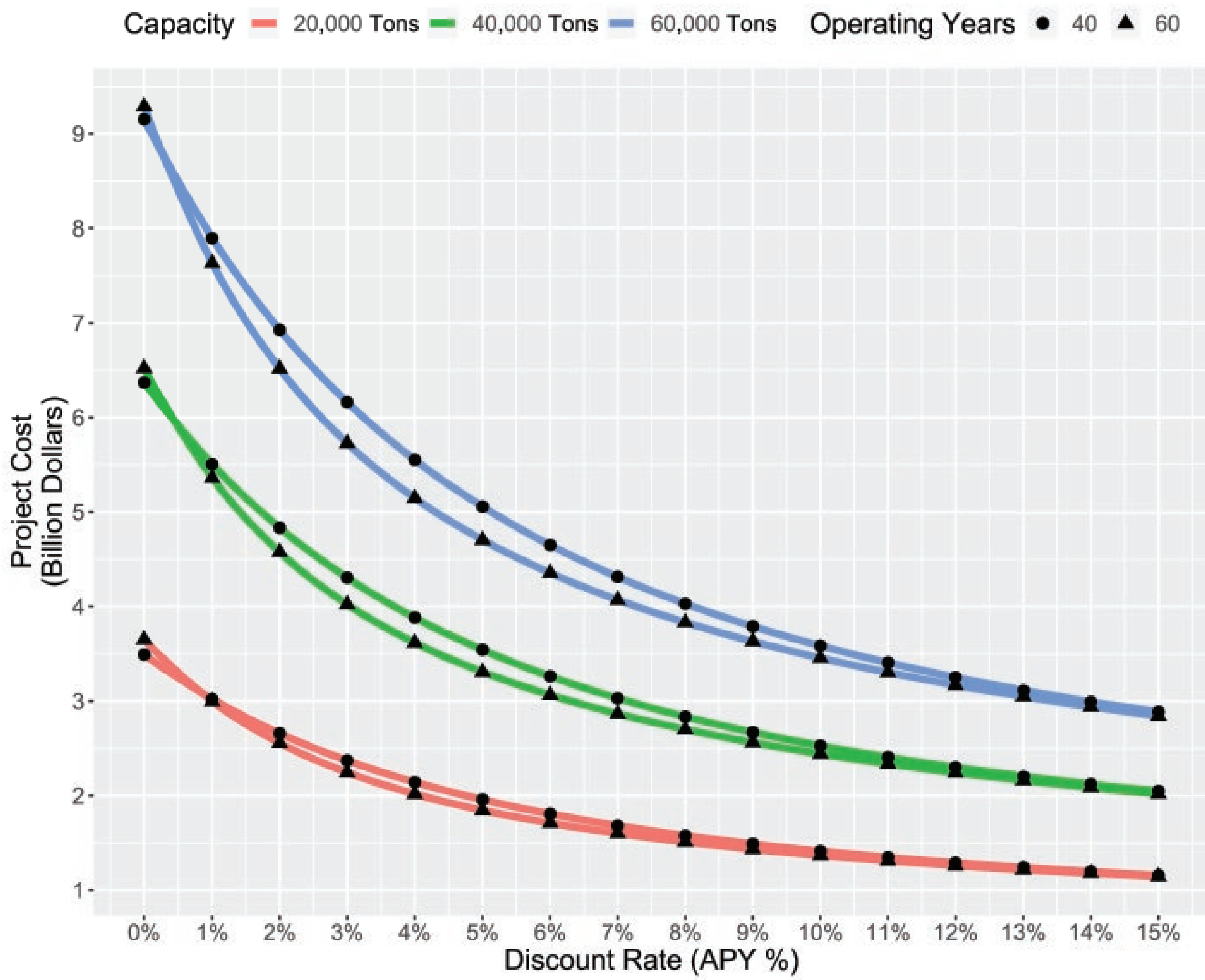


Figure 5:
Centralized Storage Project Costs



A few outcomes can be taken from these results. For any individual project, the 60-year operating life is always less costly than the 40-year project, unless there is a zero-discount rate. It may seem counterintuitive that the total cost of operation decreases when the same facility is open for a longer period. In nominal dollars, the 60-year project is always more expensive than the 40-year project, which is why the 0% discount rate project costs of the 40-year project are lower than the 60 year project.

These results indicate the cost paid to maintain the storage facility in a maintenance state is less than the equivalent value of alternative uses for the money. For example, if the company believes that they can receive a conservative return of 3% on investments, then the money not spent on closing the facility after 40 years can be invested in the market. The result is a higher final return on investment than if the 40-year project was closed.

Some commentators on a temporary centralized storage facility in Wyoming have voiced concerns that the project would become a de facto permanent facility, because the establishment of a CISF lowers the urgency of identifying a permanent disposal location (Bleizeffer, 2024; Wyoming Outdoor Council, 2019). These results support this claim. Since any of the three sized CISF facilities are cheaper to operate for 60 years, rather than 40 years, there is always an incentive to extend the operating license by the allowed 20 years. Without a cost escalation over time, such as is proposed in (SF0186, 2025), the value of extending a license always exceeds the cost of closing the facility. As a result, there is no profit motive to close the facility after it has been operating for 40 years, thereby lending credence to these considerations. Even if no direct payments are provided by the DOE for the storage capacity after 30 years, these time considerations provide an incentive to keep the SNF at the facility indefinitely. Wyoming or the NRC can strictly limit the total project operating time to 40 years, but without this external restriction, a private firm will likely decide to operate for a long period of time.

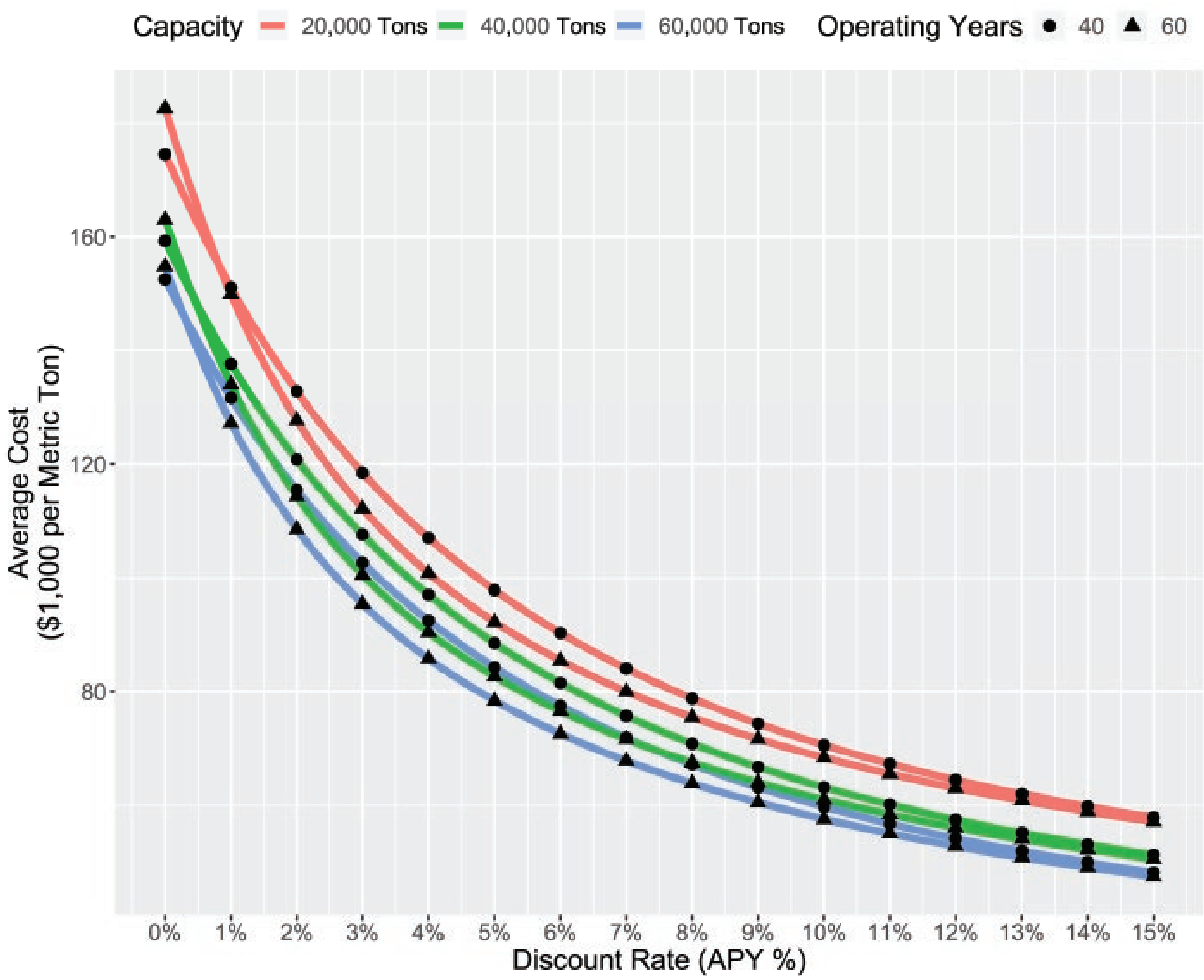
The gap between the 60-year and 40-year project costs increases with capacity, providing a larger incentive for a 60,000-ton facility to extend the materials license when compared with a 20,000-ton facility. These total costs are graduated based on size, with the 60,000-ton costing significantly more than the 20,000-ton facility. This cost difference is relevant to the type of firm that can engage in a CISF project. While a 60,000-ton facility may provide large economic benefits, capital constrained firms may find it difficult to acquire the $9 billion necessary to initiate the project. It may be more feasible to construct a smaller facility and then scale up based on future need.

One proposed facility in Lea County, New Mexico, follows this growth pattern. This project plans to accept 8,680 metric tons of SNF in phase one of the project, but can extend up to 100,000 metric tons (Holtec International, 2019). This final capacity would be sufficient to collect the nation's 86,000 metric tons of SNF (GAO, 2021).

This also suggests that economies of scale may be at play. While the marginal value of additional intermediate storage declines with size (see Figure 4), this is counteracted by declines of average costs as capacity increases. Such economies of scale were identified for the uranium enrichment sector which tends to centralize at a handful of global large scale facilities (Gebben & Peck, 2023).

To identify the changes in average cost to centralized storage, the results from Figure 5 are plotted as an average cost per ton of SNF stored in Figure 6.

Figure 6:
Average Cost of Centralized Storage Per Ton of Spent Nuclear Fuel



The average operating costs of CISF decline with capacity, suggesting a market tendency for a natural monopoly. Identifying a single intermediate storage location to house the entire nations SNF will lead to lower overall costs. However, natural monopolies can be constrained by transportation costs, and it is conceivable that a smaller facility will be more profitable than a single facility, when accounting for localized characteristics.

The value added by extending an operating license from 40 years to 60 years is found to be similar to the advantage of increasing a facility from 40,000 tons of capacity to 60,000 tons. This is identified by comparing the respective 40,000-ton 60-year cost line (green line with triangle markers), with the 60,000-ton 40-year cost curve (blue line with circle markers). At most, discount rates these two curves are nearly identical showing that the economies of scale and economies of operation time are comparable.

A final analysis of the CISF supply function is performed which evaluates the type of SNF that can be reasonably collected by the facility. As demonstrated in Figure 3, the value of removing SNF from a reactor on-site storage facility increases with the age of a reactor. So, the potential revenues from shipping the SNF to the CISF depends on the operating time of the served power plants.

Two lines are added to Figure 6. The first line plots the minimum possible value of storing a ton of SNF. That is the discounted average cost of on-site storage in the first year of a nuclear power plant's operation. The second line plots the maximum value of storing a ton of SNF, which is the discounted net present cost of storing a ton of SNF after the power plant has been retired.

If the average cost of a CISF project falls above the maximum value, then it will always be cheaper to house the SNF on site, and no CISF will be constructed. If the average cost of a CISF project is below the minimum value of SNF storage, then the nuclear spent fuel can be profitably transported to the CISF at any point in the project life. Finally, if the average CISF project costs fall in between the minimum and maximum values, then the material can eventually be transported to the CISF, but the SNF does not add to the CISF projects profitably until the nuclear power plant has operated for some amount of time. These upper and lower bounds of returns to SNF are plotted in Figure 7, along with the average project costs for each discount rate.

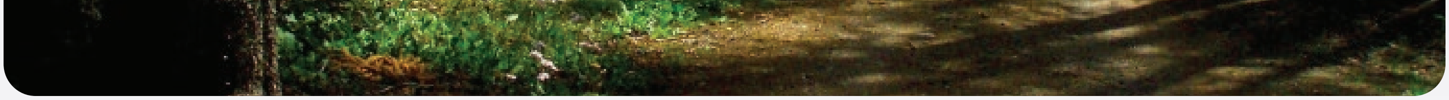
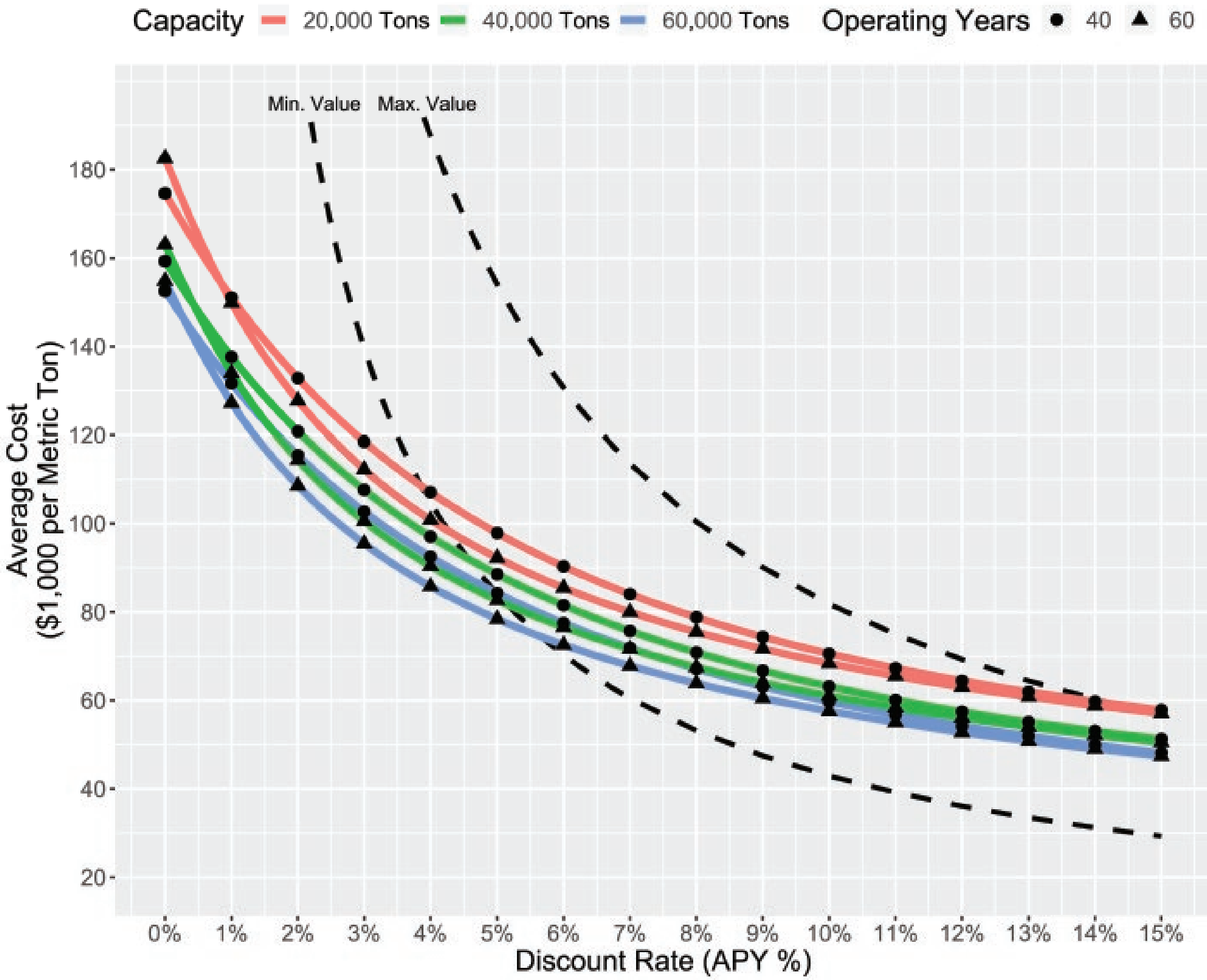


Figure 7:
Average Costs and Potential Revenues of Centralized Storage



Importantly, none of the modeled projects cost are above the maximum value of SNF line. This means that a centralized storage facility is economically viable in the U.S. The decision to construct a CISF is not sensitive to discount rates.

What is sensitive to discount rates is the age of nuclear reactors that can profitably send SNF to a CISF facility. At discount rates of less than 4%, the future costs of inaction are high enough that all SNF can be profitably transported to a CISF. At a rate of 6%, only nuclear power plants that have operated for some amount of time benefit from the facilities construction. For example, at a 6% discount rate, a 40,000-ton capacity project would spend the same amount of money to store the SNF on-site indefinitely as it costs to construct the CISF after 34 years of operation. Before this time, the CISF storage would cost more than indefinite on-site storage, and after 34 years there are cost savings to constructing a CISF facility compared to permanent on-site storage.

Table 5, Table 6, and Table 7 provide model results for the baseline projects. The max profit is the average profit per ton of SNF if the facility receives the value of storing SNF from a retired facility. The *Years to Start* is the time a nuclear power plant must operate before the CISF provides economic value.

Table 5: Outcomes from a 20,000-ton SNF facility 6% discount rate

Operating Life	Max Profit (Dollars per Ton)	Years to Start
40 Years	$40,388	43
60 Years	$45,217	39

Table 6: Outcomes from a 40,000-ton SNF facility 6% discount rate

Operating Life	Max Profit (Dollars per Ton)	Years to Start
40 Years	$49,164	34
60 Years	$54,102	25

Table 7: Outcomes from a 60,000-ton SNF facility 6% discount rate

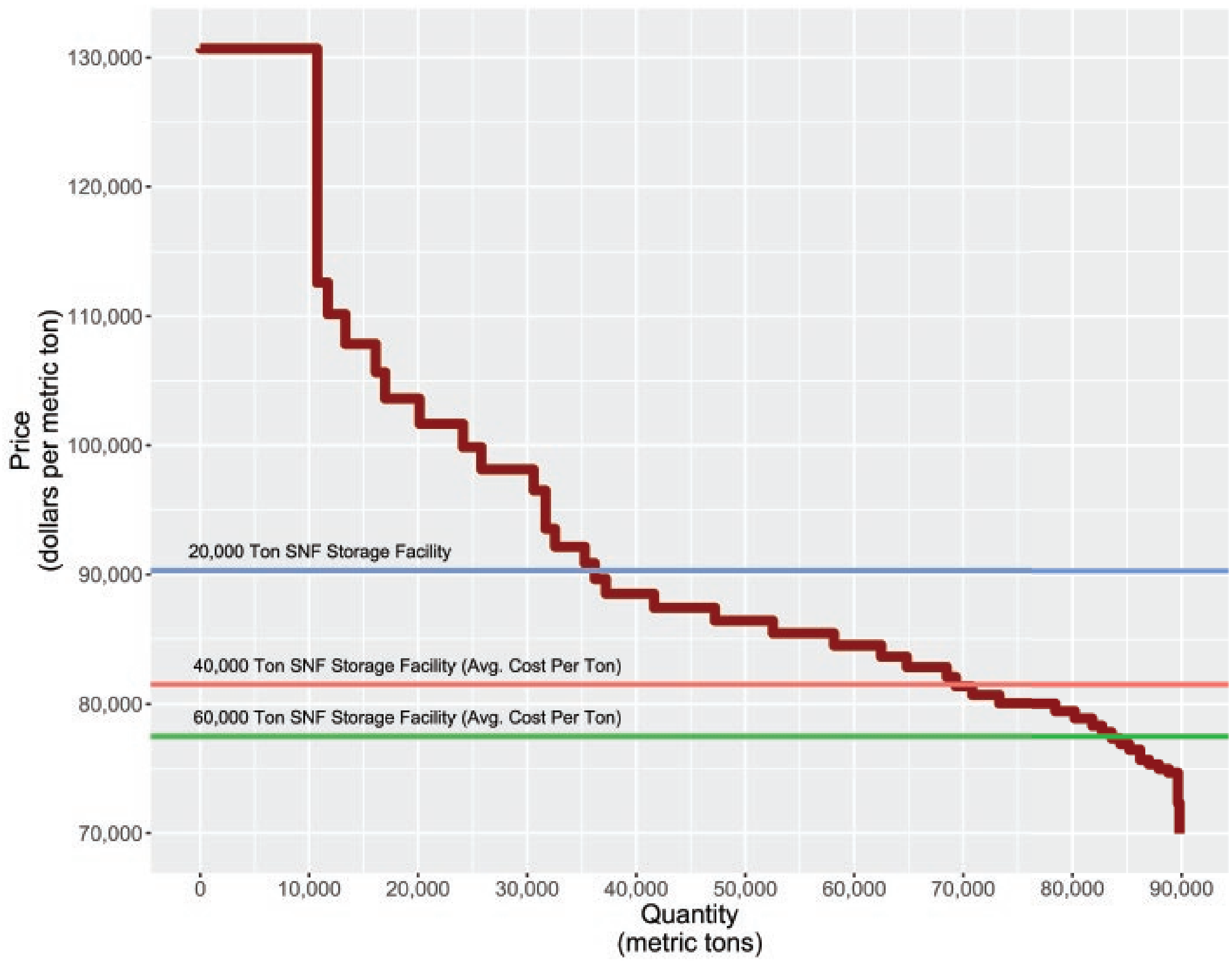
Operating Life	Max Profit (Dollars per Ton)	Years to Start
40 Years	$53,189	27
60 Years	$58,115	11

Without further analysis, it is unclear if a CISF facility is profitable under current conditions. Depending on the distribution of the age of nuclear power plants, a project may be subeconomic at the current time, although it is certain that a CISF facility will eventually be economic.

Market Outcomes: Supply with Demand

In order to assess the current market feasibility of CISF storage, this supply analysis is combined with the demand model of SNF storage. Horizontal supply curves of the average cost of CISF storage are added to the demand curve estimated in Figure 4. The combined results are provided in Figure 8. Where these average cost curves intersect the demand curve, the CISF project is economically viable[11].

Figure 8:
Supply and Demand Model of Centralized Storage



[11] If the total capcaity at the intersection point is greater to or equal the project capacity.

Based on this model, a CISF facility is economically viable given the current age of the U.S. Nuclear fleet. A 20,000-ton capacity project has the largest average cost. This line intersects the demand curve at 30,000 tons of SNF, which means the entire capacity of the project can be collected at above cost. Due to economies of scale, 68,000 tons of SNF can be stored at a 40,000-ton CISF facility for a lower cost than onsite storage, but 85,000 tons of SNF are below the cost threshold for a 60,000-ton CISF facility.

These outcomes provide the total economic benefits of the respective project. The area between the horizontal supply curve and the demand curve represents the net savings created by constructing the CISF. These benefits may be distributed between the private CISF company, the DOE, and local and State governments. The possible distribution of these project benefits is assessed further in Section 4.

The net benefits of a CISF project depend both on the willingness to pay for storage and on the amount of storage already available. For example, a CISF project plant in Andrews, Texas, plans to add capacity in 5,000-ton increments (NRC & Interim Storage Partners, LLC, 2020). Once 5,000 tons of capacity is added, the demand curve in Figure 8 will shift inward, taking the most valuable SNF out of consideration. The result is that early CISF projects provide more economic value on a per ton basis than later projects.

The total economic benefits of adding a new CISF project are calculated when various sized CISF are in operation. The total profit of the new facility is reported in Table 8, with the average profit per ton of storage capacity provided in Table 9. The blue column provides the capacity of the newly added facility, while the orange row records the total capacity of storage already in existence. The white cell values are the profits generated by adding the new facility under the ascribed conditions.

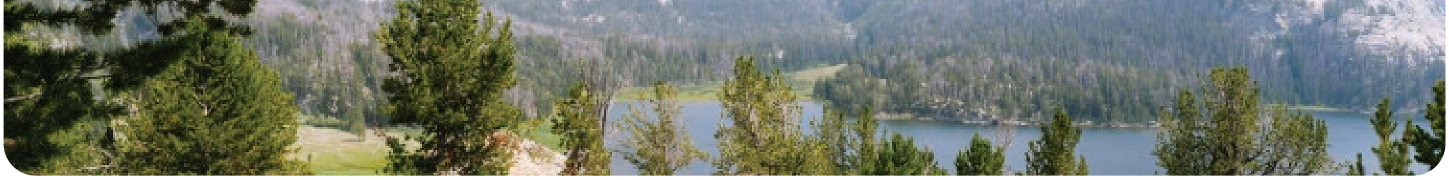


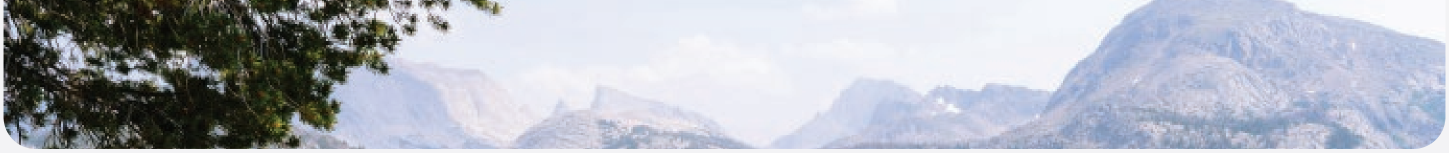
Table 8:
Total Profit of SNF Facility (Million Dollars)

Facility Size	Competing Facility Size: No Competition	10,000 ton	20,000 ton	30,000 ton	40,000 ton
20,000 ton	586	559	-111	-1168	-1,806
40,000 ton	1,037	897	492	220	-736
60,000 ton	1,379	119	742	-30	-985

Table 9:
Average Profit of SNF Facility (Dollars Per Metric Ton)

Facility Size	Competing Facility Size: No Competition	10,000 ton	20,000 ton	30,000 ton	40,000 ton
20,000 ton	29,377	27,970	-5,580	-58,394	-90,304
40,000 ton	25,916	22,437	12,297	5,488	-18,389
60,000 ton	22,993	19,885	12,373	-500	-16,418

A first mover project is predicted to always yield a positive return, whether the facility is large or small. However, existing facilities can significantly reduce the expected returns of a new Wyoming facility. While a 40,000-ton capacity project will provide $684 million in economic welfare if no other facility exists, when another 40,000-ton facility already exists, the returns are negative. After fulfilling demand to store the most valuable 40,000 tons, there is not enough SNF above the break-even price point for another 40,000-ton project to be economically viable. Despite having a lower average cost, a 60,000- ton capacity CISF project is not economically viable when a 30,000-ton capacity facility already exists, yet a 40,000-ton capacity project remains profitable. Once a large CISF begins operation, a smaller facility can fill in the gap between the capacity constraint of the large project and the remaining SNF priced above average cost. However, a second large facility is over capitalized and provides more storage than would be purchased at a going market rate.



A naïve estimate of the need for SNF storage would suggest the current 90,000 tons of U.S. SNF can support four 20,000-ton projects. The importance of this analysis is that only one or two operating CISF projects are likely to be profitable, even if there are significant volumes of SNF temporarily stored at nuclear power plants. The first mover projects will alleviate the immediate need to store SNF from projects at or near retirement, which substantially lowers the willingness to pay for additional CISF storage. Based on the previous analysis, it is certain that at total of four 20,000-ton projects can eventually be supported in the U.S., however the remaining projects will only be economically viable in the future when more nuclear power plants approach retirement.

This dynamic could create an obstacle to developing a CISF in Wyoming, as discussed in more detail in Section 3.2. Two CISF projects have been licensed by the NRC (Holtec International, 2023; NRC & Interim Storage Partners, LLC, 2020), but both projects have faced challenges obtaining approval from the respective States (American Nuclear Society, 2024; Douglas, 2021). If either of these facilities overcome these difficulties, the market demand for a Wyoming based CISF will be constrained. One countervailing consideration is negotiation by the DOE. Acquiring multiple CISF sites would reduce the market power of any one company, avoiding some risk for the DOE. This strategy would increase the number of CISF sites above the economical optimum number but lowers the expected payments to each facility. This provides an avenue for a Wyoming based CISF if two facilities are in operation, but the existing facilities would still provide a *major obstacle* to development plans.

As it currently stands, the U.S. has sufficient SNF to make a Wyoming CISF facility economically viable. This project would create up to $1 billion in direct economic value for the DOE, which is liable for the costs of onsite SNF storage (GAO, 2021). This places the economic category score as a *moderate advantage* for Wyoming.

Permanent Disposal

The previous analysis identified that given the choice between storing SNF on-site or storing multiple sets of SNF at a centralized facility, there will be a mixed outcome. Some new power plants will continue to store the SNF on site even if a CISF is available while older sites benefit from a centralized intermediate storage location. This section compares this option to establishing a permanent disposal facility prior to an intermediate storage solution. The timing of a permanent disposal facility depends on the alternative cost of intermediate storage. Where CISF costs are lower, the highest economic returns come from delaying permanent disposal and relying on CISF.

One advantage of permanent disposal is a lower transportation cost. Detailed regulations are in place to handle the transportation of hazardous materials, including SNF which adds to shipping costs (see 3.6 for more details) (§ 71.5 Transportation of Licensed Material., 2024; 49 CFR Part 174 49, 2024, p. 174) . Compliance with these regulations adds a significant cost to transporting the SNF. Opening a permanent disposal facility before an intermediate one cuts the number of train loads of SNF by half. Rather than traveling from dispersed nuclear reactors to the intermediate facility and then to a permanent location, the SNF only needs to be transported directly to the permanent disposal location.

A challenge to a permanent disposal facility is additional safety standards. For example, the EPA requires that radiation be limited to the surrounding environment for 100,000 years (EPA, 2024a). Intermediate facilities also have strict safety standards, but do not need to meet such long-time horizons. This adds significant cost to project planning and construction compared to an intermediate storage location. Future generation discounting can be complex. Using a 1% discount rate, which is a conservative intergenerational rate, a billion dollars of damages in 1,000 years would be worth $47,711 and is indistinguishable from zero within 10,000 years, much less the prescribed 100,000 years. The EPA rule implicitly weighs all future risk the same as present risk, which creates more cost to a permanent solution than to an intermediate one.

While the economies of scale for a permanent disposal facility can reduce overall costs, diseconomies of scale also exist. For example, very large energy projects face higher uncertainties in costs leading to experts underestimating total costs by an average of 97% (Callegari et al., 2018). This affects the expected value of building a single permanent disposal location for U.S. SNF. This risk can be seen in the Yucca Mountain project which cost $18 billion[12] with the project at a standstill. Engineering, political, and economic risks increase with the scale of a project.

The advantage of using a CISF followed by a permanent facility is timing considerations. As examined in Figure 4, the value of centralized storage changes as the age of the nuclear fleet increases. By applying CISF option, the high cost SNF can be offloaded in the near term. This provides more time to develop a cost-effective safe permanent disposal site.

Estimates from the Government Accountability Office find that using an intermediate storage location before sending the SNF to a permanent disposal location is 11% cheaper than directly transporting the material for final disposal. These estimates include intergenerational discounting, and risk simulation, for storing 153,000 metric tons of SNF (GAO, 2009).

Given the cost uncertainties associated with both intermediate and long-term storage projects, it is feasible that a permanent disposal facility could be economically viable in the near future.

[12] Inflation adjusted from 12.5 billion in 2009 to 2024 dollars (GAO, 2011).

Spent Fuel Recycling.

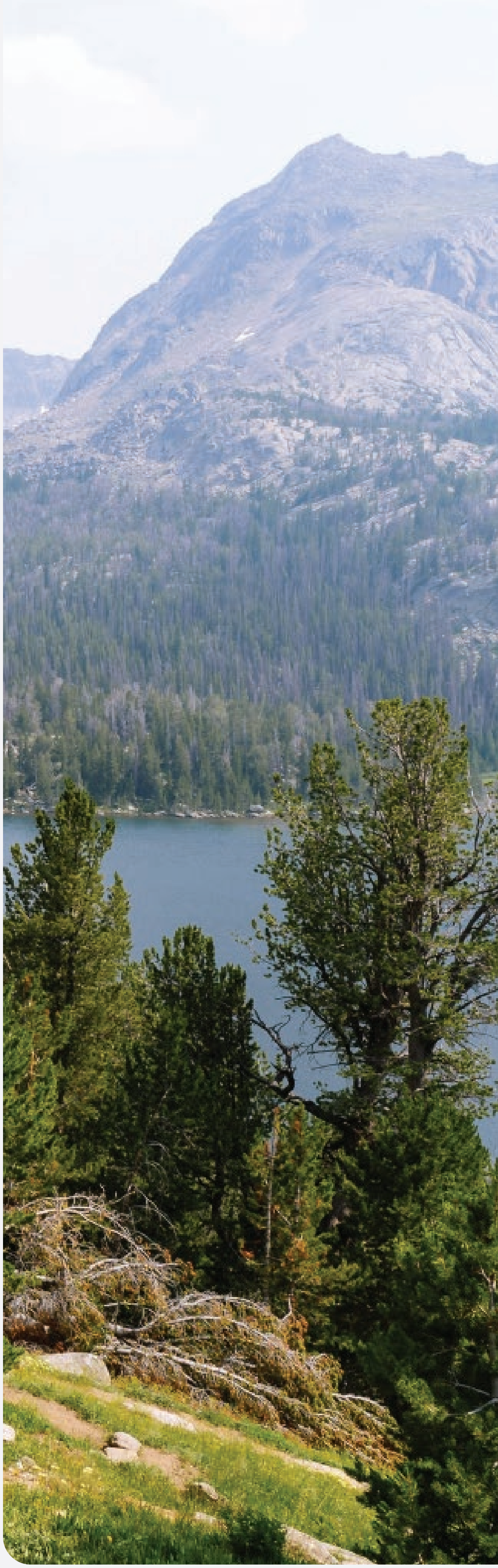
Operating a spent fuel recycling facility is made difficult by the current price of uranium and the relatively low disposal cost of SNF. Spent fuel can be recycled into a mixed oxide (MOX) fuel, which is an alternative to low-enriched uranium. This fuel is a blend of fissile material, including plutonium, which allows the material to be reused in light water reactors.(NRC, 2020b)

The economic returns for MOX generation are, therefore, linked to the uranium market. Where MOX fuel can produce the same energy as a pound of uranium, the choice to either recycle SNF or to purchase freshly mined uranium oxide is the cost difference between the two.

Because of this dynamic, the feasibility of recycling SNF can be established based on a uranium equilibrium price. This is the price of uranium at which recycling provides enough returns to investors to overcome the added processing costs.

This breakeven price has been estimated in a few economic studies. One analysis finds that the price of uranium would need to be $276 per pound for recycling to be profitable (Bunn et al., 2005)[13]. Under different assumptions, this breakeven point was identified as $239 per pound (Rothwell et al., 2014)[14].

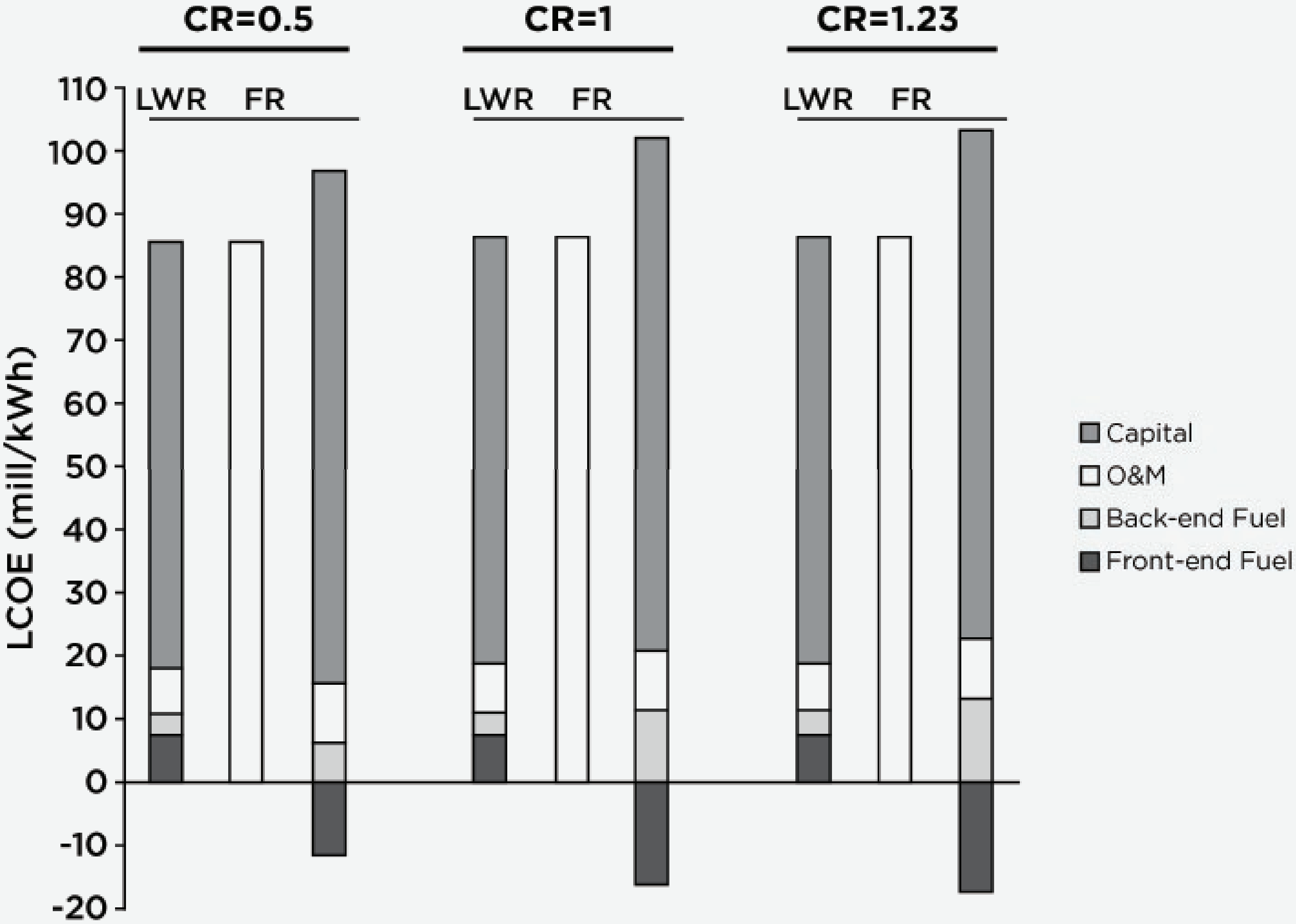
Similarly, the added costs associated with fast reactors make recycling material economically unviable at current prices. A market equilibrium analysis finds that the levelized cost of the transuranic used to fuel the fast reactor would need to be between -$26,144.68 and -$63,951 dollars per pound for the market system to balance (De Roo & Parsons, 2011). It is possible for the transuranic prices to be negative while still having a balanced system. For that to be the case, fast reactors would need to be paid to take the SNF, rather than paying for fuel. Figure 9 shows the levelized cost (LCOE) of light-water reactors (LWR), versus fast reactors (FR), under market equilibrium, while varying the conversion ratios (CR) of the fast reactors.



[13] Inflation adjusted from 2004 to 2024.

[14] Inflation adjusted from 2014 to 2024.

Figure 9:
Levelized Costs of Different Fast Reactors (De Roo & Parsons, 2011)



From this it can be seen that fast reactors currently have a higher capital cost than an equivalently sized light weight reactor. The only way to balance a system that includes both LWR and FRs is for the average cost of the two to be equal. The result is that a significant payment must be made to make the front-end fuel costs negative (paying the fast reactors for the fuel). For these payments to be reasonable, either the cost of intermediate disposal must increase, or the price of uranium must increase significantly.

Another analysis utilized a Monte Carlo simulation to estimate the relative costs of different fuel cycle systems. Current technology of MOX generation combined with fast reactors are estimated to have a uranium breakeven point of $160 per pound for a closed system breeder fast reactor (Gao et al., 2019)[15]. This is approximately double the current price (Cameco Corporation, 2024). However, advanced fuel fabrication methods can lower this equilibrium uranium price (See Section 3.4)(Gao et al., 2019).

Given the current cost of uranium and available technology, economic considerations are placed as a *major obstacle* for recycling SNF in Wyoming. Because of the cheaper disposal alternatives, the value of potentially recovered energy from recycling is not larger to overcome than the cost of this process. These considerations do not uniquely disadvantage Wyoming facilities but do limit SNF recycling opportunities.

3.2 EXISTING INDUSTRY

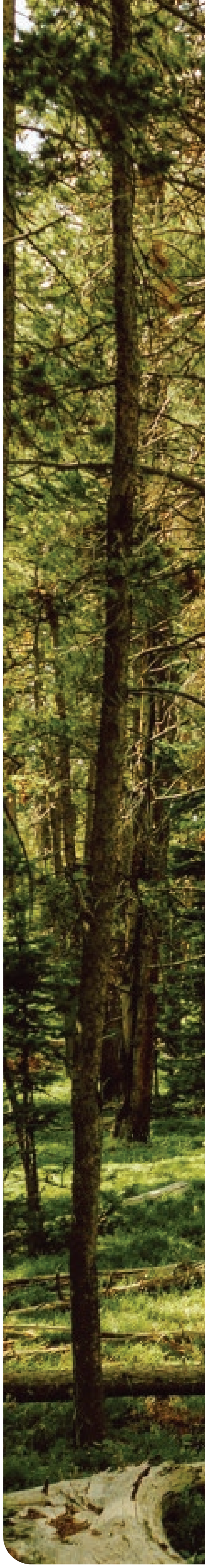
Intermediate Storage	Recycling
Minor Obstacle	Minor Advantage

Existing Industry: Scoring Criteria

Existing industries are scored as a *minor disadvantage* for developing a SNF management industry in Wyoming. Two NRC approved centralized intermediate storage facilities are in the planning phase. Both facilities have been placed on hold due to legal challenges but have not withdrawn their NRC applications.

If these facilities come to fruition, there will no longer be sufficient economic incentives to allow for a CISF to operate in Wyoming, without additional premiums paid to encourage market diversity. Either out of State facility would have notable costs and time advantages to a Wyoming facility, as environmental reports and feasibility studies have already been completed. However, the delays at these facilities limit the obstacle score to a *minor obstacle* and a Wyoming based site can be a first mover if the project is undertaken in the near future.

There is a *minor advantage* to recycling in the State as TerraPower will be one of the first commercial advanced nuclear reactors in the country and has the potential to convert SNF in the future. In the short term, the HALEU used will be recycled in the sense that more energy will be extracted per unit of uranium than in a traditional once through LWR. However, the technology applied in the TerraPower project can be used in other regions. The technological innovations tested in the State reduce barriers to development but does not provide a distinct draw to Wyoming.



[15] These values were not explicitly reported in the paper. We interpolate that a breeder system of 1.2 has a break even levelized capital cost at $275 per kilogram in 2017 dollars. This is inflation adjusted to 2024 values.

Existing Industry: Analysis

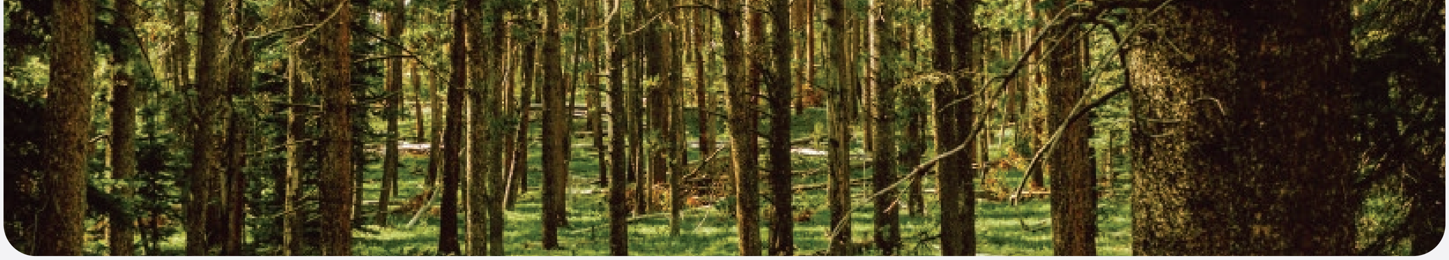
The existing industry structure presents a handful of challenges for establishing an intermediate storage facility in the State, although none of these difficulties are significant enough to make a CISF infeasible.

While the Kemmerer TerraPower nuclear facility is under construction, no other nuclear reactors currently operate in the State. The TerraPower Natrium design is three times as energy efficient as a traditional LWR reactor and other fast reactors designs can reach up to 60 times the energy efficiency of LWR (Dean, 2023; TerraPower, 2024). This efficiency reduces the advantages to colocation of a CISF in Wyoming, since less SNF is accumulated, but it does enable SNF recycling to become a viable method of SNF management.

Under a Wyoming high nuclear demand growth scenario, there will also be a *minor advantage* to CISF colocation. As evaluated in Section 3.1, the value of centralized storage increases with reactor age. Any new reactors developed in Wyoming can reasonably be expected to operate for 60 years or more, while the CISF projects are currently scheduled to operate for 40 years. The emerging nuclear sector in Wyoming has a staggered demand for centralized storage and this delay limits the benefits to Wyoming reactors from a CISF facility built in the next few years.

When considering the status of the nuclear industry in the U.S., there is enough SNF to support a new centralized storage facility in Wyoming. The demand source for SNF storage comes from existing nuclear power plants but would not be affected by new Wyoming reactors entering production. Further, the highest value fuel to send to intermediate storage is SNF stored at old power plants near retirement (see Section 3.1).

Existing and planned CISF facilities provide an alternative location to store SNF rather than a Wyoming CISF project. Three small-scale storage facilities run by the Nuclear Materials Program at the DOE's Office of Environmental Management have been established: (1) the L-Basin at the Savannah River Site (SRS) in South Carolina; (2) the Idaho Nuclear Technology and Engineering Center at the Idaho National Lab in Idaho; and (3) the Canister Storage Building and Interim Storage Area at Hanford Site in Washington (DOE, 2022a). While these facilities display the technological feasibility for a centralized nuclear storage facility, they are intended for SNF from research reactors. L-Basin at the SRS currently stores 27.5 metric tons of spent fuel (DOE, 2023b).



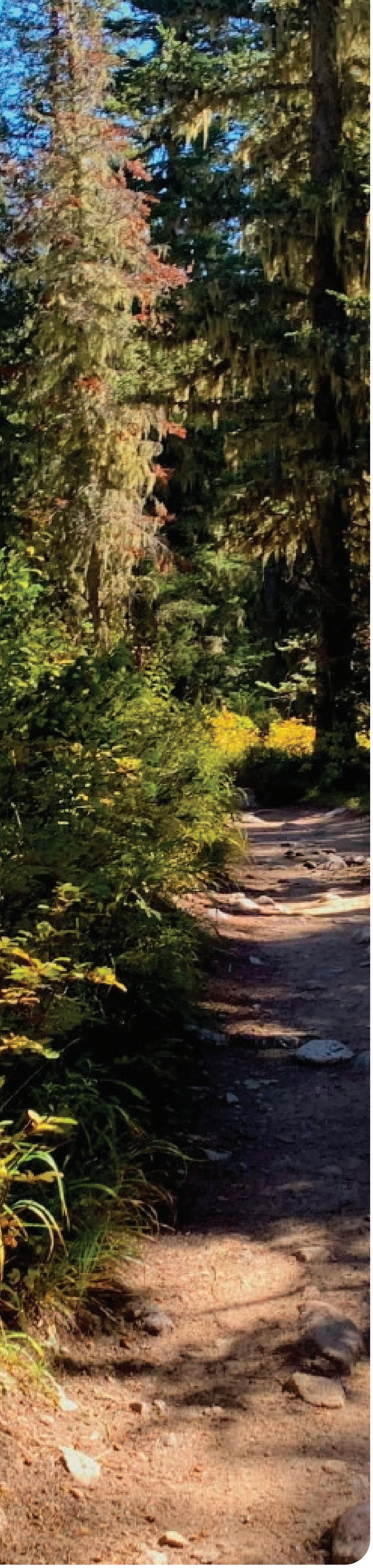
The largest potential competition with a Wyoming CISF comes from two planned CISF storage facilities: one located in New Mexico, and the other located in Texas. Both facilities have completed environmental reports with the NRC. The Holtec Southeastern New Mexico facility would eventually store 100,000 metric tons of SNF, completing the facility in twenty 5,000 ton capacity increments (NRC & Holtec International, 2020). The Interim Storage Partners facility in Texas is intends to store 40,000 metric tons of SNF, similarly adding to capacity in eight 5,000 ton capacity expansions over 20 years (NRC & Interim Storage Partners, LLC, 2020).

These alternative locations present a significant disadvantage to sourcing a Wyoming based CISF. If either facility became fully operational, the previous model estimates predict that no other SNF facility would be economically viable. The economic model in Section 3.1 suggests it is feasible to operate one large and one smaller CISF facility. However, if one facility is completed prior to the other becoming operational, the costs are likely to exceed the benefits of adding the second facility. One or two CISF facilities at full scale can be supported under current SNF storage demand, but a third facility would not be economically viable.

However, both projects are on hold due to legal challenges. The 40,000 MTU capacity facility in Texas has been curtailed by a State regulation restricting state agencies from permitting a NRC approved CISF facility (House Bill No. 7 of the State of Texas, 2021). This regulation was approved by Governor Abbot in 2021 (Douglas, 2021). The statute triggered legal challenges filed in the Fifth Circuit, which vacated the NRC license for the facility (Roma et al., 2023). However the New Mexico facility had it's NRC licenses validated by the D.C. Circuit Court (American Nuclear Society, 2024). Due to a Circuit Split, the final outcomes are uncertain, and the U.S. Supreme Court will hear the case and determine the fate of both projects (American Nuclear Society, 2024; Roma et al., 2023).

These projects can be approved by either a reversal at the U.S. Supreme Court or if the respective states decide to independently approve the projects. Either scenario would limit the opportunity for a new Wyoming CISF facility. However, as it stands, the existing industries pose a *minor obstacle* to construction of a CISF facility in Wyoming. This delay to the two pending facilities has opened an opportunity for the State to secure a new facility, but only if the facility receives direct approval from the Wyoming Governor.

The TerraPower Natrum reactor will be the first generation IV commercial fast reactor operational in the U.S. (TerraPower, 2024). This provides an opportunity to research and develop fast reactor technology in Wyoming that can be applied to SNF recycling. However, any such innovation would be applicable in any other state, and repeatable form factors allow for the reactors to be implemented in regions with the highest incentives to repurpose spent fuel.



While the existence of a fast reactor in the State is an advantage for immediate testing of small-scale recycling applications, the most significant advantage for future SNF recycling in Wyoming are the factors which promoted TerraPower to locate in the State. When evaluating Wyoming's existing industries, coal power plants and a robust energy economy are relevant to fast reactor development. The Kemmerer facility was the first nuclear power plant to be located near the site of a retiring coal power plant, taking advantage of existing energy infrastructure, especially transmission capacity and a trained workforce (Tan, 2024). Wyoming has the most potential to convert existing coal power plants of any state on a per capita basis, with ten sites available (Hansen et al., 2022; King, 2023). Only Texas has more potential to convert coal facilities to nuclear sites in absolute terms at 15 sites, and Wyoming is tied with Indiana, Kentucky, and Pennsylvania with ten sites (Hansen et al., 2022; King, 2023). However, these advantages have recently been reduced, as coal power plants respond to market and legal changes by extending operation (Wolfson, 2025).

This provides a *minor advantage* for future SNF recycling in the State. There is a direct draw to locate new generation IV reactors in Wyoming compared to other states due to the number of operating coal facilities. However, fast reactors are still cost prohibitive compared to existing energy sources, and it is not clear that all new advanced reactors will be ready to apply recycling technology. While existing coal facilities may be considered a *moderate advantage* to locating new nuclear power plants in the State, the uncertainty of which type of reactors will be deployed reduces the existence of coal and energy infrastructure of Wyoming to a *minor advantage*.

3.3 TAX STRUCTURE

Intermediate Storage	Recycling
Major Advantage	Major Obstacle

Tax Structure: Scoring Criteria

Taxes are found to provide a *major advantage* for the intermediate storage of SNF in Wyoming but are a *major obstacle* for SNF recycling efforts.

Industries with analogous market structures to SNF storage are found to have a lower tax burden in Wyoming than in all other 49 states. This is a *major advantage* to developing a project in Wyoming, establishing a unique draw to the CISF industry.

Advanced reactors are given special tax exemption status in Wyoming, but only if they use U.S. sourced uranium. Since fast reactors using SNF are not implementing traditional uranium fuel that can be clearly defined as coming from the U.S., this exemption may not apply. Because this exemption is a major cost savings for nuclear projects, this uncertainty promotes the use of fresh HALEU fuel over reprocessed spent fuel. A statutory clarification that this exemption would apply to alternative fuel sources would convert this score to a *major advantage*.

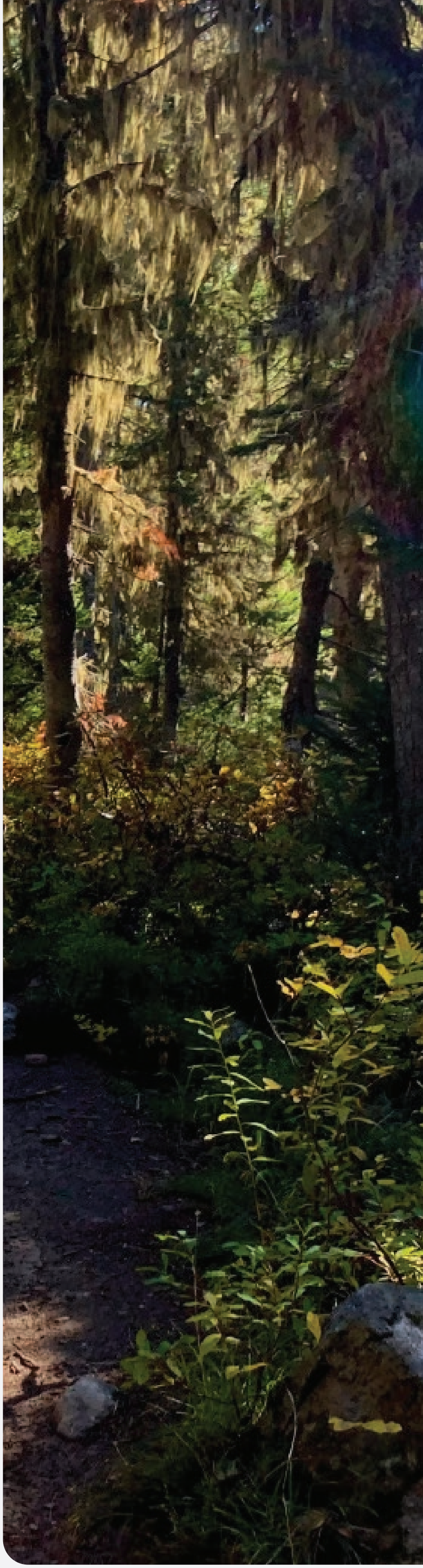
Tax Structure: Analysis

The Wyoming tax structure provides a number of incentives for a SNF storage facility to locate in the State. A CISF faces similar tax incentives as a enrichment facility, which was scored as a *moderate advantage* in a previous evaluation (Gebben & Peck, 2023). We refer readers to this report for additional details describing the numeric benefits of locating a similar facility in the State. Here, enrichment facilities in New Mexico and Idaho were found to face higher overall tax payments when compared to an expected payment in Wyoming. Both types of facilities (enrichment and CISF) are large scale projects with high building costs and undertaken by established nuclear firms.

An evaluation of effective tax rates in Wyoming found an established distribution center company would pay 15.4% in effective corporate taxes in Wyoming (Fíonta, 2022). This places the State as the lowest cost state for a distribution center (Fíonta, 2022). We selected a distribution center as the closest benchmark industry to compare with a CISF project. This is because the primary industry operating costs are transportation infrastructure and warehouse development, with sales taxes based on payments to house materials rather than selling end products.

Wyoming tax credits are more substantial for firms involved in manufacturing components, due to a tax exemption (Gebben, 2024b; Gebben & Peck, 2024; Wyoming Department of Revenue, 2022). However, the low relative tax burden for similar industries is enough to place the tax category score as a *major advantage*. The advantage is significant and is a unique advantage for a CISF located in Wyoming.

Counterintuitively, the Wyoming tax code provides a *major*



obstacle to recycling SNF. At the federal level, there is a *moderate advantage* to locating in Wyoming. Fast reactors using reprocessed SNF qualify for targeted tax advantages for locating in states like Wyoming. The Inflation Reduction Act provides up to 10% bonus in low carbon tax credits for operating in energy communities, including Wyoming[16]. The combination of possible federal tax credits in Wyoming can reduce overnight capital costs[17] of SMR's by as much as 37% (Lohse et al., 2024). These tax advantages promote the use of reactors capable of recycling SNF generally and provide a specific incentive for locating in Wyoming.

Despite this tax structure, on net the Wyoming tax code discourages recycling in the State, due to uncertainty in State tax rules. Further clarification of the rules can move taxes into a *major advantage* for the State. Wyoming levies a nuclear produced electricity tax of $5 per mega-watt which would be a sustainable cost to advanced reactors. However, this is not a major concern for most reactors due to exemptions.

Wyoming Statutes (2024) 39-23-101, part C states.

> *"Except as otherwise provided in this subsection, no tax shall be imposed on any advanced nuclear reactor operated in accordance with W.S. 35-11-2101. Beginning July 1, 2035, a taxpayer shall only qualify for the exemption authorized under this subsection for any month that not less than eighty percent (80%) of the advanced nuclear reactor's uranium used for producing electricity was sourced from uranium mines located in the United States."*

This provides a significant cost saving to nuclear power plant operations located in Wyoming, removing the tax associated with electricity production. However, it is unclear if reactors using MOX fuel or fast reactors operating with SNF would qualify for the exemption after 2035. Both the use of the terms "uranium" and "mine" adds ambiguity in the interpretation of this statute in the context of SNF reuse. The source fuel is no longer mined natural uranium. If the rule requires that the source of the uranium which produced the SNF originates from the U.S., accounting complications are created. Only 4% of uranium purchased by U.S. reactors was sourced from domestic suppliers in 2022 (EIA, 2024a). Most uranium has come from foreign sources in the last decade, so it will be challenging to identify significant volumes of U.S. origin SNF, and this would limit the SNF inventories that can be reprocessed and still receive this tax write off[18].

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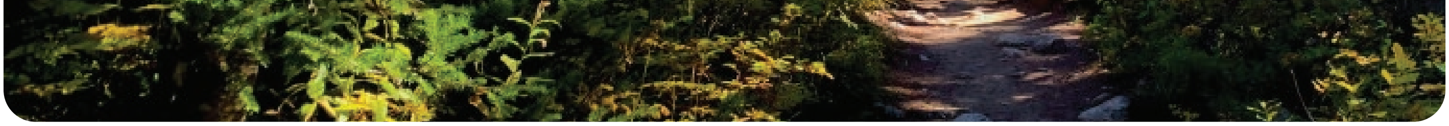
[16] See (The Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2024)

[17] Overnight capital costs are the total construction costs, without including interest paid on loans.

[18] While the U.S. has placed a recent moratorium on Russian produce uranium, existing stockpiles of spent fuel were produced primarily with foreign uranium and would be the feedstock of recycling operations.



MOX fuel may face less challenges meeting this exemption requirement because natural uranium is blended with plutonium and other byproducts to generate the fuel (NRC, 2020b). However, without clarification, reactors using MOX also face uncertainty in their qualification status. While most of the natural uranium can be sourced from the U.S. and likely from Wyoming mines, if the plutonium counts towards the total not by mass but by energy totals, then reactors using MOX would not necessarily receive this exemption. Further, if it is deemed that the reactor must use a traditional uranium fuel source, MOX would not qualify.

This consideration may become relevant in Wyoming. The TerraPower Natrium fast reactor faces a disincentive in testing SNF reprocessing if switching from U.S. sourced HALEU to processed SNF jeopardizes their tax exemption.

Providing an amendment to this statute clarifying the tax implications of recycling SNF would reduce this barrier. In fact, the clear application of this tax treatment for reprocessed SNF would make taxes a *major advantage* for SNF recycling in Wyoming.

3.4 TECHNOLOGY

Intermediate Storage	Recycling
Neutral	Minor Obstacle

Technology: Scoring Criteria

Recycling SNF with extant commercial scale technologies is cost prohibitive in the U.S. However, technological innovations and alternative recycling methods will reduce operating costs. Due to these promising research efforts, the technological obstacles for SNF are scored as a *minor obstacle* for establishing a SNF recycling industry in Wyoming. Expected technological improvements will make recycling more competitive with disposal strategies but not uniquely more in Wyoming than in other regions.

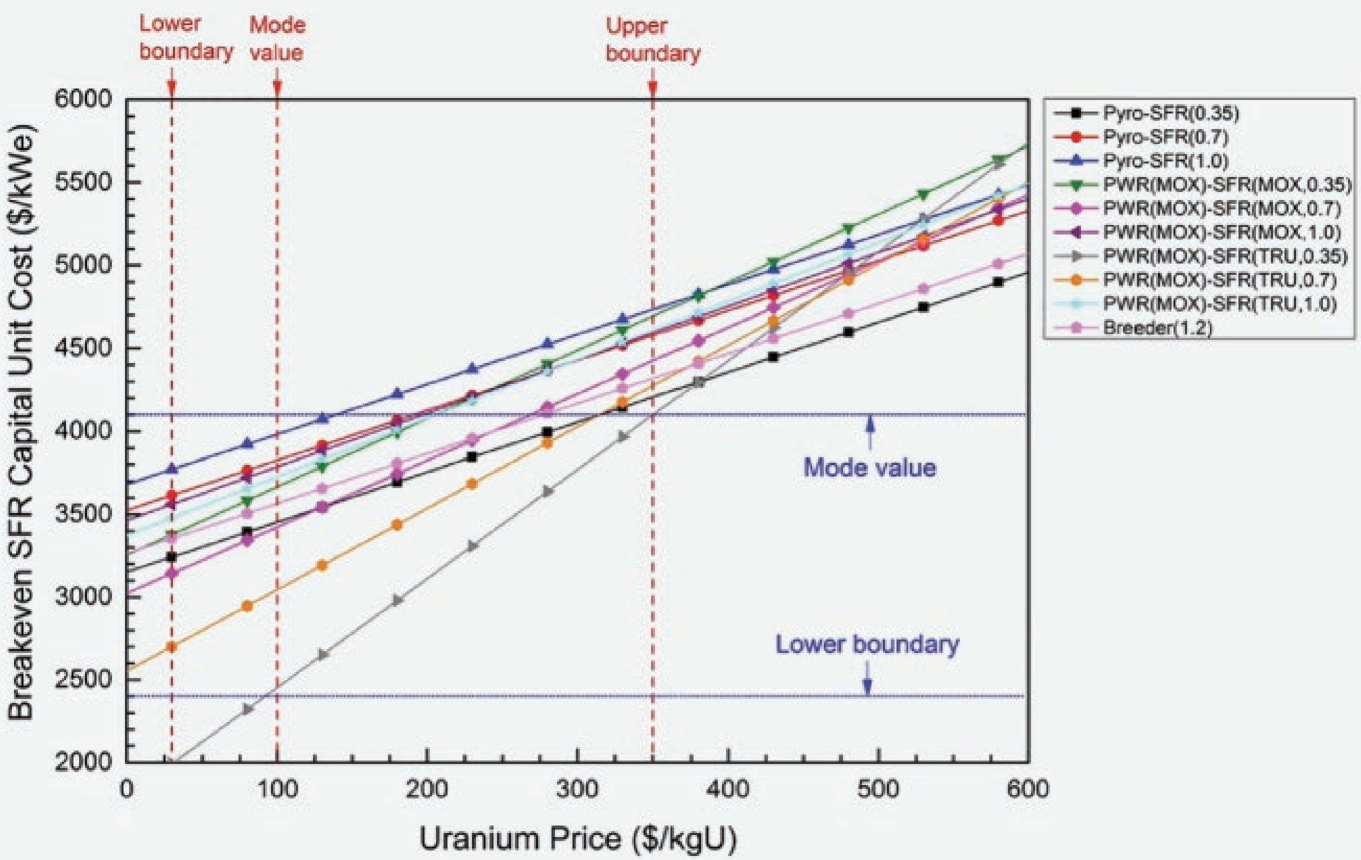
Technology: Analysis

Technology plays a key role in the availability of SNF recycling and the suite of SNF management options that are deployed in the U.S. As discussed in Section 3.1, the current combination of uranium prices, and costs of various nuclear technologies, makes a closed uranium cycle prohibitively expensive.

However, this may change in the future with the development of new methods of fuel manufacturing. Currently, plutonium uranium reduction extraction (PUREX) is the primary technology employed in SNF recycling (Paiva & Malik, 2004). In this procedure, the material undergoes a reaction in a aqueous phase where chemicals selectively concentrate the desired material (Canner, 2021). One non-aqueous processing method, showing promise, is pyroprocessing, which applies high temperature oxidation (IAEA, 2021). This process enhances a range of transuranic elements, rather than targeting plutonium (IAEA, 2021). This has the advantage of reducing proliferation risks, as the transuranics are not directly applicable in nuclear weapons without additional processing (Woo et al., 2020).

While pyroprocessing has been tested since the 1980's, it has yet to be commercially operated. Current estimates place the total cost at $783 per pound of metal, which is a significant reduction from previous costs estimates of $1,181 per pound (Kim et al., 2023). Continued cost reductions in recycling technology could make the process economically viable. Figure 10 provides the estimated break-even levelized capital cost of fast reactors, used in different fuels cycles plotted against the uranium price.

Figure 10:
Baseline Costs of Closed Fuel Cycle Methods (GAO et al., 2019)



This demonstrates the importance of the technological readiness of different recycling methods. At the mode projected capital cost, the lowest cost fuel system has a neutral fuel conversion ratio of 1 applying a pyroprocessing method. This technology could have a break-even uranium price of $70 per pound[19]. Uranium prices are $80 per pound in 2024 enough to support this method if the technology is fully deployable (Cameco Corporation, 2024). On the other end of the spectrum, a MOX fuel system with a low conversion ratio of 0.25 would have a break-even uranium price of $196 per pound, more than double the current market price.

19 $\frac{\$125}{kg}\,\frac{kg}{2.2\ lb}\,\frac{1.23\ 2019\ dollars}{2024\ dollars}=\frac{\$69.88}{lb}$

The federal government has funded eleven research projects involving SNF recycling with the goal of lowering costs and making SNF recycling commercially viable (Advanced Research Projects Agency-Energy, 2022). This has the potential to significantly reduce the time frame at which recycling SNF becomes economically viable, from around a hundred years to a decade (Baschwitz et al., 2017; Rothwell et al., 2014).

These developments are not a certainty, and the cost reduction path must be sustained to incentivize new fast reactors and SNF recycling in Wyoming. The fruit of current research will determine if the State will be able to adopt this technology.

The development of such technology will not uniquely advantage Wyoming recycling efforts compared to other regions, but it could broadly promote the use of advanced reactors. One challenge for Wyoming reactors is that the bulk of SNF that could be processed is located at existing LWR reactors which are clustered toward the east of the country. For these reasons this factor is set as a *minor disadvantage* for SNF recycling in Wyoming. Current costs are prohibitive, and sources of SNF are distant from the State, but research efforts may decrease these cost barriers.

Technology is scored as a neutral factor for intermediate waste storage. No technological obstacles were identified for continued development of intermediate storage.

3.5 LOCATION

Intermediate Storage	Recycling
Minor Advantage	Minor Advantage

Location: Scoring Criteria

The location *scoring criteria* for the management of SNF in Wyoming is a *minor advantage*. Both centralized intermediate storage and recycling industries benefit from the State's low population, seismic conditions, and terrain. Some portions of the State are disadvantaged by elevation changes, cold weather, and infrastructure constraints. However, there are regions of Wyoming that are amenable to CISF operations, placing the overall score as a *minor advantage*.

Locating fast reactors in the State, such as the TerraPower Kemmerer Project, would encourage SNF recycling. The location factors for fast reactors are similar to intermediate storage facilities and likewise are scored as a *minor advantage*.

Location: Analysis

Eleven location-based criteria have been defined for identifying an optimal permanent SNF geologic storage facility by the DOE (10 CFR Part 960 Subpart D -- Preclosure Guidelines, 2024). For each category a qualifying criteria, a disqualifying criteria, as well as favorable and unfavorable considerations are outlined. The categories considered include:

1. Population density and distribution
2. Site ownership and control
3. Meteorology
4. Offsite installations and operations
5. Environmental quality
6. Socioeconomic impacts
7. Transportation
8. Surface characteristics
9. Rock characteristics
10. Hydrology
11. Tectonics

While licensing an intermediate storage facility will follow different criteria these guidelines are assessed as conditions which simplify licensing a CISF and reduce costs.

Portions of Wyoming possess several of the factors considered to be a favorable for a storage facility, including:

- A low population density in the general region of the site.
- Remoteness of the site from highly populated areas.
- Generally flat terrain.
- Absence of surface-water systems that could potentially cause flooding of the repository.

On the other hand, the State may find it difficult to meet some of the favorable conditions concerning logistics such as:

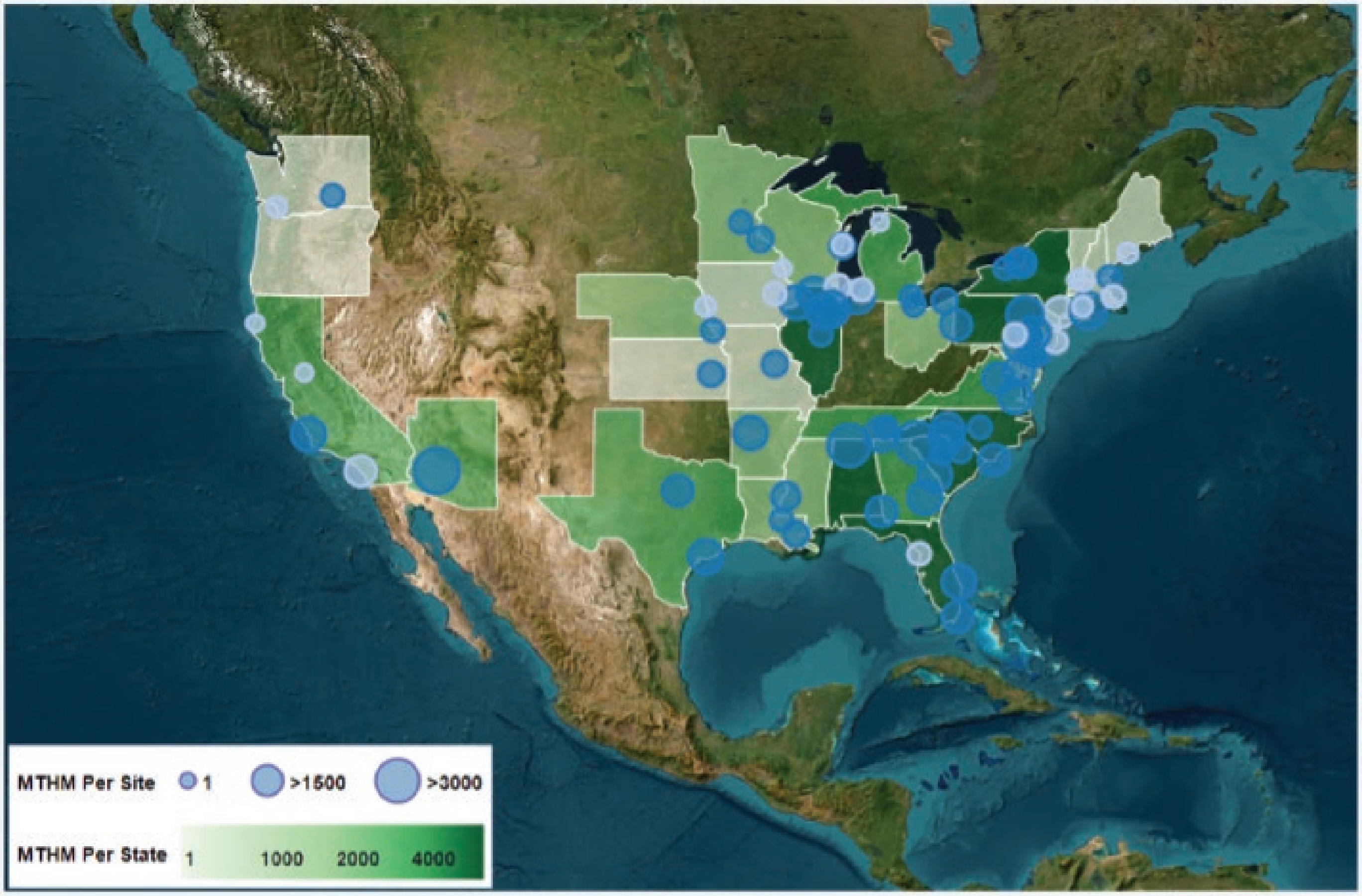
- Availability of an adequate labor force in the affected area.
- Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.
- A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

The remote, level, and low population regions of the State that are preferred candidates for a CISF may likewise be constrained by available labor and access to the States infrastructure. Compared to other states with proposed SNF storage facilities, such as Nevada, Texas, and New Mexico, winter road closures will create difficulties for operating a CISF in Wyoming.

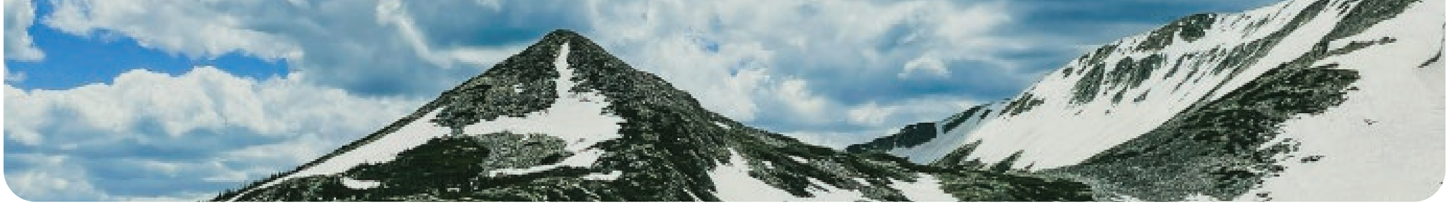
A labor impact analysis is performed in Section 4.2, which finds that total jobs created by the facility, including induced effects, would reach 900 per year during operation. Acquiring this number of employees in low-population Wyoming regions is likely to be a binding constraint on growth in the early phases of the project.

Another potential barrier to industry development is the location of existing SNF on-site storage facilities. The location and volume of SNF stored across the U.S. is provided in Figure 11. Light blue circles indicate that the reactor is closed, and dark blue circles indicate that the reactor is still in operation.

Figure 11:
Locations of Commercial Spent Nuclear Fuel in the U.S. (CURIE, 2024)



There is little SNF being temporarily stored in the Mountain West region. Further, most SNF which is stored at a retired facility, having the most urgent need for a CISF, is in U.S. coastal states. This increases the distance to ship SNF to a Wyoming facility, when compared to alternative locations. This can be overcome as the most significant cost of transportation of SNF is in loading and safety rather than distance transported (Rothwell, 2021).



Considering each of these location factors, the development of a CISF facility in Wyoming is scored as a *minor advantage*. Companies seeking to develop a facility are provided with several location specific advantages in the State. However, these must be weighed against some deterrents, including high transportation costs created by being distant from existing SNF facilities and labor constraints. A judgment call must be made when comparing these factors. We place the overall score as a *minor advantage*, because there are regions of the State that meet many of the preferred attributes of a CISF which are not common across the country. The identified challenges are either minor or otherwise can be overcome with infrastructure improvements. Importantly, none of the disqualifying criteria were determined to rule out a facility in Wyoming, and all qualifying criteria are met in at least some corridors of Wyoming. This cannot be said for all states, allowing Wyoming to become a candidate for a CISF facility.

Location factors to consider when locating advanced nuclear reactors was previously placed as a *minor advantage* for Wyoming (Gebben, 2024a). This is applicable to fast reactors used for recycling SNF in the State. However, MOX production may be advantaged by the colocation of uranium mines in Wyoming that supply the natural uranium to blend the fuel. Since the natural uranium does not need to be shipped in specialized canisters, the Wyoming mines provide only a minor cost reduction for MOX fuel fabrication (Charette, 2015; Gebben & Peck, 2023). The advanced reactor siting considerations provide a *minor advantage* to Wyoming industry. Any generalized growth in the sector can be applied to Wyoming firms, but there are few distinct location advantages in the State.

3.6 LEGAL

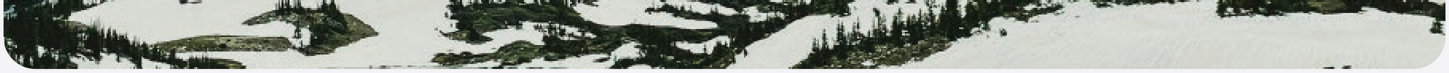
Federal	
Intermediate Storage	**Recycling**
Severe Obstacle	Major Obstacle

State	
Intermediate Storage	**Recycling**
Severe Obstacle	Major Obstacle

Legal: Scoring Criteria

This section explores the legal considerations from the perspective of both generators and governments. Both temporary storage and permanent disposal are heavily regulated at the State and federal level. However, the federal government is obligated to manage and permanently dispose of this fuel as mandated in the Nuclear Waste Policy Act of 1982 (NWPA)[20] (GAO, 2021).

[20] Pub. L. No. 97-425, §§ 111-113, 96 Stat. 2201, 2207-12 (1983) (codified as amended at 42 U.S.C. §§ 10131-33)



A U.S. firth circuit ruling has determined that the NRC cannot issue licenses to a private CISF, which prevents any state from permitting a storage facility. An appeal is currently being argued before the U.S. Supreme Court. Further, Wyoming law requires that a permanent disposal facility be ready to receive SNF from a Wyoming intermediate storage facility before a license can be issued. No permanent disposal facility exists preventing the State from approving a CISF project. Both the federal and State legal requirements forestall further development of a CISF creating two server obstacles to industry growth.

The same rules that limit intermediate storage place restrictions on moving SNF for the purpose of reprocessing. Spent fuel generated in Wyoming can be reprocessed providing a means for some industry development. These considerations place the spent fuel recycling legal score in the *major obstacle* category.

Legal: Analysis

Federal Obligations

The Nuclear Waste Fund (NWF), a $47.7 billion federal fund composed of fees paid by nuclear power generators, was intended to pay for the construction and operation of a permanent, centralized storage solution (DOE, 2023a). The NWPA required that the federal government take custody of all nuclear waste by 1998: this task failed thanks to difficulties in securing a location for permanent disposal. As a result, the U.S. government has paid out more than $9 billion in on-site storage costs to nuclear power generators.

While other sites were considered both for permanent disposal solutions and monitored retrievable storage, ultimately Yucca Mountain in Nevada was identified as a potential permanent disposal site. However, the Yucca Mountain project was halted in 2010, and despite some efforts to revive it, such as the policies set forth and adopted by the DOE from the Blue Ribbon Commission on America's Nuclear Future, progress has remained stagnant (Hamilton et al., 2012).

Temporary storage sites, often referred to as monitored retrievable storage (MRS) or consolidated interim storage facilities (CISF), have also been considered by the DOE. Preliminary work for MRS siting was authorized by the NWPA, but elected officials from states identified as potential candidates for such a project opposed it. Apart from on-site storage, the L-Basin at the Savannah River Site (SRS) in South Carolina, Idaho Nuclear Technology and Engineering Center in Idaho, GE's Morris Operation[21], and the Canister Storage Building and Interim Storage Area at Hanford Site are the only locations that store and manage SNF[22]. The Nuclear Materials Program at the Office of Environmental Management under the DOE is responsible for these sites, but they are small-scale facilities compared to what would be required for the safe storage of SNF from commercial nuclear generators.

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[21] The Morris Project was planned to be a reprocessing plant, but this plan was scrapped in 1974 and the site was switched to a wet storage facility 1982 (WNN, 2022).

[22] There is currently one deep geologic repository for transuranic waste, the Waste Isolation Pilot Plant (WIPP), located in New Mexico (DOE, 2022b). However, WIPP is only accepts waste generated from research and weapons manufacturing (DOE, 2023c).

Any entity seeking to build a SNF storage site, whether permanent or temporary, is bound by federal regulation set forth by the NRC. These regulations include standards for protection against radiation, licensing, environmental protection, and physical protection of facilities and materials. Licensing requirements for the independent storage of SNF are found in NRC, 10 CFR Part 72 (NRC, 2023). The project must also be under the purview of the DOE as the NRC lacks the authority to grant licenses to private companies (Pearl, 2023).

Under this NRC licensing authority two commercial CISF facilities have applied for operating licenses. However, both facilities have faced opposition from the host State. A Texas lawsuit against the NRC has recently generated a precedent which strictly limits private CISF construction options in Wyoming. Texas issued a law banning SNF storage in the State after NRC approval was granted (Douglas, 2021). Texas alleges that the NRC does not have the authority to issue a license to private CISF facilities, both based on the Nuclear Waste Policy Act and because state authority was superseded by issuing a federal license to operate.

The fifth circuit ruled in favor of Texas, in part stating:

> "Reading these provisions together makes clear that the Nuclear Waste Policy Act creates a comprehensive statutory scheme for addressing spent nuclear fuel accumulation. The scheme prioritizes construction of the permanent repository and limits temporary storage to private at the reactor storage or at federal sites. It plainly contemplates that, until there's a permanent repository, spent nuclear fuel is to be stored onsite at-the-reactor or in a federal facility."
> (*Appeal from the Nuclear Regulatory Commission Agency No*. 72-1050, 2023)

Due to a circuit split the NRC's appeal was taken up by the U.S. Supreme Court (Bubenik, 2024). Under this fifth circuits decision, Wyoming cannot issue a CISF permit to private parties, creating a *severe obstacle* which precludes development. The future federal legal score is likely to change depending on how the Supreme Court rules. If this circuit opinion is upheld in full it will remain impossible for Wyoming to issue a private CISF permit. The only option for CISF development in the State would be the approval of permanent disposal, or potential a federally owned CISF. Alternatively, the Court may rule that Texas law takes precedence over NRC licensing rules, but that the NRC can continue to issue licenses pertinent to federal operating requirements. In that case, the obstacles score would be mitigated, and Wyoming could allow an NRC licensed facility in the State but would not be forced to do so. A third scenario is that the Court rules in the NRC's favor, allowing them to issue licenses that are in opposition to State law. This would reduce the legal obstacles to Wyoming CISF development but would increase the existing industries obstacles. The two licensed facilities in New Mexico and Texas would make a third CISF in Wyoming subeconomic based on the previous analysis in this report (see Section 3.2).

NRC guidelines have not been developed for spent fuel reprocessing. Efforts were made to clarify rules for reprocessing in 2008 when companies were developing commercial reprocessing technologies. However commercial projects have been put on hold, so the NRC has stopped developing these rules in order to avoid unnecessary costs. (Doane, 2021).

This moves the SNF recycling federal legal score from what would be a *minor obstacle* to a *major obstacle*. Additional clarity in the reprocessing rules would allow a Wyoming reprocessing industry to develop with less uncertainty. Without these rules companies may face delays caused by licensing ambiguity which would add millions of dollars to project costs. The recent fifth circuit court decision does not obviously restrict spent fuel recycling, although the volume of spent fuel that can be housed on site before a reprocessing facility would be defined as a private CISF is not clear. Since development of a reprocessing facility can continue but NRC rules are uncertain federal legal consideration are scored as *major obstacle*.

State Regulations

Constructing and maintaining a SNF repository in Wyoming is a subject that comes up every few years in the Wyoming Legislature. Most recently, Rep. Donald Burkhart Jr., Co-Chairman of the Joint Minerals, Business and Economic Development Committee, brought a draft bill to the committee in October 2024 (Bleizeffer, 2024). The idea of building a repository in Wyoming has yet to gain much traction. In a letter from former Governor Mike Sullivan to the Fremont County Commissioners in 1992, Sullivan concisely summed up the issue with the following statement:

> *This is not an issue that simply pits antis or "environmentalists" vs. "proponents". It cuts across all segments of Wyoming citizens and has caused them to assess personal values, emotions, economic realities, their personal image of Wyoming, the image they want others to have of Wyoming and ultimately their vision for this great state* (Sullivan, 1992).

Any high-level radioactive waste storage facility must comply with the regulations set forth by Chapter 11 Article 15 of Wyoming Statute Title 35 – Public Health and Safety. Applications to build such a facility must include technical feasibility; environmental, social, and economic impacts on the local region; compliance with federal regulations; and a description of emergency procedures. Perhaps the most pressing piece of legislation described in the article is the need for legislative approval prior to construction which will only be issued based on a suite of factors such as: (1) the siting being in the best interest of the people of Wyoming; (2) not causing irreversible damage to the environment, public health, or economy of both the local area and Wyoming as a whole; (3) the benefits offset the social costs; and (4) sufficient safeguards are met. The application process includes a nonbinding feasibility agreement and study on which the public will be allowed to comment. The application fee is $80,000 and recurs annually over the course of the study as adjusted for inflation.

Approval from the Wyoming government is an important hurdle as the debate over SNF storage in Wyoming has been ongoing for decades since Gov. Mike Sullivan vetoed the Department of Energy's attempt to create a monitored retrievable storage (MRS) facility in Wyoming in 1992 (Sullivan, 1992).

Wyoming Statue 35-11-1505 (part c) provides veto power to develop a CISF to both the Governor of Wyoming, and the legislature via the Management Council. The statute states.

> "With permission of the governor and the management council, an applicant for either a monitored retrievable storage facility or an independent spent fuel storage installation may enter into a preliminary but nonbinding feasibility agreement and study with the director which shall be submitted to and reviewed by the director, governor and the management council."

Most recently, Co-chairman of the Minerals, Business, and Economic Development Committee, Rep. Donald Burkhart Jr. has revived interest in the subject and claims that there is a potential for more than $4 billion per year from spent nuclear waste storage (Bleizeffer, 2024). While much of the reservation of the Legislature has historically come down to the people of Wyoming not wanting a facility in the State, other concerns such as congressional action and a shaky federal government record on timelines have also been cited.

Even if the votes exist to approve the facility, a State license cannot be issued unless a federal permanent SNF storage facility is identified, thereby guaranteeing that the CISF will not become a permanent operation[23].

Wyoming Statue 35-11-1503 (b) states:

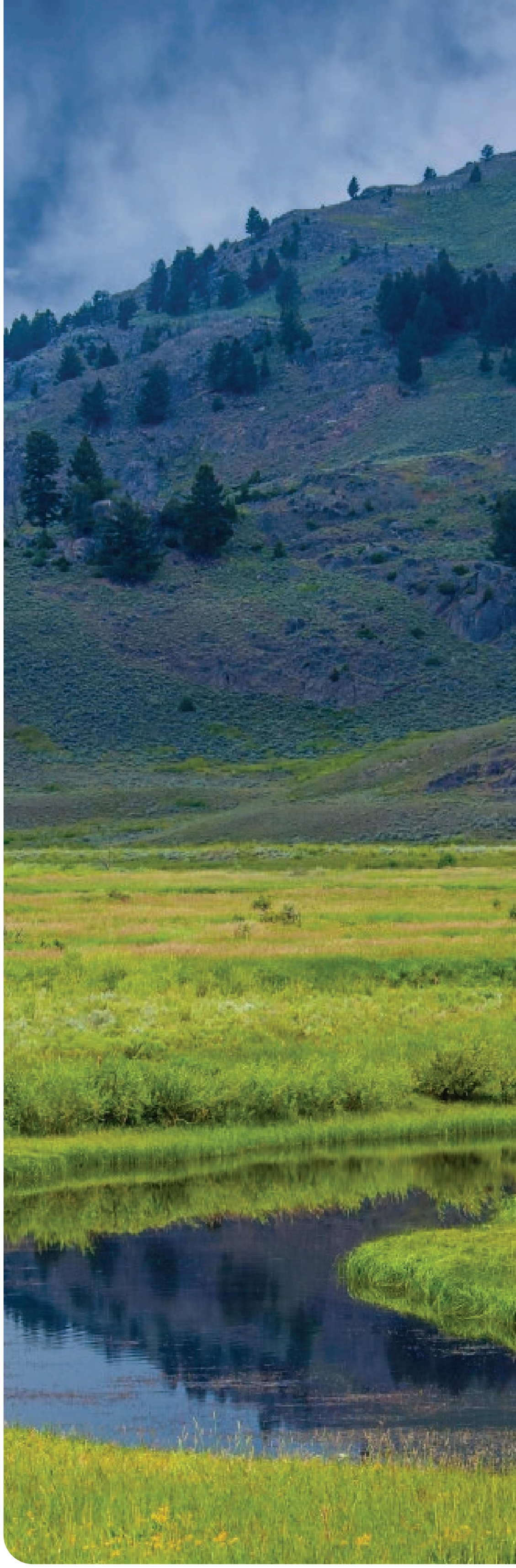
> *"Following any public review of the report as provided in this section,* ***but in no event before the United States department of energy issues a final environmental impact statement...for a permanent repository for high-level radioactive waste,*** *the director shall submit the report to the legislature."*
> (Emphasis added)

[23] Refer to (*Joint Minerals, Business & Economic Development Committee*, 2024b)

Since Yucca Mountain is no longer a viable location for permanent SNF storage, Wyoming faces a *severe obstacle* in acquiring a CISF. No permanent spent fuel storage alternatives are available strictly limiting the States' ability to host a CISF facility.

The draft Joint Minerals, Business and Economic Development Committee bill[24] which was sent to chamber for approval as House Bill 0016 seeks to remove this barrier and reduce the cost of licensing a CISF in Wyoming. A key attribute of the bill is that it would remove the requirement that a permanent disposal facility be identified for a State permit to be issued, instead requiring only substantial assurance that the facility would be temporary (HB0016, 2024). Additionally, under the proposed senate bill SF0186[25] the requirement for a permanent disposal facility would be removed, but a financial punishment would be assessed for non-compliant CISF that hold SNF longer than the predefined time period (SF0186, 2025).

Further NRC environmental and technical reports would be sufficient for permitting a CISF in Wyoming under the proposed bill (HB0016, 2024). This removes the requirements for State level economic and environmental impact studies which are already required by the NRC. The bill would reduce the costs associated with developing a Wyoming CISF by eliminating redundant reports in cases where the content of the State report is substantially similar to NRC guidelines. Additionally, the bill would change the definition of high-level radioactive waste to exclude SNF matching the NRC definition of high-level waste. This streamlines the regulatory process, cutting out the requirements for Department of Environmental Quality licensing. The passage of this bill does not eliminate the requirement that a facility receive State approval but would lower the difficulties faced to permit a Wyoming CISF. If either bill becomes law the State legal score will change from a Server Obstacle to either a Moderate Obstacle or a *moderate advantage* depending on how much support a CISF receives from the Wyoming Governor and Management Council[26].



[24] 25LSO-0253

[25] Tilted "Advanced nuclear reactor manufacturers-fuel storage" sponsored by: Senators Cooper, Anderson, Crum and Driskill and Representative(s) Larsen, L and Wylie

[26] See (Joint Minerals, Business & Economic Development Committee, 2024a; *Joint Minerals, Business & Economic Development Committee,* 2024b)

Similarly, SNF reprocessing is made more difficult by Wyoming law. The proposed changes in the Joint Mineral Committee bill would not lower the legal cost of spent fuel reprocessing as much as it would for intermediate storage facilities. The bill excludes SNF from the definition of high-level radioactive waste by applying the definition of the Nuclear Waste Policy Act of 1982. This definition reads:

> *"The term ''high-level radioactive waste'' means— (A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste"*

From this definition the regulations surrounding high-level radioactive waste would be applicable to reprocessed spent fuel. This increases the State licensing cost for commercial fuel reprocessing facilities requiring additional State approval and impact analysis.

Further large-scale SNF reprocessing in Wyoming is made impossible due to State regulations and for the same reasons CISF facilities are not feasible. SNF cannot be transported into the State without approval, and the identification of a permanent disposal facility where the final nuclear material can be sent. Spent fuel recycling reduces the volume of nuclear material that needs to be stored, but the remaining material requires special treatment. Because reprocessing does not eliminate all waste products the restrictions on the import of SNF to Wyoming apply to nuclear materials brought for reprocessing.

Yet the challenges of approving a reprocessing facility do not rise to the level of a severe obstacle, where there is no means to develop the industry without changes to the law. Wyoming provides exemptions to SNF storage rules for advanced reactors that operate in the State. This allows fast reactors such as the Kemmer TerraPower project to recycle the SNF they generate during operation. This constricts the potential scale of reprocessing but provides a path to permit small quantities of SNF reprocessing, placing the State legal requirements as a *major obstacle* to SNF reprocessing.

BENEFITS AND COSTS

The benefits and costs associated with developing a CISF in Wyoming are estimated. Direct and spillover employment and tax revenue inducement are found using an input-output model of various CISF project scales.

To complement this estimate of benefits a survey methodology is used to convert the subjective concerns of Wyoming citizens about hosting a CISF into a dollar metric. We identify that individuals are willing to pay to have a CISF located in a state other than Wyoming, for reasons other than personal risk. This generalized social cost is compared to the project benefits to assess whether constructing the project can improve the welfare of most Wyoming residents.

4.1 GENERAL BENEFITS AND COSTS

There are non-monetary cost considerations when evaluating the total value of large projects. These include any increased risk to the public, changes to the environment, adjustments in land values, and the general opinion of Wyomingites.

Economists have developed tools to assess these costs not quantified in a market. For example, environmental quality can be valued based on home price changes (Abelson & Markandya, 1985; Heberling et al., 2024; Palmquist, 1989). As an example, consider a coal power plant that begins operation in a city. When factors such as number or rooms, building age and amenities are factored into housing price estimates, the difference between home prices that are downwind of the power plant vs those upwind represents the monetary value placed on avoiding emissions by people buying a home.

This methodology of hedonic pricing has been applied to the nuclear industry, with surprising results. Homes near nuclear power plants have typically been identified as having higher values than comparable homes farther away (Clark & Allison, 1999; Munro & Tolley, 2018). This is attributed to an increase in local amenities afforded by the reactor, which outweighs any added risk of radiation exposure. Taxes from the facility fund amenities such as city parks and roads, which improves the quality of life of residents. This effect has been identified in other settings, for example, horizontal gas wells drilled in areas where land owners do not receive payments for the right to drill reduces property values, but if royalties are paid to home owners land prices increase in response to hydraulic fracturing (Bennett & Loomis, 2015; Muehlenbachs et al., 2012; Munro & Tolley, 2018). This makes it difficult to untangle the negative and positive amenities of nuclear development, although it can be said that the net economic impacts outweigh costs.

Another non-monetary cost is risk to public health. Here, economists rely on the value of statistical life (VSL) to assist in cost and benefit analysis. While the name can be confusing, this concept is not the value placed on a life, but rather the revealed value of a risk of death. For example, any time someone drives on the highway, they have taken on a risk of death or serious injury, yet the expected benefits of driving are considered greater than this cost by the individual. Economists look for revealed values of risk to determine the VSL, or rather the cost of increasing the risk of death. As an example, non-bachelor's degree office workers will be paid less than ranchers or lumberjacks that take on more risk at work. The difference between the hourly rate of these jobs, divided by the total added risk, provides a data point for the VSL.

While precise risk data is difficult to obtain for a Wyoming project, a dry storage facility in Pennsylvania was assessed as having a less than one in 1.8 trillion chance of failure in the first year of operation. Such a failure would result in a single latent death. The risk is reduced to one in 3.2 hundred trillion in each year of operation. The risk calculation by the NRC includes a range of failure points including floods, tsunamis, volcanic activity, heavy rain, traffic accidents, seismic activity, meteorites, lighting and other natural disasters. (Bjorkman, 2007; Chen et al., 2010)

The U.S. Bureau of Labor Statistics places the VSL at $13.7 million dollars, which would place the total risk value of a Wyoming CISF at less than a penny, when utilizing these risk estimates. Higher risk has been identified for transportation, with the total risk of radiation exposure reaching approximately one in a billion, for all transported materials (Cook, 2014). However, even in the event that this exposure occurs a latent death is not expected from the radiation, making traffic accidents the highest risk from transporting the SNF (Cook, 2014). Vastly scaling up these estimates does not significantly change the economic rationale. Assume that the actual risk is underestimated by a factor of 1000, and that the number of deaths is 100 rather than zero. In that case the VSL cost of the facility is $1,370. Making health risks a minimal factor in the economic evaluation of the project.

This result means that even if engineering estimates of risk are severely underestimated the financial benefits of CISF development outweigh this non-monetary consideration. If the only concern of the State is decreasing the risk of death for citizens, money brought in from the facility could be spent to improve safety standards in other areas. For example, if the facility brought in $1 million in tax revenue that money could be applied to road improvements, addiction hotlines, or emergency preparedness efforts. A million dollars applied to these programs would prevent more deaths than would be avoided by not building the CISF storage facility.

Survey of preferences

A final cost consideration is the social cost of a project by Wyoming citizens. Individuals sometimes value a resource from a conceptual standpoint alone which is referred to as a contingent value by economists. For example, people donate money to charities that support environmental enhancements at locations they will never visit. If someone is willing to donate to preserve Alaskan wildlife despite never visiting this wilderness, they have revealed that they value the cleanliness of that landscape and are willing to pay money to promote that value. However, this type of social cost is difficult to measure, since there is not always a market to identify the price of these non-use values of resources. For this reason, a survey is conducted to estimate the dollar value placed by Wyoming citizens on avoiding a CISF in the State. This price can inform policy makers of the expected social costs to citizens to be weighed against the project benefits.

Since there have been heated debates over whether a CISF should be built in Wyoming, contingent evaluation is likely to be at play. For example, some people have expressed concern that constructing a CISF in Wyoming would change the perspective of Wyoming as a beautiful and clean State (Wyoming Outdoor Council, 2019). These Wyoming citizens would be willing to pay money to avoid the construction of the CISF based on this concern, even if they would not be directly impacted by the facility.

The survey utilizes a dichotomous contingent evaluation methodology (Arrow et al., 1993; Ciriacy-Wantrup, 1947). We ask 630[27] participants if they would support a CISF site in their state[28], when the facility decreases tax payments. Half the survey takers are told that taxes will increase if the facility is not built, and the other half are told that taxes will decrease if the facility is built. It should be noted that these two policies[29] are identical. The only difference is whether the state happens to have a budget surplus or a budget deficit; in either policy the facility reduces the total tax burden on the citizens. However, the literature has consistently found that individuals will pay more to avoid a loss, than they would pay to receive the equivalent benefit (Kahneman et al., 1990, 1991; Plott & Zeiler, 2005). When participants are asked if they would pay to avoid a spent nuclear fuel facility, this is referred to as a willingness to pay (WTP) policy. If on the other hand, they are asked if they would accept a payment to allow the facility to be

[27] 600 responses were collected across the U.S. in a manner that matches basic demographic data of the U.S. including age, sex, and ethnicity. The remaining 30 response were collected by limiting the survey to only people living in Wyoming. This allows us to include a Wyoming fixed effect in the model.

[28] Using the survey platform Prolific (Prolific, 2024)

[29] The two policies presented are either 1) a tax decrease if the facility is built, or 2) a tax increase if the facility is not built.

built this is referenced as a willingness to accept (WTA) policy. The estimate of this discrepancy quantifies the political challenges of gaining approval for the CISF when the project can be rejected without paying a cost other than lost State revenue.

Participants are randomly assigned a value of the tax savings, which could be $25, $50, $75, $100, or $200. They are then asked if they would support building the SNF storage facility if they received the prescribed one-time tax benefit[30]. If they support the project the tax value is reduced by half, and they are asked again. If they would not support the project the tax value is doubled. This provides a range of reported values for avoiding CISF in Wyoming. These price ranges are used in a regression analysis to estimate the average WTP and WTA to avoid a CISF facility.

We isolate the contingent value of the project from other concerns by carefully constructing the survey design. Participants are told explicitly that the facility would not be in their own county, other tax benefits to the state are negligible, and the facility has low employment. This removes the expected risk of living near the facility[31] and the social benefits of employment and taxes[32]. The estimated contingent value captures the remaining general concerns and benefits for the state, such as tourism effects, and environmental quality that cannot be quantified via other methods.

This design allows us to answer another question important to policy makers. We seek to find out how much opposition to a CISF facility is driven by uncertainty of risk. Half of the participants are provided with more information about the facility, explaining that the risk of a disaster is only one in a billion. The difference in reported contingent value by those given more information and those not given information quantifies the effect of informing the public of risk.

[30] Tax benefits are limited to a one-time payment, so that the time value of money does not need to be estimated across populations. Participants are told that taxes will change for only one year, they are also given an understanding check before starting the tax benefit questions. If they do not record that the tax benefit only lasts a single year on this understanding check a new page is displays that provides this information in bold font.

[31] Which can be calculated with engineering reports.

[32] Which are estimated directly using an input-output model

Two data issues are managed through statistical methods in the model. Approximately 40% of respondent's self-report a protest vote, where they refuse to place a dollar value on the CISF facility, and another 10% report a cost of zero. This aligns with previous surveys of Wyoming views of nuclear power, which find that 40% of respondents are concerned about the health and safety related to nuclear-based electricity generation (Western & Gerace, 2023). Similarly this survey found that 20% or respondents were not concerned about the health and safety of storing nuclear waste in Wyoming (Western & Gerace, 2023).

We consider a reported cost of zero (willing to pay to acquire the facility) as a valid response. Some people place a premium on supporting the nuclear sector or on reducing the cumulative risk of SNF exposure in the U.S. making the project a net benefit. However, values of less than zero are censured by the survey design. If an individual would be willing to pay $100 to bring the facility to Wyoming this is recorded as approximating zero. To account for this a spike model is used (Aizaki et al., 2022). This accounts for positive values to the project, by expanding the distribution of the responses clustered at a price of zero.

Because there is no cost to someone saying "no" to each policy proposal, most protest votes misrepresent the true willingness to host a spent nuclear fuel facility. While private ethical concerns are worth considering in the project costs, these responses are implausible and bias the results. For example, individuals would not be willing (or able) to pay 10 million dollars to avoid the project in Wyoming. Even if an individual survey taker only considers the environmental quality of the State with no concern for individual income; receiving a large enough tax payment would improve net environmental quality. As an example, a $1,000 payment made to build a Wyoming CISF could then be donated to a wildlife rescue fund providing an environmental benefit larger than the environmental cost associated with the CISF facility. This makes the self-reported protest vote responses not plausible from an economic perspective. Survey respondents that self-report an infinite cost to the facility, have rejected the survey construction to express as strongly as possible their opposition to a CISF project.

Due to this data concern, an inverse propensity weighting method (IPTW) is applied. We remove the reported protest votes from the data set, and then weight the remaining data points. The data is weighted so that the final data set is similar to the original attribute balance of the original data. For example, women report a higher level of concern for the CISF construction than men on average, so more women are removed from the data set due to providing a protest vote. Therefore, women with high levels of concern for the environment but who do not provide a protest vote are weighted higher than men who have a low reported concern. If the unobserved contingent value costs match those of individuals with similar concerns and demographics, this provides an unbiased estimate of the true contingent evaluation.

A final procedural concern is hypothetical bias (Ajzen et al., 2004; Arrow et al., 1993; Hensher, 2010; Murphy & Stevens, 2004). The survey's participants are not required to pay the proposed tax increase or receive the benefits of tax avoidance. As a result the survey question is hypothetical and responses overstate willingness to pay to avoid a spent fuel facility (Hensher, 2010; Murphy et al., 2005). Different methods have been used to account for this bias, including explaining the cause of the bias to survey takers, and applying adjustments to the results based on the survey methods (Aadland & Caplan, 2006; Furno et al., 2019; Murphy et al., 2005).

The hypothetical bias is most pronounced when the estimated contingent value is large (Murphy et al., 2005). As a result, the IPTW method partially corrects for this bias, by downweighing participants that report extremely large contingent values, which are unlikely to be paid if such a proposal were up for a vote. Furthermore, the survey emphasizes that the DOE is seeking a host state, and that the survey is in response to an actual policy consideration. However, we do not deploy deception in the survey, so participants know that the policy proposed is not actually on the *ballot* in their own State and is just one of many possible options. Hypothetical bias is therefore expected to be present in the reported values.

To correct this an adjustment factor is applied. In previous research a meta-analysis was used to predict the level of hypothetical bias for WTP survey estimates (Murphy et al., 2005). In this meta-analysis the market price of goods was compared to the self-reported contingent value found in various surveys. Using a linear regression model, the actual price paid is mapped to survey design parameters and the survey estimate of willingness to pay (Murphy et al., 2005). This equation[33] is used to calibrate the model. Additionally, hypothetical bias has been found to affect willingness to pay settings differently than willingness to accept scenarios (List & Gallet, 2001; Penn & Hu, 2021). This gap is largest where participants do not consider the survey to directly affect policy outcomes (Vossler et al., 2023). While the bias may be small for private goods, public goods such as land quality, are found to have higher bias from WTA estimates compared to WTP (Penn & Hu, 2021). For the case at hand, we apply a correction factor by dividing the WTA responses by 4.17 based on a WTA meta-analysis[34] (Penn & Hu, 2021).

We report two regression results based on this methodology. In the first model, all recorded data points are included allowing protest votes to count in the final contingent valuation. In the second model only non-protest votes are included. The final Wyoming contingent valuation estimate falls in between these two models and applies the IPTW method.

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[33] The equation applied is $\ln(Price) = 0.2856 \cdot \ln\left(\frac{CV}{1.67}\right) + 0.1603 \cdot \left[\ln\left(\frac{CV}{1.67}\right)\right]^2 + 1.09051$ where price is the unbiased willingness to pay of participants, and CV is the estimated contingent values found from the survey. The 1.67 factor is an adjustment for inflation from 2004 to 2024. Based on the original regression, the dummy variables "choice", and "calibrate" are one, and all others are zero. We adjust for inflation from 2004 to 2024 dollars which changes the coefficients.

[34] The correction factor (CF) is the survey estimated WTA divided by actual revealed WTP. From a meta-analysis linear regression, the CF for the current survey is $CF = e^{0.98+0.448} = 4.17$. This estimate assumes there is no model selection bias (number of data points approximate infinity). The estimate applies a public good dummy of one, but all other dummies (student, peer reviewed, auction, within, value of time, and non-traditional) are zero. (Penn & Hu, 2021)

Estimates of the factors that affect the payment are provided in Table 10. Variables with asterisks are found to be statistically significant, meaning that the estimate is not likely to be caused by random chance. The model predicts the likelihood that a survey taker will reject the project, and the associated tax benefits. Therefore, a negative number next to a variable means that increasing that variable raises the chance of someone supporting the CISF project. Note that the reported payment estimates in Table 10 are not yet adjusted for hypothetical bias or censored protest votes.

Table 10:
Double Bounded Dichotomous Choice Survey Results

Dependent Variable:	Response of 'No, do not build'.			
	All Data		Protests Excluded	
Model:	(1)	(2)	(3)	(4)
Variables				
Payment ($ log)	-0.006***	-0.007***	-0.010***	-0.011***
	(0.0004)	(0.0005)	(0.001)	(0.001)
Tax Increase	-1.174***	-1.13***	-1.083***	-0.921***
	(0.188)	(0.210)	(0.216)	(0.210)
Relative Concern	0.217***	0.223***	0.116***	0.117***
	(0.018)	(0.021)	(0.022)	(0.0206)
Age Group	0.089	0.083	-0.045	-0.046
	(0.056)	(0.063)	(0.065)	(0.063)
Given Information		-0.212		0.129
		(0.202)		(0.202)
Male		0.143		0.194
		(0.205)		(0.205)
Eduction Level		0.014		-0.008
		(0.077)		(0.077)
Population Density (log)		-0.075		-0.026
		(0.061)		(0.061)
Home Value ($ log)		0.186		0.127
		(0.183)		(0.183)
In Wyoming		-0.292		-0.285
		(0.489)		(0.489)
Constant	1.990***	0.279	1.365***	-0.141
	(0.250)	(2.08)	(0.282)	(2.08)
	Per capita payment estimate			
Mean	$322.61	$286.50	$76.07	$72.12
Median	$294.50	$261.05	$18.10	$21.83
Fit statistics				
Observations	624	491	319	258
Log-Likelihood	-665.21	-549.52	-487.53	-405.38
AIC	1,340.44	1,121.04	985.064	832.76
BIC	1,362.62	1,167.19	1003.89	871.85

IID standard-errors in parentheses
*Signif. Codes: ***: 0.001, **: 0.01, *: 0.05, .: 0.1*
Logistic distribution with a spike at zero estimated.
Payment is dollars received if the facility is built
Population density and home values are linked at the zip code level

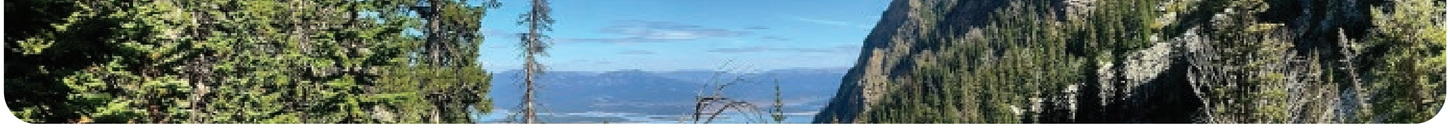
These results provide multiple insights into the reported value of avoiding a CISF facility. Only three factors are found to consistently change the probability that a CISF facility is supported. These include the size of the tax benefits (Payment), whether the participant was told a tax increase would occur without the project (Tax Increase), and average level of self-reported concern of the project risks compared with social benefits (Relative Concern)[35]. After accounting for these three factors no other variables are statistically significant, including living in Wyoming.

As will be elaborated with additional analysis, a respondent's level of concern can be affected by these other attributes. After accounting for levels of concern, there are no differences in willingness to pay between sexes, or age groups, but concern levels vary across these categories. In other words, if an 18-year-old and a 50-year-old report an identical level of concern about the project their willingness to pay is the same, but 50-year-olds have a higher level of concern on average. This means that demographics affect the willingness to pay to avoid a CISF but only through the average relative concern response.

These variables each have the expected effect on the views of SNF storage. Increasing the tax benefits of the project results in higher CISF support. People with higher average levels of concern about the project are willing to pay more to avoid the construction. Finally, if the tax benefits from the CISF are explained as preventing a tax increase (WTP) instead of providing a tax reduction (WTA) respondents are more likely to support the project. This matches the conclusion of the behavioral economics literature, but the magnitude of this effect is striking, and helps to explain the "not in my back yard" phenomenon observed for CISF projects.

One surprising result is that providing safety information does not have a statistically significant effect on support for the project. This non-result is important for policy makers. Other surveys have found that people informed about nuclear energy are more likely to support nuclear development (Bisconti, 2023). Housing values can increase due to the existence of a nuclear powerplant, which is attributed to nuclear industry experts viewing risks as minimal (Gamble & Downing, 1982). It might be drawn from these studies that providing new safety information to individuals could bolster support for nuclear projects. Yet these results put that conclusion into question. Providing project information to non-experts is unlikely to be effective at increasing project support, even if experts tend to be more supportive of nuclear projects.

[35] Relative concern is a calculated value. We ask participants to rank six



The effect of information leading to higher support for nuclear energy projects could be driven by self-selection. Individuals that have significant knowledge of the nuclear industry are already more likely to support nuclear energy. If someone is open to the benefits of nuclear energy, they may investigate the industry more closely, or even pursue a career such as nuclear engineering. On the other hand, someone with significant concerns about nuclear energy has little incentive to learn more about the particulars of nuclear energy. An alternative explanation for this result is that the type of information provided matters. A person with a deep understanding of the issues surrounding nuclear energy has conducted their own research over a period of time. When we provide a single unsolicited piece of information, this may be less trusted than a self-initiated study. In either case it is important for policy makers to understand that additional information provided to the public is unlikely to persuade citizens of the safety of a CISF projects in isolation.

The final evaluation of Wyoming contingent value costs of a CISF are estimated using the IPTW model estimate, with additional corrections for hypothetical bias. The covariates are the same as in model 2 and 4 of Table 10. We predict the model for each age and gender category and apply the prediction to the demographic distribution of Wyoming as observed in U.S. Census[36]. The average relative concern in each demographic group is applied to the whole category before utilizing a correction factor for hypothetical bias. The per capita Wyoming contingent value is reported in Table 13, with the values estimated both for a theoretical tax deduction from the project, and for an avoided tax increase. Table 11 reports the total contingent value when summing this adjusted value across the adult population of Wyoming.

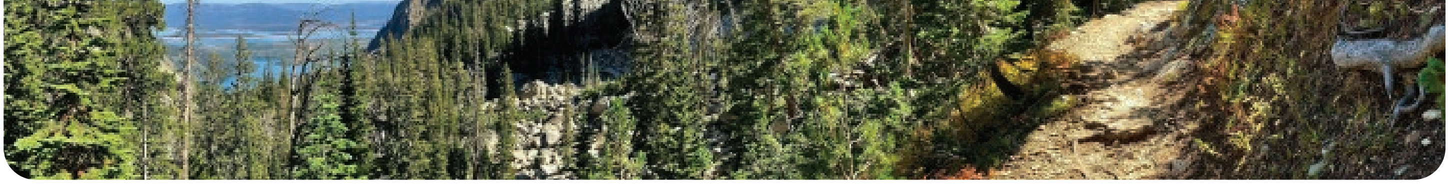
Table 11: Wyoming Per Capita Contingent Value of Avoided CISF

	Tax Deduction	Tax Avoided
Median	$30	$17
Average	$38	$41
All Data Median	$101	$88

Table 12: Wyoming Total Contingent Value (Million dollars)

	Tax Deduction	Tax Avoided
Median	$11.2	$6.5
Average	$14.4	$15.4
All Data Median	$37.9	$32.9

36 Data from (Wyoming Administration Economic Analysis Division & U.S. Census Bureau, 2020)



Each of these values is useful for a different application of the contingent value estimate. Economic welfare estimates should be taken from the average effects. The willingness to pay estimate is the cardinal metric for contingent evaluation (Arrow et al., 1993). This corresponds to the average tax avoided entry in the contingent evaluation metric of $41 per person. The reason that a WTP estimate is preferred to a WTA metric is that it directly makes the participant think about economic tradeoffs. Where Wyoming seeks to maximize citizen welfare, a total contingent cost of $15.4 million dollars can be assessed on the project, requiring at least this value in return to be a net benefit to the State.

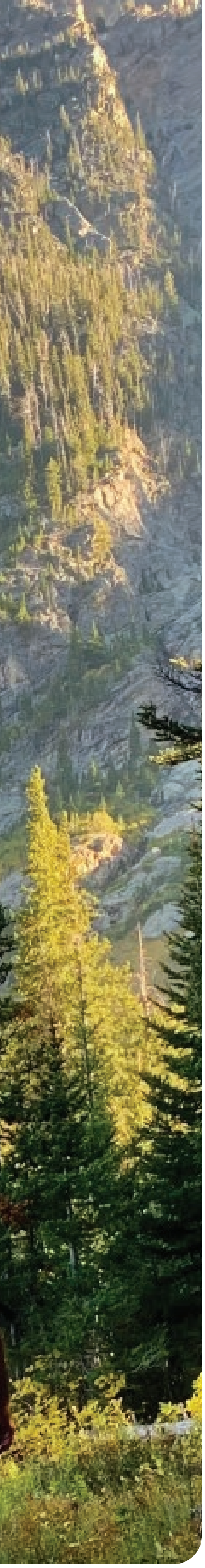
After applying an adjustment factor for hypothetical bias, the WTA and WTP estimates converge. Prior to adjusting for this bias the WTA estimate is $160 per person compared with $103 in WTP, a 60% difference. After adjustment WTP is 7% larger than WTA. This difference is within the expected range of uncertainty, making the difference statistically insignificant. This could be an indication that public sentiment about spent nuclear fuel is an unreliable metric of actual perceived costs. Because a CISF policy falls into a WTA paradigm, the self-reported level of concern is much larger than what individuals are likely to vote for. For example, a public opinion poll about hosting a CISF is likely to underestimate the number of people who would vote for a CISF approval when the project costs and benefits are made clear. This initial opposition may create additional obstacles to approval. This can help explain why Fremont County had previously approved a CISF project, but there was additional expressed concern at the State level debate (Sullivan, 1992).

These numbers also provide insights into the political feasibility of CISF approval. A popular vote referendum would need to provide at least the median value estimate to gain majority support. The policy would fundamentally be a WTA question, since the voter can reject the project at no cost. This suggests that Wyoming citizens require at least $30 per person or $14.4 million in total benefits from the project for it to win democratic majority support. Interestingly the support for a CISF facility will increase if the State faces budget shortfalls due to declining coal and oil severance taxes. If the SNF storage facility benefits are used to avoid a looming tax increase, then a lower threshold needs to be reached with only $17 per person or $6.5 million in total returns.

These results can also be compared to the survey using the IPTW method, but not correcting for hypothetical bias. This is shown in Table 13.

Table 13: Unadjusted Wyoming Per Capita Contingent Value of Avoided CISF

	Tax Deduction	Tax Avoided
Median	$124	$38
Average	$160	$103
All Data Median	$420	$219



As expected, these estimated costs are much higher than the hypothetical correction model. This suggests that most Wyoming citizens will report a higher level of opposition to hosting a CISF than would be borne out by actual votes. This large discrepancy is produced by a few factors. For example, this survey does not directly affect policy so it is in a respondents advantage to overestimate their own contingent value in order to push policy in the direction they desire (Vossler et al., 2023). An alternative explanation is that people are less familiar with decisions involving public goods when compared to private goods leading to a overestimation of the actual value of the service (List & Gallet, 2001). A final possibility is that respondents wish to answer "correctly" viewing a rejection of the CISF as the morally correct viewpoint. Overstating their true willingness to pay comes with no cost but has the benefit of signaling a pro-social behavior. However, a real vote on policy would bear a cost leading to lower WTP than was originally reported.

These numbers can also be applied as an upper bound estimate of total social costs. By downweighing the dollar value of protest votes, the weighting method increases the proportion of respondents that provide a reported value based on their true willingness to pay, reducing hypothetical bias. Where the hypothetical bias is completely removed by this procedure the results in Table 13 are accurate, where hypothetical bias is largely uncorrected the results of Table 12 are a better estimates. As a result, the actual WTP likely falls between these two models. In the case of WTP between $41 and $103 and for WTA between $38 and $160 per person. Future research will explore the effect of this weighting procedure on hypothetical bias mitigation.

An additional analysis of this survey data is conducted, which sheds light on the reasons for opposing or supporting a CISF project. We ask participants to rank their level of concern about a CISF project in their state, based on six categories[37], and to rank the importance of six possible benefits to the CISF project[38]. Prior to the data completion we expected to identify clustering of types of concerns and anticipated benefits that correspond to underlying political beliefs. For example, whoever strongly supports industrial growth of their state might rank job creation as an important benefit, and tourism reduction as a major concern. People with these beliefs may view the project in a different light than someone who is concerned about health and safety.

To test this hypothesis a correlation matrix of each category is provided in Figure 12. The first column "Should build" is a variable which is one if a respondent indicates they would support the project at either of the two price points they were given in the survey.

[37] Environmental damage, health risks to self, health risk to others, impact on tourism, cultural site impact, and social justice

[38] Job creation, support of low carbon energy, tax revenues, national energy security, lower energy costs, and promotion of the nuclear industry.

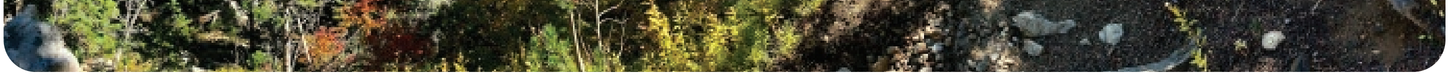
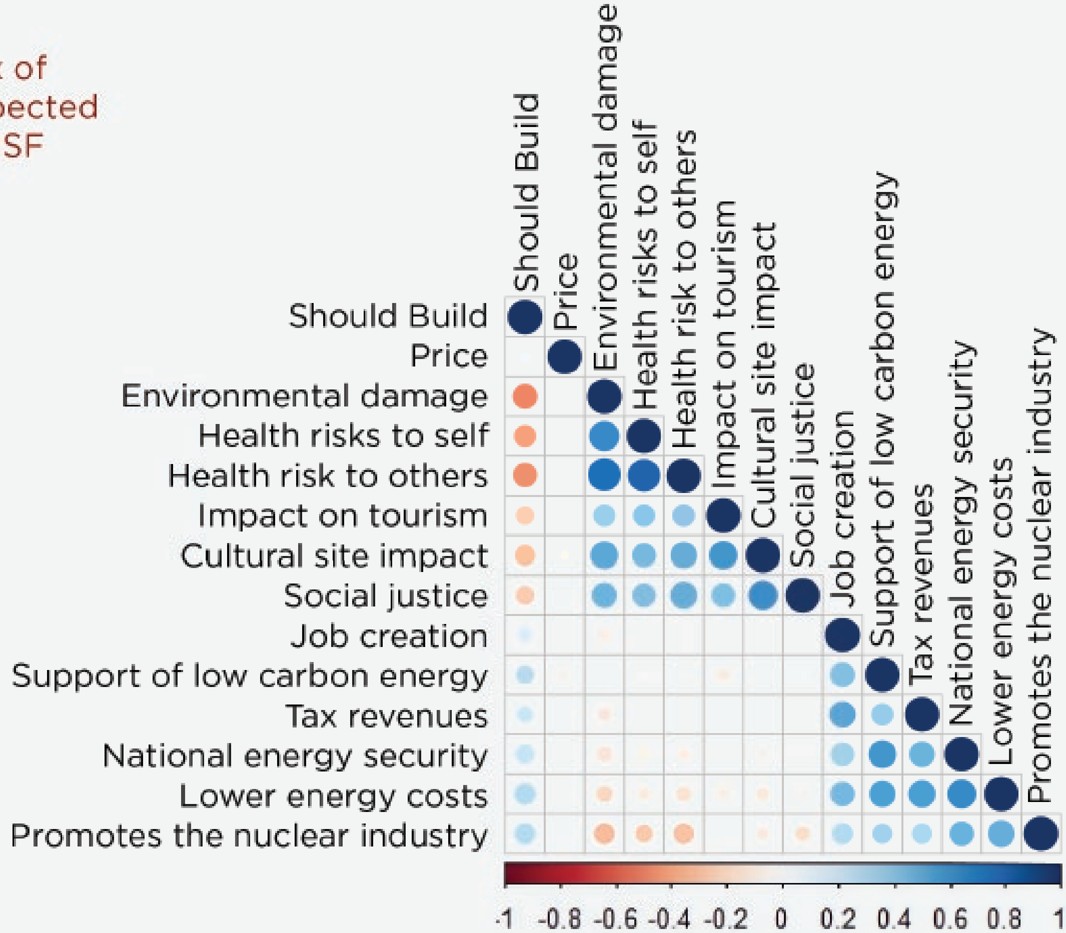


Figure 12:
Correlation Matrix of Concerns and Expected Benefits from a CISF Project



A few points can be drawn from this correlation matrix. Strikingly the level of reported concern of all six categories are strongly correlated with each other, as are all reported levels of benefits. A k-mean machine learning algorithm is applied to identify the optimal number of opinion clusters (MacQueen, 1967). This method determines that individuals can be categorized into two main groups, those that view the project as providing average benefits, and those that view the project as having significant downsides. No subgroups are found to be important in cluster identification. This aligns with the observation that a large portion of the survey responses indicated they would never support the CISF project.

Some nuance in opinion is observed in the data. For example, people with a high reported concern in any category have a negative correlation with viewing the promotion of the nuclear industry as an important benefit. Within this group however, those that report social justice as a major concern have a weak positive correlation with considering the promotion of low carbon energy to be an important benefit.

Of all the categories, people who report a high level of concern about “health risk to others”, or “environmental quality” are most likely to oppose the project. Those that view “support the nuclear industry”, “lower energy costs”, and “support of low carbon energy” as important benefits are the most likely to support a CISF project.

Since there are only two primary types of respondents, the kernel density distribution of the average concern index and average benefit index is displayed in Figure 13.

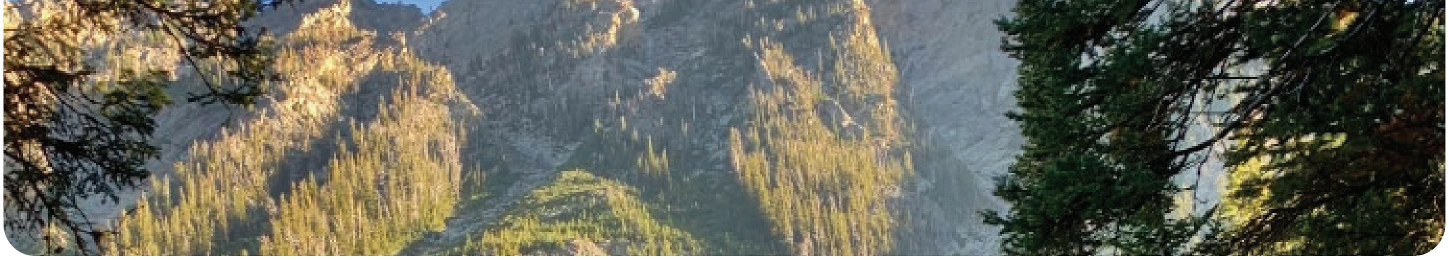
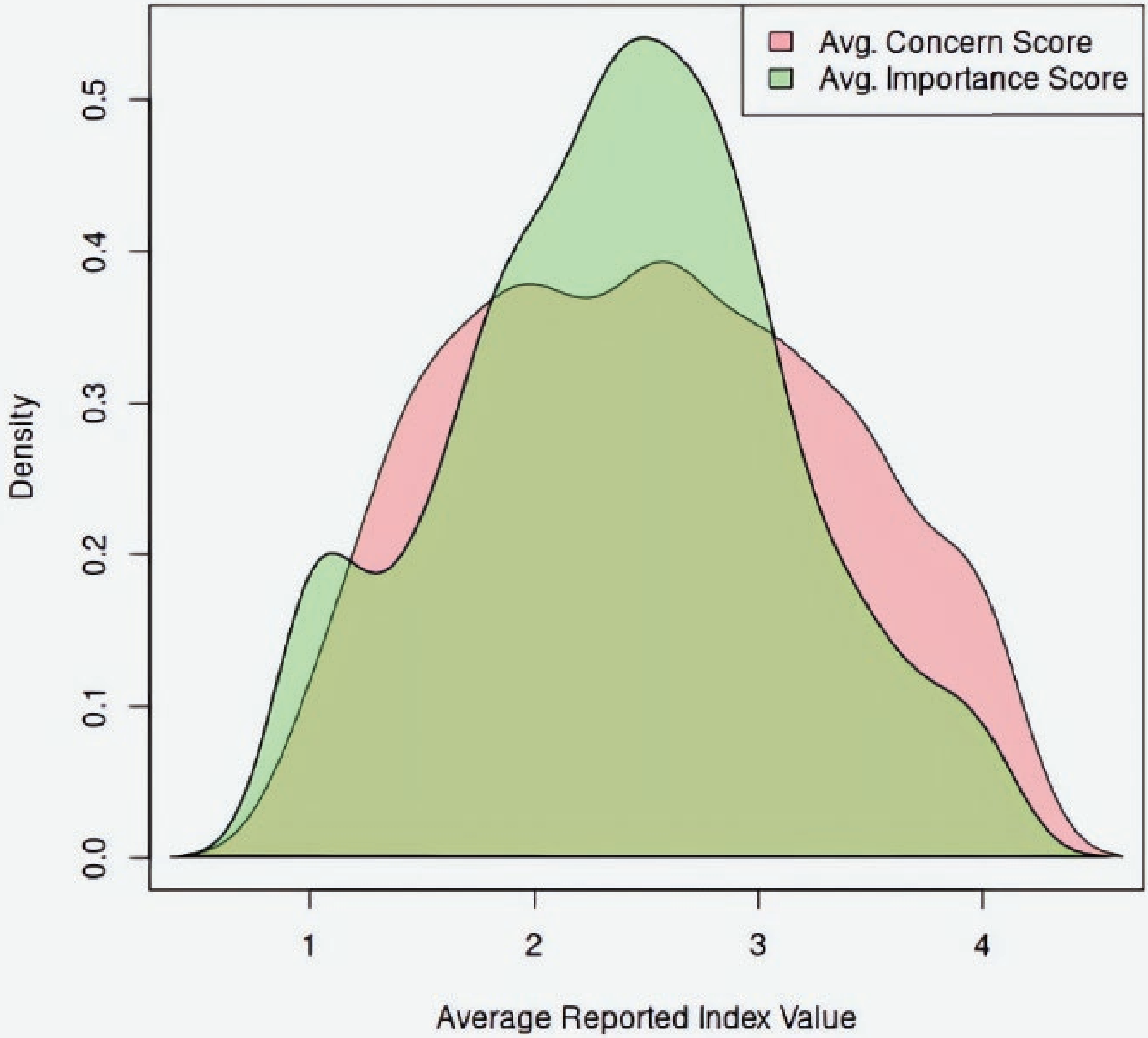
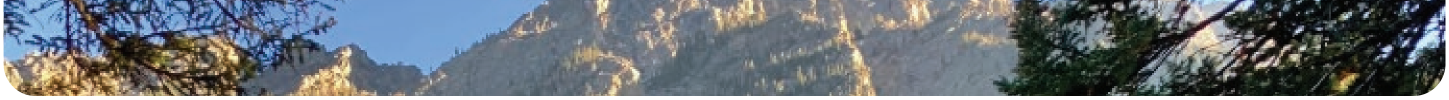


Figure 13:
Distribution of the level of concerns and importance of benefits from a CISF



The distribution of the average concern index is not the same as the distribution of average importance of benefits index. Average concern is more evenly distributed with a mild skew towards higher concern. On the other hand, the importance of benefits is centered around a response of “somewhat important”, “or not important”. There is a large clustering of responses towards the left tail where each category was ranked as “not important at all”. This suggests that the expected benefits play a smaller role in project support than the average concerns.



Finally, we evaluate how demographics and information influence one's propensity to support or oppose the CISF project. We perform regression analysis on three indicators of opinions about the project. A logit model is used to predict the likelihood that a respondent will support the CISF even if there are no tax benefits to them which we defined as "Strong Support". Likewise, the same model setup is used to predict if a respondent reports that they will never support the project no matter how large the tax benefits which we define as "Strong Opposition". Finally, an ordinary least squares regression is used to predict the characteristics associated with elevated levels of concern. This variable is highly significant in the regressions of Table 10. Here we disentangle which variables affect the contingent valuation, through changing concern. These model results are presented in Table 14.

Table 14:
Logit Model of Level of Support for a CISF

Dependent Variables:	Strong Support	Strong Opposition	Relative Concern
Model:	(1)	(2)	(3)
	Logit	Logit	OLS
Variables			
In Wyoming	0.9717	-0.0214	-0.7382
	(0.8955)	(0.4741)	(1.464)
Male	0.6643*	-0.5709***	-2.844***
	(0.3438)	(0.1925)	(0.5935)
Age Group	-0.1260	0.2814***	0.7987***
	(0.1030)	(0.0616)	(0.1863)
Given Information	0.9626***	-0.2923	-0.5560
	(0.3562)	(0.1932)	(0.5953)
Tax Increase	-19.19	-0.4991***	0.6173
	(1,099.8)	(0.1926)	(0.5937)
College degree	0.3507	0.0031	-0.2874
	(0.3672)	(0.2028)	(0.6246)
Population Density (log)	0.1816	-0.0481	-0.0492
	(0.1165)	(0.0599)	(0.1841)
Home Value ($ log)	-0.1715	0.0670	-0.8114
	(0.3510)	(0.1961)	(0.6077)
Avg. State Income	-0.1301	-0.5761	6.272**
	(1.810)	(1.010)	(3.112)
Constant	-0.1753	3.882	-44.31*
	(14.09)	(7.788)	(24.00)
Fit statistics			
Observations	490	490	490
Squared Correlation	0.19109	0.08306	0.09637
Pseudo R^2	0.29315	0.06260	0.01520
BIC	293.28	697.60	3,279.8

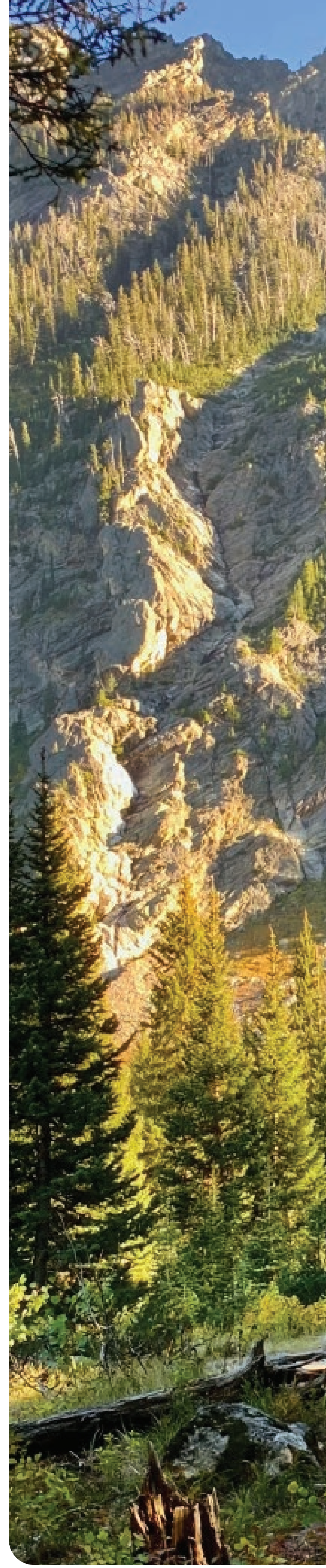
IID standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Each of these models adds to the interpretation of the primary results. The model finds that men are more likely to strongly support a CISF, less likely to strongly oppose the CISF, and are less concerned about the projects risk than women. This matches other studies which find women tend to oppose nuclear energy at a higher rate than men for Wyoming and the U.S. in general (Bisconti, 2023; Western & Gerace, 2023). Our findings indicate that men and women have no difference in project support when controlling for relative levels of concern. Taken together, a person's level of concern about the project is the main driver of opposition of a CISF, but women are more concerned about the facility outcomes than men.

A second outcome is that age does not significantly affect someone's strong support for a CISF, but older people report higher levels of concern and consequently higher rates of strong opposition. The literature generally supports the trend that older people are more risk averse than younger adults (Albert & Duffy, 2012). From this it follows that perceived risk from a project increases with age, but perceived benefits are not significantly affected by age. A risk averse person is willing to pay a premium in order to avoid a loss compared to the value they place on an equivalent benefit.

Corroborating this view is the effect of the "Tax Increase" variable. When the outcome of not building the facility is phrased as causing a tax to increase the rate of strong opposition drops. Relative concern and strong support are unaffected by this phrasing, suggesting that risk averse individuals are less likely to oppose the project when not building it imposes a new cost. On the one hand they place a premium on avoiding the health and environmental risk of the project, but on the other hand they place a premium on avoiding a new cost through a tax increase. A consistent interpretation of these results is that risk aversion influences the strong opposition to SNF storage facility.

A final point derived from these results is that providing information does raise the likelihood of someone strongly supporting a SNF facility but has a negligible influence on opposition rates. This highlights the importance of distinguishing the effect of information on different groups. For individuals that already consider the benefits of the project to be significant, informing them that engineering reports find the facility to be very safe, lowers their contingent cost of building the facility. Once given this information they are much more likely to support the facility even if no direct benefits are received to themselves personally.



However, this does not mean that this type of information can be used to increase the general willingness to host a CISF in the State. People who are skeptical about the project benefits and concerned about the project costs are unaffected by additional safety information. This can explain the correlation identified between industry knowledge and support for the nuclear industry (Bisconti, 2023). If people who have a generally positive view of nuclear industry seek out additional information, they may become more convinced of the safety and efficiency of nuclear power. However, these people are motivated to look for new information. Therefore, the information effect may be driven by sorting. Future efforts intended to provide information to the public should focus on establishing long-term engagement with the sector, rather than providing simple facts about a nuclear project.

A final note can be made about policies intended to give safety information to residents near a CISF facility. Providing information, or economic nudges can result in disbelief by those given the information (Bolton et al., 2018; Zlatkin-Troitschanskaia et al., 2020).

An example of the sort of policy that could inadvertently increase public concern was reported to us by a survey participant. They state:

> *"I used to reside [near] a nuclear plant. …All residents in a nearby radius to the plant [were] offered free iodine tablets along with a calendar offering tips on how to evacuate (with a coupon attached) to receive these free iodine tablets to be used to protect against radiation. I was never afraid of living there, just very concerned whenever they did the yearly testing and sent out these calendars. Hence, me moving to another state that is nuclear facility free."*

This response is counter to the intended goal of this policy but is a rational response. Potassium iodine tablets are given to residents living within ten miles of a nuclear power plant, through funding from the NRC (Joseph & Thompson, 2017). The uptake of potassium iodine can reduce the amount of radioactive iodine that is absorbed by the thyroid during radiation exposure from a reactor failure (NRC, 2021).

Providing these tablets reduces the risk of thyroid cancer if an unforeseen disaster takes place. However, the NRC states that such a failure is extremely rare, and tablets are provided as an additional safeguard (NRC, 2021). Yet by increasing the actual safety of residents, supplying potassium iodine tablets can increase the perceived risk of living near the facility. For some people, being supplied with these tablets signals that the facility is unsafe since the tablets would only be provided if they were expected to be used.

Similarly, providing information to respondents could increase skepticism of the facility safety. Stating that the facility has almost no risk of failure may be perceived as attempting to downplay the actual risks. Engineering studies, safety programs, and information campaigns with the goal of helping citizens make informed decisions about nuclear projects could result in more confusion than clarity if such considerations are not accounted for.

4.2 ECONOMIC IMPACTS

Outcomes in employment and State revenue from a future SNF storage facility in Wyoming were estimated. This was done through a combination of micro economic models of the Wyoming economy and game theory models of potential federal payments.

The benefits and costs of a SNF storage industry in Wyoming were evaluated using an input-output model (Leontief, 1986). In these models, the inputs of one sector are treated as the outputs of another and the system of equations is balanced with available data. The model applied comes from IMPLAN, which includes sector level data unique to Wyoming, allowing for the economic impacts to be tailored to the unique economic linkages in the State[39].

Direct Payments

In addition to any benefits that come from construction and operation of the facility, the DOE is likely to pay a fee to the host state, providing another revenue stream. Ascertaining what fee will be paid is difficult because there is a range of possible payments. These payments can be made whether the CISF is private or federally operated. Since the DOE has liability for the SNF either option provides economic value which they can incentivize by paying an individual state.

We apply the modeled project profits found in Section 3.1 to identify a reasonable range of payouts from the DOE to Wyoming. The total economic benefits of constructing a CISF were estimated by comparing the net present value of the status quo storage method and constructing a CISF. This total benefit is divided among the agents involved, primarily the DOE, the State of Wyoming, and the private firm that constructs the facility. In principle, the DOE can pay the State up to the total value of the project. In that case, the benefits would be reallocated to the State, and the DOE would be no better or worse off than if the facility was not constructed. This places the upper bound of total payments at $1.38 billion, for a CISF facility built in 2024.

[39] More information on the IMPLAN modeling process is available at IMPLAN.com.

However, two factors will likely reduce this expected payout. The first factor is that the value of building a CISF increases with time, reducing the incentive to build the facility today. The second factor is that multiple states may bid to host the facility, which will drive down the fee paid to the DOE.

Taking this first consideration into account, it is important to observe that most SNF is stored at operating nuclear facilities. The cost to store the SNF at an operating facility is lower than the cost to manage the material at central storage location (Jarrell et al., 2016; Rothwell, 2021). However, SNF is more costly to store on site than at an intermediate facility after the nuclear power plant closes (Rothwell, 2021). Because the vast majority of SNF is stored at operating nuclear power plants, the cost of storage would increase by switching to intermediate storage. As the nuclear fleet ages, the value of adding the facility also increases (see Figure 3). This means that there is a value added by waiting to initiate a CISF storage facility. Accounting for this growth, the DOE will pay less for a facility in the current year than they will in the following year. By waiting an additional year, they will save some costs, and the payment for a CISF is constrained by this growth rate in project value.

For example, assuming the value of building the centralized storage facility today is $400 million, the cost to store the waste on site for one year is $1 million, and the value of building the facility next year is $11 million. In this case, the DOE gains a total value of $10 million by waiting one more year. If this growth in value is constant, then the net present value of $10 million paid every year indefinity, at a 5% return rate is $210 million. To induce the DOE to build the facility today, the total payment to the private company and the State cannot exceed $90 million. As the age of the average SNF in the U.S. increases, the payment will increase. After all current nuclear power plants are retired, this growth rate becomes zero.

This outcome can be observed in Figure 14. In this figure, the total value of building a CISF in the given year is estimated. SNF produced by the existing nuclear fleet is forecasted into the future. Then the date until retirement of each reactor is predicted (EIA, 2024b), and the value of SNF is estimated based on the previous SNF price model.

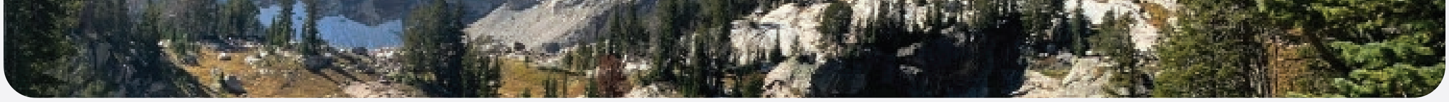
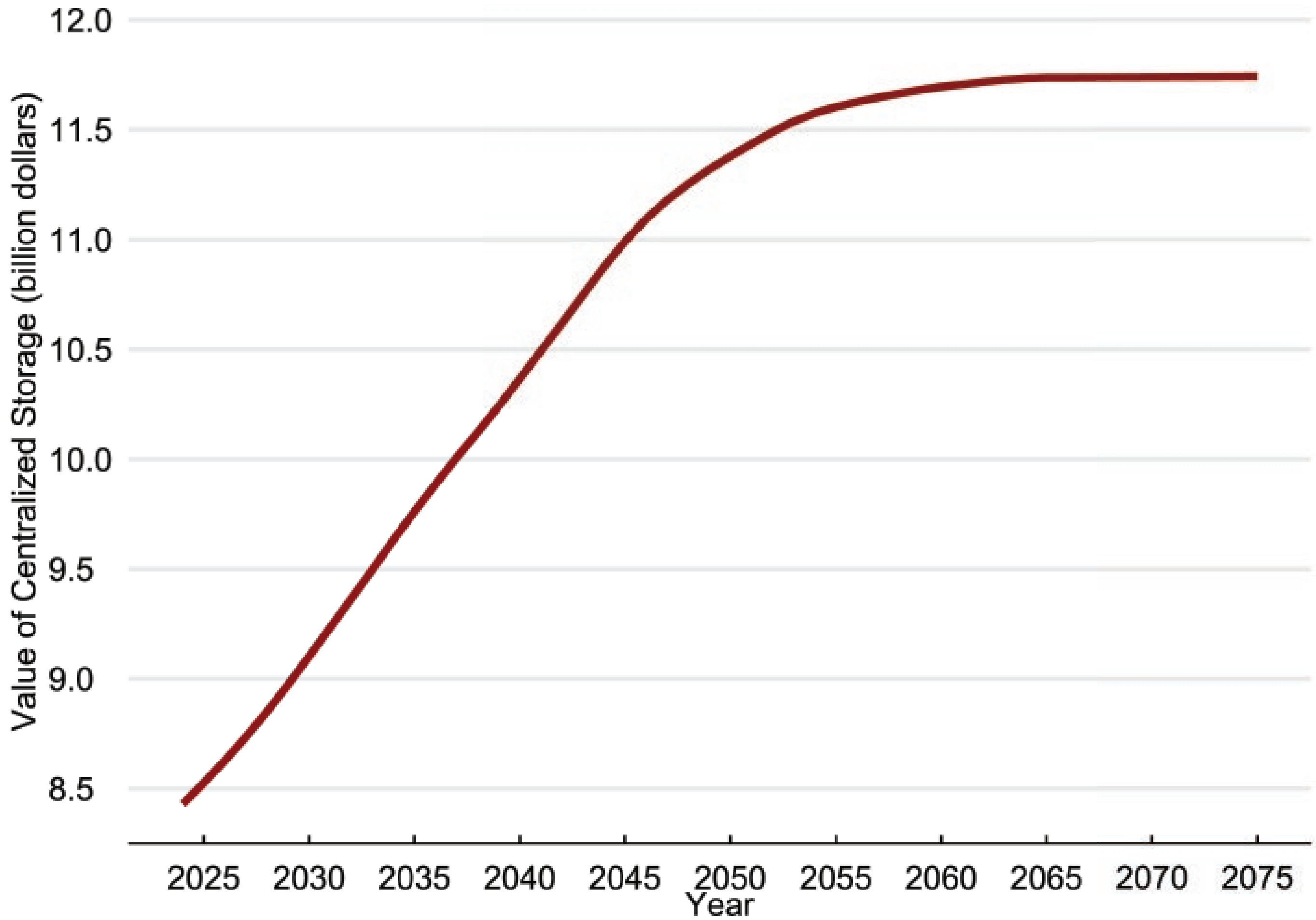


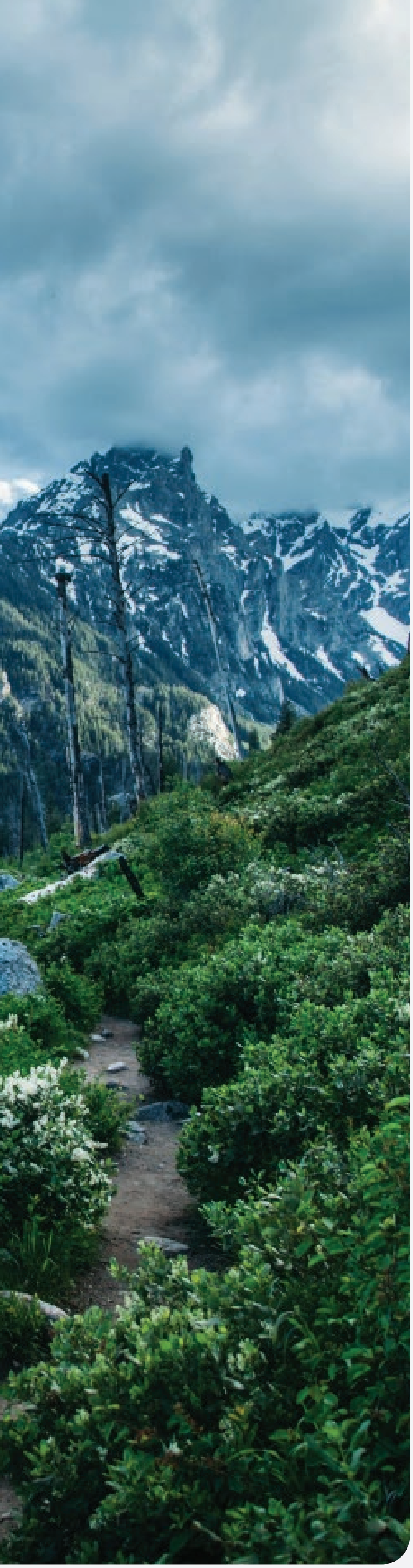
Figure 14:
U.S. Avoided Cost from Construction of a CISF



In each year the existing and new SNF draws closer to retirement increasing the overall cost, until all reactors are retired, and the project value levels out at $11.7 billion. This example shows that the rate that avoided costs grow by delaying the facility can significantly affect the value paid for a facility today.

The second factor to consider is competition with other storage sites. If two or more states are seeking to establish a SNF storage facility, then they may each reduce the bid to acquire the project resulting in a prisoner dilemma with no payments to either state (Bohnenblust et al., 1948; Poundstone, 1993).

Since the DOE has offered payments to states, but at a much lower rate than the maximum value of the project, there is evidence that an equilibrium rate above zero was reached (Bleizeffer, 2024; Reynolds, 2022; Wyoming Outdoor Council, 2019). Therefore, we develop a game theory model that accounts for competition between states, as well as the future value of SNF.



This model assumes Texas, New Mexico, and Wyoming each bid to receive a CISF project with suggested payments to the state from the DOE, but those bids may be rejected in the political process. The probability that other states will receive the project before Wyoming limits total payments. A equilibrium where no state would benefit by changing their strategy is found, which is referred to as a Nash equilibrium based on the innovations of John Nash (Nash, 1950).

The values of the model are calibrated with the outputs from Section 3.1. The total avoided costs of building a CISF are the payments. The growth rate in the CISF value is found by assuming all U.S. SNF ages one more year. The cost of storing all SNF at reactor sites for one more year, the total project cost of the CISF and the probability that a state can achieve a political outcome supporting the CISF are also considered. The model details are elaborated in Appendix C.

The DOE payments to Wyoming are reported based on the calibrated model, while allowing the probability that other states will enter the market to vary. Policy makers can make individual judgment calls about the expected odds of competition from other states based on evolving political climate. The model results are the best estimate given current data, but they depend on multiple assumptions of project costs, benefits, and timing, as well as the game theory construction. These results demonstrate the expected trends in payments depending on the likelihood of competition with Wyoming, however the exact values provided should be treated as having a significant margin of error.

The annual payments to Wyoming for hosting a CISF project are plotted in Figure 15[40]. The odds that another state will be able to make a project proposal viable within the same time frame as Wyoming is provided on the x axis. These are converted to average annual payments spread over the 40-year project, assuming a 6% discount rate. The red line represents the reported payment of $15.2[41] million dollars by the DOE for a CISF project (Wyoming Outdoor Council, 2019). The current expected payments for a Wyoming CISF facility can be identified with this figure by adjusting the odds of another state approving a project, relative to 2019 when this payment was reported.

[40] Based on a 6% discount rate over a 40-year payment period.

[41] Inflation adjusted to present dollars

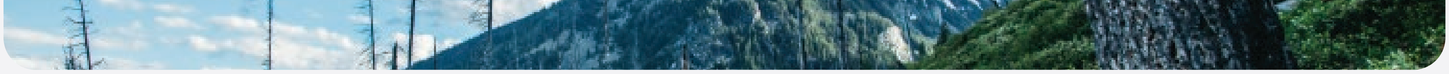
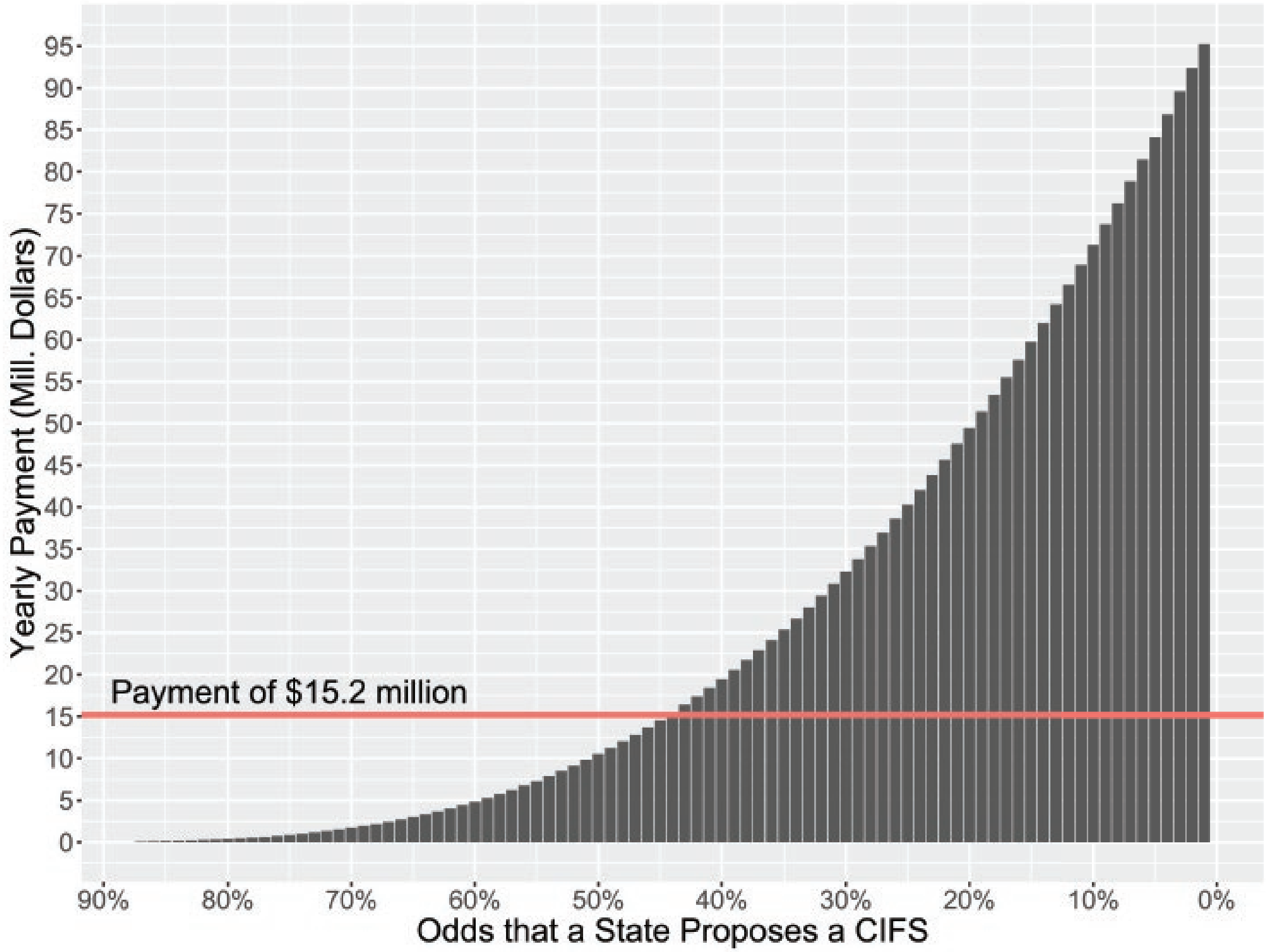
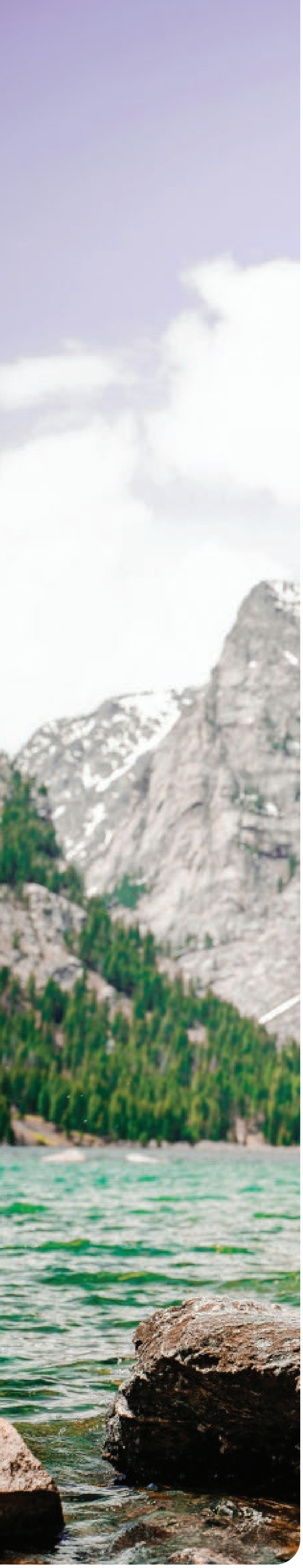


Figure 15:
Game Theory Prediction of Payments to Wyoming from the DOE



The expected payout increases as competition diminishes. The highest possible payment occurs if there is a zero percent chance that any other state can host a SNF central storage facility. In that case, the State is a monopoly, being the only supplier of centralized storage. On the other end of the spectrum, if many other states are interested in developing a CISF, and these states have already approved the project, the expected payment drops to zero. The actual payment depends on the feasibility of approving a CISF in Wyoming compared to alternative sites in other states.

Under the model assumptions, the previous DOE payment of $15.2 million, is consistent with the expectation that both New Mexico and Texas have a 43% chance of finalizing a project plan in the same time span as a Wyoming project. If the legal obstacles to a CISF project in Wyoming are minimized, the expected State payments will increase. These payments do not include the payments made to a private company, which may also be substantial. Further, this payment estimate will increase under different assumption of discount rate. For example other studies have applied a social discount rate of 3% as opposed to our market rate of 6% which raises the average value of storage (Rothwell, 2021).



We create three counterfactuals to predict the upper and lower bounds of payments to the State. On the one hand, two other states have NRC approved CISF plans which reduces the barriers to entry. On the other hand, political obstacles have restricted these projects from being initiated. A lower bound estimate of payments assumes that legal barriers will be mitigated in these other states, increasing the odds of an alternative site becoming available to 50%. Here, the payments would be $168 million total, or $10.5 million per year. Alternatively, if the political gridlock in other states continues, but Wyoming can approve a facility, the odds of a comparable facility opening in another state is assumed to reduce to 30%, this would supply a payment of $515 million total or $32.3 million per year. The baseline case is the observed payment structure of $15.2 million. This total payment is adjusted to three project sizes, with the lowest payment scenario occurring with a 20,000 SNF capacity facility, and the highest value occurring with a 12,000 SNF capacity project.

Economic Impacts

By developing a CISF in Wyoming, the State would receive economic benefits from the construction and operation of the facility. These values are estimated using the IMPLAN[42] input-output.

The CISF project model in Section 3.1 are used as a baseline for the IMPLAN model. The 20,000-ton and 60,000-ton facility are modeled as separate impacts.

Three time periods are considered, the planning and construction phase, operating phase, and decommissioning period. Tax revenues from facility operations and decommissioning are calculated as a net present value at the time of the project start date applying a 6% discount rate.

The construction phase is evaluated as an industry output shock in the IMPLAN category of a new manufacturing structure, and in architectural, engineering and related services. The facility impacts are based on estimates in Fremont County. During operations, shipping costs are modeled as an impact to rail transportation, additions to overpacks are a manufacturing structure impact, administration costs are an impact to office administration, and other operating costs are an impact to facilities support services. Decommissioning costs are evaluated as an impact on environmental and other technical consulting services. Both the operation costs and the decommissioning costs are modeled in Wyoming generally since Fremont County does not have enough economic data to estimate these specific categories of impacts.

[42] For more information on the IMPLAN modeling process, visit IMPLAN.com

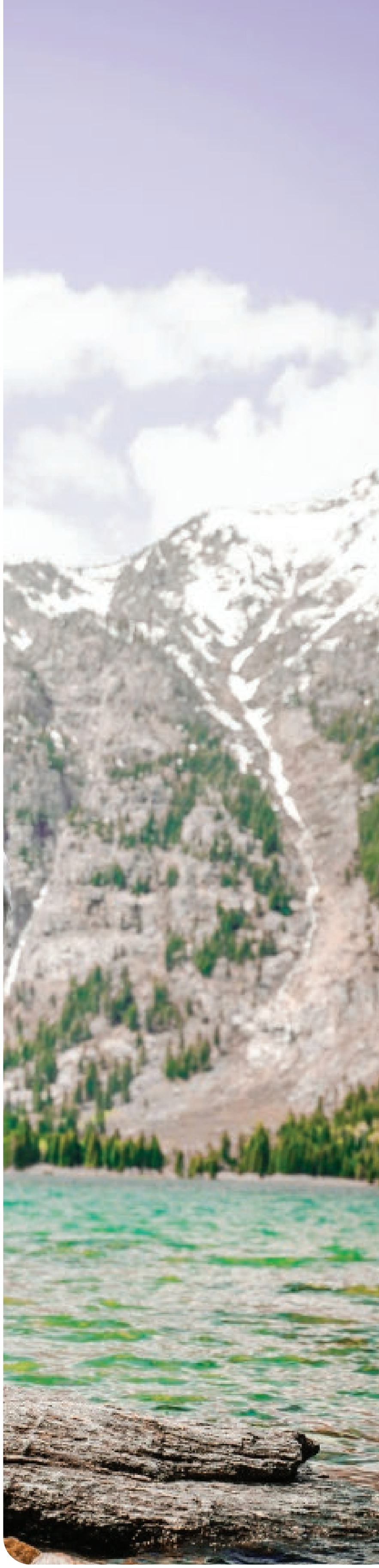
In the construction phase, the 20,000 ton SNF storage facility would add 5,700 jobs[43] with 75% of the employment coming from the direct effect of hiring construction workers, engineers, and other jobs. The remaining 25% of impacts occur from spillover and induced effects, such as spending at restaurants. Wyoming would receive $15.2 million in tax revenue with Fremont County acquiring $1.2 million. Here, most of the tax revenue comes from indirect inducement effects, with only 30% of tax revenue acquired directly from the project operations.

The 60,000 ton facility adds a total of 12,800 jobs. Wyoming state tax revenue would be $34 million, with $2.78 million collected in Fremont County. The relative split between direct and indirect payments are substantially similar with the 20,000 ton projects.

During facility operations, at a 20,000-ton facility the State can expect an addition of 900 employees, 70% of which will be direct. The largest segment of this direct employment comes from development or installation of overpacks to store the SNF with 350 jobs required. Therefore, total employment is substantially reduced when the facility ceases adding new SNF requiring overpacks. State taxes would increase by $2.1 million annually and county taxes by $0.26 million annually. 30% of taxes would come from direct effects. An operating 60,000-ton capacity storage facility induces 2,500 employees, $5.76 million in annual State tax revenues, and $0.7 million in annual county tax revenues.

Decommissioning is a major cost but won't take place until 40 years of operation. The State tax revenue from decommissioning is expected to be $4.3 million with an additional $5.2 million at the county level. 37% of this tax is paid directly by the project. When discounted over the facility operating life the net present value from the State and local taxes are $0.47 million. During decommissioning, a total of 1,700 person-years of employment will be necessary, 66% of which are direct.

The total net present value of the facility, including the discounted value of operation and decommissioning is $52.6 million for the 20,000-ton operation, and $67.8 million at a potential 60,000-ton SNF storage site. The impact of a 120,000-ton facility is estimated using an escalation factor of 0.6 for jobs and tax revenue, leading to a total tax revenue expectations of $108.5 in net present terms. A summary of economic impact estimates is provided in Table 15.



[43] In terms of person-years which is the equivalent of hiring one full time employee for a single year. This accounts for seasonal and part time jobs by adding up the total hours worked.

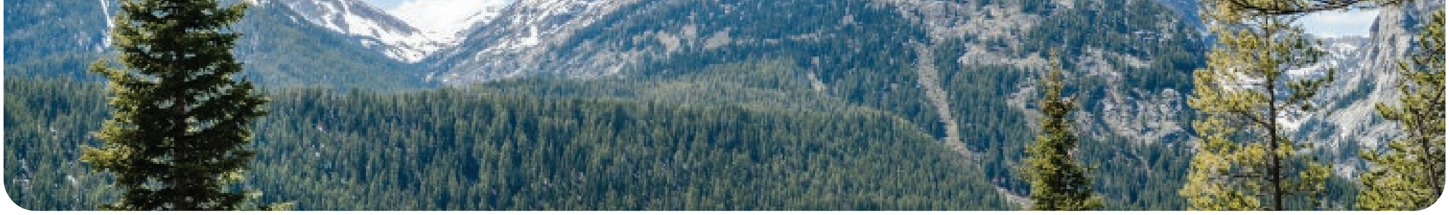


Table 15: Economic Impact Summary

Scenario	Low	Middle	High
Storage Capacity (Metric Tons)	20,000	60,000	120,000
Jobs During Construction	5,700	12,800	24,500
Jobs During Operation[44] (Yearly)	900	2,500	4,000
Contingent Value Cost (Mill. USD)	-70.6	-15.4	-16.7
Tax Revenue (Mill. USD)	52.6	67.8	108.5
DOE Payment (Mill. USD)	28	243	515
Net Value (Mill. USD)	10	295.4[45]	606.8

The estimated contingent value is included as a cost. The net value is the total value of tax revenue, and DOE payments, minus the sum of the contingent value of each Wyoming citizen. In the high scenario the lowest contingent value estimate is used. This is the sum of the median price a resident would pay to avoid the facility in the State across the population, applying a correction for hypothetical bias. For the middle scenario the average price a Wyoming citizen would pay is used rather than the median, with hypothetical bias adjustment[46]. Finally, the low impact scenario applies to the cost that represents the average tax deduction residents would require to support the facility without applying a correction factor for hypothetical bias. This upper bound cost treats the self-reported contingent values as an accurate reflection of the true project costs.

The range of expected outcomes for Wyoming net benefits are all positive, ranging from $10 million to $612. Wyoming has the highest expected value of a CISF project of any states when factoring in contingent value due to the population density. The expected per capita contingent social costs are not significantly different in Wyoming from other states. However, with fewer people the total benefits are divided among a lower population. This raises the relatively expected benefits per capita while the expected costs per capita are comparable to other regions. For example, New Mexico a location considered for a CISF could provide benefits to citizens averaging $38 per person from the income acquired by a CISF in the low-capacity scenario. Wyoming on the other hand can provide benefits averaging $140 per person with the same project. Since the expected contingent value

[44] Estimates include induced jobs which are not directly associated with operating a CISF.

[45] A highly conservative estimate of the middle scenario net benefits can be made by assuming the DOE provides no financial support to Wyoming, and to estimate the CV social cost without applying an adjustment factor. Here total NPV remains positive at $29.3. Whether the total NPV is positive is therefore not sensitive to federal payment or CV model assumptions.

[46] It is reasonable to assume that the IPTW method properly accounts for hypothetical bias. That places the middle scenario at a contingent value cost at $38.5 million dollars, and the net present value of the project at $272.3 million.

is $41 per person New Mexico will have a negative NPV in the lower bound scenario, while Wyoming receives a net benefit. On net this makes Wyoming one of the states most capable of gaining popular support for a CISF, however, as noted in the survey results there are still significant obstacles to reaching a consensus in the State. This also explains the difficulties the DOE has had in identifying a willing host state as even the states with the highest potential benefits from hosting the project are unlikely to find majority support for the project.

One other indirect benefit of constructing a CISF project in Wyoming is a reduction of the risk of radiation exposure at a national level. These results highlight a political paradox worth accounting for in policy decisions. For the U.S. as a whole, developing a CISF facility is a net positive to nuclear safety, and cost. Currently 28 states have stored spent nuclear fuel near reactors. This means at least 28 locations are at risk of radiation exposure. Even if this risk is small, collecting all the SNF at one location reduces that total risk by approximately 96%. Consequently, concentrating all the U.S spent fuel at one location lowers the total risk of exposures to people and the environment while also reducing operating costs.

The benefits to the U.S. can be observed in the contingent value survey results. The willingness to pay to avoid the facility in someone's own state could be viewed as the willingness to pay to have the SNF stored in a different state. This means a Wyoming site provides a benefit to other U.S. citizens.

The paradox presented by this outcome is that a CISF receives much more support when voted on at either the national level or the local level, than at the state level. For example, Fremont county has already supported a referendum to approve a CISF facility (Sullivan, 1992). The benefits from the facility are concentrated within the county, increasing the average support from Fremont residents. Similarly, if a vote were held on a national level, any selected location for a SNF storage facility would be approved since it would reduce the cost of storage for taxpayers and reduce the number of people living near SNF storage locations. Yet at the state level it is more challenging to approve a project, since there is a general level of concern for the State, and the benefits are divided among more people than at the local level. It is peculiar that there can be both local and federal support for a project but a rejection at the state level. Also, Wyoming is the most likely state to support a CISF project simply because the benefits would be divided among fewer people, and not because of any engineering benefits of locating a CISF in the State. This is not a matter of population density, which materially changes the number of people living near the CISF, but rather the total population of a State which does not directly affect safety. A generalized state patriotism creates a social cost for people living very far away from the facility. Therefore, the total social cost is driven by the size and boundaries of states, although on the surface social cost should primarily be linked to actual risk.

CONCLUSION

The study evaluated the opportunities and barriers of creating a spent nuclear fuel management industry in Wyoming. Five factors evaluated were found to promote either a CISF facility or spent nuclear fuel recycling in Wyoming, with eight total identified obstacles.

Factors Supporting Development

- **CISF**
  1. Wyoming has a tax structure favorable to a CISF project.
  2. There is enough demand for SNF storage to support a new Wyoming facility.
  3. Regions of the State have low seismic disturbances, little risk of water contamination, and a low population required to license a CISF.

- **Spent fuel recycling**
  1. Wyoming is the first state to approve a fast reactor for commercial use
  2. Regions of the State have low seismic disturbances, little risk of water contamination, and a low population required to license a CISF.

Barriers to Development

- **CISF**
  1. Federal legal challenges to NRC licensing prevent private CISF facilities from developing.
  2. Wyoming requires a permanent SNF disposal location to be identified before a CISF can be hosted
  3. Past attempts to approve a project in Wyoming have failed

- **Spent fuel recycling**

    1. Spent nuclear fuel recycling is not cost competitive with current technologies and uranium prices.
    2. Federal rules have not been created by the NRC
    3. Wyoming law limits access to out of State SNF for processing
    4. It is unclear if advanced reactor tax incentives can be applied to fast reactors used to recycle SNF
    5. Most spent nuclear fuel is not located near Wyoming which would be used to supply a recycling operation.

If the obstacles to developing a CISF are overcome Wyoming would see a range of benefits that scale with the size of the project. These include:

Benefits of a Wyoming CISF project

1. 1,900-8,166 additional construction employment during a three-year building period.
2. 900-4,000 additional jobs during facility operation
3. 28-515 million dollars in direct payments from the DOE

The main cost to Wyoming citizens was found to be an aversion to the facility being built. This is based on considerations such as concern about how the Wyoming environment would be perceived after the facility is built, and the effect on tourism. The total costs of a Wyoming CISF are identified as:

Costs from a Wyoming CISF project

1. $15.4 million that Wyoming citizens would pay to avoid the facility.
2. The value of statistical life costs associated with the risk of radiation exposure from a CISF project is found to be nearly zero. Indicating that most people take higher risks, such as driving, without requiring compensation.

Based on this analysis, a Wyoming spent nuclear fuel management industry will be able to expand in the coming years if legal requirements are changed at both the State and federal level. Without this change no further development can be expected.

The final paper in this series will evaluate the last link in the nuclear supply chain, nuclear produced electricity. This will provide context to these past five reports creating a standard to compare the advantages, challenges, and the economic impacts across the entire nuclear sector.

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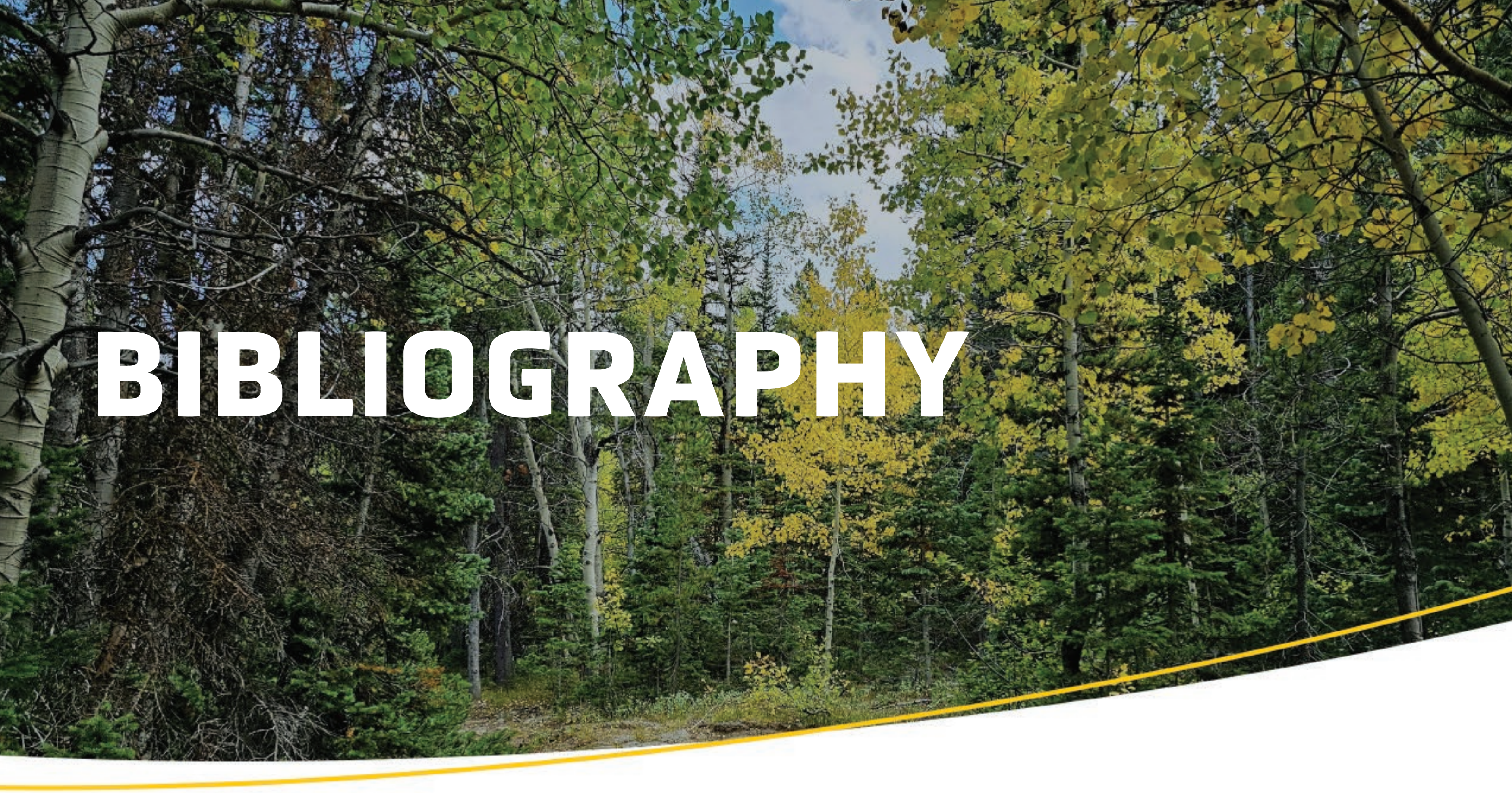

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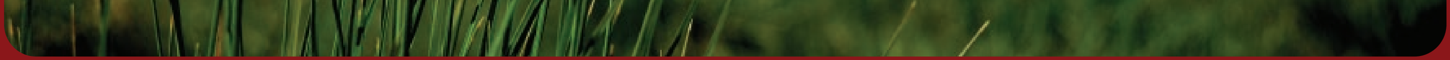

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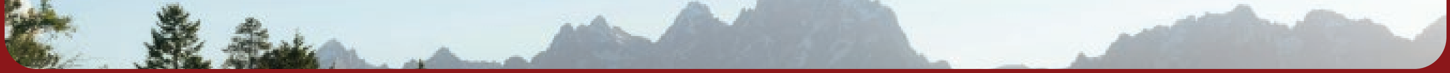

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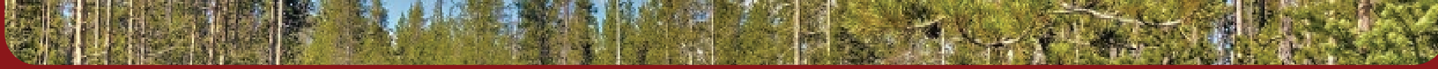

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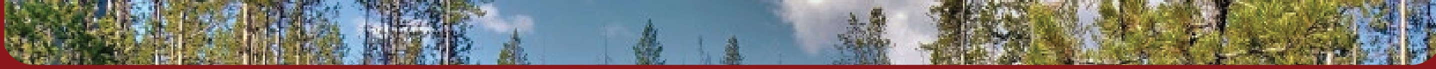

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APPENDIXES

APPENDIX (A) GENERALIZED CENTRAL STORAGE FACILITY COST ESTIMATE DETAILS

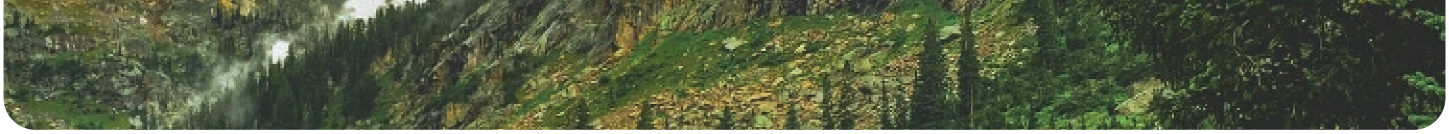
Eleven categories of costs are included in the model.

1. Transportation Infrastructure
2. GISF Infrastructure
3. Fuel Storage Facility (initial cost)
4. Fuel Storage Yearly
5. Transportation Casks and Transport Equipment
6. Decommissioning
7. Loading or unloading (labor)
8. Concrete Overpacks
9. Administrative
10. Other Operating Costs
11. Design, Engineering, Licensing and Startup Professional Services

The project is assumed to pay the cost of transportation infrastructure, GISF Infrastructure, transportation flasks and equipment, and design costs in year zero, before the project is operational.

Next, a 20-year shipping period begins. Fuel storage costs, concrete overpacks, other operating costs, and the labor costs of loading and unloading the material are ongoing from year one to 21.

In the 60-year project this is followed by a period of 20 years, where transportation, overpack and loading costs cease, but caretaker labor costs begin. These are the costs necessary to monitor and maintain the existing SNF.



In both projects the final 20 years include the cost of shipping the SNF to the final storage facility, and other operating costs. decommissioning costs accrue in year 40 or year 60. Administrative costs continue from year zero to the end of the respective project.

The capital costs derived from the initial report are provided in Table 16, cost calculated on a yearly basis are provided in Table 17.

Table 16:
Project Capital Costs ($1,000 Not Adjusted)[47]

	20,000 ton	30,000 ton	40,000 ton
Transportation Infrastructure	$97.40	$176.50	$224.40
GISF Infrastructure	$37.40	$40.80	$43.90
Fuel Storage Facility (Initial Cost)	$10.70	$20.90	$32.30
Fuel Storage Facility (Over 20 Years)	$33.10	$66.20	$99.30
Transportation Casks and Equipment	$94.60	$189.30	$270.40
Design, Engineering	$67.40	$67.40	$67.40
Decommissioning	$112.80	$225.00	$338.00

Table 17:
Project Labor and Other Yearly Operating Costs ($1,000 Not Adjusted)[48]

	20,000 ton	30,000 ton	40,000 ton
Administrative	$2.70	$3.20	$3.60
Concrete Overpacks	$26.00	$52.00	$78.00
Other Operating Costs	$21.60	$41.30	$61.00
Labor: Loading or Unloading	$5.30	$8.00	$9.90
Labor: Caretaker	$3.70	$3.70	$3.70

Costs are escalated using producer price indexes, or the CPI from 2009 values to 2024. A “nuclear building” index is developed which is the average growth in Nuclear Radiation Detection and Monitoring Instruments PPI, and the Construction Materials PPI (U.S. Bureau of Labor Statistics, 2024b, 2024e). While imperfect this average better accounts for the nuclear specific equipment used at the facility, which has a slightly slower rate of cost increases compared to general construction material. The current project costs were escalated by multiplying a cost category by the values Table 18

[47] Adapted from (Energy Resources International, Inc. et al., 2009). Fuel storage costs are calculated on a year-by-year basis, since the original report does not account for discount rate.

[48] See (Energy Resources International, Inc. et al., 2009)

Table 18:
Cost Escalation from 2009 to 2024[49]

Cost Category	FRED Series ID	Adjustment Factor
Construction	WPUSI012011	1.80
Inflation	CPIAUCSL	1.47
Rail	WPU3011	1.61
Engineering Services	PCU5413354133	1.40
Nuclear Detection Equipment	PCU3345193345195	1.63
Nuclear Capital	NA	1.71

Transportation infrastructure was escalated based on average construction costs. GIFS infrastructure, fuel storage facility, and concrete overpacks were escalated as nuclear buildings. Loading and unloading costs are escalated by freight and mail transportation by rail PPI. Design and engineering costs are escalated with the engineering services index. All other values are inflation adjusted using the consumer price index.

Final reported values are based on a private discount rate of 6%, to estimate a conservate private return on capital. However, results are calculated for discount rates from 0-15% for robustness.

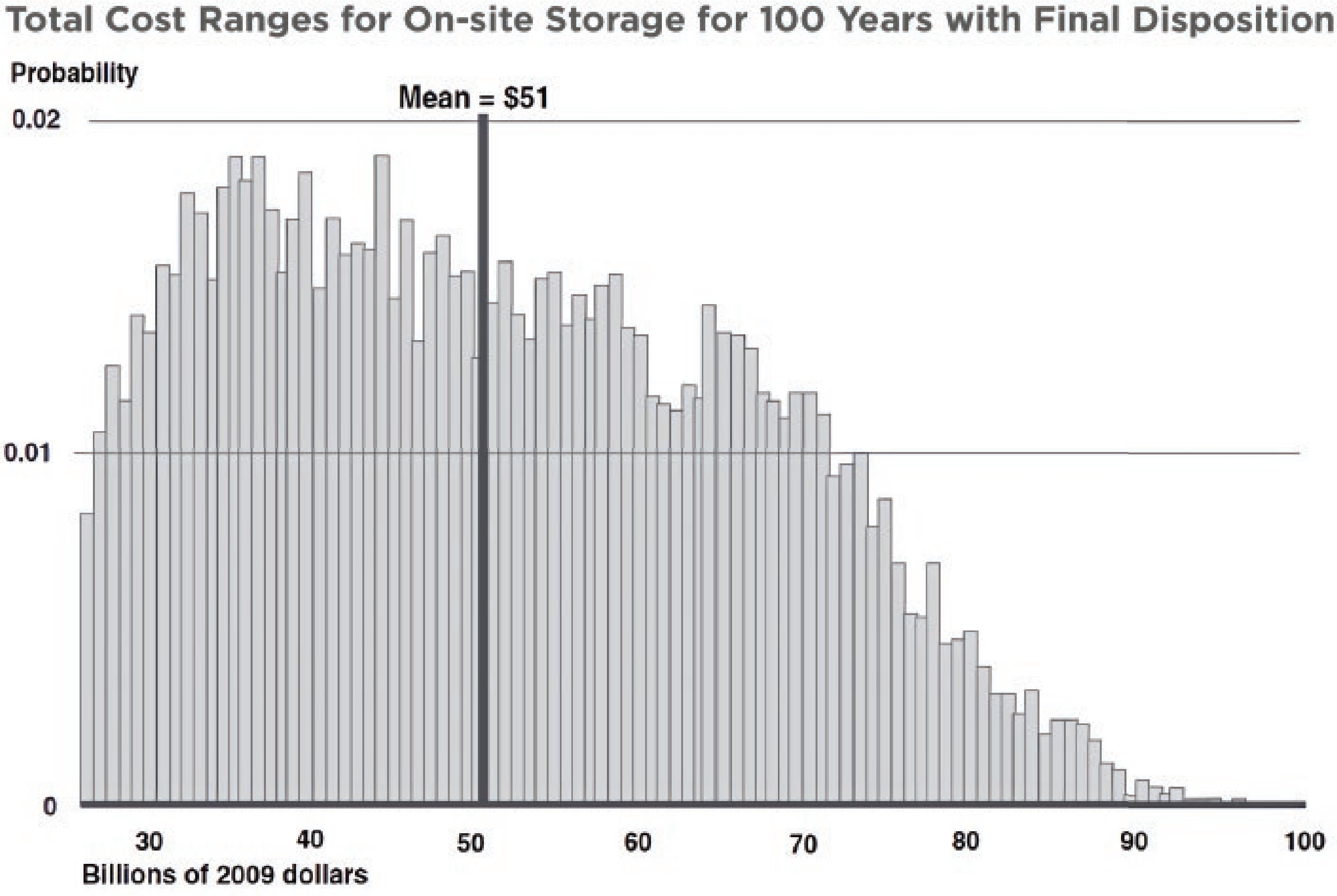
APPENDIX (B) COST DISTRIBUTION OF PERMANENT DISPOSAL AND CISF PROJECTS

There is also a cost component of temporal risk management. The final cost of onsite storage is not known in advance. Canisters degradation, natural disaster frequency, and labor costs are all uncertain in the long run. Investment in a centralized storage facility narrows the range of expected cost outcomes. The construction cost of the facility sets a floor on the long run operating costs, but also reduces the risk of high maintenance costs occurring in the future.

Figure 16 provides a distribution of possible costs from on-site storage scenarios, based on the Government Accountability Office model of storage scenarios. This can be compared to the same analysis completed for a centralized intermediate storage facility provided in Figure 17.

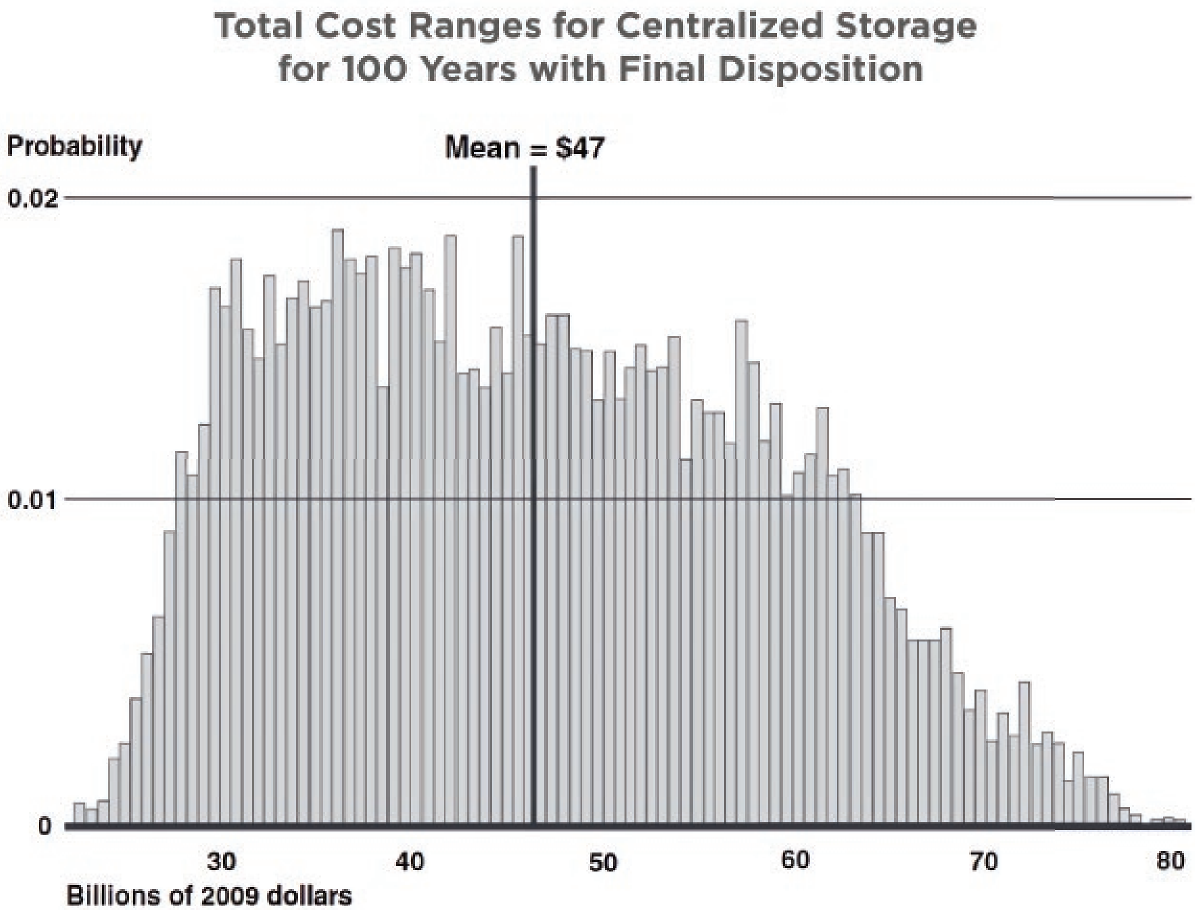
[49] See (U.S. Bureau of Labor Statistics, 2024b, 2024e, 2024a, 2024c, 2024d)

Figure 16:
Range of On-Site Storage Costs (GAO, 2009)



Source: GAO analysis of expert and DOE provided data.

Figure 17:
Range of Centralized Storage Costs (GAO, 2009)



Source: GAO analysis of expert and DOE provided data.

There is a difference in the distribution of these projected costs. For the decentralized storage methods, there are more situations where the total cost of the project is under 30 billion dollars compared to the intermediate storage plan. Under uncertain costs of future spent nuclear fuel management, on site storage performs better than intermediate storage strategies if the actual cost is lower than the average expected cost. However, if management costs are greater than expected the onsite storage strategy expenses can ballon. This leads to a higher probability density at the tail ends of the distribution of the on-site management strategy. The investment in establishing a centralized storage facility narrows this band, preventing cost escalations but creating unnecessary expenses in low management cost scenarios.

APPENDIX (C) GAME THEORY MODEL OF CENTRALIZED STORAGE

To estimate a plausible DOE payment to States that host a SNF storage facility we develop a multi-player, multi-stage game theory model.

In this model there are two payment functions, one for the DOE, and one for a number of U.S. states that can host a CISF. The DOE cannot operate its own CISF until a permanent disposal location is identified. Because of the contentious nature of locating a permanent SNF disposal area U.S. has no proposed sites, and any future permanent disposal project is likely to occur in the distant future. Because of this the DOE must rely on private companies to build a CISF and lower total operating costs. However, states have halted proposed private CISF facilities from being constructed in their jurisdiction. Sometimes the existing government supports a project, and then later elections reverse this decision.

Based on these considerations the DOE is treated as playing a repeated game with each state where a CISF is technically and politically viable. The private company is in a competitive market, and so the payment to the company is always the market rate of return on capital, here assumed to be 6%.

On the other hand, there are only a few states able to bid for the project allowing them to compete in a game to earn revenues above the market rate. While any number of state players can be modeled, we assume that three states are candidates for the project. Texas, and New Mexico once approved projects which are now on hold, and Wyoming has put a planned project in Fremont County up for consideration multiple times since the 1990's. Thus, three states is a plausible starting point for the model.

Because of the observed political risks of revoking a project each state is viewed as placing a bid for the DOE to accept a project in the State. In any given year, a state legislature can propose a project based on an expected payment from the DOE, and the DOE is told directly what payment the state will accept for the project to begin in the current year. However, this offer may be revoked by not making it through final state approval, or because of a change in state government. In the next year, other states become aware of the past period's bids by the other states, representing the fact that states can make decisions based on past observed behavior, but will not know the offers contemporaneously.

In any year the DOE will accept the lowest bid that also provides a net benefit compared to either inaction, or the value of repeating the game again.

One possible Nash equilibrium is a prisoners dilemma, where each state lowers their bid to increase the probability of receiving all of the benefits from constructing a CISF (Bohnenblust et al., 1948; Poundstone, 1993). In that case the total payment drops to the reservation price of the states, providing all economic profits to the DOE.

We are interested in a stable long-term Nash equilibrium where payments to the States are above the reservation value. This is possible in the repeat game setting, since punishment can be enforced against a state, when the bid drops below the passively agreed upon rate.

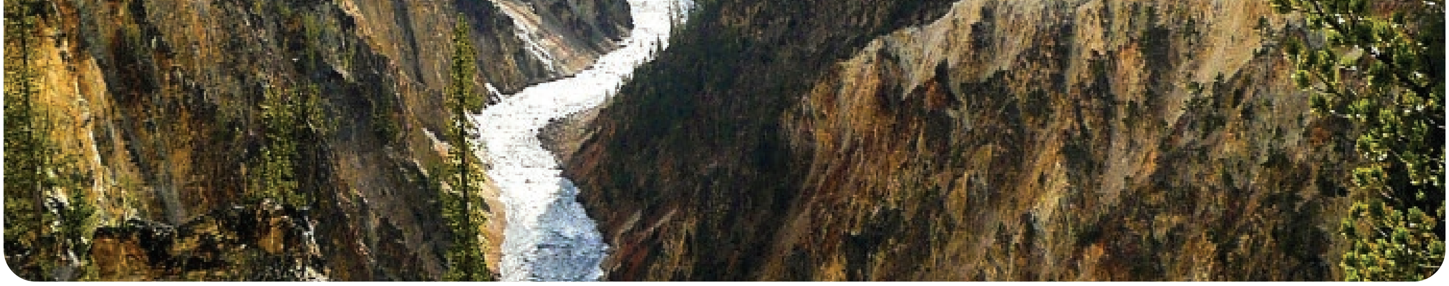
To identify bounding conditions, we begin by modeling the profit function and strategies of the DOE. Here the joint equilibrium outcome is assumed to be reached, so the bids from each state are identical.

The payout for the DOE is.

$$\pi_t = S_1 \cdot (\overline{M_t} - Pay) + (1 - S_1) \cdot (\frac{\pi_{t+1}}{1+r} - C_t)$$

π_t is the net benefits received by the DOE today, $\pi_{(t+1)}$ is the expected net benefits of the DOE after waiting one more year, with r being the yearly discount rate, $\overline{M_t}$ is the total value of the project to the DOE (gross), *pay* is the state bid for the project and what is paid out in state benefits to host the SNF facility, S_1 is a dummy variable that is one when the DOE strategy is to accept the proposed payment to the State, and C_t is the cost to store the SNF for another year on site. The cost of storing the waste in the given year is avoided by accepting the offer today.

For this equilibrium to exist, state bids must be low enough to benefit the DOE. If the bids are higher than the total value of the CISF project then the DOE would reject all bids, preferring to store the SNF on site. The bids also must be lower than the value of repeating the game in the next period. As was evaluated in Section 3.1, the value of constructing a new facility increases as the nuclear fleet ages. Because the returns increase with time, the total payment in the present year is suppressed. This growth in value reduces the cost to waiting another year, thereby lowering the maximum bid for a project in the current year.



Based on this a condition for equilibrium where the bid is accepted is:

$$\overline{M_t} - Pay \geq \frac{\pi_{t+1}}{1+r} - C_t$$

$\pi_{(t+1)}$ is the expected profit from accepting the bids in the next year. It is assumed that the growth rate in the project value is linear thereby implying that if the current bid is not low enough to induce acceptance in this year, then the project will never be accepted. From this assumption ϖ_(t+1) is defined by:

$$\pi_{t+1} = \overline{M_{t+1}} - Pay$$

Combining with the equilibrium condition yields:

$$\overline{M_t} - Pay \geq \frac{\overline{M_{t+1}} - Pay}{1+r} - C_t$$

$$\overline{M_t} - \frac{\overline{M_{t+1}}}{1+r} + C_t \geq Pay - \frac{Pay}{1+r}$$

$$\overline{M_t} - \frac{\overline{M_{t+1}}}{1+r} + C_t \geq Pay \cdot (1 - \frac{1}{1+r})$$

$$Pay \cdot (1 - \frac{1}{1+r}) \leq \overline{M_t} - \frac{\overline{M_{t+1}}}{1+r} + C_t$$

$$Pay \leq \frac{\overline{M_t} - \frac{\overline{M_{t+1}}}{1+r} + C_t}{1 - \frac{1}{1+r}}$$

$$Pay \leq \frac{(1+r) \cdot (\overline{M_t} + C_t) - \overline{M_{t+1}}}{(1+r) - 1}$$

$$Pay \leq \frac{(1+r) \cdot (\overline{M_t} + C_t) - \overline{M_{t+1}}}{r}$$

This constraint says that the avoided cost in the future limit's current payments. By accepting a bid today, the present storage costs are avoided, and the total project values are acquired today, so $\overline{M_t}$ and C_t are brought into future dollars, this is compared to the future value of $\overline{M_{t+1}}$. Increasing the value of future projects or decreasing the cost of SNF storage reduces the maximum payment that would be accepted by the DOE.

This is not the only equilibrium condition. If the DOE profits of accepting the bid today are less than storing the SNF on site indefinitely they will reject the bid. The previous constraint limits bids to be only those that are less beneficial to accept in the future. The second constraint limits accepted bids to those that provide a net benefit when compared to inaction. This constraint is:

$$Pay \leq \overline{M_t}$$

Therefor the maximum bid that can be an equilibrium, from the perspective of DOE acceptance is:

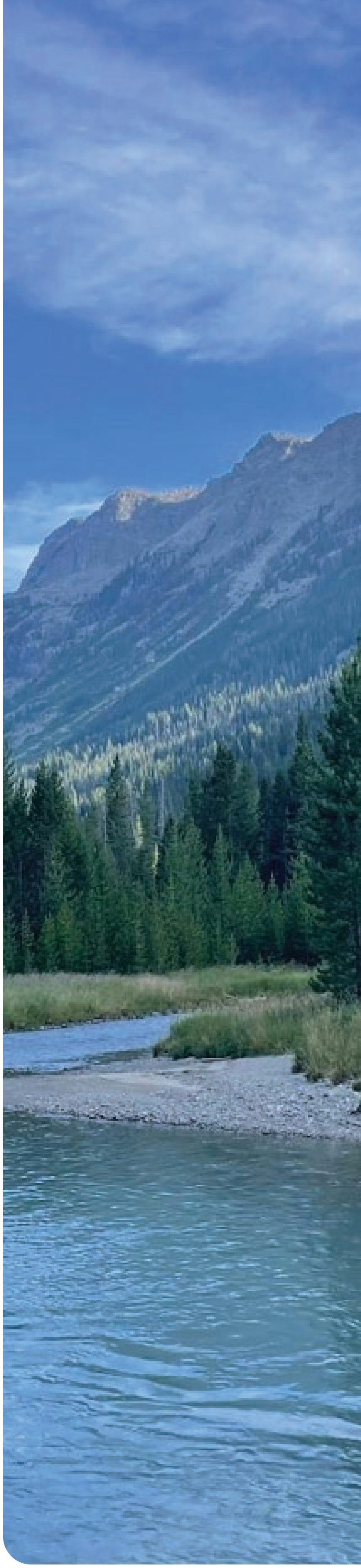
$$Pay \leq Min\left(\overline{M_t}, \frac{(1+r)\cdot(\overline{M_t}+C_t)-\overline{M_{t+1}}}{r}\right)$$

Next this information is considered by the three states, which can place a payment bid each year. Their profit function is:

$$\pi_t = S_{cheat} \cdot \varphi^2 \cdot \text{Pay}_{cheat} + (1 - S_{cheat}) \cdot \left[(1 - 2\varphi - \varphi^2) \cdot \text{Pay}_{cop} + (2\varphi + \varphi^2)\frac{\text{Pay}_{cop}}{2} + \varphi^2 \cdot \frac{\text{Pay}_{cop}}{3}\right]$$

Where φ is the probability that any one state provides a valid bid each year. This is assumed to be the same for each state for simplicity, but the model can accommodate variable odds of accepting a bid by the three states. S_{cheat} is a dummy for using the strategy of defecting and bidding the maximum rate the DOE would accept (Pay_{cheat}) in the current year. This breaks the cooperative agreement, so the total future expected profits are zero, and if another state bids at the cooperative rate (Pay_{cop}), that state wins the project and the cheating state has a payment of zero.

If two or more states bid at the cooperative rate the DOE is indifferent between which project to accept, therefore the expected payouts are the cooperative payout divided by the number of bids made. For example, if two states bid, each state in the bid process has a 50% chance of being selected so the value of the bid is $\frac{\text{Pay}_{cop}}{2}$. Half the time the bidding state receives all the payment Pay_{cop}, and the other half of the time the state receives zero value. A risk neutral state values this at chance at a rate of $\frac{\text{Pay}_{cop}}{2}$.



This equation can be reduced with the steps of:

$$\pi_t = S_{state1} \cdot \varphi^2 \cdot \mathrm{Pay}_{cheat} + (1 - S_{state1}) \cdot \mathrm{Pay}_{cop} \left[(1 - 2\varphi - \varphi^2) + \frac{2\varphi + \varphi^2}{2} + \frac{\varphi^2}{3}\right]$$
$$\pi_t = S_{state1} \cdot \varphi^2 \cdot \mathrm{Pay}_{cheat} + (1 - S_{state1}) \cdot \mathrm{Pay}_{cop} \left[1 - 2\varphi - \varphi^2 + \varphi + \frac{\varphi^2}{2} + \frac{\varphi^2}{3}\right]$$
$$\pi_t = S_{state1} \cdot \varphi^2 \cdot \mathrm{Pay}_{cheat} + (1 - S_{state1}) \cdot \mathrm{Pay}_{cop} \left[1 - \varphi - \varphi^2 + \frac{\varphi^2}{2} + \frac{\varphi^2}{3}\right]$$
$$\pi_t = S_{state1} \cdot \varphi^2 \cdot \mathrm{Pay}_{cheat} + (1 - S_{state1}) \cdot \mathrm{Pay}_{cop} \left[1 - \varphi - \frac{\varphi^2}{2} + \frac{\varphi^2}{3}\right]$$

In equilibrium the cheat strategy cannot provide higher returns than the cooperative strategy, therefore for an equilibrium to exist the following condition must be met.

$$\mathrm{Pay}_{cop} \cdot \left[1 - \varphi - \frac{\varphi^2}{2} + \frac{\varphi^2}{3}\right] \geq \varphi^2 \cdot \mathrm{Pay}_{cheat}$$

Solving for the cooperative payment rate provides:

$$\mathrm{Pay}_{cop} \geq \frac{\varphi^2 \cdot \mathrm{Pay}_{cheat}}{1 - \varphi - \frac{\varphi^2}{2} + \frac{\varphi^2}{3}}$$

The cheat payment has an upper-bound found previously as the maximum payment the DOE would accept in the current year. Placing this value into the equation provides.

$$\mathrm{Pay}_{cop} \geq \frac{\varphi^2}{1 - \varphi - \frac{\varphi^2}{2} + \frac{\varphi^2}{3}} \cdot Min\left(\overline{M_t}, \frac{(1+r) \cdot (\overline{M_t} + C_t) - \overline{M_{t+1}}}{r}\right)$$

Based on the economic analysis in Section 3.1 the total value of housing all SNF in the U.S. is \$8.43 billion. The average cost per ton of SNF under economies of scale is \$77,502. The cost of storing all SNF at a CISF is therefore \$6.96 billion. This places the total economic value of a large CISF project at \$1.47 billion. This economic value can be distributed among the DOE, and host state based on this game.

The cost of on-site storage based on the volume of SNF housed at powerplants is found to be \$593 million per year. We estimate the value of constructing a CISF storage facility in the following year, by increasing the age of all operating nuclear reactors by one year. This sets $\overline{M_{t+1}}$ at \$8.53 billion, with a total value after deducting project costs of \$15.7 million. When assuming a discount rate of 6% this provides.

$$Pay_{cop} \geq \frac{\varphi^2}{1-\varphi-\frac{\varphi^2}{2}+\frac{\varphi^2}{3}} \cdot Min\left(1570, \frac{(1.06)\cdot(1{,}470+593)-1{,}570}{0.06}\right)$$

$$Pay_{cop} \geq \frac{\varphi^2}{1-\varphi-\frac{\varphi^2}{2}+\frac{\varphi^2}{3}} \cdot Min(1570{,}10329)$$

$$Pay_{cop} \geq \frac{\varphi^2}{1-\varphi-\frac{\varphi^2}{2}+\frac{\varphi^2}{3}} \cdot 1{,}570$$

Combining the upper and lower bounds of payments provides a result of:

$$1{,}570 \geq Pay \geq \frac{\varphi^2}{1-\varphi-\frac{\varphi^2}{2}+\frac{\varphi^2}{3}} \cdot 1{,}570$$

This provides a range of payments that are feasible under the model assumptions presented. It is however worth considering whether the upper or lower bound payments are more likely outcomes.

There are two factors which may drive the payments toward the lower end of this range which is reported as the expected payments to Wyoming.

First, each state can see the bid of other states. The projects in New Mexico and Texas, receive a payment lower than this maximum bound but higher than zero. Any bid less than the maximum sets a new possible equilibrium so long as no other state drops below that threshold. The observed payments suggest that some cooperation was achieved but the existing projects bid down the cooperative rate towards this lower end. If no cooperation was reached the total payments would be zero, with a prisoner dilemma outcome, which is not observed.

Second the current states in the bidding game lose revenue if another state enters the bidding process. The higher the cooperative payment rate achieved the more likely it is that other states like Nevada, Arizona, and Idaho will make serious bids. This lowers the revenue of each existing player, creating an incentive for all states considering building a CISF to reduce payments toward the lower end of the cooperative range.

Based on these factors we report the conditions where:

$$Pay = \frac{\varphi^2}{1-\varphi-\frac{\varphi^2}{2}+\frac{\varphi^2}{3}} \cdot 1{,}570$$

As the final payment outcome. Further, the project payments are estimated on a yearly basis by applying a discount ratio, making yearly payments over 40 years equivalent to the lump sum payment of the variable Pay, at a 6% discount rate. This factor is approximately 1/16 total payment to yearly payments.

APPENDIX (D) SURVEY DESIGN

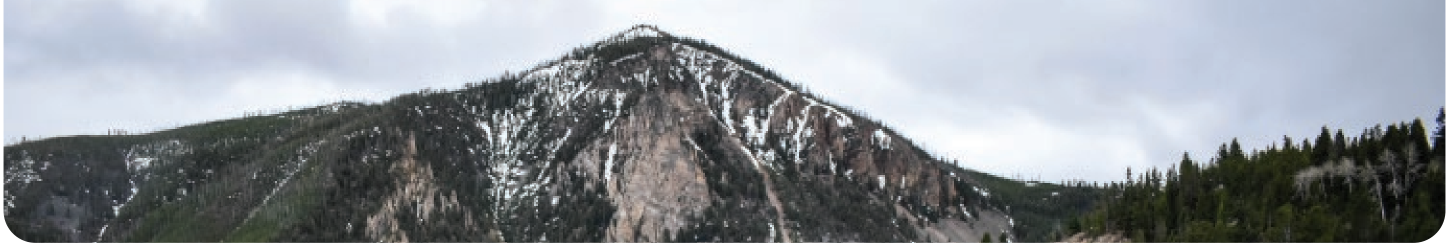
The general methodology is as follows. We first provide background information about SNF facilities, explaining that a CISF is being planned in the U.S. We then explain that a final location has not been selected and are seeking opinions about locating it within their state of residence.

Background

A temporary spent nuclear fuel holding facility is planned to be built in the US. This will store nuclear waste from 92 nuclear reactors operating in 28 states. The facility is expected to operate for 40 years before the material is moved to a final storage location in another location.

Your State could host this facility. State approval is required for construction. We are seeking your opinions about building this facility in your State.

With permission we record the zip code of each survey taker, allowing us to correlate regional characteristics with willingness to accept a SNF facility. All participants are shown basic information about possible facilities. We allow survey respondents to not provide a zip code, or record an IP address, but they must at least provide their state of residence. We automatically extract a survey taker ID from the prolific platform, which allows us to gather demographic data, including sex, age, and student status without explicitly asking in the survey.



The SNF facility we propose only employees one to two full time workers and does not bring in tax revenue to the State except from a one time fee. We also state that the proposed facility would not be in their county of residence, and the transportation route of SNF will not enter their county. These constraints to the facility are provided to isolate the perceived cost associated with building the facility from the benefits. This information is as follows:

Facility and Proposal Information:

Payments:

- The State is paid a *one time* fee to host the nuclear spent fuel storage facility. This fee is used to reduce the tax bill of each State resident, but only for one year.
- The facility brings in no sales taxes, and minimal property taxes.
- It employees two full-time workers.

Risk:

- The proposed facility is not in your county of residence.
- The population density near the proposed facility is rural with less than 500 people per square mile.
- The transportation route of nuclear spent fuel does not cross your county of residence.

By proposing a facility that relies on passive safety features, respondents will not consider employment benefits from the facility which we assess explicitly in a later section. Further, by limiting the tax benefits to a single year we can evaluate the total cost without accounting for the time value of money which will vary between participants. Each reported value of the project will be listed in present dollar terms rather than considerations of long-term returns. Finally, by stating that the facility will not be located in their county of residence we seek to remove the perceived risk to self. The goal of the survey is to identify the intangible concerns of citizens other than direct risk which should only be considered for the residence who are affected by the facility. This provides the associated costs for Wyoming residents who are not explicitly affected by the construction but may be concerned about the effect on the State in general.

To emphasize these points participants are asked for two understanding checks. We ask how many years the facility will bring in tax revenue, and whether the facility will be in the county where they live. If they answer either question wrong, the correct answer is displayed in bold with further elaboration. This helps ensure that responses are based on the information provided, and that the results are not driven by a misunderstanding of the procedural set up. As an example, participants are asked how many years the facility will change taxes. If they select any answer except "For one year" They are shown:

University of Wyoming

Taxes will change for **only 1 year**.

The storage facility would pay a upfront one time fee to build in the State.

To determine if information matters, we randomly show half the participants risk information provided in this report about the expected risk of the facility being built. This text includes

University of Wyoming

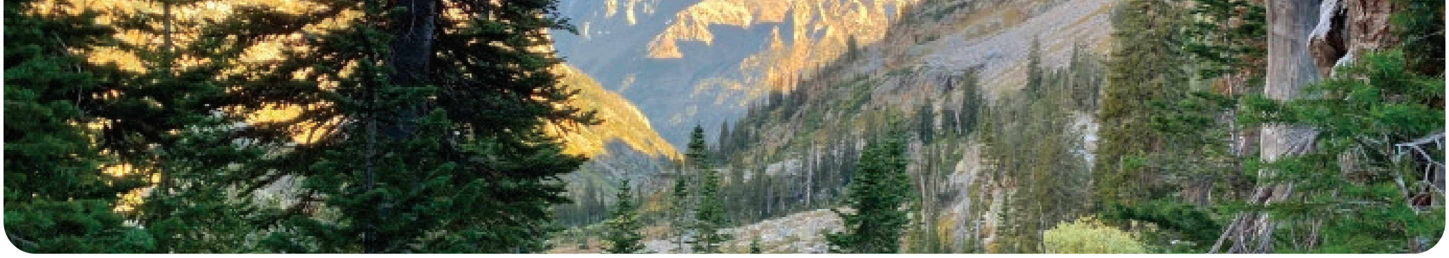
The Department of Energy has completed an engineering report at a similar facility.

- The risk of an event that exposes radiation outside of the building is one in a billion.
  - This is approximately the same risk of death when driving 34 feet on a U.S. highway. There are 13.3 deaths per billion miles driven in the U.S.
- If a failure occurs people living within two miles of the facility would be exposed to high levels of radiation.

In the analysis we compare the reported value of avoiding the SNF storage facility for participants given this information with those who were not given information. Those results highlight whether information about risk is a key driver of reported cost. This has policy implications as the sensitivity to this information provides a metric for the potential for clear explanations to affect opinion. In previous studies of Wyoming, it has been found that more people are uncertain of their opinion about nuclear energy than any other electricity source (Western & Gerace, 2023).

Following this, participants are randomly assigned one of two survey variants. The literature has consistently identified a discrepancy between survey responses that are framed as a payment and those framed as a benefit. This is referred to as the willingness to pay and the willingness to accept discrepancy (Boyle et al., 2021; Plott & Zeiler, 2005). In the case at hand, we divide the survey into two policies which are technically identical. In one case we explain that the tax revenue from the facility would be used to lower the taxes of each State resident. This is a feasible policy, as the tax revenue from a project can replace other taxes in a state budget. In the other survey, we express that taxes are expected to increase in the coming year, and the tax revenue from the facility can be used to offset this tax increase. This is also feasible, since the tax revenue acquired can be used to offset budget deficits. In fact, this is the same policy but re-worded. Whether tax rates are expected to rise or whether they remain the same the revenue from the facility is being applied to lower tax rates.

However, we expect that this wording difference will change participant responses. For a few possible reasons. First, behavioral economics identifies that individuals require a much higher payment to give up something they already possess when compared to the payment they would pay to acquire the same item if they did not already own it (Kahneman et al., 1990). This is referred to as the endowment effect which is driven by a variety of factors including an aversion to loss, considerations of fairness, and cognitive biases (Kahneman et al., 1991). Another contributing factor is budget limitations. For example, a homeowner who offered one million dollars to sell their family home to develop new infrastructure can refuse this offer. However, if they were required to pay a million dollars to keep their home, they would be unable to afford this cost. This effect could derive from strategic considerations or true subjective value. It is conceivable that an individual would be willing to give up a million dollars of income to preserve a home that has historical significance to them. On the other hand, such a withholding could be strategic in nature. If the project is worth significantly more than one million dollars, they could receive a one-million-dollar payment by holding out, even if they would sell the home for only $300 thousand. In the case at hand, it is possible that conscientious objectors will report a much higher willingness to accept a storage facility than a willingness to pay to avoid it. They can vote “no” to a referendum allowing the construction of a SNF facility no matter how large the tax benefits, but they could not afford to pay a large amount to avoid the facility.



Whether the reported willingness to accept versus willingness to pay should be considered by policy makers is a philosophical question. Typically economists prefer to report willingness to pay, since it tends to be lower and more accurately reflects to resource scarcity tradeoffs (Arrow et al., 1993). However, an argument can be made for using willingness to accept. The State of Wyoming can refuse to accept a SNF storage facility. This makes the political problem one of willingness to accept and not a willingness to pay. The variants are as follows

University of Wyoming

The Department of Energy has completed an engineering report at a similar facility.

- The risk of an event that exposes radiation outside of the building is one in a billion.
  - This is approximately the same risk of death when driving 34 feet on a U.S. highway. There are 13.3 deaths per billion miles driven in the U.S.
- If a failure occurs people living within two miles of the facility would be exposed to high levels of radiation.

University of Wyoming

Taxes will decrease if the State receives the income from the nuclear spent storage facility. The final tax reduction is unknown. You will be asked to decide if the storage facility should be built given different sized tax rebates.

Note: If the tax rebate is larger than the amount you pay in taxes, you would receive an equivalent check payment.

The value of the tax rebate or cost increase is assigned at random. This value can be any of the following $75, $50, $100, $200, or $25. An example of this is provided below.

University of Wyoming

If the facility is built you will receive a tax rebate of $50.

Should the storage facility be built?

- ○ Yes, build the facility and receive $50 in tax rebates
- ○ No

If they answer yes, the value is cut in half, and they are asked again. If they answer no the value is doubled. This provides a bounded range of possible values from the survey taker. If they answered no twice we ask if they are willing to build the facility at any price. This identifies protest votes. If they answer yes twice, we ask the respondent if they would support the facility even if no tax benefits were provided. This helps determine if a spike model is appropriate where a clustering of people value the avoidance at zero dollars, due to indifference (Kriström, 1997).

Next, we ask follow up questions to pinpoint the participants reasoning for their answer. First the length of time the person has lived in the State is asked. These are placed into bins with the lowest time being “Less than 1 year”, and the largest being “Since birth”. Ones affinity toward the state can reasonably affect the relative value of tax income and the subjective value of SNF storage costs.

If the survey taker has moved within the last 19 years, they are asked for the primary reason for the move.

What was the primary reason for your move to the State?

- ○ Employment or Job Opportunity
- ○ Education
- ○ Family and/or personal reasons
- ○ Retirement
- ○ Lifestyle or Quality of life
- ○ Environmental reasons
- ○ Other

The reason for moving is a revealed preference for certain amenities and is used to group participants.

Following these respondents report their relative concern of factors such as environmental damage, health risk to others, and impact on tourism, on a scale from “Not concerned at all” to “very concerned”. Similar questions are asked about possible benefits including job creation, low carbon energy, and national energy security. These questions are as follows:

How would you rate the importance of these possible benefits from building a nuclear storage facility in the State?

	Very Important	Important	Slightly Important	Not Important At All	don't know
Job creation	○	○	○	○	○
Support of low carbon energy	○	○	○	○	○
Tax revenues	○	○	○	○	○
National energy security	○	○	○	○	○
Lower energy costs	○	○	○	○	○
Promotes the nuclear industry	○	○	○	○	○

How would you rate the concern of these possible costs from building a nuclear storage facility in the State?

	Very Concerned	Concerned	Slightly Concerned	Not Concerned At All	don't know
Environmental damage	○	○	○	○	○
Health risks to self	○	○	○	○	○
Health risk to others	○	○	○	○	○
Impact on tourism	○	○	○	○	○
Cultural site impact	○	○	○	○	○
Social justice	○	○	○	○	○

The response to these questions is averaged to create a level of concern and importance variable. Which is a main driver in willingness to pay.

Finally, we provide an attention check test. Survey takers are asked two non-ambiguous questions about simple facts but are required to pick an incorrect answer. For example, they are asked:

This number test is simple. Select the number seven from the options below. This is an attention check

Answer based on the text above, 2+2=?

- ○ 2
- ○ 3
- ○ 4
- ○ 6
- ○ 7
- ○ 22

If the participants fail both attention checks, they are removed from the survey.

The willingness to accept or pay to avoid the facility is estimated to assume a spike at zero with a logarithmic distribution thereafter, which provides a flexible function for payments which are never zero, but have a continuous probability distribution (Aizaki et al., 2022; Alberini et al., 1997; Muse et al., 2021).

APPENDIX (E) CONTINGENT VALUES ESTIMATE NOT ADJUSTED FOR HYPOTHETICAL BIAS

Table 19: Wyoming Per Capita Contingent Value of Avoided CISF Without Adjustment

	Tax Deduction	Tax Avoided
Median	$124	$38
Average	$160	$103
All Data Median	$420	$219

Table 20: Wyoming Total Contingent Value Without Adjustment (Million dollars)

	Tax Deduction	Tax Avoided
Median	54.8	16.7
Average	70.6	45.3
All Data Median	185.4	96.7

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