SMR Feasibility at Fort Wainwright, Alaska

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Doyon Utilities, LLC

Revision	Status	Date	Reviewer
C	Complete	17 May, 2023	Annesley Black

May 17, 2024

Contents

1 Executive Summary

The Department of Defense needs a resilient and secure energy supply that is increasingly carbon free to meet legislative goals for greenhouse gas emissions reductions. Advanced nuclear has the potential to address these competing demands, especially in remote environments such as Alaska. This feasibility study examines the technical and financial feasibility of a Nuscale small modular nuclear reactor in replacing a coal-fired cogeneration plant at Fort Wainwright in Alaska. Resources necessary, process flow modeling to look at the operating conditions and calculate the electrical output and thermal output, a general arrangement for the physical layout, a single line diagram for the electrical system, and an economic analysis for the proposed SMR are evaluated in the following study. The electrical output for the design is 21 megawatts and the thermal output is 109 megawatts. The net present value is $1.32 billion according to the economic analysis and the carbon offset potential is about 98,000 tonnes of CO_2 for switching from coal-fired electrical generation to nuclear. Therefore, an SMR is a viable solution to replace the current coal-fired cogeneration plant at Fort Wainwright.

2 Introduction

2.1 Frame the Problem

"The Department of Defense Plan to Reduce Greenhouse Gas Emissions" lays out strategies for decarbonization of both operational and installation energy use while increasing overall readiness and resilience of the Department of Defense (DOD) as a response to the National Defense Authorization Act for fiscal year 2022 requirement [1]. The DOD tracks energy use in terms of installation and operational energy use. Installation energy includes electricity, heating and cooling, as well as fuel to power non-tactical vehicles and equipment, and it represents 37% of the Department's total greenhouse gas (GHG) emissions [1]. Operational energy is not considered within the scope of this report. Additionally, the "United States Army Climate Strategy" prioritizes climate change mitigation and adaptation measures, setting a goal of 50% Army net GHG emissions by 2030 compared to 2005 levels [2]. Line of effort 1 is focused on installations and includes an intermediate objective of on-site decarbonized power generation for Army critical missions on all installations by 2040 [2].

As the most energy-intensive organization within the U.S. government, accounting for about 80% of the federal government's energy use, the transition from fossil fuels will be extensive. Successful military capabilities require sufficient and secure supplies of energy, indicating a need to shift and diversify the current energy mix. Relying on the U.S. electrical infrastructure is a national security concern given the susceptibility to weather and cyber-attacks leading to an increased risk of outages that will affect critical operations at military installations. The trade-off between resilient and assured electricity for critical operations at military installations while meeting carbon-free energy goals cannot be met on renewable energy generation alone. Additionally, it is logistically easier to move low-enriched uranium, as one uranium fuel pellet creates as much energy as one ton of coal [3].

Within the broader United States, modeling efforts demonstrate that net-zero by 2050 will require 770 Gigawatts of clean energy if renewable build out is bound by limitations from land use and transmission expansion [4]. New nuclear will be necessary by 2050 to help meet this demand, with modeling estimates indicating 200 or more Gigawatts of new nuclear capacity needed [4]. Therefore, advanced nuclear has a role in meeting clean and base load demand within the DOD, but there are commercial applications as well. One potential route to addressing the advanced nuclear implementation gap is overcoming first of a kind (FOAK) risks associated with the first reactor designs through initial military investment and scaling the industry to commercialization subsequently. Other examples of military technology becoming commercialized include internet, GPS satellite navigation, and microwave ovens [5].

2.2 Introduction to the Project

Given the need for advanced nuclear technology to meet emissions reduction goals set by policy such as the Operational Energy Strategy and Army Climate Strategy, Fort Wainwright, a remote military installation in Fairbanks, Alaska, is an ideal location for an SMR. Doyon Utilities will own and operate the plant, replacing the aged coal cogeneration plant currently in operation at the base, and utilizing the current centralized infrastructure for electricity and district heating to the installation. The NuScale design, described in more detail in the SMR Overview section, is NRC licensed, removing a significant barrier most SMRs face, licensing at the national level. The SMR will be sized appropriately to demand and there will be opportunity to sell excess heat and electricity to the Railbelt grid and local adjacent Fairbanks community with minimal additional infrastructure.

2.3 Project tools

The project tools for collaboration include a shared timeline for completion of key deliverables to ensure completion by relevant deadlines. The report will be shared through Overleaf for collaboration and WhatsApp iirc will be the platform for remote communication. Multiple meetings are scheduled each week to discuss project progress. See Table 1 for the breakdown of lead author and editor broken down by each section.

Section	Lead Author	Editor
Introduction	Annesley	Pall
Background	Annesley	Pall
Resource Assessment	Annesley and Pall	Annesley and Pall
Technical Design	Pall and Annesley	Pall and Annesley
Economic Analysis	Pall	Annesley
Environmental and Social Issues	Annesley	Pall
Conclusion	Pall	Annesley

Table 1: Revision table by section allocating section leads for each teammate to write and edit, respectively.

2.4 Introduction to the Report

The feasibility study consists of background information such as an overview of the current technology within the field of SMRs and a description of the selected NuScale design. The site location, at the Fort Wainwright coal cogeneration plant, will be described in detail while addressing specific challenges and opportunities the site offers. Lastly, the Fairbanks and Alaskan community will be described as background information for the project.

The resource assessment will include fuel calculations and procurement, necessary electrical infrastructure, a description of the road infrastructure and how the SMR will be shipped, as well as benefits for the client, Doyon Utilities LLC, and the source and estimation for cooling water requirements during operation.

The technical design will include a process flow diagram indicating major components and operating conditions throughout the plant. A general arrangement will cover the overall arrangement of the structural elements of the project in space. The single line diagram will display the layout of the electrical infrastructure throughout the plant. The economic analysis will cover costs for similar plants in operation. There will also be estimations for the total upfront capital expenditure, the operating costs such as fuel and maintenance, and a net present value (NPV) calculation to estimate the financial viability of the plant. The environmental and social issues section includes discussions on carbon offset potential of switching to nuclear, safety concerns within the field of SMRs as well as additional value streams that can be incorporated into the project to make it more valuable to different associated stakeholders, including the local community.

3 Background

3.1 SMR Overview

Small modular reactors (SMR) , which are advanced nuclear reactors that are under 300 megawatts of energy output, can be mass produced and are a fraction of the size of traditional nuclear reactors. SMR's are a potential solution to reduce electricity prices and reduce carbon emissions for the army, industry, and the local community.

This section will consist of a brief overview of small modular reactor (SMR) technologies followed by a more detailed overview of our selected reactor design. The main components are that it is a light water-cooled pressurized water reactor (PWR) with a 2-year fuel cycle and a 60-year design life [6]. The rated capacity is 45 megawatts per module [6]. The Army has around 20 megawatts of power use currently based on the size of the old coal plant used for its power, the excess electrical and thermal energy is to be marketed for local utilities. For our design, we assume one module and will design room for additional modules to be added in the future if needed.

Technology selection ended in the NuScale reactor design being chosen. The other reactors that were considered are below:

- HTR-PM: HTR-PM is a Chinese SMR design, it is already operational in Bejing at 210MW output with gas cooling, this design is approved according to Chinese regulations [7].
- NuScale Power Module: Developed by NuScale Power, the NuScale Power Module is probably the most well known SMRs. Each module has a capacity of 45 megawatts electric (MWe), 160 megawatts thermal (MWth), and a plant can stack up to 12 modules. It is not the smallest, yet it is notable for its modular design and advanced safety features. It uses 5% enriched uranium [6].
- KLT-40S: Developed by the Russian nuclear engineering company OKBM Afrikantov and already in operation. The KLT40S is a pressurized water reactor (PWR) known for marine propulsion in icebreakers. It has a thermal output of around 300 MWth, with an electrical capacity of around 70 MWe. It uses 20% enriched uranium [8].

The selection of the Nuscale 45 megawatt design is based on its safety features, the convenience of it being based in the USA, and already having Nuclear Regulatory Commission (NRC) approval which is needed to sell energy to commercial markets [9].

3.2 Site Location

Fort Wainwright is a military base at 65° north latitude in the Fairbanks North Star Borough of Alaska, meaning the installation has a subarctic climate [10]. The proposed SMR will serve as a replacement for the 20-megawatt coal cogeneration plant at the base. The coal plant is well beyond its design life and needs to be replaced or upgraded. The site is the northernmost point on the Railbelt electrical grid that connects Fairbanks to Anchorage. The current centralized system of utilidors, or underground pipes, can be used for SMR district heating.

The current environmental impact statement (EIS) evaluating alternatives for replacing the coal-fired power plant describes the current system. The combined heat and power plant (CHPP) was completed by U.S. Army Corps of Engineers (USACE) in 1955 and is operating well beyond the typical design life for a similar installation [10]. The current CHPP has six coal-fired 150,000 pound per hour steam boilers, three extraction-type condensing steam turbines, and a single back-pressure turbine [10]. The CHPP produces all heat necessary for the installation with steam from the boilers through a 30 mile underground system of utilidors, or underground tunnels, as well as up to 19 MW of electricity [10]. The rest is purchased from the local utility, Golden Valley Electric Association. Electricity is distributed through overhead distribution lines, underground distribution circuits, street lighting circuits, and airfield lighting cables [10]. The EIS recommends distributed gas boilers which would only provide heating for the installation with all electricity purchased from GVEA [10]. Many, including the client, Doyon Utilities, argue this recommendation lacks consideration of issues with supply chain and does not take advantage of the current centralized infrastructure existing on-site [10]. As seen in Figure 1, the peak demand of the installation is projected to be larger than 33 megawatts in future years and the thermal load is approximately 100 megawatts [11].

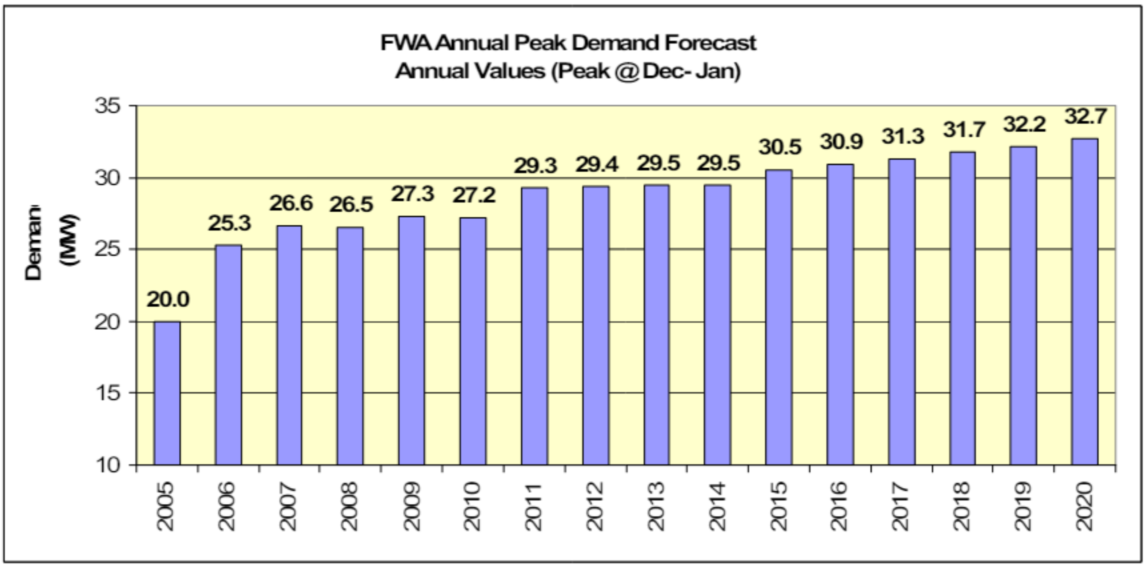

Figure 1: Annual peak electricity demand forecast at Fort Wainwright [11].

The current discussion on future alternatives fails to consider small modular nuclear technology. Siting a modular reactor at Fort Wainwright would allow for use of the current centralized infrastructure while providing both electricity and thermal energy for the base, without relying on the local utility and compromising energy independence and security at the installation. Nuclear is the highest energy density source and the modular nature helps with scalability, upfront cost, and passive safety features, making it an excellent option for resilient and independent energy production necessary within a subarctic training environment to enable mission readiness. More knowledge on siting SMR technology within a subarctic environment is necessary to determine the feasibility.

3.3 Local Community

There is no current nuclear energy within Alaska, but there is a growing interest as the modular reactor technology can provide both clean electricity and heat with price stability, high energy density, and modularity. There are 10 Alaskan communities, not including those with installed hydroelectric capacity, with sufficient heating and electric loads to match small modular reactor capacities [12]. Nuclear power plants are heat engines that can provide high thermal efficiencies for both heat and electricity generation, heating being particularly valuable within the cold environment of Alaska [12]. The challenge is that many Alaskan communities do not have district heat systems [12]. Despite the need for additional infrastructure, SMR technology can still give more price stability and lower emissions than reliance on imported fuel oil, making SMR technology a relevant solution for Alaska's energy issues

[12].

Alaska has a lot of interest in advanced nuclear technologies as most of rural Alaska is currently being run on diesel generators. Electricity and home heating prices are high because of the cost of shipping fuels far distances. The current electricity mix by source is seen in Figure 2. Oil, coal, and natural gas dominate the electricity production and there is still a significant need to diversify Alaska's energy mix, which SMRs can help with. Additionally, the Alaska legislature has recently made changes to simplify the advanced nuclear regulation process, largely due to the Eielson Pilot Microreactor [13].

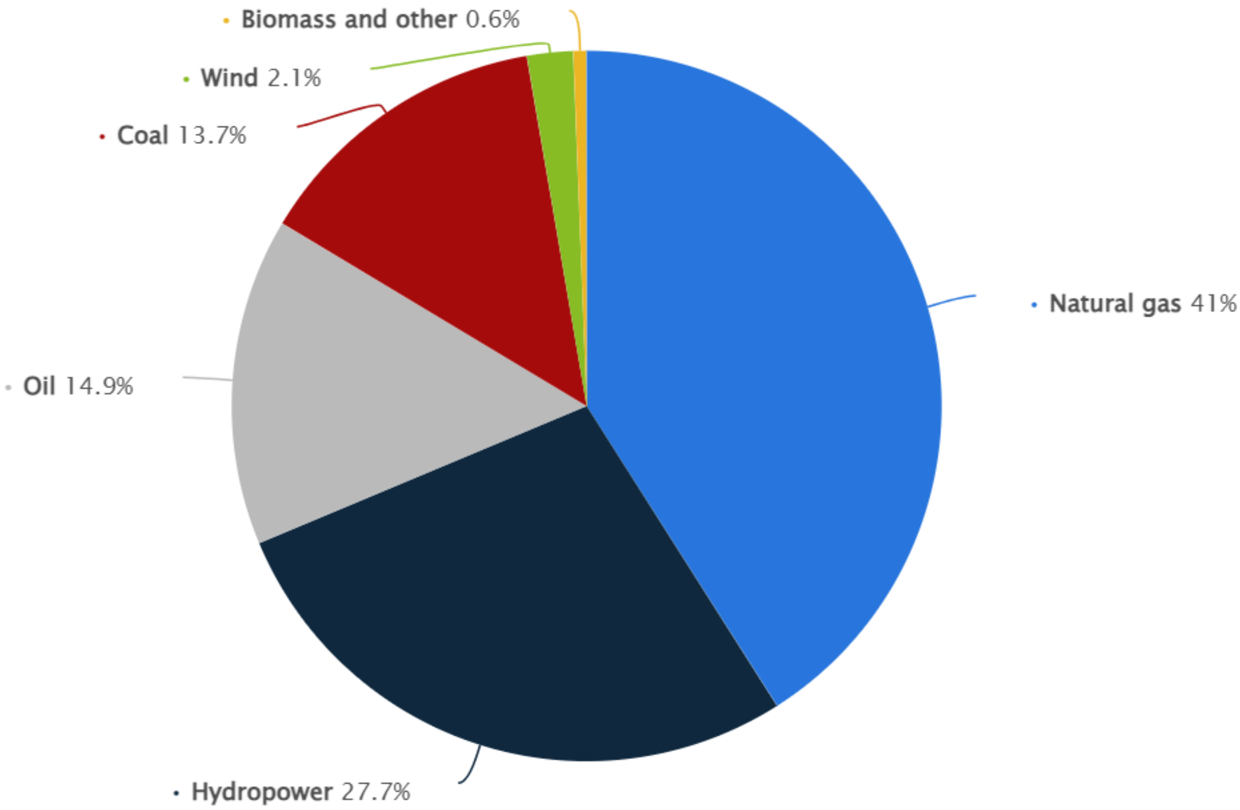

Figure 2: Electricity production by source in Alaska [14].

Fort Wainwright is adjacent to Fairbanks, the second largest city in Alaska with a population of approximately 32,000 people [15]. They currently get their electricity from another coal-fired power plant with a rated capacity of approximately 25 megawatts, but siting the NuScale SMR at Fort Wainwright will provide the opportunity to displace some of this coal by selling heat and electricity to the local grid. This could have benefits to the local community and the Railbelt system as a whole, providing stable and clean power while diversifying the electricity mix for the state. The current Fairbanks economy includes mining, tourism, military operations, and the University of Fairbanks [15]. The economy and location make the Fairbanks North Star Borough the third highest energy consumption in the state, consuming an average of 70 megawatt-hours per capita each year, 2.3 times the national average [16]. The city of Fairbanks is less than 3 miles from Fort Wainwright, making the possibility of additional electrical infrastructure to connect the SMR to Fairbanks feasible and worthwhile for the community, gaining access to potentially cheap and carbon free electricity and heat, as well as for Doyon, an additional revenue stream to help pay back initial capital investment.

4 Resource Assessment

4.1 Fuel Procurement

For fuel wattage calculations 5% enriched uranium is assumed with 55 gigawatt-days per ton [17]. Assuming 1 reactor of 45 megawatts, fuel consumption per year would be 0.3 tons per year, using . Since the refueling cycle is 2 years this will have 0.6 tons per 2 years. Fuel will be procured from the Paducah Gaseous Diffusion Plant in Kentucky. Disposal is assumed to go through the Nevada National Security Site.

$$\text{Fuel mass (tons)} = \frac{\text{Total energy (GWd)}}{\text{Specific energy (GWd/t)}} = \frac{365.25\,\text{d} \times 0.045\,\text{GW}}{55\,\text{GWd/t}} = 0.298\,\text{t} \tag{1}$$

4.2 Electrical Infrastructure

The grid already has energy infrastructure from an old coal power plant and for this document, it is assumed that the power line is large enough to carry 45 megawatts and laying cable and connection is only required at the power plant site. The electrical infrastructure can be seen in Figure 3.

Figure 3: Current grid infrastructure in Alaska at the macro level along with a micro level visual for the grid connection at the 20 MW coal cogeneration plant [18].

4.3 Roads, Ports, Servicing

The nearest large port is in Anchorage, Alaska. It is assumed heavy equipment is sailed there, then trucked to Fort Wainwright. The fuel, equipment, and staff will arrive to the power plant by road. For servicing the plant, fueling, and placing equipment the current state of the road system is considered sufficient. The current road to the Fort Wainwright power plant is a 2 lane paved road (Oak Avenue)that seems suitable for heavy transportation, the law in Alaska allows transportation of 50,000 pounds (22.6 tons) by road [19]. Figure 4 gives an overview of the roads and pond layout in relation to the power plant.

Figure 4: Fort Wainwright coal power plant roads and water pond.

4.4 Water Requirements

The coal cogeneration plant has a cooling pond located next to it as seen in Figure 4 in the previous section. This will provide water for cooling within the SMR. If water usage exceeds the capacity of the current cooling pond, the plant is located near the Chena river.

Assuming a 2 meter depth, the area can be calculated with the scale found on Google Maps (175mx275mx2m). There is approximately 100,000 cubic meters of water within the pond.

Water consumption can be roughly estimated by using the heat transfer in the condenser and dividing it by the energy required to vaporize 1 kilogram of water to find the necessary mass flow rate of water for cooling. Using the mass flow rate from equation 2, the daily water flow rate can be calculated:

$$\frac{56{,}953\,\text{kJ/s}}{\frac{2{,}256\,\text{kJ}}{1\,\text{kg water}}} = 25\,\text{kg/s} \tag{2}$$

$$\frac{25\,\text{kg/s} \times 3600\,\text{s} \times 24\,\text{h}}{1000\,\text{kg/m}^3} = 2{,}160\,\text{m}^3/\text{d} \tag{3}$$

The reservoir, assuming no rain, will then last for 46 days:

$$\frac{100000\,\mathrm{m}^3}{2160\,\mathrm{m}^3/\mathrm{d}} = 46\,\mathrm{d} \tag{4}$$

Thus, to ensure adequate water supply it is necessary to monitor the water level of the reservoir and replenish the reservoir from the Chena River when necessary, which is approximately 1 kilometer north from the power plant.

4.5 Benefits for Client

Doyon Utilities LLC has a vested interest in the success of the Fort Wainwright cogeneration plant as the electric utility company that operates 12 utility systems for three military facilities in Alaska [20]. The 50-year utility privatization contract at the three military installations, signed in 2007, allows for long term security in investment payback, meaning the upfront capital for an SMR could be feasible at Fort Wainwright [20]. Therefore, they will own and operate the SMR power plant. Doyon Utilities currently has approximately 200 employees [21]. Owning and operating an SMR could provide the potential for job creation for Doyon as well as new opportunities for specialized training programs.

5 Technical Design

This section will include a process flow diagram and a general arrangement for the NuScale reactor as described in the SMR Overview section. The key design documents include a process flow diagram, a general arrangement, and a single line diagram.

5.1 Process Flow

The power cycle for the NuScale design is a Rankine cycle. See Figure 5 for the model. The inlet temperature for the hot water from the reactor through the steam generator is assumed to be 310°C. The operating pressure is 128 bar, thus water boils at 328°C and our design temperature is set just below this [6]. The mass flow rate of steam is calculated as 72 kilograms per second exiting the steam generator through the CoolProp tool within Excel. Steam will be diverted with a mass flow rate of 42 kilograms per second before entering the turbine into a heat exchanger which will produce hot water for district heating. The remaining 30 kilograms per second of steam will run the turbine. The thermal output is the heat transfer calculated across the heat exchanger. The net electricity output is 21 megawatts and thermal output is approximately 109 megawatts according to the Coolprop Excel model. The thermal and electrical outputs are appropriate for the current base energy demands. There is a potential for additional modules to be installed in the future if demand increases, or there is a desire to sell more electricity or hot water to the local community.

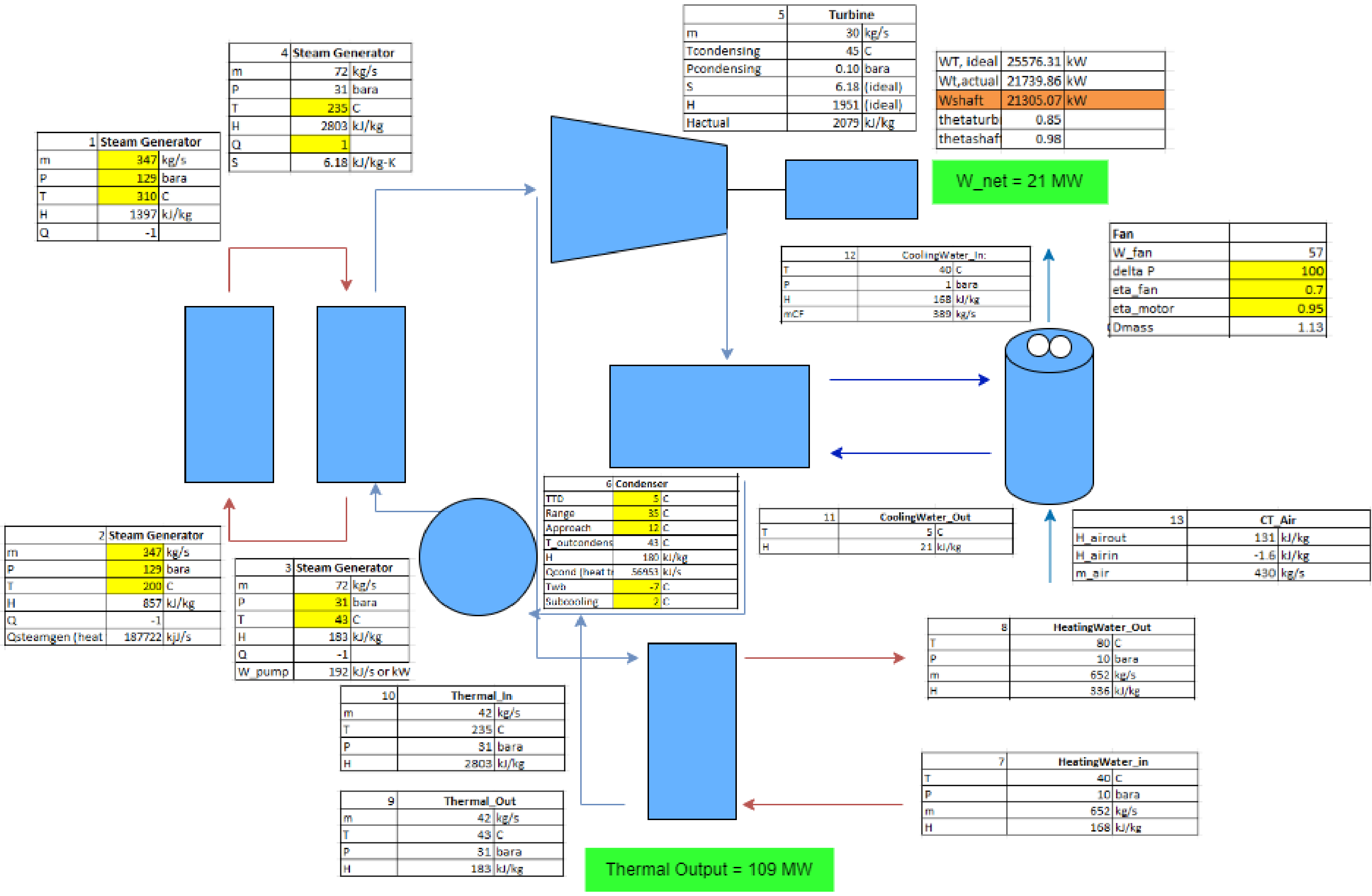

Figure 5: Process flow diagram for a Rankine cycle NuScale SMR.

Figure 6 plots the temperature between the fluids in the cross-flow steam generator. The pinch is calculated at 3°C for the steam generator. The influent water boils and maintains a constant temperature as expected once it turns into steam.

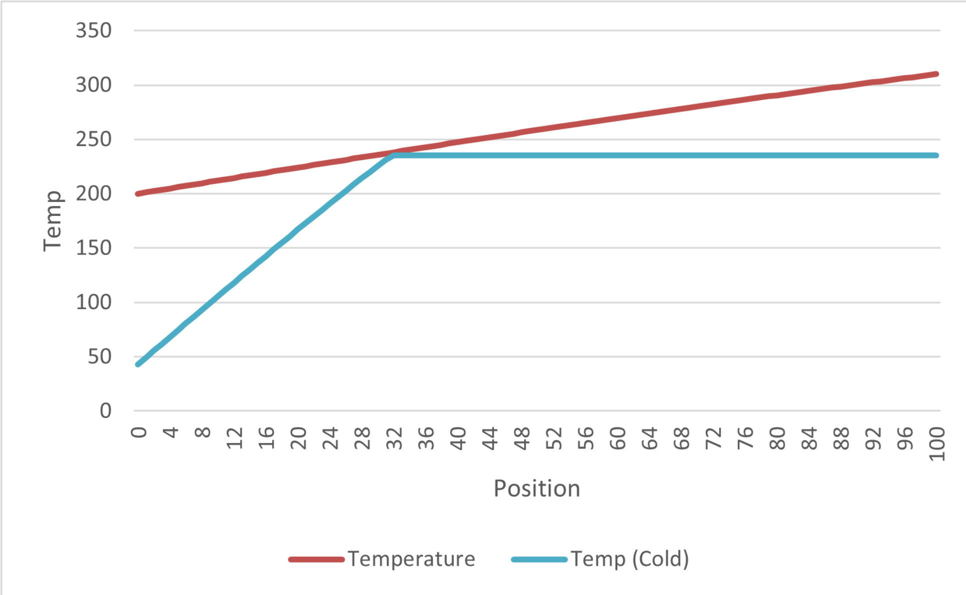

Figure 6: Temperature displayed throughout the heat exchanger process in the steam generator.

Figure 7 is the temperature throughout the hot water heat exchanger. The calculated pinch is 3°C. The incoming working fluid is 235°C and heats the hot water from 40°C to 80°C where it can then be exported to the base for district heating. The effluent working fluid can then be cycled back into the system just before the pump at 43°C.

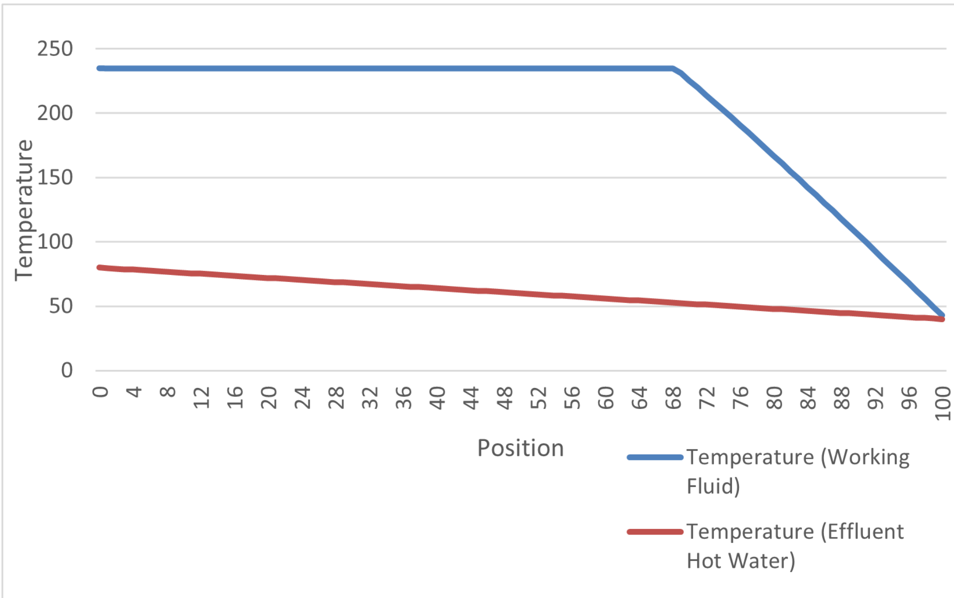

Figure 7: Temperature displayed throughout the hot water exchanger.

5.2 General Arrangement

The general arrangement lays out how key elements of the plant are arrayed in space and facilitates interdisciplinary cooperation. The necessary components within the plant for an SMR are displayed in Figure 8. The plant footprint area will remain the approximately the same as the coal cogeneration plant.

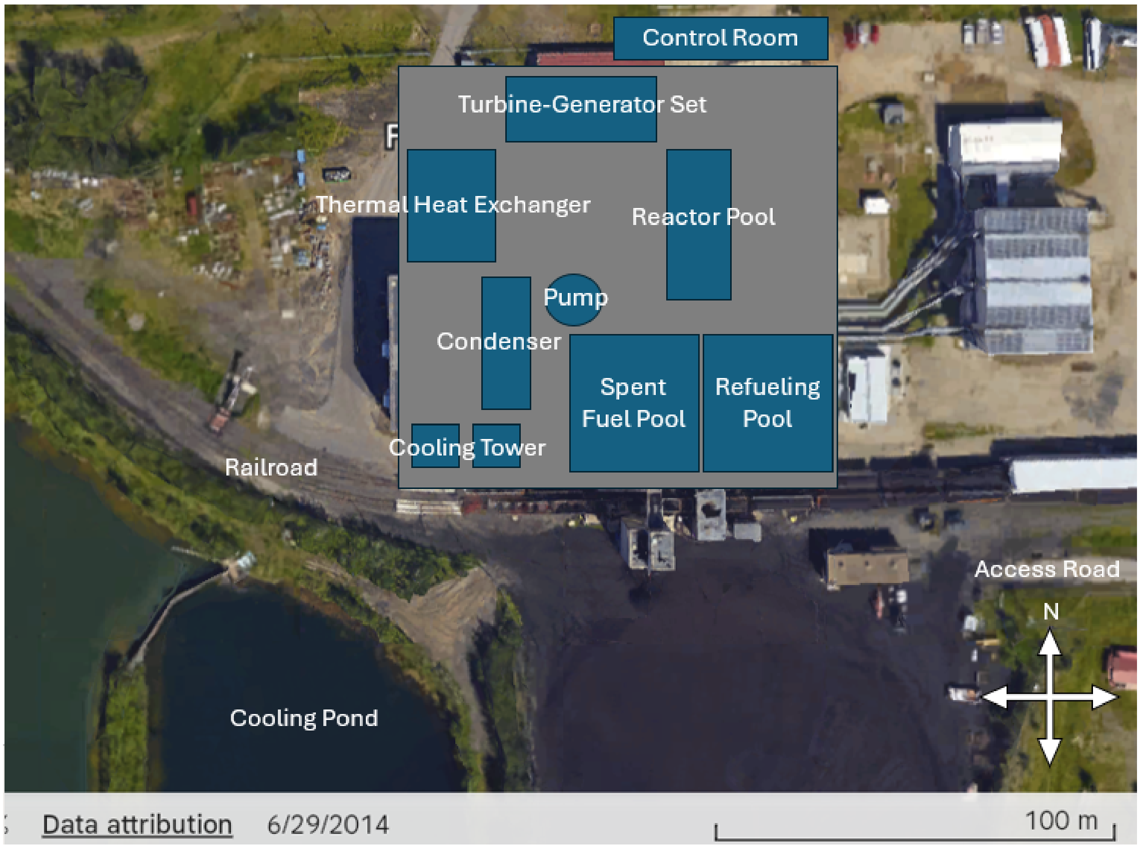

Figure 8: The general arrangement for the proposed Nuscale SMR.

5.3 Single Line Diagram

The main generator for the nuclear reactor runs on 12.47kW which can be fed fairly directly to Fort Wainwright. There is a transformer up to 138kV so power can be fed into the grid and sold. The main elements, working fluid pumps and cooling tower fans run on 4.16kV along with a backup diesel generator at this voltage level. The lubricant pumps for lubricating equipment, the control system and the uninterruptable power supply (UPS and battery for it) all run on 480V. Standard utility such as lighting runs on 120V. An overview can be found in Figure 9.

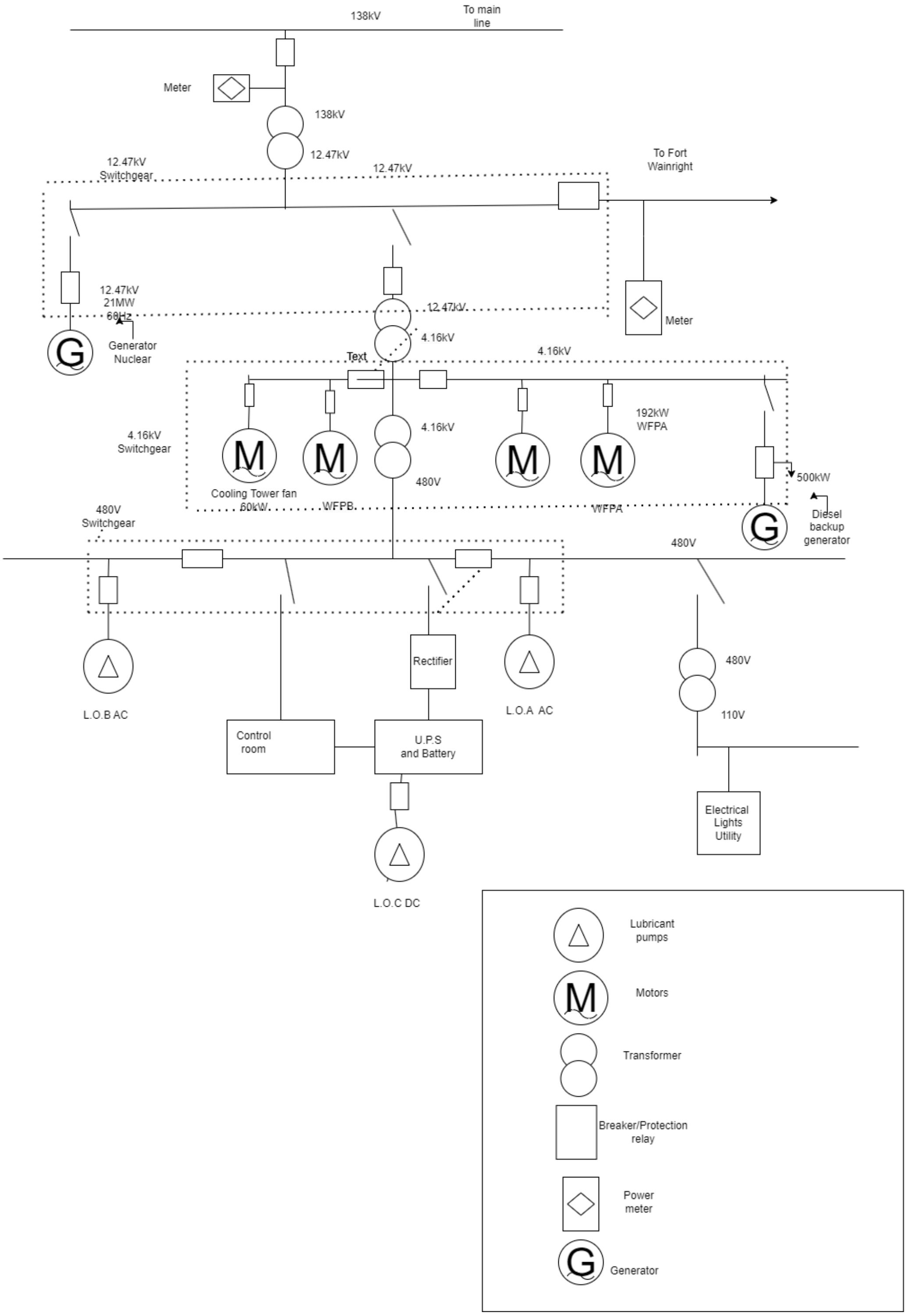

Figure 9: Single line diagram for the power plant.

5.4 Summary and Key Design Metrics

The technical design for the NuScale reactor at Fort Wainwright outlines a system for generating both electricity and district heating. Utilizing a Rankine cycle, the reactor operates at an inlet temperature of 310℃ and an operating pressure of 128 bar. With a steam mass flow rate of 72 kg/s, the system produces an electrical output of 21 MW and a thermal output of approximately 109 MW. A portion of the steam is diverted for district heating, enhancing the plant's efficiency and utility to the the base and local community. The layout of key components within the plant ensures efficient operation and interdisciplinary cooperation in the design process, with a footprint comparable to the existing coal cogeneration plant. The single line diagram, illustrating the electrical distribution and interconnection layout, provides additional clarity on the system's configuration and operation.

Key Metrics and Inputs into Financial Model:

- Net Generation: Electrical output of 21 MW and thermal output of approximately 109 MW.
- Steam Mass Flow Rate: 72 kg/s, with 42 kg/s diverted for district heating and 30 kg/s for turbine operation.
- Operating Parameters: Inlet temperature of 310℃ and operating pressure of 128 bar.
- Potential for Expansion: The design allows for future scalability to meet increased demand or to optimize revenue generation by selling surplus electricity or hot water to the local community.
- Footprint Comparison: The plant's footprint remains approximately the same as the coal cogeneration plant, ensuring efficient land utilization and infrastructure compatibility.

These key metrics and inputs provide essential data for the financial model, guiding decision-making processes and investment strategies for the NuScale reactor project at Fort Wainwright.

6 Economic Analysis

6.1 CAPEX

Using the equation for an exponential estimate of power plant cost.

$$\frac{C_i}{C_o} = \left(\frac{K_i}{K_o}\right)^n \tag{5}$$

- C_i, C_o: cost of size i and size o (reference) plants or equipment

- K_i, K_o: size or rating of units

- n: scaling exponent, typically around 0.6-0.7, but here 0.8 is chosen since this is a modular size

Usually, the equation has the exponent 0.6-0.7 when using a sizing factor, however this is an independent module so we assume a higher exponent, chosen as 0.8. The power plant is assumed to cost one-twelfth of the size of the Oregon NuScale project which had 12 modules, \$0.775 billion a module, using the equation then we get \$1.27 billion Capital expenditure [22]. The financing is assumed to be a 20-year loan at 7% interest for 80% loan finance of investment. The remainder will be financed from investors or the army. This comes up to a payback of \$ 96.3 m. payment of interest and principal [23].

6.2 OPEX

The market price for 5% enriched uranium is around 1900€ (\$2,041), for 298kg/year that comes up to 608218\$/year. [24] 10 people are assumed to work at the plant with an estimated salary of \$60,000 per year per person. Electricity costs 19 cents/KWh in Fairbanks Alaska to industries [25] . Maintenance of the reactor is unknown. Therefore, an assumed cost of \$5 million per year is used for minimal OpEx range calculation purposes. Uranium disposal is assumed to be uranium dioxide which has a mass of 10,960 kg/m^3. Uranium disposal services charge \$323.2 per cubic foot which is around 28 liters. Fuel disposal cost will then be approximately \$313 (see equation 4).

$$\frac{298\,\text{kg}}{\left(\frac{28\,\text{L}}{1000} \times 10.960\,\text{kg/m}^3\right)} \times \$323.2 = \$313{,}198 \tag{6}$$

The simplified operation can be found in Table 2, the OpEx will not be likely to be less than this, however, for the common model purposes we assume the operational cost to be 1% of CapEx, which is around 2 times the number found as the total in Table 2.

Cost	Staff	per unit [$]	Requirement [kg/y]	Salary/staff [$]	Total per year
Uranium [kg]		2041	298		608,218
Staff	10			60000	600,000
Disposal U [kg]		1,051	298		313,198
Maintenance		5,000,000			5,000,000
Total cost					6521416

Table 2: Table of minimal cost of plant operation.

The numbers used to calculate the financial model are found in Table 3.

Constant	Value	Units
Net Hot Water [80℃]	9423221	m^3
Tariff rate water	3.65	m^3
Capacity factor (th)	85%	%
Net Electricity Production	21.1	MW
Capacity factor (electric)	95.00%	%
Tariff rate	190	MWh
Hours per year	8766	h
OpEx	1.00%	% of CapEx
CapEx	1273907668	$
OpEx [$]	12739077	$
% debt	1019126134	80%
% equity	254781534	20%
Loan duration (tenor)	20	y
Interest	7%	
Discount rate	10.00%	

Table 3: The constants used for financial model calculations.

6.3 NPV

Doing a 20 year NPV estimate with 7% interest, 80% financed by loan and 20% financed by investors, the NPV is $1.3 billion, in the financial model the construction time for the operation is not taken into consideration. It is worth mentioning that the NPV becomes negative if the cost of thermal is less than 60% of the given value in Table 2, the CapEx and electric prices both had negligible effect on the net present value. The data used for financial model calculations can be seen in Table 4.

Year	0	1	2	3
Electricity generation	0	175820	175820	175820
Thermal generation		71344896	71344896	71344896
Revenue	0	293814587	293814587	293814587
(Fuel cost)	0	0	0	0
OpEx	0	12739077	12739077	12739077
Specific OpEx [€/MWh]	11	11	11	11
EBITDA	0	281075510	281075510	281075510
Interest	0			
Debt payment	$0	($96,198,298)	($96,198,298)	($96,198,298)
FCF	($254,781,534)	$184,877,213	$184,877,213	$184,877,213
Present value [10%]	($254,781,534)	$168,070,194	$152,791,085	$138,900,986
NPV	$1,319,182,399			
IRR	72.56%			
Discount rate	10.00%			

Table 4: First 3 years of the model used for NPV calculations.

6.4 Sensitivity analysis

Sensitivity analysis was done on the main contributing parameters, Capital Expenditure, price of hot water, and price of electricity from the range of 50% to 150% of the chosen value as can be seen in Figure 10.

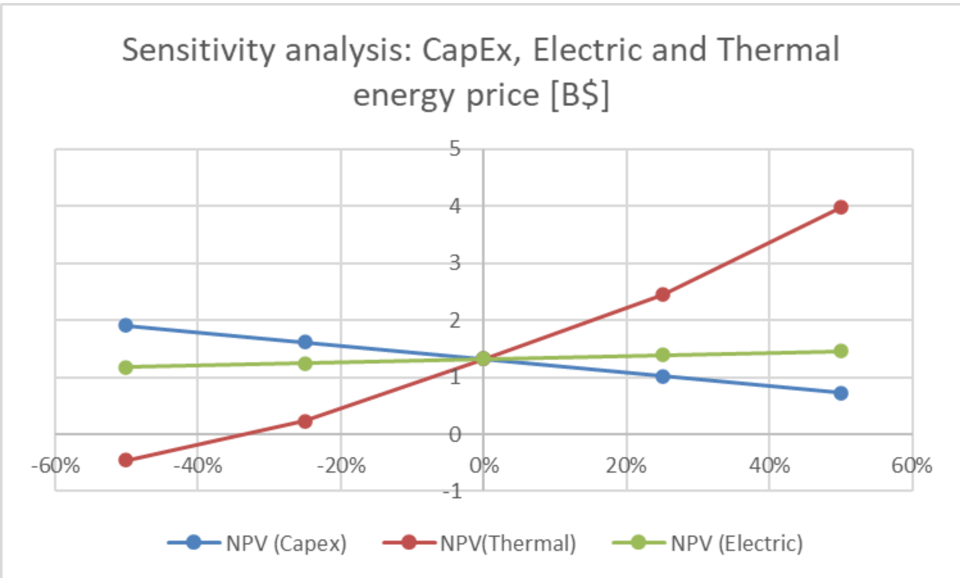

Figure 10: Sensitivity analysis using water cost, electric cost and capital expenditure in multiples of 0.5 to 1.5.

6.5 Financial conclusion

In order to get the wattage that the Nuclear Power plant is able to provide, a considerable amount of coal or oil is needed. Using the specific heat water, amount of of coal, oil, and nuclear that are needed to heat 20.5 million cubic meters of water per year (approximately 109MWth) Table 5 below was created.

Specification	Value	Unit
Energy density coal/kg	30000	kJ/Kg
Energy density oil/L	42000	kJ/Kg
specific heat water	4.18	kJ/Kg
starting temperature	40	℃
Output temerature	80	℃
Oil /L	0.003980952	L/L
Oil /Y	81909339.54	L/y
Price oil	1.488888889	$/L
Coal/L	0.005573333	kg/L
Coal/y	114673075.4	kg/y
Price coal/kg	0.13	$
Oil price per year	$121,953,906	$
Coal price per year	$14,907,500	$
Uranium price per year	$414,348	$

Table 5: Price of heating utility hot water by source.

It's noteworthy to highlight that the processed energy available for customer consumption totals $71,344,896, derived from the NuScale module at 109MWth/year, which remains more economical than the cost of oil alone and likely to be more economical than having a power plant process the coal for thermal and electric energy.

The 20 year net present value of the project is very positive, $1.3 billion, with a free cash flow of $185 million. The finance is 20% equity and 70% loan at 7% interest and a yearly payment of $96 million and cost of operation of $12.7 million. The project can be both very profitable and be cheaper than the thermal energy from both coal and oil.

7 Environmental and Social Issues

7.1 Carbon Offset Potential

As mentioned in the Introduction and Background sections, greenhouse gas emissions reductions are becoming increasingly important for the DOD. There is significant potential to reduce emissions from installation energy production such as the coal-fired plant at Fort Wainwright. Therefore, understanding the carbon offset potential of switching from coal to nuclear as the generation source is an important decision making point for stakeholders in the project, particularly when communicating with the Army about the project and requesting Army funding. The total carbon offset potential is 98,000 tons of CO_2 equivalent per year. See below for calculations.

Calculation for coal electricity generation over one year assuming a 58% capacity factor and 20 megawatt rated capacity [26].

$$20 \text{ MW} \times 58\% \times 8760 \text{ hours} = 101{,}616 \text{ MWh} \tag{7}$$

Calculation for nuclear electricity generation over one year assuming a 95% capacity factor and 20 megawatt rated capacity.

$$20 \text{ MW} \times 95\% \times 8760 \text{ hours} = 166{,}440 \text{ MWh} \tag{8}$$

Carbon emissions over a year of coal-fired electricity generation using an emissions factor coal [17].

$$970 \text{ tonnes } CO_2\text{(eq)/GWh} \times 101.616 \text{ GWh} = 98{,}568 \text{ tonnes } CO_2\text{(eq)} \tag{9}$$

Carbon emissions over a year of nuclear electricity generation using an emissions factor for nuclear [17].

$$6 \text{ tonnes } CO_2\text{(eq)/GWh} \times 166.44 \text{ GWh} = 999 \text{ tonnes } CO_2\text{(eq)} \tag{10}$$

Total carbon offset calculation for switching from coal to nuclear electricity generation.

$$98{,}568 \text{ tonnes } CO_2\text{(eq)} - 999 \text{ tonnes } CO_2\text{(eq)} = 97{,}569 \text{ tonnes } CO_2\text{(eq)} \tag{11}$$

7.2 Safety Concerns

There is a lot of misinformation regarding the safety of nuclear, especially with the new emerging field of advanced nuclear. It is important to note the specific design features of advanced nuclear that distinguish it and make it safer than traditional large reactors. Figure 11 compares death rates of nuclear to coal, indicating nuclear is the safer technology with only 0.03 deaths per terrawatt-hour while coal has 24.6 deaths per terrawatt-hour.

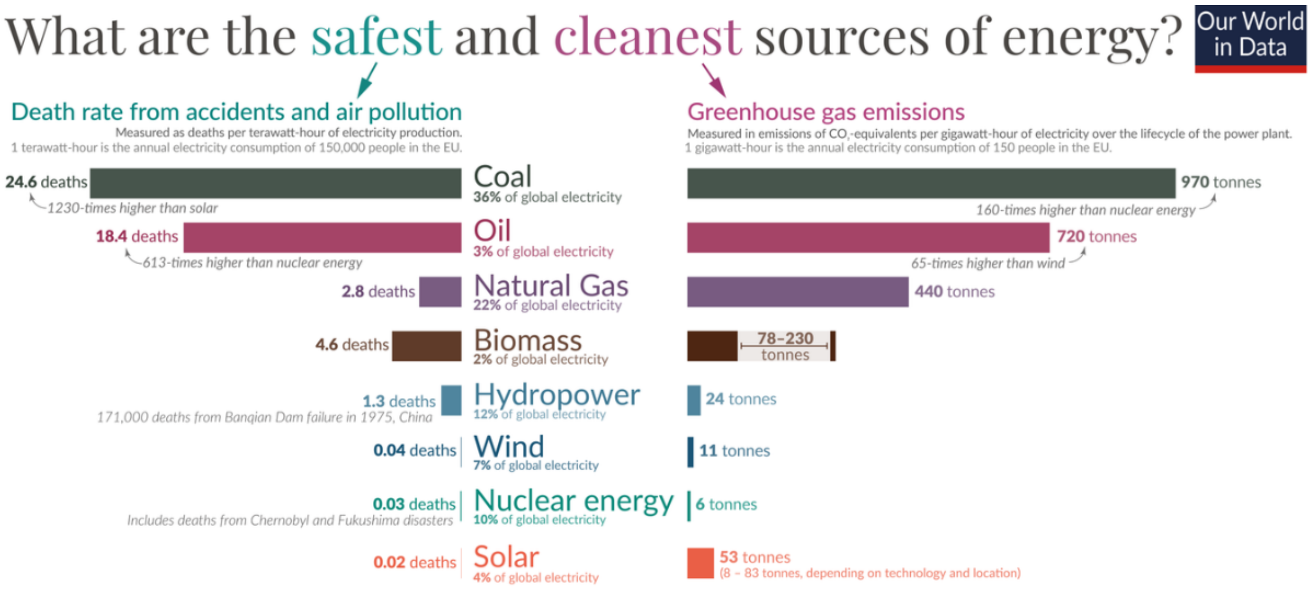

Figure 11: Death rates per terrawatt-hour of electricity production and carbon dioxide equivalent emissions per gigawatt-hour by generation source [17].

7.3 Additional Value Streams

This covers potential additional value streams the proposed SMR can provide. Considering benefits beyond cost is crucial for decision-making when it comes to investing in nuclear technologies. Potential value streams include excess heat utilization, the potential to sell to the local grid, grid stability for the Railbelt, clean and cheap power for the local community, community engagement such as tours, education, and research cooperatives, and job creation as well as technical training opportunities.

Other projects that could complement the SMR project include integrating it with a data center, given Alaska is very cold and would not require much refrigeration. Wood treatment could also be done with excess heat. There is potential for green hydrogen production with excess electricity.

8 Conclusion

Overall the project is feasible technologically and financially and the old coal plant site of Fort Wainwright has a lot of the infrastructure already present. There is access to the Anchorage port by railroad or highway for shipments. The project's thermal and electrical power model are online and running and suitable for specific energy demands onsite.

8.1 Background

In the background section, an overview of Small modular reactors (SMR) what they are and their wattage and listing feasible reactors along with reasoning for reactor choice. Site Location was discussed along with the existing decommissioned coal power plant that already exists on Fort Wainwright along with existing infrastructure. Alaska has no nuclear currently but there is growing interest in the topic of modular reactor technology for thermal and electric use. The relatively low price and volume of shipped nuclear fuel would be highly suitable for the remote area of Fairbanks.

8.2 Resources

Necessary resources include 0.6 tons of fuel per the 2 year fueling cycle and water as well as road access for shipments and electrical infrastructure. The fuel for the process is procured and disposed of in the US, and the electrical infrastructure from the coal plant would be a valuable backbone on which new cables, transformers, and cabinets could be added to accommodate increased wattage. There are highways and railroads from Anchorage port to Fairbanks. The Anchorage port is suited for our equipment shipping needs. Water requirements are fulfilled using a nearby cooling pond with around 100,000 cubic meters of water, supplemented by the Chena River located approximately 1 kilometer north. The plant requires around 2,160 cubic meters of water per day, and the cooling pond can supply 46 days of water before needing to be replenished. Doyon Utilities LLC has a 50-year utility privatization contract allowing for a long-term investment payback of the SMR plant which they will operate and own. The plant servicing would provide jobs and education opportunities for Doyon and the Alaska population.

8.3 Technical Design

The process flow diagram and analysis of each of the heat exchangers provide and in depth understanding of the different operating conditions at each step within the Rankine cycle and offer a calculation for the total electrical and thermal output, 21 megawatts and 109 megawatts, respectively. The general arrangement gives an overview of the necessary components of the proposed SMR and their layout within the plant footprint, an approximately

100 square meter area. The single line diagram provides an overview of key elements for the electrical system and the different voltage levels for operations.

8.4 Economics

In this section, the capital expenditure and cost of finance (CapEx), operational expenditure (OpEx) including staff, fuel procurement and disposal, and cost of maintaining the plant to calculate the operating income are covered. The plant has an initial investment of $1.27 billion financed 80% by loan 20% of equity and OpEx of $ 12.7 million. Using the CapEx and OpEx along with, loan payment calculations, the NPV was calculated to be $1.32 billion with free cash flow (FCF) of around $ 185 million a year.

8.5 Future Work

High-level technical and economic analysis suggests an SMR is feasible at Fort Wainwright. The next step is a more detailed technical and cost analysis to move the project forward. Additionally, nuclear misinformation needs to be addressed within the community to make the project viable. Alaskans are still very divided on the support of nuclear. Current polls of the local community indicate that 47% have not heard about advanced nuclear technology and 24% have heard very little [27]. When educated about nuclear microreactors, public support climbs to 74% [27]. Therefore, there is potential to gain public support for the project if appropriate educational programs are implemented.

Additional value streams can also be considered to add the most benefit for the community and implement appropriate subsequent uses with excess energy from the SMR plant, or in the case that the capacity increases in the future. These could include a data center, green hydrogen production, and using excess heat and electricity for the local grid, offering an additional revenue stream as well as clean and cheap power to the surrounding local community. There should be additional work to explore options and identify feasible added value projects to maximize benefit to all stakeholders.

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