WASTE HEAT TO ELECTRICITY: TECHNO-ECONOMIC FEASIBILITY OF THE ORGANIC RANKINE CYCLE AT UCALGARY'S CENTRAL HEATING PLANT

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INTRODUCTION

- In 2012, the University of Calgary established a 15-megawatt natural gas combined heat and power (CHP) cogeneration plant on its main campus (Northshore Environmental Consultants, 2023).
- The CHP plant meets main campus' heating needs during winter by directing waste exhaust gases into a heat recovery unit, generating 200 ℃ hot water for campus-wide heating and hot water usage. However, during warmer months of the year, when there is less demand for heating, excess heat is bypassed and exhausted into the atmosphere.
- The Organic Rankine Cycle (ORC) converts low-temperature heat into electricity, making it useful for industries that produce waste process heat, thereby conserving resources on-site.

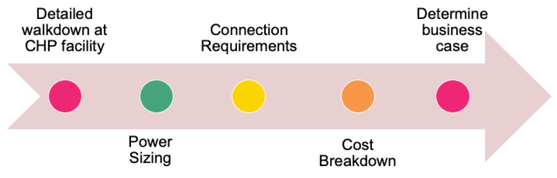
RESEARCH QUESTION

What is the techno-economic feasibility of integrating an Organic Rankine Cycle (ORC) generator to capture the surplus thermal energy and generate additional electricity at the University of Calgary's cogeneration facility?

PROJECT DIMENSIONS

- **Energy:** Improving the efficiency of the district energy and cogeneration system at the University of Calgary.
- **Environment:** Offsetting electricity purchases from the Alberta grid and using waste heat instead, the project contributes to reducing Scope II carbon emissions.
- **Techno-economics:** Selection and integration of a suitable commercial ORC generator into the University's heating and cooling infrastructure. The technical study focuses on the mechanical and electrical integration: linking the High-Temperature Hot Water (HTHW) distribution system and cooling water as an input to the ORC generator, then connecting the electricity output from the ORC generator to the CHP microgrid. A project breakdown of capital, maintenance, and decommissioning costs is obtained.

METHODOLOGY



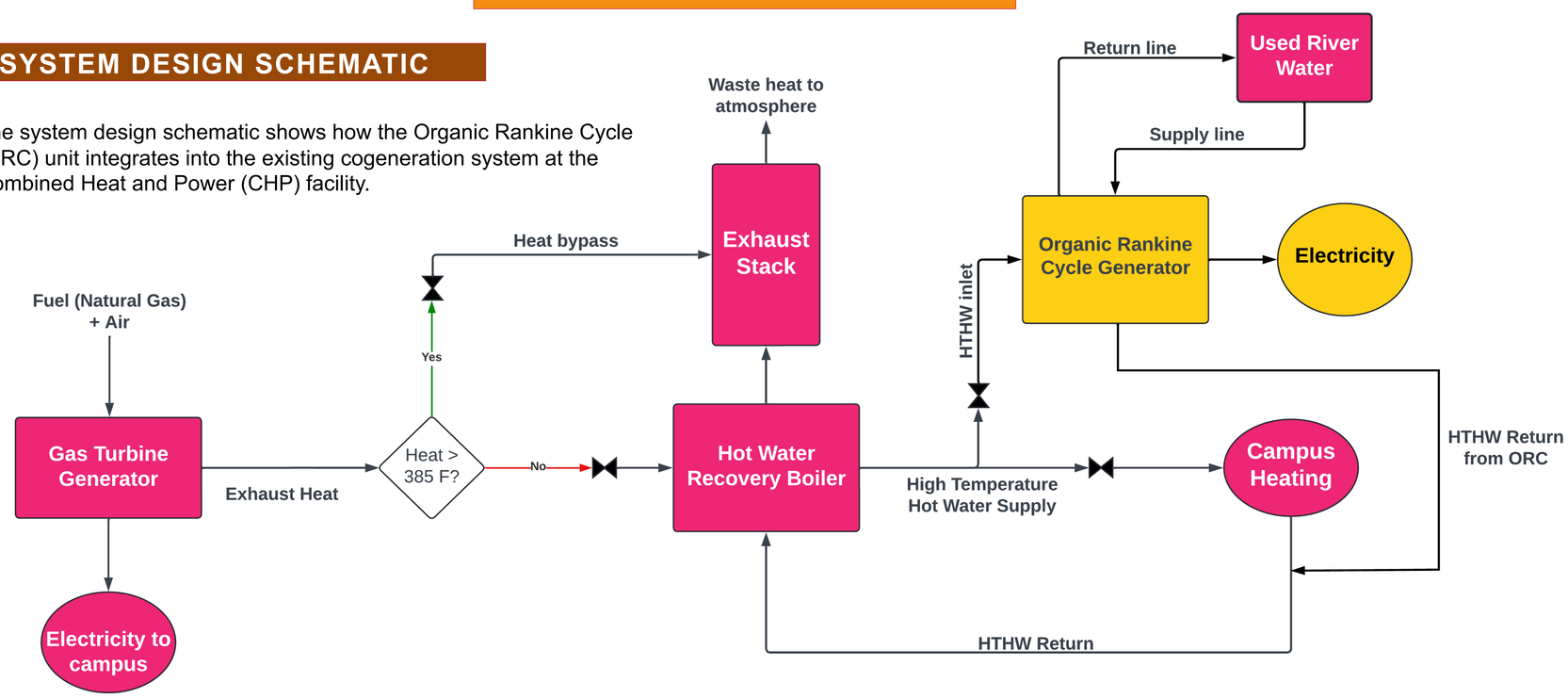
REFERENCES

- Quoilin, S., Broek, M. V. D., Declaye, S., Dewallef, P., & Lemort, V. (2013). Techno-economic survey of Organic Rankine Cycle (ORC) systems. *Renewable and Sustainable Energy Reviews*, *22*, 168–186. https://doi.org/10.1016/j.rser.2013.01.028
- Government of Alberta. (2023). *TIER Regulation Fact Sheet*. Alberta Environment and Protected Areas. https://www.alberta.ca/system/files/custom_downloaded_images/ep-fact-sheet-tier-regulation.pdf
- Northshore Environmental Consultants. (2023, June). *University of Calgary Central Heating Plant 2022 TIER Quantification Methodology*.

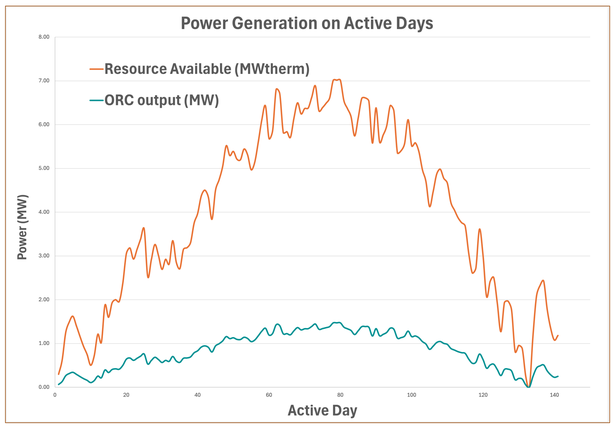
RESULTS

SYSTEM DESIGN SCHEMATIC

- The system design schematic shows how the Organic Rankine Cycle (ORC) unit integrates into the existing cogeneration system at the Combined Heat and Power (CHP) facility.



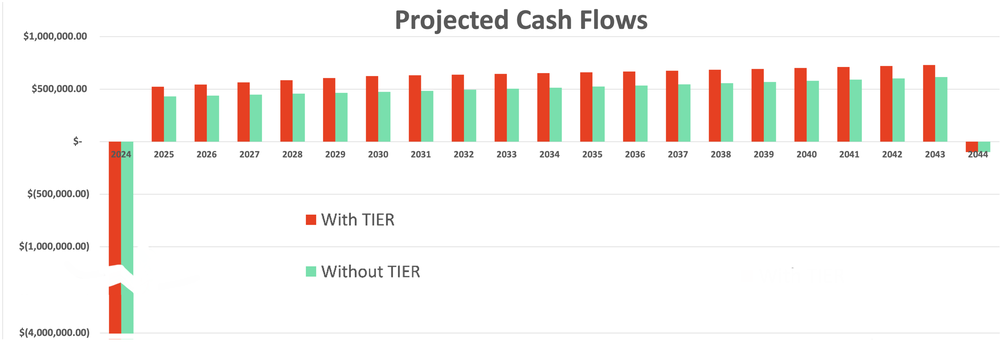
POWER GENERATION



- Organic Rankine Cycles achieve peak efficiencies of around 20% (Quoilin et al., 2013). As this energy is freely available, the ORC proves valuable for electricity generation.
- The total annual electricity generated by the 1.5 MW ORC model is 2,810,589 kWh.

CASH FLOWS

- Projected cash flows are analyzed both with and without TIER output allocation applied.
- For each MWh of electricity generated using waste heat recovery technology, the university is exempt from paying carbon taxes on 0.3626 tonnes of CO2e for their overall campus emissions in 2023 (Government of Alberta, 2023).
- The output allocation of 0.3626 tonnes of CO2e per MWh is set to decrease by 2% annually starting in 2023.



CONCLUSION

- Overall, the project results indicate a strong business case for further investigating the implementation of an ORC unit, as it shows promising financial benefits for the University and offers environmental incentives through the reduction of Scope II emissions.

ENVIRONMENTAL ASSESSMENT

- **Over a 20-year project life, the total abated emissions amount to 26,420 tonnes of CO2e.**
- The average home in Canada uses about 11,111 kWh of electricity per year (Statistics Canada, 2024), which results in about 5.2 tonnes of CO2 emissions annually.
  - Therefore, the yearly emissions savings from this project are equivalent to emissions from 254 Canadian homes per year.

FINANCIAL ANALYSIS

- Without any government backing, the project has a positive Net Present Value (NPV) of over one million dollars, an Internal Rate of Return (IRR) of 7% (which exceeds the discount rate used to determine the NPV), and a payback period of a decade—half the project's lifespan.
- When TIER credits are applied, the financial results improve further, demonstrating the project's potential for profitability.

	With TIER credits	Without TIER credits
NPV	$2,606,747 CAD	$1,067,601 CAD
IRR	10%	7%
Simple payback period	8 Years	10 Years

LIMITATIONS

- **Technical limits:** Return temperature requirements at Central Heating Plant, thermodynamic efficiency of ORC, cost savings for electricity in Alberta generally lower than other regions, heat output limit of 58 GJ/hr from boiler.
- **Accuracy:** Electricity price approximations to model spot price system at UCalgary, average temperature variations on campus modelled.

FUTURE WORK

- More detailed engineering scope to ensure compatibility between the ORC and the CHP facility and to generate more accurate cost estimates.
- Control system analysis to balance the ORC's inputs and outputs with the facility's temperature requirements.