COMMERCIAL SCALE THERMOELECTRIC OTEC: A COMPUTATIONAL OPTIMIZATION

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WHAT IS THERMOELECTRIC OTEC?

Thermoelectric (TE) ocean thermal energy conversion (OTEC) uses TE materials to convert the temperature difference between the ocean's cold deep waters and warm surface waters into electricity.

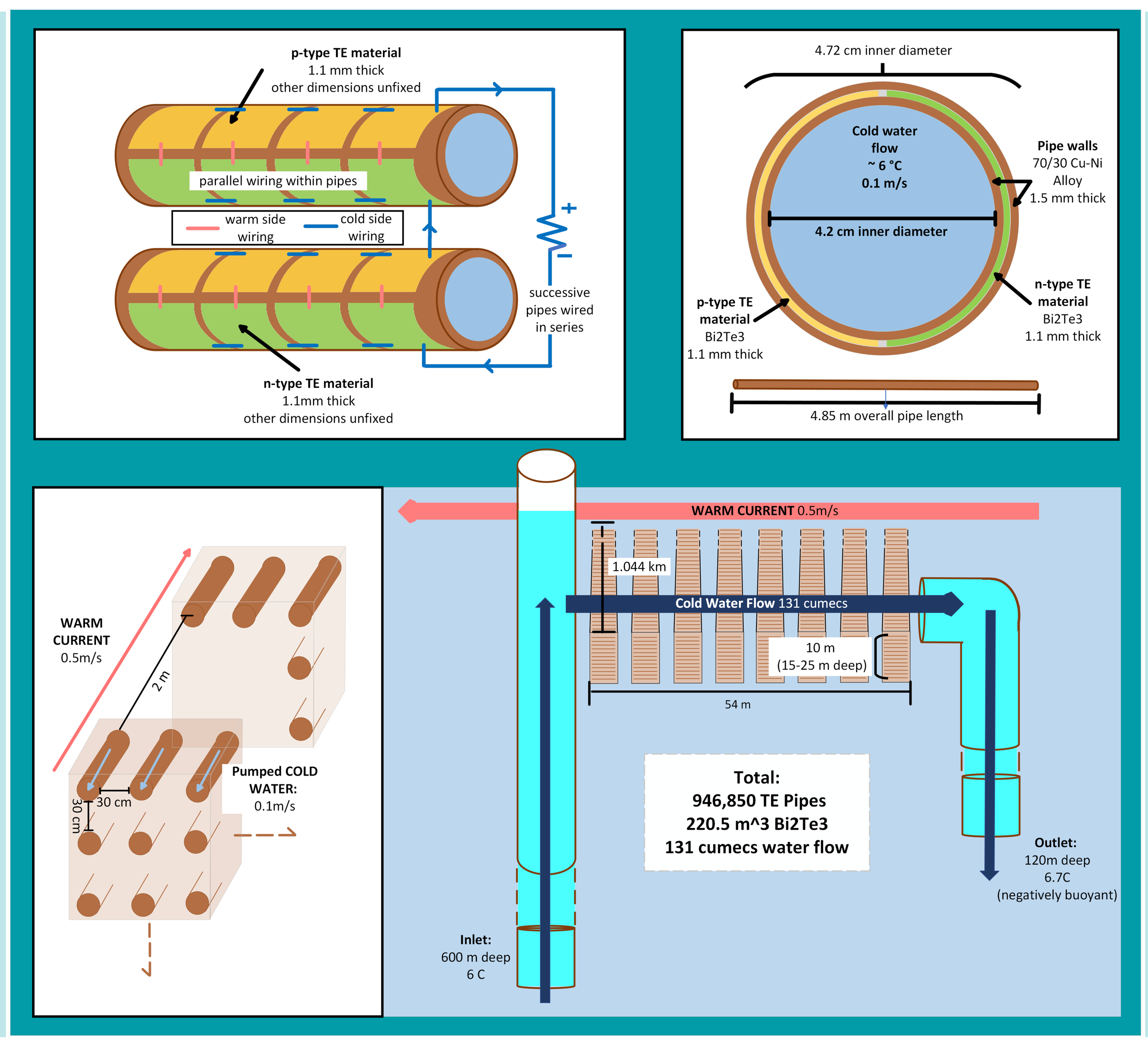
WHY THERMOELECTRIC OTEC?

Dependable Thermocline always exists, no energy storage needed

Reliable Few moving parts, corrosion and biofouling resistant

Abundant Requires a smaller temperature difference than conventional OTEC

Renewable Emits zero fossil fuels



RESEARCH GOALS

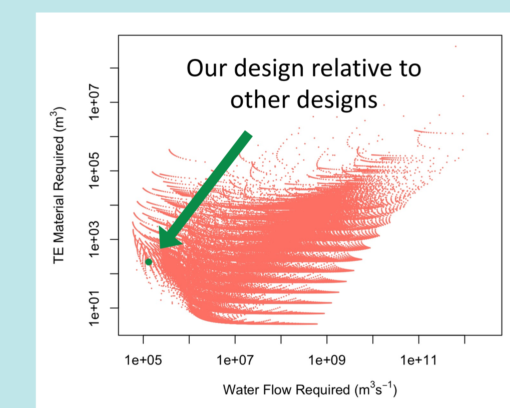
To design a 500 MW TE OTEC plant that

1. Minimizes the **water flow** required
2. Minimizes the **TE material** required

PLANT DESIGN

A large pipe brings cold water from 600 m down to the surface. The cold water passes through a series of small pipes surrounded by warm ocean currents.

TE materials in the pipes' walls convert the temperature difference into electricity. The cold water is returned 120 m down.



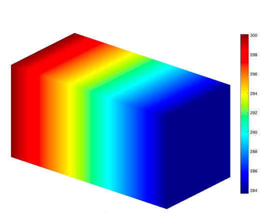
THERMOELECTRIC LEGS

GOALS

Find the optimal shape, thickness, and cross-sectional area for each TE leg

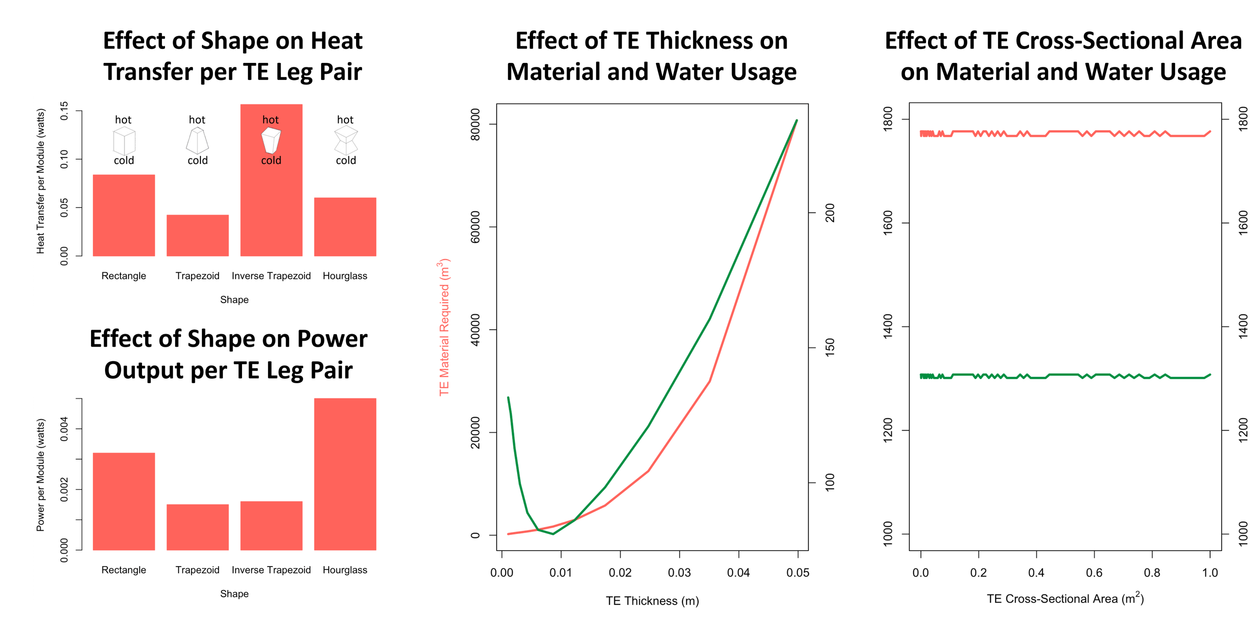
METHODOLOGY: Model in MATLAB

- Temperature distribution within TE leg
- Heat transfer through TE leg
- Electrical resistance of TE leg



Temperature distribution within a TE leg, modeled with the heat equation

DATA AND RESULTS



Shape and width were determined by modeling TE legs independent of pipe design

KEY TAKEAWAYS

- Hourglass shape performs the best followed by the rectangle
- TE material required increases with thickness
- Minimum water flow required with thickness of 8.65 mm
- Cross-sectional area is insignificant

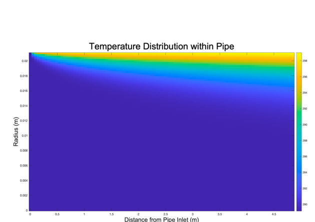
PIPE DESIGN

GOALS

Find the optimal length, radius, and water flow velocity for each pipe

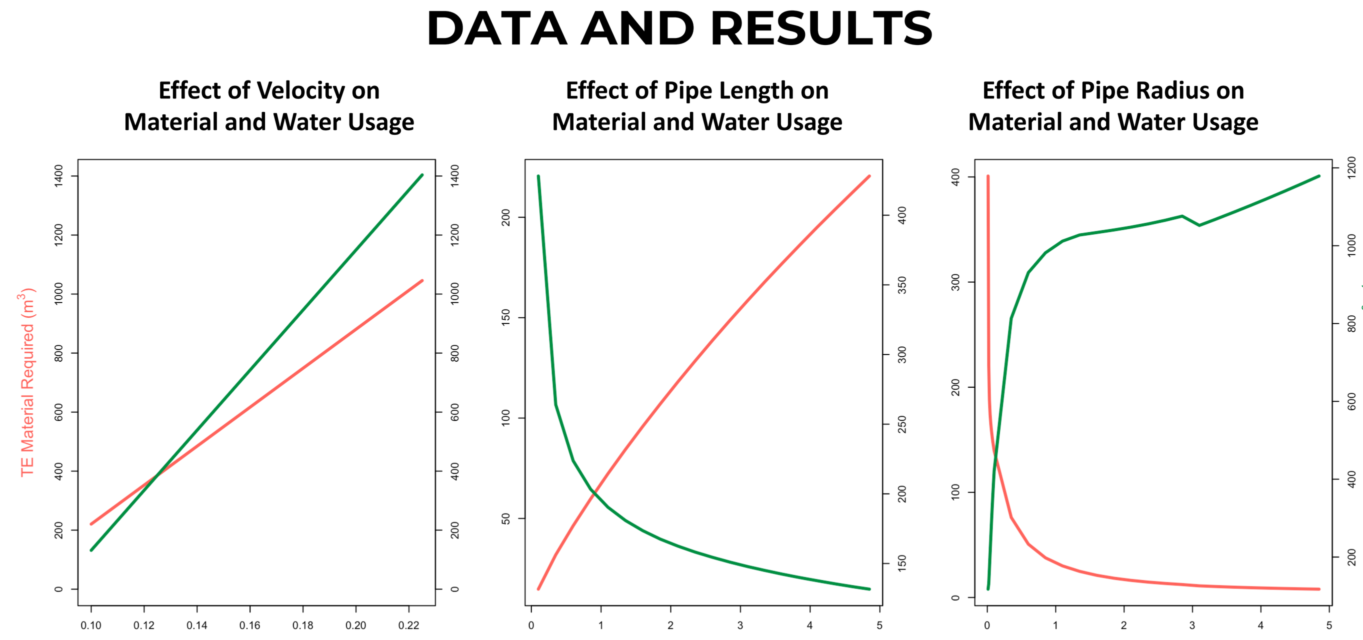
METHODOLOGY: Model in MATLAB

- Temperature distribution within pipe
- Heat transfer through TE legs
- Accounts for energy to pump water



Temperature distribution within a pipe, modeled with a heat balance equation

DATA AND RESULTS



All variables except the variable of interest were held constant at these values: 0.021 m pipe radius, 4.85 m pipe length, 0.1 m/s velocity, 0.0011 m TE thickness

KEY TAKEAWAYS

- TE material and water flow required increase with velocity
- TE material required increases with pipe length and decreases with pipe radius
- Water flow required decreases with pipe length and increases with pipe radius

PIPE & PLANT LAYOUT

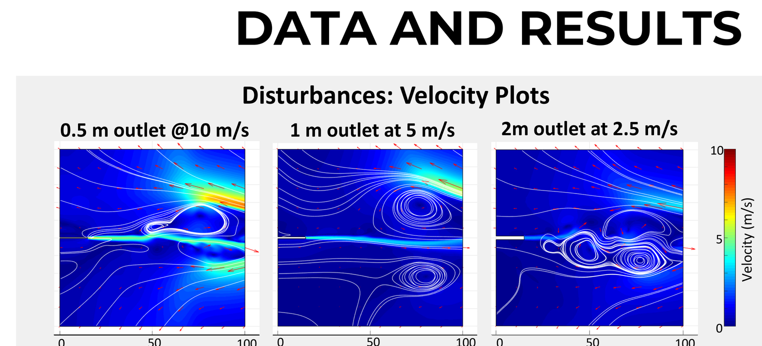
GOALS

Determine optimal pipe spacing and how to intake and output water

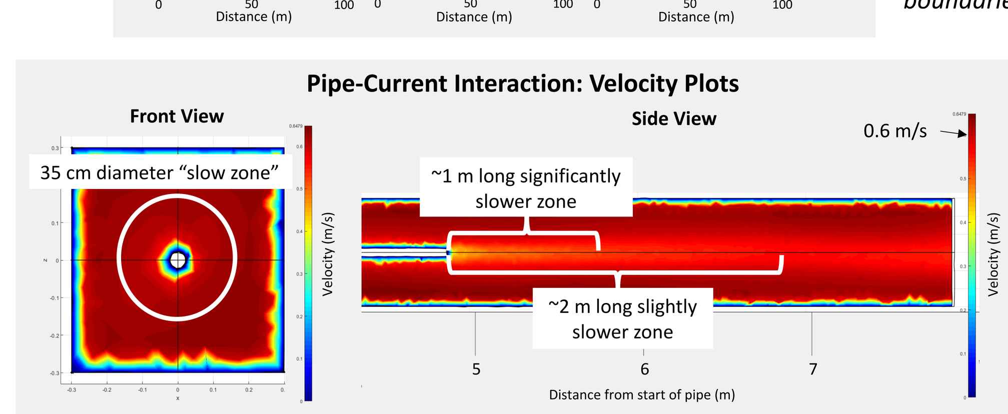
METHODOLOGY: Simulations in FEATool Multiphysics & Analysis of ocean temperature profiles

- Velocity distribution of ocean current surrounding pipe
- Disturbances from water outflow
- Considers environmental impact

DATA AND RESULTS



2-D Velocity plots for constant discharge of 5 m²/s. Pipe extends 15 m into a 100 m x 100 m box with neutral outflow/pressure boundaries.



Slices of a 3D plot showing changes to the velocity of an ocean current starting at 0.6 m/s as it flows past one TE pipe.

KEY TAKEAWAYS

- Pipes need to be at least 35 cm apart perpendicular to flow and 2 m apart parallel to flow
- Slow and large outflow is optimal to reduce disturbance
- Outflow must be below the light limiting depth of 120 m
- Pipes placed 15-25 m below the surface minimize wave stress and maximize temperature

Future Explorations

- **Internal pipe structure**: Can you induce turbulence to better dissipate heat but minimize pumping energy costs?
- **System design**: What is the best way to connect the TE pipes?
- **Surface ocean dynamics**: More accurate model of warm side ocean currents
- **Sustainability**: Can you easily recycle the materials after the plant's lifespan?
- **Economic competitiveness**: What are the upfront and maintenance costs?
- **Microscale plant feasibility**: In our models, micro & millimeter scale dimensions were optimal. Is a plant of this scale feasible durability & construction wise?
- **Create a prototype**

References

Liu, L. (2014). Feasibility of large-scale power plants based on thermoelectric effects. New Journal of Physics, 16(12), 123019. https://doi.org/10.1088/1367-2630/16/12/123019

Şişik, B., & LeBlanc, S. (2020). The influence of leg shape on thermoelectric performance under constant temperature and heat flux boundary conditions. Frontiers in Materials, 7. https://doi.org/10.3389/fmats.2020.595955

Wang, Y. T., Liu, W., Fan, A. W., & Li, P. (2013). Performance comparison between series-connected and parallel-connected thermoelectric generator systems. Applied Mechanics and Materials, 325-326, 327–331. https://doi.org/10.4028/www.scientific.net/amm.325-326.327

Seatrec. (2021, August 27). Vertical temperature profile. Seatrec. Retrieved February 15, 2022, from https://seatrec.com/vertical-temperature-profile/

Makai Ocean Engineering. (2022). Ocean Thermal Energy Conversion. Makai Ocean Engineering. Retrieved February 15, 2022, from https://www.makai.com/ocean-thermal-energy-conversion/

Jayadev, S. T.., Benson, D.K., & Bohn M. S. (1979). Thermoelectric Ocean Thermal Energy Conversion. Solar Energy Research Institute U. S. Department of Energy. https://www.nrel.gov/docs/legosti/old/254.pdf

Powell, C. A., & Michels, H. T. (2000). Copper-Nickel Alloys for Seawater Corrosion Resistance and Anti-Fouling - A State of the Art Review.

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