PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

Coaxial Reversible Medium-Deep Geothermal Heat Well Technology: A Sustainable Heating Solution

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Keywords: Sustainable alternatives, coaxial medium-deep geothermal heat wells, low-temperature heating networks, thermal energy storage, waste heat utilization, grid stability.

ABSTRACT

Heating systems are significant contributors to carbon emissions, particularly in Northern Europe, where they account for up to 30% of CO_2 emissions. This situation necessitates a comprehensive re-evaluation of heating practices, especially those reliant on fossil fuels. Transitioning to sustainable alternatives, including the electrification of heating systems, is critical. Central to this transition is the integration of industrial-scale heat pumps, which require reliable heat sources. Medium-deep geothermal heat wells (MDGHWs), located at depths of 1,000 to 3,000 meters, present a promising solution.

MDGHWs facilitate a multifaceted approach to energy management within local low-temperature heating networks, providing essential heating, cooling, and thermal energy storage year-round. The coupling of MDGHWs with industrial-scale heat pumps enables the establishment of efficient networks that operate continuously. In winter, these systems supply necessary heat, while in summer, they provide cooling services and recharge geothermal wells. A key advantage of this approach is the utilization of waste heat generated within the local network for thermal storage, enhancing overall efficiency and minimizing energy waste. When powered by renewable energy sources, MDGHWs can operate sustainably, offering a carbon-neutral solution for district heating.

QHeat is pioneering the transformation of heating and cooling systems through innovative geothermal technology. The advanced coaxial deep geothermal system has undergone extensive testing in collaboration with leading Finnish experts. This patented design optimizes energy extraction from deep thermal wells while mitigating performance issues. The coaxial MDGHW technology generates heat equivalent to approximately 40 traditional geothermal wells, significantly enhancing thermal exchange and reducing energy losses. Furthermore, the thermal well design allows for the underground storage of waste heat, ensuring stability within heating networks. This technology not only reduces operational costs but also enhances the environmental performance of buildings. The integration of coaxial flow technology improves heat pump efficiency by enabling lower temperature differentials, extending system lifespan, and reducing maintenance costs. This approach achieves significantly higher Coefficient of Performance (COP) rates compared to conventional systems while also reducing land use by 97%, a critical factor in densely populated areas. Additionally, the technology facilitates the underground storage of excess renewable energy, effectively balancing supply and demand. This capability is essential in today's energy landscape, where variability in renewable energy generation poses challenges for grid stability. Ultimately, this approach ensures that local geothermal networks can adapt to fluctuating energy availability while maintaining reliable service delivery.

In conclusion, local geothermal low-temperature heating networks utilizing MDGHWs and industrial-scale heat pumps represent an innovative approach to achieving sustainable, carbon-neutral heating. By leveraging geothermal resources, efficient systems can be created to meet today's energy needs while supporting future climate goals.

1. INTRODUCTION

As climate change intensifies, the demand for sustainable energy solutions becomes increasingly critical. Heating systems, especially those relying on fossil fuels, represent a major contributor to greenhouse gas emissions globally. In Northern Europe, heating systems account for approximately 30% of CO_2 emissions, underscoring the urgency for innovative and sustainable heating technologies.

Medium-deep geothermal heat wells (MDGHWs) offer a promising alternative, utilizing the Earth's natural heat efficiently while minimizing carbon footprints. By operating at depths of 1,000 to 3,000 meters, MDGHWs can tap into stable geothermal resources, providing a sustainable heating solution that aligns with current climate goals. This paper aims to explore the design, operation, and benefits of coaxial reversible geothermal heat well technology, emphasizing its potential applications in low-temperature heating networks.

2. LITERATURE REVIEW

2.1 Geothermal Energy: An Overview

Geothermal energy is derived from the Earth's internal heat, originating from both residual heat from the planet's formation and the decay of radioactive isotopes. This energy source is abundant and largely untapped, especially in regions with favorable geological conditions.

According to the International Energy Agency (IEA), geothermal energy has the potential to supply more than 10% of the world's energy needs, making it a crucial player in the transition to renewable energy systems.

2.2 Traditional vs. Modern Geothermal Systems

Traditional geothermal systems typically extract heat from shallow depths and are limited by geological conditions. In contrast, MDGHWs can exploit deeper resources, overcoming some of the limitations of conventional systems. For instance, while ground-source heat pumps (GSHPs) rely heavily on shallow ground temperatures, MDGHWs leverage higher thermal gradients available at greater depths, enhancing overall efficiency and effectiveness.

2.3 Challenges in Current Geothermal Applications

Despite the potential of geothermal energy, several challenges persist:

- Geological Variability: The effectiveness of geothermal systems heavily depends on local geological conditions. Not all regions are suitable for deep geothermal installations, which limits widespread adoption.

- High Initial Costs: The capital investment required for drilling and infrastructure can be prohibitive, particularly in urban settings where space is limited. The cost of drilling deep wells can vary significantly based on geological conditions, depth, and technology used.

- Technical Limitations: Conventional geothermal systems often face operational inefficiencies, including heat loss during transport. Additionally, issues related to groundwater contamination and induced seismicity must be addressed to ensure public acceptance.

The coaxial design of MDGHWs addresses these limitations by optimizing heat transfer, enhancing scalability, and reducing land use, making it a viable solution for densely populated areas.

3. TECHNOLOGY OVERVIEW

3.1 Company Overview

Quantitative Heat Oy, or more familiarly QHeat, is a company specialized in geothermal energy. The company has developed a new co-axial geothermal heating and cooling system. QHeat was founded in 2018 and its technology has been patented and tested in cooperation with Finnish experts and universities. QHeat has successfully delivered Finland's 5 first co-axial deep geothermal heating plants and has currently 2 projects on going. In 2022, The Finnish Climate Fund granted capital loan to QHeat that has been allocated to the purchase of new, efficient drill equipment for drilling deep heat wells. Currently focusing on new market entries with first projects in Estonia and negotiations in the Nordic countries.

3.2 Coaxial Reversible Medium-Deep Geothermal Heat Wells

MDGHWs utilize a coaxial configuration that allows for simultaneous heating and cooling, maximizing thermal exchange and minimizing energy losses. The system operates at depths where temperature gradients are significantly higher, making it possible to extract thermal energy efficiently. Research indicates that coaxial systems can achieve efficiency levels that are 20-30% higher than traditional geothermal systems.

QHeat geothermal wells are based on coaxial flow technology, which helps to keep the temperature difference between the cool and warm flow. This well design was innovated as the traditional shallow ground wells could not be scaled deeper because the heated liquid cools down in the well when it is transferred up. Our well is about 1000 – 2000 m deep, has a coaxial current and an isolated inner pipe. One well can provide heating to 15 000 square meters of commercial real estate so QHeat is not targeting single-family houses.

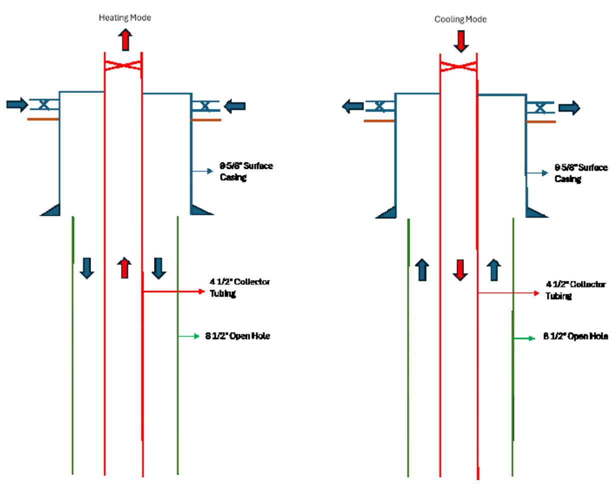

Figure 1: A typical 2000 meter Coaxial Well Design

3.3 Operational Principles

The operational principles of MDGHWs hinge on conductive heat transfer, which enables the system to achieve higher efficiencies than convective systems. The inner insulated pipe is designed to extract thermal energy from the Earth, while the outer pipe returns cooler fluid, creating a continuous loop of heat exchange. This design minimizes thermal losses and enhances the overall Coefficient of Performance (COP), a critical metric for assessing the efficiency of heating systems. COP rates for MDGHWs have been reported to exceed 6.0 in optimal conditions, making them highly efficient compared to conventional systems.

The QHeat concept relies solely on conductive heat transport within rock, a property that shows minimal variation in populated areas. Traditional geothermal methods, by contrast, often rely on convective systems, where high-temperature fluid convection occurs. However, this convection is rare and challenging to predict before a project begins. The global heat flux in the Earth's crust serves as a reliable proxy for heat wells at depths of around 2 km. As shown in the data below, only small variations are observed, unlike in convective systems. Conductive geothermal solutions are also globally scalable.

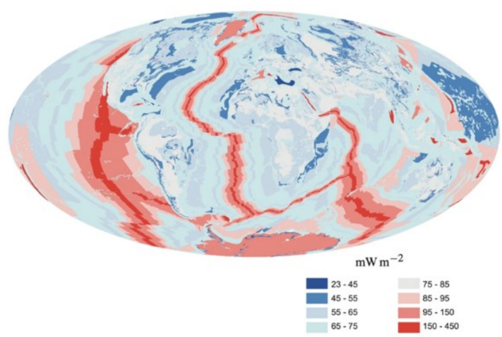

Figure 2: Global Heat Flux Map of the Earth's Crust

3.4 Advantages Over Conventional Systems

1. Higher Thermal Exchange Rates: The coaxial design significantly improves thermal exchange capabilities, enabling MDGHWs to generate heat equivalent to approximately 40 traditional geothermal wells.

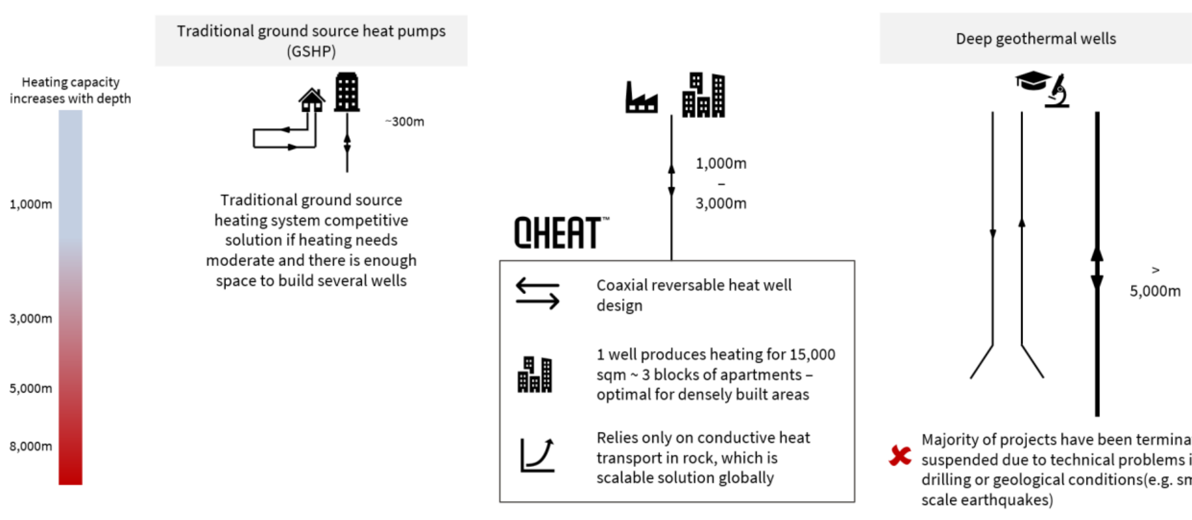

Figure 3: Heating Capacity of Coaxial Wells vs. Traditional Systems

2. Reduced Land Use: By utilizing a compact coaxial design, MDGHWs can be installed in urban areas with limited land availability, reducing the overall land footprint required for geothermal installations by up to 97%. This is particularly beneficial in densely populated cities where land scarcity is a significant concern.

Table 1: Land Use Comparison

Heating System Type	Land Use (hectares per MW)
Coaxial MDGHW	0.01
Traditional GSHP	0.4

3. Improved Efficiency: The coaxial flow technology enhances the COP of heat pumps by allowing for lower temperature differentials. This not only extends the lifespan of the systems but also reduces maintenance costs. Lower temperature differentials also enable the use of lower-cost materials and components, further decreasing overall project costs.

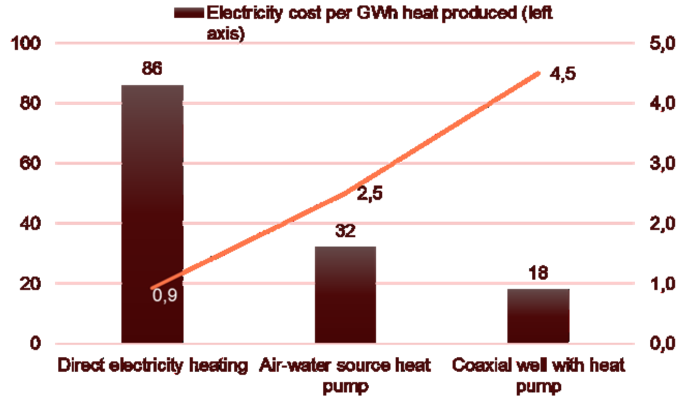

Figure 4: Comparison of Coefficient of Performance (COP) for Different Heating Technologies

4. CASE STUDIES

4.1 Successful Implementations in Finland

QHeat has successfully delivered large-scale geothermal heating and cooling solutions in several Finnish municipalities, demonstrating the technology's effectiveness in real-world applications.

4.1.1 Project A

Located in a densely populated urban area, this project utilized MDGHWs to provide heating for a residential complex covering over 15,000 square meters. The project achieved a COP of 5.0, resulting in substantial reductions in energy costs and greenhouse gas emissions. The project also demonstrated the capability of MDGHWs to adapt to seasonal energy demands, effectively providing both heating and cooling.

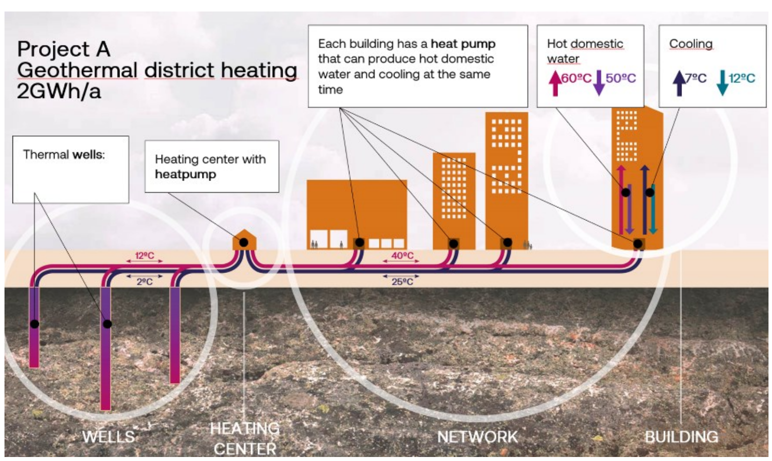

Figure 5: Project in a Densely Populated Area to Provide Heating for a Residential Complex

4.1.2 Project B

This project integrated MDGHWs with industrial applications. The coaxial wells integrates heat storage technology into waste-to-energy plants, emphasizing the potential of QHeat's technology to store excess heat and use it during peak demand. The purpose of this storage is to increase efficiency, reduce reliance on fossil fuels, and optimize economic and environmental outcomes.

During warmer months, the waste-to-energy plant produces excess heat, which is stored in geothermal heat wells. These wells retain the heat until it's needed during colder periods. When demand for heating spikes in colder months, the stored heat is released, providing additional capacity to the heating network without relying on additional power sources.

As results enhanced efficiency and lower emissions by storing heat rather than wasting it, the plant operates more efficiently, which translates into lower emissions overall. Also reduced fossil fuel or electricity dependence with the stored heat available during peak hours, the plant can avoid using fossil fuel or electricity-based peak power plants, which are typically used to meet sudden spikes in demand.

Figure 6: Biomass Power Plant Case

Top Graph – Current Heat Sourcing: Shows the current heat management at the biomass power plant, where a peak power plant is used to meet demand spikes.

Red Line: Indicates the fluctuation in outside temperature, which drives the need for peak heating.

Green Area: Represents the energy supplied by biomass power plant. However, additional energy is provided by a peak power plant (gray area) during high-demand times, resulting in higher emissions and fossil fuel use.

Bottom Graph – Heat Sourcing with Heat Storage: Illustrates how integrating QHeat's heat storage reduces reliance on peak power plants.

Heat Storage (Orange): During periods of excess heat production, this heat is stored and later used to meet peak demand, reducing or even eliminating the need for the peak power plant.

Result: Biomass power plant can operate using only bio-waste as an energy source, enhancing sustainability and minimizing fossil fuel usage, even during peak times.

4.2 Quantitative Analysis

The performance metrics collected from these projects reveal the advantages of MDGHWs:

- Thermal Output: The average thermal output exceeded initial projections, validating the technology's efficiency.

- Operational Costs: The integration of MDGHWs resulted in operational cost reductions of approximately 40%, demonstrating the financial viability of geothermal solutions.

Table 2: Summary of Project Performance Metrics

Project	Area Covered (sqm)	COP	CO2 Reduction (%)	Operational Cost Reduction (%)
Project A	15,000	5.0	50	40
Project B	20,000	4.8	60	35

Using MDGHWs can result in competitive or lower costs per MWh, making them attractive for sustainable heating projects.

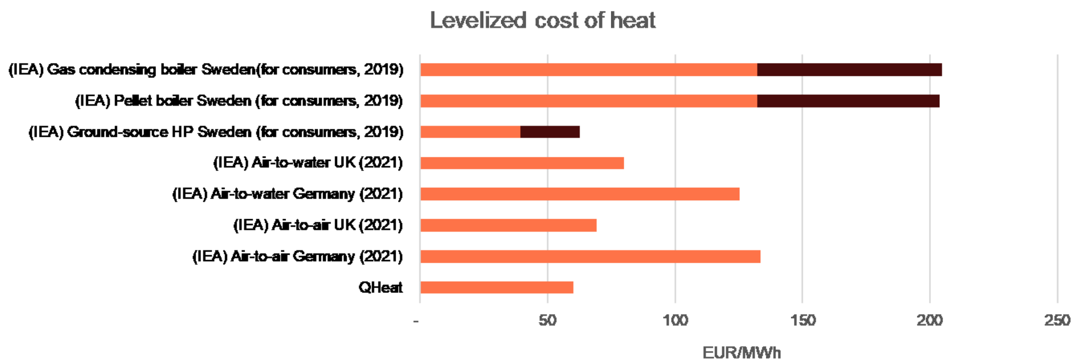

Figure 7: Levelized Cost of Heating

5. DISCUSSION

5.1 Implications for Urban Heating

The integration of MDGHWs into urban heating networks can significantly reduce reliance on fossil fuels and decrease overall carbon emissions. By tapping into deep geothermal resources, cities can transition towards a low-carbon heating future that aligns with the European Union's climate goals and commitments to reducing greenhouse gas emissions. Studies indicate that widespread adoption of geothermal heating could reduce urban emissions by up to 50% in the coming decades.

5.2 5th Generation District Heating and Cooling (5GDHC)

The implementation of heat storage and low-temperature heating networks, referred to as 5th Generation District Heating and Cooling (5GDHC), involves the use of bidirectional and heat pump-assisted nodes. These systems necessitate at least one adjustable node, preferably a storage node, within the network area, such as the QHeat well. Over 100 such systems are currently operational across Europe, utilizing various primary energy sources. To achieve European Union targets, thousands of small-scale 5GDHC systems, each with a capacity of around 1 megawatt (MW), are set to be constructed. Notably, Europe is transitioning directly from the existing 3rd Generation District Heating (the current Nordic standard) to the more advanced 5th Generation systems.

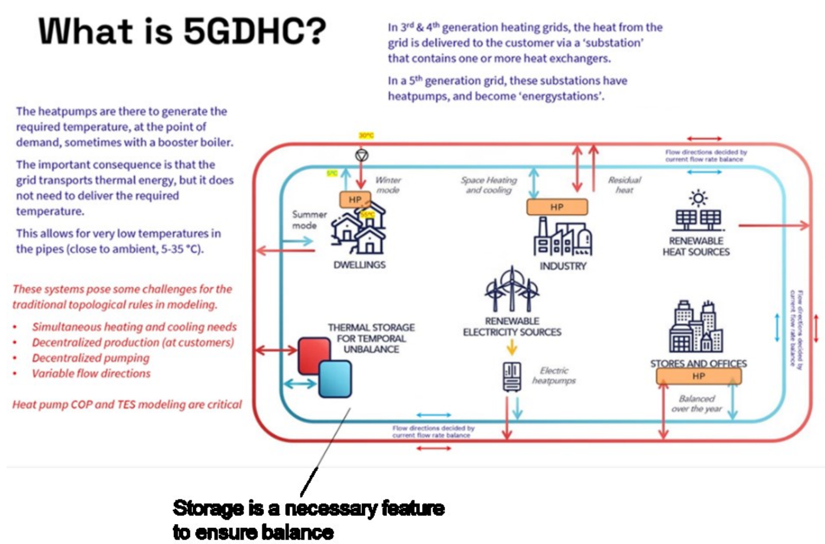

Figure 8: 5th Generation District Heating and Cooling (5GDHC)

5.3 Policy and Economic Incentives

Governmental policies and financial incentives play a crucial role in promoting the adoption of renewable energy technologies. Supportive frameworks, including grants, subsidies, and tax incentives for geothermal projects, can facilitate the transition to sustainable heating solutions. Policymakers must prioritize investments in research and development to enhance geothermal technologies and streamline permitting processes.

5.4 Scalability and Future Applications

The potential for expanding MDGHW technology to regions with similar geological characteristics presents significant opportunities for widespread adoption. Future research should focus on optimizing drilling techniques, enhancing system integration, and developing innovative financing models to maximize the efficiency and scalability of geothermal heating systems.

Data centers produce significant amounts of excess heat, which can be utilized for heating purposes in alignment with the EU taxonomy and various local incentives. Connecting data centers to heating networks not only ensures the effective use of this surplus heat but also offers substantial economic benefits. While excess heat generation is continuous, the demand for heating can vary, making heat storage solutions essential for optimizing these economic advantages. By implementing storage systems, data centers can better match heat supply with demand fluctuations, enhancing overall efficiency. As we move forward, the future of combined heat and power (CHP) systems may evolve into combined heat and district heating (CHD) systems, reflecting a shift towards more integrated and sustainable energy solutions.

5.5 Market Potential

The total addressable market for geothermal heating is substantial, with estimates exceeding €10 trillion globally. With 60% of European heat currently generated from fossil fuels, transitioning to geothermal solutions represents a massive market opportunity. According to projections, the European heating market will require 50% of all energy demand, making geothermal technologies essential in achieving climate goals. QHeat's estimated production capacity of 23,000 heat wells could contribute significantly to meeting these targets.

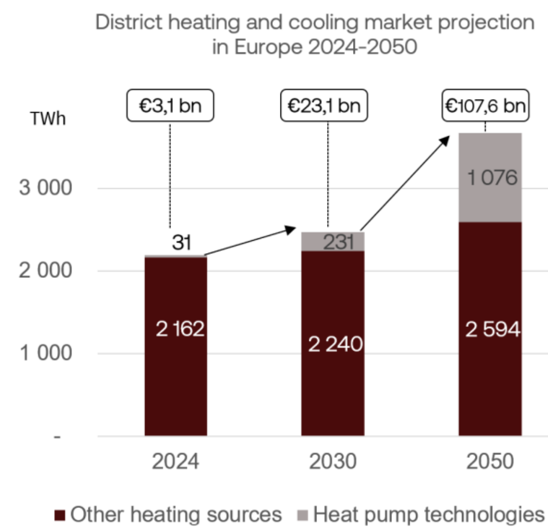

Figure 9: District Heating and Cooling Market Projection in Europe 2024-2050

6. CONCLUSION

The Coaxial Reversible Medium-Deep Geothermal Heat Well (MDGHW) technology offers a robust and sustainable solution to the challenges posed by traditional heating systems. By effectively harnessing the Earth's geothermal resources, this innovative technology not only meets current energy demands but also aligns with future climate goals, helping to combat the pressing issue of global warming. The unique design of MDGHWs enables efficient heat exchange, significantly reducing reliance on fossil fuels and minimizing greenhouse gas emissions.

Moreover, as cities around the world strive to reduce their carbon footprints and transition to sustainable energy systems, MDGHWs emerge as a viable alternative that promises to reshape the future of heating and cooling in urban environments. The integration of this technology within existing heating networks can enhance energy efficiency and provide cost-effective solutions for both consumers and municipalities.

However, for MDGHWs to realize their full potential, continued research, development, and investment are imperative. Collaboration between governments, industry stakeholders, and researchers will be crucial in optimizing the technology and addressing any challenges related to implementation and scalability. Policymakers should also prioritize supportive regulations and incentives to encourage the adoption of MDGHWs in urban planning and energy strategy frameworks.

In conclusion, the advancement of Coaxial Reversible MDGHW technology represents a significant step towards sustainable energy solutions. As we move forward, embracing such innovative approaches will be vital in achieving energy resilience and sustainability, ultimately contributing to a greener and more sustainable future for urban populations.

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