Duke Climate Research Innovation Seed Program (CRISP)

Duke University Central Campus Geothermal Test - Phase II:

Characterizing Fractured Durham Basement Rock for ATES Cooling & Heating

Quarter 3 Report – Jan, Feb, Mar 2024

Manolis Veveakis

Principal Investigator

29 Mar 2024

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Executive Summary – CRISP & Bass Connections Quarter 3 Report

In Quarter 3 - covering Jan, Feb, and Mar, both CRISP/Nicholas Institute - Bass Connection and Duke University Office of Facilities Management supported investigations took place. CRISP-Bass Connection supported core lithology and photography was completed. Core scanning by CT was continued. Bass Connection experiential education projects associated with ECS590 and CEE690 in 3 areas – well logging, water level, and project communication - were continued.

We participated in an DU Office of Sustainability arranged field tour and presentation of Aquifer Thermal Energy Storage at Chiller Plant II for the Duke University Trustee's Energy Task Force. This event was attended by more than a score of Task Force members, students, faculty, and staff. Working on a request from Facilities Management, an ATES geology assessment proposal was submitted for subcontracting via the Associated Engineers Inc.

In Quarter 3 the Bass Connection educational with 4 main group projects. These included work on the porosity and permeability properties of the core, lithology description and photography, well log and water level measurement, social media reporting of the ATES assessment tour for the DU Trustee Energy Task Force. The Concept Papers for these Bass Connection projects are included in the Q2 Report.

An opportunity to leverage the CRSIP and Bass Connection support for further development of the ATES was offered by Facilities Management by the way of a request for a campus geology assessment project. The proposal was to be submitted as a subcontract to the DU associated engineering AEI Inc. The text of this proposal is attached here, along with a proposed budget. We also submitted to the Department of Energy Advance Research Project Agency – Energy the final version of our near-surface geology Dark Fiber seismic exploration pilot project.

In Quarter 4 we are planning to collaborate with Cornell University to test the permeability of the sandstone sections and fractures found in our study of the CCGT borehole. A schedule of activities with Cornell is attached in the Appendix

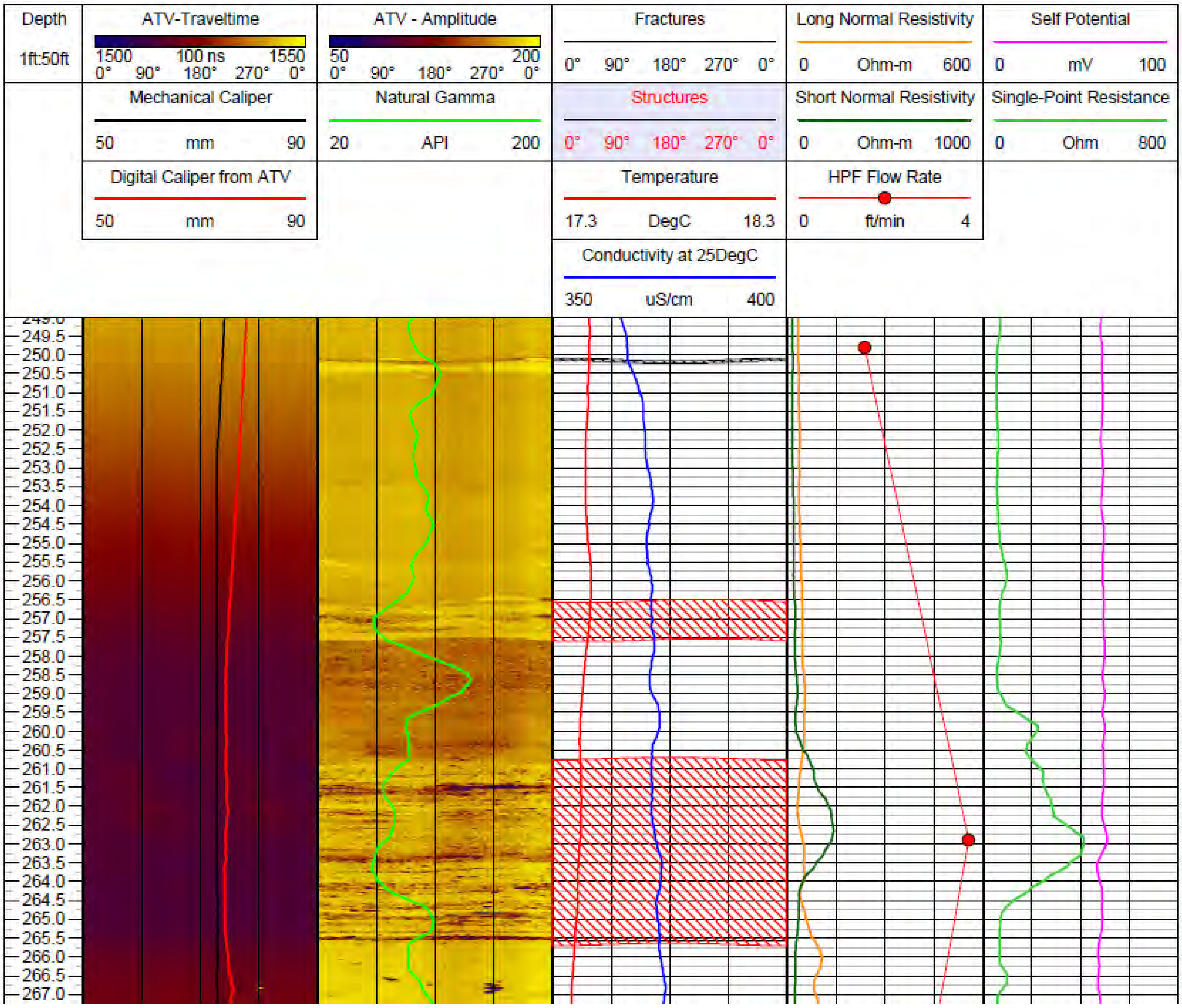
CRISP/Bass Connection post drilling activities and engagement

Well logging and other well measurements.

Heat Pulse Flowmeter.

Based on the initial well logging and core photo data from Fall 2023, it appears that there are several 5 to 25 ft long sections of porous sandstone and a half dozen open fractures. (See Table next section.) It followed that the permeability of these sections and fractures was the next logical step in assessing the CCGT borehole and geology potential for ATES.

For cost effective testing of this permeability, in consultation with DU Facilities Management who also participated in supporting this effort, we selected the Heat Pulse Flowmeter method. A photo of this tool is shown below and a section of well log with the HPF measurements is shown on the next page. We also recorded a video of this operation for use in the geothermal class.



Unfortunately, when the HPF tool was run to the bottom of the CCGT borehole it became stuck. Fortunately with further assistance and support from DU FM we were able to retrieve this tool and complete the measurements in the well.

Water level baseline

To prepare for the change in water table level decrease associated with the southern spring leaf-out, we completed 2 sets of sounding. These established the following baseline water level in Feb 2023 as:

CCGT borehole 2/23 average 23.1 ft below wellhead.

Physical properties –

Core Lithology – the porous sandstone sections

The full length of the 667 ft CCGT borehole's basic lithology has now been compiled as part of a Bass Connection project. A total of 4 students (1/4 of the ECS590/CEE690 class !) participated in this study. A significant finding is the presence of several sections of sandstone, which appear in visual inspection to be porous at the 1 to 4% (or more) level.

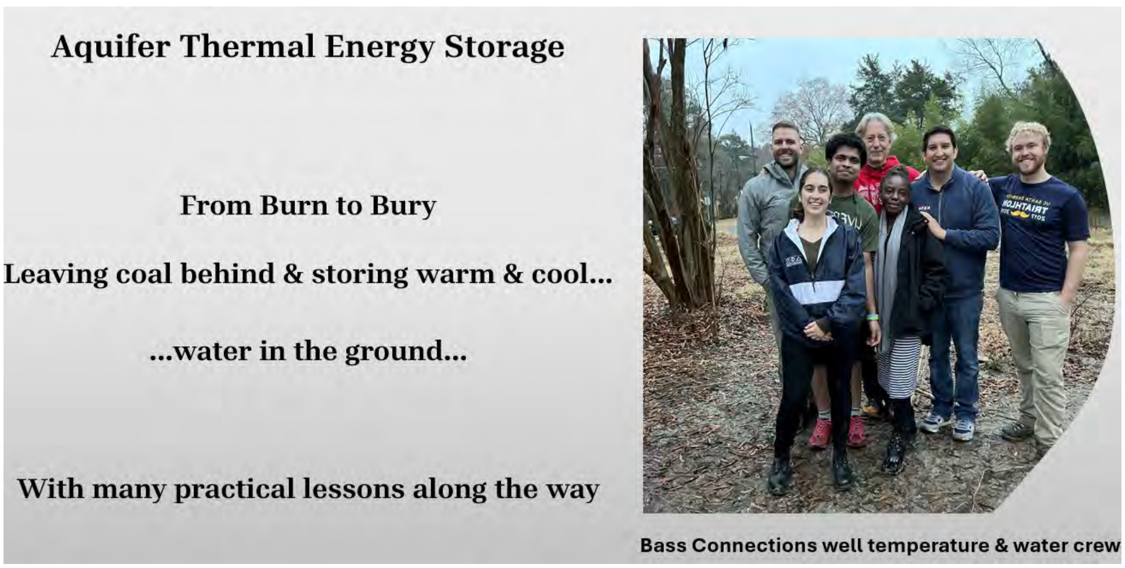
A table of these findings is copied below. It shows that slightly more than 1/3 of the CCGT borehole is drilled into sandstone, some of which may have useable permeability. This will be tested in Quarter 4 when we collaborate with Cornell University in a permeability skin depth logging experiment at CCGT.

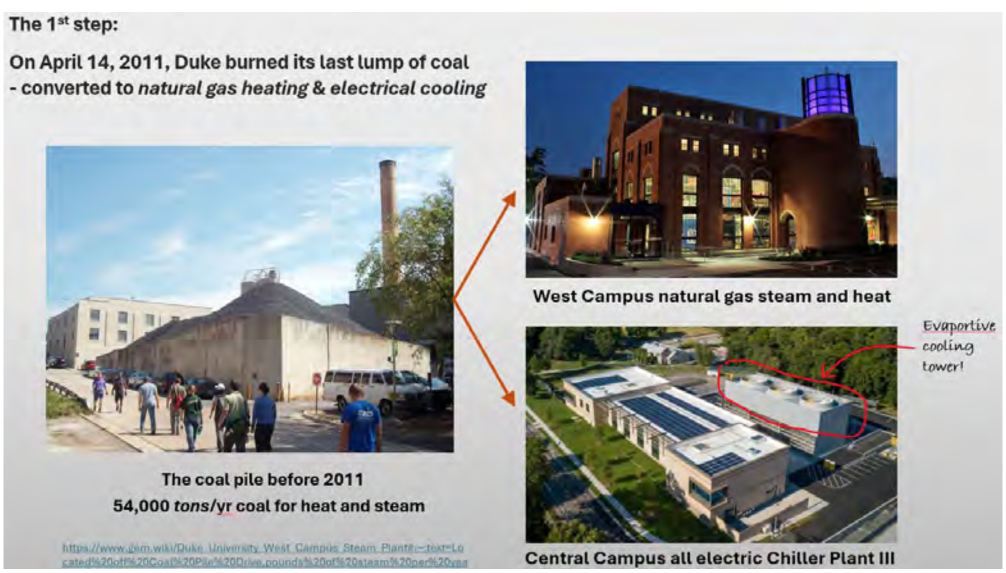
Sandstone Range of Interest (ft)		Sandstone Thickness (ft)
Top	Bottom	
30	40	**10**
50	70	**20**
76	98	**22**
120	146	**26**
150	176	**26**
213	223	**10**
251	261	**10**
271	285	**14**
400	412	**12**
442	452	**10**
508	532	**24**
584	626	**42**

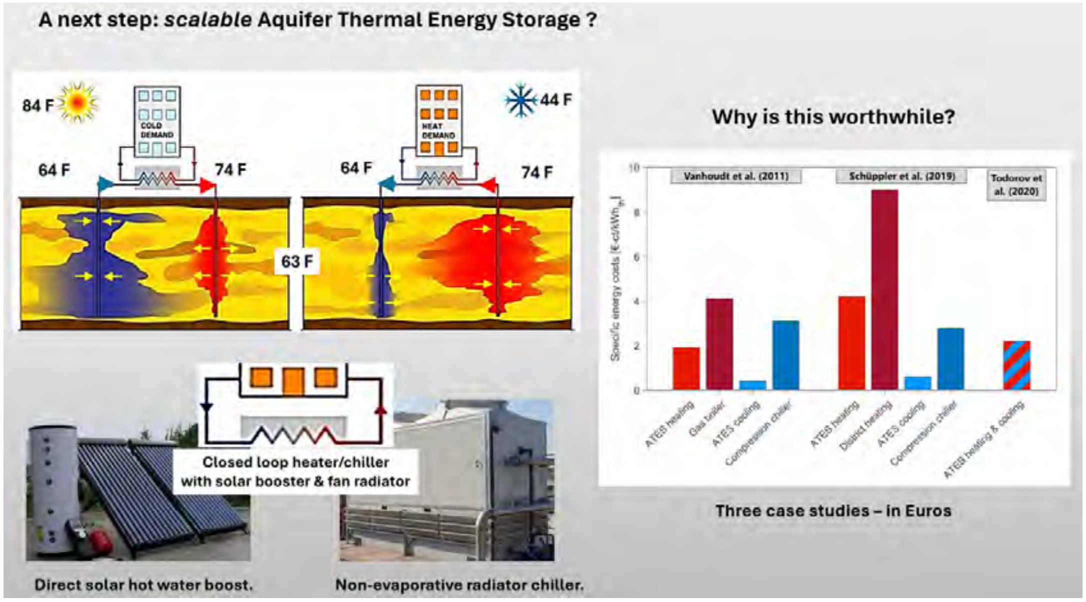
Duke Trustee Energy Task Force field trip and materials

A group of 12 Duke University Trustees and Associates have been tasked to review and provide guidance for future DU development plans. Our CRISP group was asked to present a field tour of the potential Chiller Plant II assessment proposal. Reduced size handout pages are copied below, and a Sustainable Duke article by ECS590/CEE690 Bass Connection students is both attached in the Appendices and can be read at:

. https://sustainability.duke.edu/blog-post/dukes-sustainability-tour-showcasing-ates-system-duke-leadership/







What are the steps and costs to seeing if it is *practical* at Duke? What did it? What will it? Cost

Step 1: Geology (1st *sine quo non*). e.g. ~667 ft DU CCGT* core drilling: $130,000

Initial rock-type results from CCGT Phase 2022 & 2023 are encouraging.

Are the rock-types at each of the Chiller Plants also encouraging?

what is needed → ~1,000 ft of Heating/Cooling Plant core drilling: **~$195,000/site**

Step 2: Hydrogeology (2nd *sine quo non*). CCGT *lab* & *field* ATES tests: $ 45,000

Bass Connections students and Faculty working on CCGT well and data.

e.g. Rock-type and well log characteristics in Manolis Veveakis lab.

e.g. CT scans of core poroperm in Laura Dalton's lab.

e.g. Heat Pulse Flowmeter flow zone tests in CCGT 22 Feb – Peter Malin & BC*.

what is needed → Heating/Cooling Plant core well ATES tests: **~$ 65,000/site**

CCGT $175,000* **~$250,000/site**

* NSOE Dean's Innovation, CRISP, & Bass Connections grants.

Project Leverage

DU Facilities Management subcontract for ATES assessment

Copied below is an abbreviated Executive summary of this proposal for further assessing the near surface geology of Duke Campus for potential ATES development. The full proposal is attached in Appendices.

Investigation of Duke University Campus Near-Surface Geology for

Aquifer Thermal Energy Storage

Executive Summary. This investigation of Duke Campus near-surface geology for potential Aquifer Thermal Energy Storage builds on exploratory core drilling and hydraulic testing currently underway on Central Campus. It is proposed to (1) complete characterization of the Central Campus core, (2) complete hydraulic testing of the borehole, (3) conduct a detailed surface investigation of West Campus geology, (4) report on these tasks, and (5) develop and execute (if funds are available) a <1 km deep ATES-oriented exploratory well at Chiller Plant II. Potential DoE and/or donner funding for this well will also be sought.

The proposed tasks are planned for a period of 12 months, from 01 April 2024 to 31 March 2025. The Central Campus core is being preliminarily characterized by Bass Connection student projects. The core will be transported to, and analyzed further at, the US Continental Scientific Drill Laboratory at the University of Minnesota. It will be archived there for future reference.

Simple hydraulic tests of the CC well have been planned and contracted for the next 3 months. This includes a collaboration with Cornell University on a new in-situ permeability testing method. The results of these tests will be analyzed and reported shortly thereafter.

As a member of a small team of Duke faculty seeking to engage alternative geothermal energy at Duke, we have been part of several grant submissions and a Duke Trustee Energy Task Force in-person information and potential ATES site tour. We propose to continue this search as part of the scope-of-work discussed here. We plan to submit, and participate in submitting, external funding applications for on-campus ATES R&D support. These include potential applications to the US Department of Energy (ARPA-E and GTO), the National Science Foundation (NSF) – specifically the partnership with industry (NSF RISE partnerships) - and Duke alumnae and associated community private donners.

Based on the current results it is clear that the past picture of the near-surface geology of Duke Campus needs to be revisited and NC Geololgical Survey's map revised. After reconnaissance surveys of marked outcrops and topographic features, sites for further appropriate geophysical investigations will be selected. The results of these studies will be used to propose a Chiller Plant II relevant site for a more technical advanced ATES assessment well. If support for such a well can be found in the 2nd quarter of 2024, preparations and drilling can be completed by the end of quarter 3/beginning quarter 4. The remainder of the proposed 12-month study will be devoted to either further near-surface investigations for later drilling or then studies of the complete well and core materials.

DoE Concept Paper submitted: Duke Optical Fiber Net for ATES

On Mar 22 2024, in collaboration with Assistant Professor Tingjun Chen of Electrical Engineering, we submitted to the US Department of Energy a Concept Paper for a new near-surface geological exploration method using DU optical fiber lines and connection. The abstract of this Paper is copied below and a complete version is in the Appendices.

USING DARK FIBER NETWORKS FOR ASSESSING AQUIFER THERMAL ENERGY STORAGE POTENTIAL: A DUKE UNIVERSITY PILOT STUDY

Peter Malin, Duke University (Durham, NC)

1. OVERVIEW

ARPA-E Contact:	
Technical Category:	Category 4: Technologies that facilitate (2) the storage of intermittent renewable energy.
Funding Request:	$375k
Project Duration:	18 months
Project Abstract:	We propose to use Duke University Dark Fiber as Distributed Acoustic and Temperature Systems (DAS and DTS) to characterize the campus subsurface for potential shallow Aquifer Thermal Energy Storage (ATES). This pilot study will leverage the existing fiber optic sensing infrastructure at Duke University and the 200-300 m deep ATES test drilling Duke supported in 2022 and 2023. The objective is to evaluate the potential of Dark Fiber DAS and DTS sensing for mapping of the underground energy reservoirs in otherwise inaccessible areas of urban infrastructure.

Appendices – Full text of materials mentioned in main report

Quarter 4 schedule for Duke and Cornell University collaboration

Sustainable Duke Article on proposed Chiller Plant II ATES study

DoE ARPA-E Concept Paper for Dark Fiber use in near-surface study

DU Facilities Management subcontract for ATES assessment

ECS-CEE 590-690 / Cornell / DU Facilities Management CCGT - Borehole Permeability Stimulation Test.

Apr 2nd to 6th, Central Campus drill site.

For real-time on-site updates call Prof Malin 214 934 0752

Tu 2 Apr 0900 to 1620

0900 to 1400 Cornell team rigs up and runs pre-stimulation tests in borehole;

1500 to 1420 ECS590/CEE690 Lectures: permeability penetration test; Cornell Snee Hall BTES system. Rm A158 LSRC.

We 3 Apr 0800 to 1200

Parratt Wolff Drilling runs borehole silt and water column clearing – "water flush."

Th 4 Apr 0800 – 1600 (?)

Parratt Wolff runs packer and pressure treatments; Cornell activities as appropriate.

Fr 5 Apr 0800 – 1600 (?)

Cornell re-runs full post-treatments survey.

› Blog

› Duke's Sustainability Tour: Showcasing ATES System to Duke Leadership

BLOG

Duke's Sustainability Tour: Showcasing ATES System to Duke Leadership

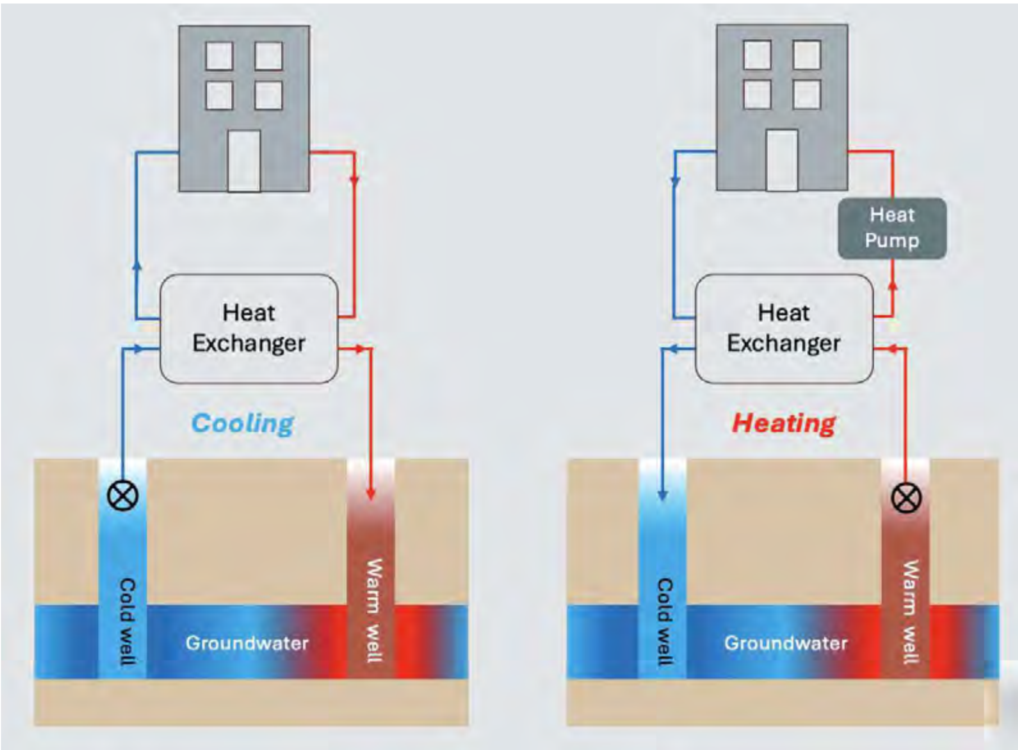
By Qiuying Liao & Xinyi Wen // *March* 19, 2024

On a sunny Tuesday morning (Feb. 20, 2024), Duke's sustainable faculties, Sustainable staff, and students welcomed members from Duke's leadership and journeyed around Duke's reclamation pond to showcase the sustainable efforts the university has made over the years. As the sun cast its golden glow, the air buzzed with conversations about the proposed Aquifer Thermal Energy Storage (ATES) system as a new sustainable energy solution to fulfill the Duke Climate Commitment.

The two lead Duke researchers on this project, Dr. Brian G. McAdoo, the Associate Professor of Earth and Climate Science, and Dr. Peter Malin, the emeritus professor of Earth and Climate Science, highlighted ATES systems as a promising sustainable energy source for building heating and cooling. According to the Office of Sustainable Duke, in 2023, over 2.3 million MMBTU of energy was used, with 53% coming from natural gas. Challenges in cost-effectiveness with renewable sources like solar and wind hinder a smooth transition to cleaner energy.

Dr. Brian McAdoo introduced the current energy challenges and how the ATES system can provide a sustainable solution. Credit: Tavey Capps

ATES systems provide an alternative, utilizing mid-temperature ranges (60 - 200 degrees) widely available in deep sedimentary basins, covering 50% of Earth's land surface. The proposed ATES systems involve two wells-one for cool water storage and the other for hot water storage. In winter, hot water is pumped to release heat into buildings, and in summer, it absorbs heat. Heat pumps increase the aquifer temperature to the needed level for space heating.



This diagram shows how the ATES system works during the summer (left) and the winter (right). Graphic created by Xinyi (Wendy) Wen

Dr. Malin shared the current process with the tour attendees, accompanied by a learning tour of the future ATES test site. Recent achievements include completing borehole drilling in Phases I and II, reaching depths of 352 feet and 667 feet, respectively. Dr. Malin has also integrated the project into a class within the Bass Connections program, providing students with hands-on experience in geological assessment technologies. Under his guidance, students can design projects contributing to the larger ATES initiative.

Led by Dr. Laura Dalton, an Assistant Professor in the Department of Civil and Environmental Engineering at DU, the team explores the properties of geomaterials for the ATES system. These rocks, identified during the Duke Central Campus Geothermal Test (CCGT) well investigation, are crucial for understanding the aquifer's storage capacity. If a significant number of rocks with higher porosity and permeability are found on campus, the ATES system can store a substantial amount of water, offering immense potential for energy storage to meet heating and cooling needs.

Dr. Laura Dalton and her three Ph.D. students utilize the cross-cutting technology TESCAN UniTOM XL X-ray micro-CT Scanner to aid in measuring the porosity and permeability of the rocks from the Duke Central Campus Geothermal Test {CCGT) well. Credit: Dr. Laura Dalton

During the tour, Brian pointed out that ATES not only provides sustainable options but, more importantly, helps solve community problems.

In North Carolina, ATES systems can alleviate the energy burden of low- and moderate-income (LMI) communities, especially during extreme weather. The average energy burden for NC households at 50% of the Federal Poverty Level (FPL) is 32.8%,[1] with rural counties facing the heaviest energy burdens across all income brackets due to heating and cooling needs. Implementing ATES systems not only reduces carbon emissions but also provides more affordable energy, offering equitable and economic solutions for decarbonizing energy.

If successful, this initiative would represent a groundbreaking effort in establishing the first ATES system in the northeast region of the United States, holding significant potential to address the pressing energy issue.

Office of Sustainable Duke

9 Smith Warehouse, Bay 3

114 S. Buchanan Blvd. Durham, NC 27701

sustainability@duke.edu

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2. IMPACT

Global energy demands for heating and cooling account for about 12% of the total energy demand (e.g. Perera et al., 2023). Using ATES for sustainable seasonal heating and cooling (Figure 1a) can reduce the energy consumption for this sector resulting in energy savings ranging from 20% to 60%. For instance, the heating and cooling costs at Duke University comprise about half of the total energy costs. The energy cost reduction achieved by using geothermal technologies such as Aquifer Thermal Energy Storage (ATES) can vary widely depending on factors such as location, building size, climate, energy prices and the upfront costs. Due to higher upfront costs, the payback time for the ATES systems is 5-15 years, compared to 3-10 years for the conventional HVAC systems.

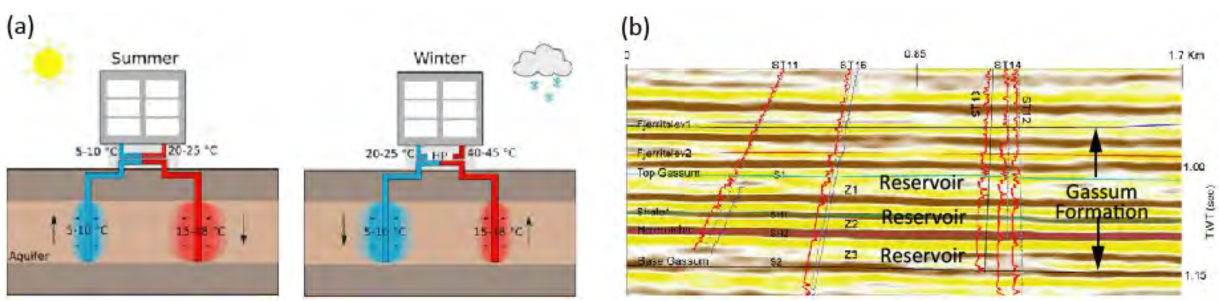

Figure 1. *(a) ATES schematics. (b) An example of using seismic profiling to map an aquifer (Gassum formation) in Stenlille, Denmark. Well logs - gamma ray (red) and P-wave velocity (blue) - are used to identify the formations with depth. The three identified reservoir zones (Z1, Z2 and Z3) within the Gassum Formation are proposed for energy storage (Pasquinelli et al, 2020).*

Finding a suitable underground reservoir for ATES requires extensive geological and geophysical characterization of the subsurface, including drilling, well logging and application of the surface geophysical methods. This project addresses the use of Dark Fiber technology to seismically map potential thermal energy storage reservoirs in otherwise inaccessible areas of high cultural activity. Recent studies using Dark Fiber for seismic mapping of the near subsurface in otherwise inaccessible areas – e.g. Stanford University campus – show it can provide this type of information. Developing a methodology for using Dark Fiber DAS and DTS for the reservoir imaging can open large urban areas for ATES development and reduce the upfront costs.

3. STATE OF THE ART

ATES installation requires the presence of porous/fractured rocks in close proximity to the buildings to be heated or cooled. After being established as technically viable with shallow assessment drilling (200-300 m), a critical key to ATES is the depth and lateral extent of suitable rock, which affects the cost of drilling and the reservoir capacity. The present solution to determining the subsurface geological structure is drilling with logging with approximate costs of $50-$300 per meter. High resolution seismic profiling methods such as controlled-source (e.g. vibroseis) multi-channel reflection, refraction and vertical seismic profiling can be used to laterally extend the drilling findings. Figure 1b shows an example of using conventional seismic methods with well control (from Pasquinelli et al., 2020) to determine the extent of the subsurface aquifers needed for underground energy storage. Seismic methods provide a cost-effective alternative to drilling multiple boreholes. The approximate costs for seismic field surveys is $2000 - $10000 per 1 km of a survey line. Once interrogators and fibers are in place, this cost is much smaller.

However, conventional seismics cannot be used in urban areas with high density of buildings and people movement. A large number of seismic receivers needed and controlled source access make conventional seismic mapping in these settings impossible or very low resolution compared to DAS methods.

4. INNOVATION

We propose to utilize the existing fiberoptic networks to perform an alternative type of seismic survey to map the subsurface reservoirs and determine their suitability for ATES construction. Subsurface imaging using DAS can be performed using both low impact active sources such as small weight drop carts and passive ambient noise, surface waves from cultural noise sources of the seismic energy. We propose to evaluate the performance of the following techniques: 1) seismic reflection/refraction using active sources to map the top of potential ATES aquifers, 2) ambient noise cross-correlation to obtain the waveform Green's functions for high resolution profiling, and 3) using surface waves from man-made sources to invert for the velocity structure.

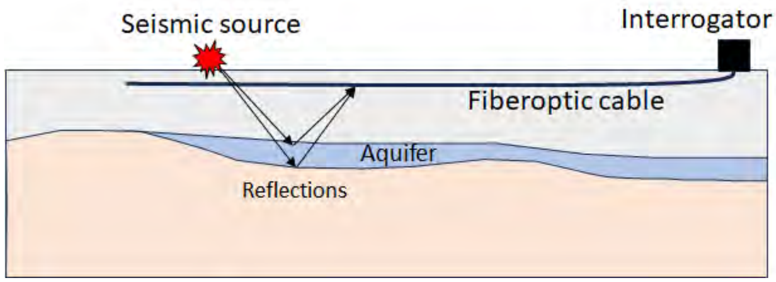

Figure 2. *A schematic illustration of a basic concept of using Dark Fiber DAS for a seismic survey.*

5. RISKS AND CHALLENGES

The main risk of the proposed methodology is the potential absence of the suitable aquifer in the study area, which can only be determined after the completion of the survey.

Other challenges of the proposed work include the presence of seismic and acoustic noise in the urban environment and potentially high attenuation in the upper subsurface layers. Using seismic reflection/refraction methods in these conditions can lead to low signal to noise ratio and poor resolution of the seismic sections. Thus, any geophysical survey, including the ones using Dark Fiber DAS approach, has to be tailored for each individual case and would require new innovations to be successful.

The dark fiber network is readily available in the proposed study area; however, this may not be the case in other locations, which would limit the use of the proposed methodology. Large organizations (e.g. universities, businesses, and government buildings) can use their own fiberoptic networks to make this technology cost effective.

6. PROJECT PLAN

The objectives of this pilot study include the evaluation of the distributed fiber optic sensing networks for mapping of the underground water reservoirs in urban environments. The project will leverage the existing Duke University (DU) fiberoptic infrastructure and the geological results from the drilling performed at the DU campus in 2022-2023 (Figure 3a-b). The current DU owned distributed vibration/temperature sensor (DVS/DTS) consists of 50 kms of fiberoptic cable surrounding the 8,000+ acre DU campus. The spatial resolution of DAS seismic profiling can be on the order of 2 m. The map in Figure 3a shows the location of the Duke Central Campus ATES assessment drilling site and the fiber footprint around campus. Fortuitously, the Dark Fiber surrounds a known hydraulically receptive diabase rock that underlies DU west campus.

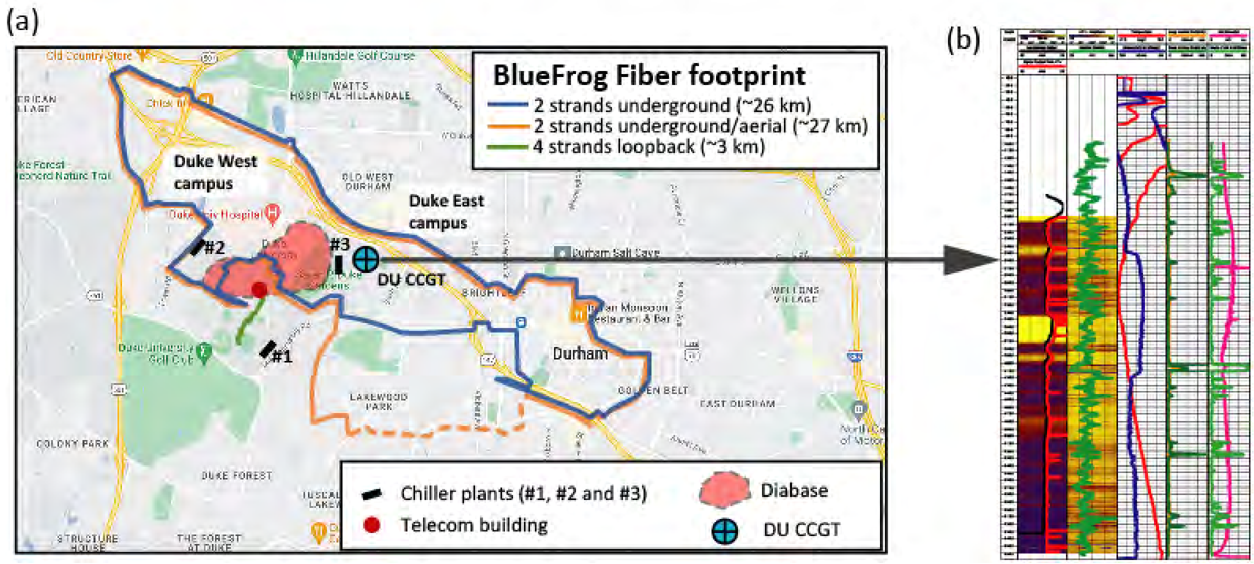

Figure 3. *(a) Map of the Duke University campus showing the locations of the target horizon (diabase) with respect to the BlueFrog fiberoptic cable locations and the CCGT borehole. (b) Geophysical well logs from DU CCGT borehole.*

The proposed work will include seismic data acquisition, processing and analysis. Acquisition of seismic data require adding distributed acoustic sensing (DAS) capabilities to the present DVS and DTS already in place at Duke. Using the results of the seismic data analysis as well as the existing geological and borehole data we will build the 3D structure of the subsurface.
The deliverables will include the geologic cross-section through the area of study, as well as all required progress reports describing the method and the results.

7. TEAM

- Duke University is the principal organization.
- The PI - Prof. Peter Malin (Duke University Nicolas School of the Environment) – has more than 35 years of experience in geothermal exploration, seismic instrument development and seismic wave propagation. His current research interests are in seismic mapping of fluid reservoirs and the mechanics of fracture permeability.
- Prof. Tingjun Chen (Department of Electrical and Computer Engineering, Duke University) will be a CoPI. Prof. Chen is a head of an Integrated Fiber Sensing and Communication Living Lab in the Research Triangle sponsored by NSF.
- Research Scientist Dr Anastasia Stroujkova has more than 20 years of experience in seismic profiling methods and wave propagation.

8. ESTIMATED BUDGET

- Salaries
  - **a.** Malin 2 mo $24k
  - **b.** Chen 1 mo $12k
  - **c.** Stroujkova 6 mo $60k

d.	Tech	0.5 mo	$4.5k
e.	Res Assis	9 mo	$38k
			$200k

- Benefits 36% **$53k**
  DAS usage **$25k**
  Computer software **$6k**
- Overhead 63% **$145k**

Total **$375**

Investigation of Duke University Campus Near-Surface Geology and External Support for Aquifer Thermal Energy Storage

Proposed by

SeisFOCUS geosciences LLC

To AEI Inc.

6 March 2024

Investigation of Duke University Campus Near-Surface Geology for

Aquifer Thermal Energy Storage

Contents

1. Executive summary

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Based on the current results it is clear that the past picture of the near-surface geology of Duke Campus needs to be revisited and NC Geololgical Survey's map revised. After reconnaissance surveys of marked outcrops and topographic features, sites for further appropriate geophysical investigations will be selected. The results of these studies will be used to propose a Chiller Plant II relevant site for a more technical advanced ATES assessment well. If support for such a well can be found in the 2nd quarter of 2024, preparations and drilling can be completed by the end of quarter 3/beginning quarter 4. The remainder of the proposed 12 month study will be devoted to either further near-surface investigations for later drilling or then studies of the complete well and core materials.

Our Tasks, Quarterly Reports, Final Report, and Deliverables Section formally lays out our reporting obligations. It also includes provisions for informal communications of intra Quarter reports and other communications. Included in our Deliverables are results from our Phase I and II Central Campus Geothermal Test drilling: maps, cross sections, lithology logs, well logs, core, borehole hydrology and hydrogeology tests.

We also plan to seek in person updates with both AEI Engineers and Duke Facilities staff on a frequent but irregular basis.

2. Technical background to the ATES initiative

In Fall 2022 an initial 352-foot-deep core hole was drilled at this site. The bottom 20 feet of this well crossed a high-angle fault and appeared to penetrate fractured basement rocks. Field inspection by a North Carolina Geological Survey senior geologist suggested they may represent older rocks thought to underlie campus and the Durham area (personal communication, Phil Bradley, NC Geological Survey, 2023). If so, and extending sufficiently to further depths, they might serve as reservoirs for ATES.

In Fall 2023 the Central Campus core hole was extended to 667 ft. The resulting cores revealed that the faulted section of the 2022 well was not a contact with basement rocks. Instead a continued section of the same younger sediments found in 2022 reached the bottom of the extended well. Lithological analysis of the combined cores suggests these sediments are from a different source than the supposedly analogous rocks found east of Duke. Moreover their thickness and structural position are at odds with the NCGS's map of Campus geology. This proposal addresses these differences as they might be related to a successful implementation of ATES at the Chiller Plants.

A number of 2023-24 academic year Bass Connection student projects have been set up to study the cores. One Earth and Climate Science based project has found that greater than 50% of this section is sandstone. The porosity and permeability of the cores is currently being studied at DU Civil and Environmental Engineering using the cores.

Under the auspices of the U.S. Continental Drilling Program more advanced measurements and characterization of the CC core will be done at the USCSD laboratory at the University of Minnesota. Transport to and test there is being partially supported by Bass Connection funding, with oversight and follow-up being supported by this proposal. The results of these tests will be included in the geoscience studies proposed here, especially in relation to their relevance to the ATES initiative. USCSD measurements include, for example, assessing thermal properties and analyzing rock-water chemistry reactions not currently available at Duke.

3. Near-surface geology and hydrogeology investigations.

The CC borehole has established that the lithology and structure previously thought to underlie Duke campus needs to be revised. This has increased the uncertainty of what the geology around the Chiller Plants might look like, especially for ATES applications. As one example of this variation from the more established eastward dipping stratigraphy in the eastern Durham Basin, the sediments encountered in the CCGT borehole appear nearly flat lying and less geochemically mature. Perhaps they might even be from a different protolith, one to the west of the current basin edge.

To mitigate this limitation both a reconnaissance of NC Survey marked and missed outcrops will be completed, along with an in-field review . Based on this study sites for potential geophysical tests will be selected and appropriately completed as resources are available.

We propose to use, as resources are available, a number of low cost geological and geophysical tests of campus near-surface geology. For example, based on the results from the CCGT borehole, determining the geological configuration of the diabase projected to underlie west campus is turning out to be potentially critical. We have been testing the use of a hand-held spectrometer to categorize and profile the diabase versus Durham Basin sediments. Current short profiles on campus suggest that diabase is identifiable by relatively low energy and density emissions. If born out, we will conduct a profiling campaign as part of the geological recon of campus diabase outcrops.

In addition to the spectral mapping, we will seek to determine the location and depth of the diabase using refraction profiling. The presence of diabase is highly likely to be very apparent in such profiles, given its typical high seismic velocity contrast in comparison to Durham basin sediments. Use of the refraction method would follow the spectral mapping. If a likely depth to the top of the diabase could be established at a specific location on campus, then a short geotechnical borehole could be use to establish its thickness, and thereby its potential relevance to ATES. Especially if located near one of the Chiller Plants.

An outstanding question remains with respect to completing a direct drilling assessment of ATES at, for example, Chiller Plant II. This site is roughly 1.2 miles (1.9 km) directly west of the CCGT borehole. Here, based on past geological cross sections versus the CCGT results, there are two alternative hypothesis: assuming the latter cross section, a much thinner Durham Basin sediment layer on top of Carolina Basement rock, or then, assuming the former, a thicker, fault bounded, section of more horizontal western Durham Basin strata.

There also remains the question of diabase underlying this site and its thickness as relates to ATES applicatoins. It is likely that solution to both these questions will require assessment drilling immediately next to the Chiller Plant II.

We are currently conducting hydrogeology investigations at the CCGT site, some of which will continue on under the work proposed here. Results from these and earlier studies will be integrated into the R&D plan proposed here. Among these future tests we have already arranged for is a weeklong campaign of permeability measurements and packer flow tests. In a special arrangement with colleagues from Cornell University we will test selected intervals of the CCGT with a new penetration variable permeability instrument and crew from Cornell University.

4. Past and potential future external support for ATES at Duke.

Over the past 36 months noticeable changes have occurred in the Federal and private sustainable energy R&D funding sector. We describe in this Section our basis and plans for seeking support for the work necessary to understand the potential use of near-surface geothermal energy on Duke campus, especially the opportunity for ATES.

As discussed in Section 7, reviews of our several past grant applications were returned with the prerequisite of a pilot demonstration before significant funding. Our internally supported Central Campus Geothermal Test borehole was, in part, aimed at this requirement. Since the relevant geology of campus was essentially unknown, this reviewer-originated requirement was a significant barrier toward ATES and other types of more advanced sustainable energy beyond ground source heat pumps. Our internally funded Central Campus Geothermal Test borehole began breaking down this barrier while also providing a notable experiential educational opportunity for Duke students, faculty, and Staff.

In 2021 we were members of the team that secured the first pilot study support for exploring Duke campus geology for near-surface geothermal applications. We received funds for drilling the 1st, Phase I, Central Campus Geothermal Test borehole from the Nicholas School of the Environment Dean's Innovation Fund. Our 2nd, Phase II, funding for continued drilling of the CCGT well was received from the Nicholas Institute for Sustainable Energy, through their Climate Research and Innovation Program, CRISP.

We propose now to use the results from these – and importantly, follow-on – efforts to seek external and donner support for geothermal energy and other types of environment sustaining, near-surface geology applications. (E.G. carbon sequestration and ground water remediation.) Examples of public funding available in the short term are shown in Section 7.

5. Tasks, Quarterly and Final Reports and other Deliverables.

We propose that our project objectives, deliverables, and Quarterly and Final Reports be organized in 3-month quarters, starting nominally in April or May 2024. While we may write and distribute informal interim summaries of results on shorter intervals, we plan formal reports at the end of each of the project Task periods describe below.

(i) 2024 Quarter II activities and Quarterly Report. Complete CC well hydraulic studies: Heat Flow Pulse meter, slug test, and in-situ permeability tests. Oversee and compile on campus lab core and CC site hydraulic test studies and report of results. CC site and well security. End of the academic year summary of well logging, lithology, poro-perm/Bass Connection associated measurements. Campus near-surface geology recon; Initial near-surface geology/geophysics investigations. Chiller Plant II ATES exploration well funding and technical development.

(ii) 2024 Quarter III. CC well thermistor and piezometric monitoring studies: recorder operation, measurement compilation and analysis, site maintenance . Continued near-surface geology/geophysics investigations. Chiller Plant II assessment drilling development completed; potential end of quarter drilling started.

(iii) 2024 Quarter IV. CC well thermistor and piezometric monitoring studies: recorder operation, measurement compilation and analysis, site maintenance. Continued near-surface geology/geology investigations. Chiller Plant II assessment drilling completed: core characterization, well logging, and hydraulic tests progress and/or completed.

(iv) 2025 Quarter I. Lab and field activities completed. Data compiled, interpreted, reported and archived. Project Final Report with ATES development conclusions.

6. Cost proposal

(i) 2024 Quarter II Activities, Reports, and Deliverables.

	Monthly
CC site field, lab, and desk studies/management and reporting.	$4,991.07
CC shed, thermistor, and piezometer installation/maintenance.	$3592.26

(i) 2024 Quarter III Activities, Reports, and Deliverables.

	Monthly
Near-surface geo investigations. Chiller Plant II design/drilling; Report.	$4,991.07
CC thermistor, and piezometer data retrieval and analysis.	$3592.26

(i) 2024 Quarter IV Activities, Reports, and Deliverables.

	Monthly
Near-surface geo investigations. Chiller Plant II logs/hydraulics; Report.	$4,991.07
Chiller Plant II thermistor/piezometer installation/maintenance.	$3592.26

(i) 2025 Quarter I Activities, Reports, and Deliverables.

	Monthly
Wrap up site, field, lab, and desk studies/management/final report.	$4,991.07
Chiller Plant II shed, thermistor/piezometer maintenance/analysis.	$3592.26

Totals	**12 mo**	**$103,000**

7. Supplementary materials.

a. List and short discussion of past public and limited distribution grant applications.

1. $75k from NSOE 2022 (awarded) Phase I core drilling to 352 ft at CCGT site
2. RTI – Research Triangle University 4 yr collaboration $4M (not awarded)

2. $50k from Bass connections 2023-2024 (awarded) Phase II Engineering and Science

3. $75k from CRISP 2023-2024 (awarded) Phase II core drilling of CCGT to 667 ft

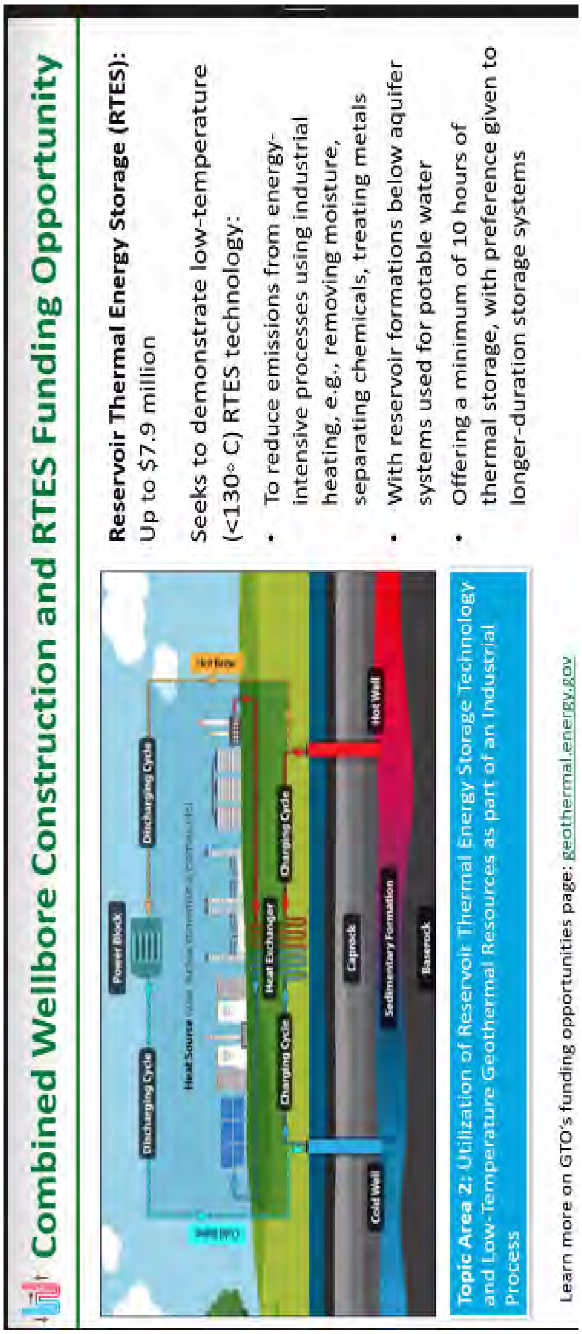
4. $16M from DoE EFRC call, 2022 (not awarded) Need pilot demonstration, industry

5. $2M from DoE DARPA 2022 (not awarded) Need pilot demonstration, industry

6. $2M from NSF DMREF 2023 (not awarded) Need pilot demonstration

b. Potential external support announcements: relevant DoE and NSF opportunities

US Department of Energy.



https://sustainability.duke.edu/blog-posUdukes-sustainability-tour-showcasing-ates-system-duke-leadership/

US National Science Foundation.

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These NSF Directorate of Geosciences (GEO) iHub-facilitated funding opportunities through the new Division for Research, Innovation, Synergies and Innovation (RISE) can transform your thinking about what GEO is and does.

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