Sept. 9th, 2020

Heating Electrification Strategies to Decarbonize BU's Charles River Campus

1. Problem Definition & Overview of Approach
2. Electric Heating Technology & Key Issues
3. Heating Electrification Refrofit Strategy for Large AHU Buildings

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Overview

- BU's Climate Action Plan aims to eliminate BU CRC's carbon emissions by 2040
- 40% of BU's CRC Greenhouse gas emissions stem from heating its buildings

Why Electrify Heating Systems of Existing Buildings?

- If BU purchases renewable electricity, electric heating systems enable BU to become carbon neutral & meet its CAP goals
- To reduce carbon emissions now, we need to retrofit existing buildings

Scope of Problem

- 211 buildings[1] | 10 M ft^2 CRC[1] | $12M of NG use[1,2] | 20-year timeframe

Driving Question: How can we electrify the greatest % of BU's fossil heating systems in the shortest time given limited capital and operating budgets?

1. 2016 Utility Data, excludes rentals
2. NG Price of $13.83/MMBtu

Characteristics of CRC Building Portfolio

Buildings Analyzed:

Types of Building	% of CRC Heating Energy Use?	Area (GSF)	# of Blgs:	Buildings to Retrofit
Large Buildings with AHUs[1]:	**44%**	**3,400,000**	**15**	
Laboratory	22%	1,070,000	6	Metcalf Science Center, Photonics, LSEB, CILSE, 730 Comm Ave., Engineering Research Building
Activity	9%	840,000	4	Fitrec, Agganis, Yawkey, Case Center
Residences	8%	780,000	2	StuVi 2, StuVi 1
Educational	6%	660,000	3	Questrom, Law School, EPIC
Brownstones:	**8%**	**1,000,000**	**133**	Bay State & South Campus Brownstones
Buildings Addressed:	**52%**	**4,400,000**	**148**	

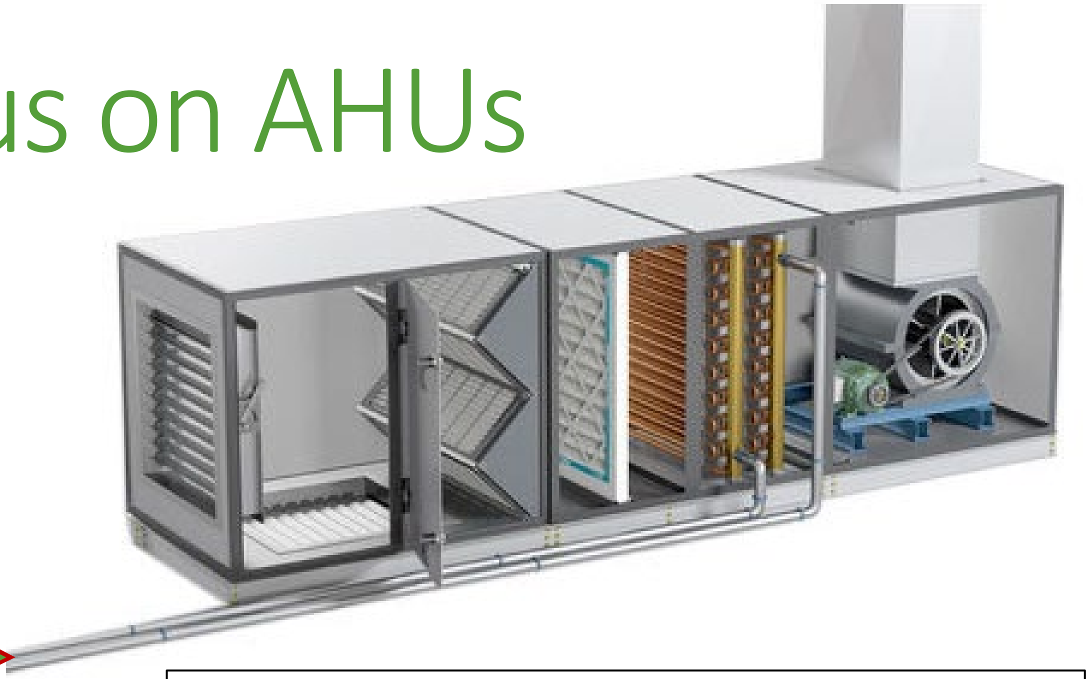
Buildings not Analyzed:

Type of Building	% of CRC Heating Energy Use?	Area (GSF)	# of Blgs:	Buildings to Retrofit
Steam Plant w/o AHU	15%	880,000	3	Warren Towers, West Campus Towers, CAS
Future in Question: Use & Renovation	10%	280,000	5	Mugar, Social Work Building, GSU, Hariri Institute, Physics Research Building
Misc Possibly with AHU	3%	400,000	3	Myles Standish Hall, 25 Buick St., Kilachand Hall
Smaller Buildings not Considered	20%	4,040,000	52	
Buildings not Analyzed:	**48%**	**5,600,000**	**63**	

1. Air Handler Units (AHUs) are a central pieces of HVAC equipment that enable quicker, less intrusive building electrification

Retrofit Approach: Focus on AHUs

Existing Natural Gas Boiler



High Temp (180°F) Air Handler Unit (AHU)

44% of CRC Heating Energy Use

- Central piece of HVAC equipment
- <u>Replace NG boiler with electric alternative to decarbonize entire heating system!</u>

High Temp Heat Pump

- Produces 180°F[1] water → essential for existing AHU
- Lower COP than typical Heat Pump

*AERMEC's NRP Air-Source Heat Pump & Cleaver-Brooks' Gas Boiler pictured

Electric Heating Technology

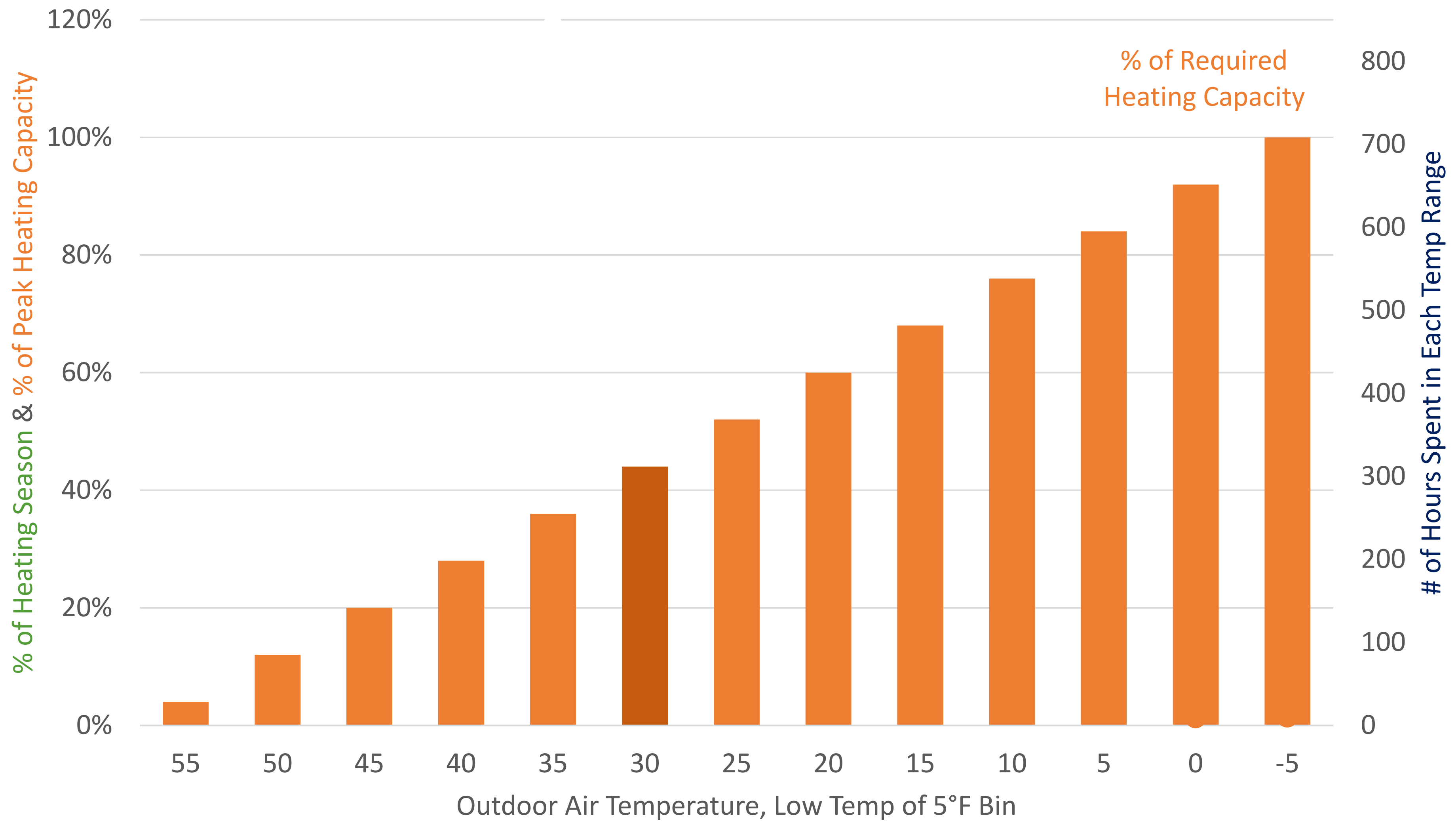
- Conventional Electric: lowest capital cost but lowest efficiency
- Ground-Source Heat Pumps: highest capital costs & highest efficiency
- Air-Source Heat Pumps: lower capital costs & moderate efficiency
- High Temp (180°F) Heat Pumps: lower COPs than traditional Heat Pumps
- Hybrid Heat Pump Systems: combination of heat pumps & electric boilers

	Conventional Fossil	Conventional Electric	High Temp Heat Pumps	
Technology	**Natural Gas Boiler**	**Electric Boiler /Resistance**	**High Temp Air-Source Heat Pump**	**High Temp Ground-Source Heat Pump**
Abbreviation	NG Boiler	Conventional Electric	ASHP/HT	GSHP/HT
Coefficient of Performance (COP)	0.85	1.0	2.0	2.5
Equipment Cost per Installed Ton ($/Ton)	$200	$200	$3,600	$8,600[1]

1. GSHP equipment costs include cost of bore hole
2. VRF systems include cost of in-room terminal unit

Hybrid System Strategy: Heat Pumps & Electric Boilers

- **Minimizes capital**
- **Maximizes utilization** of expensive heat pumps
- Use **low-cost electric boilers for coldest 20%** & 100% backup
- Good for both ASHPs & GSHPs



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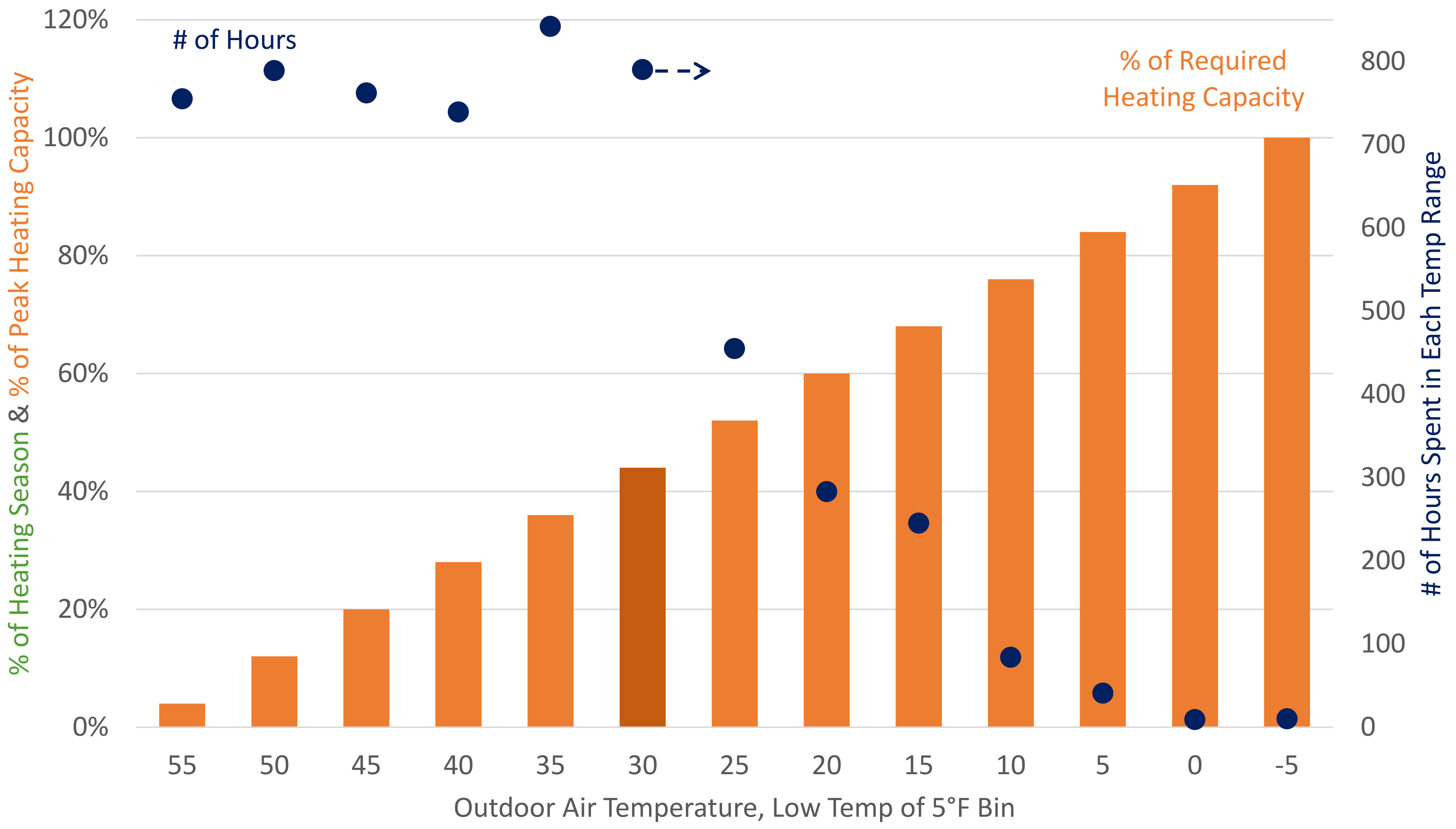

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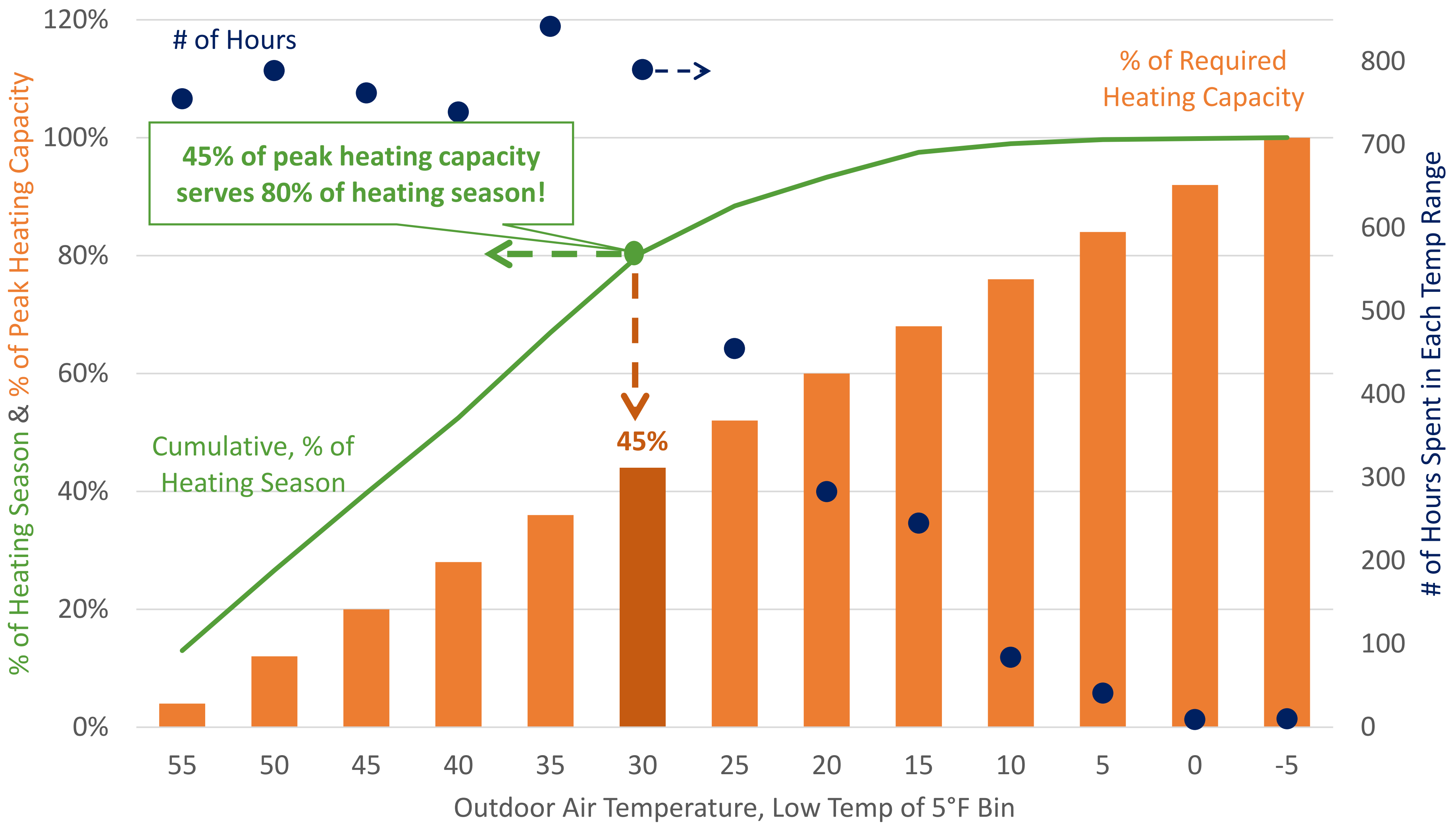
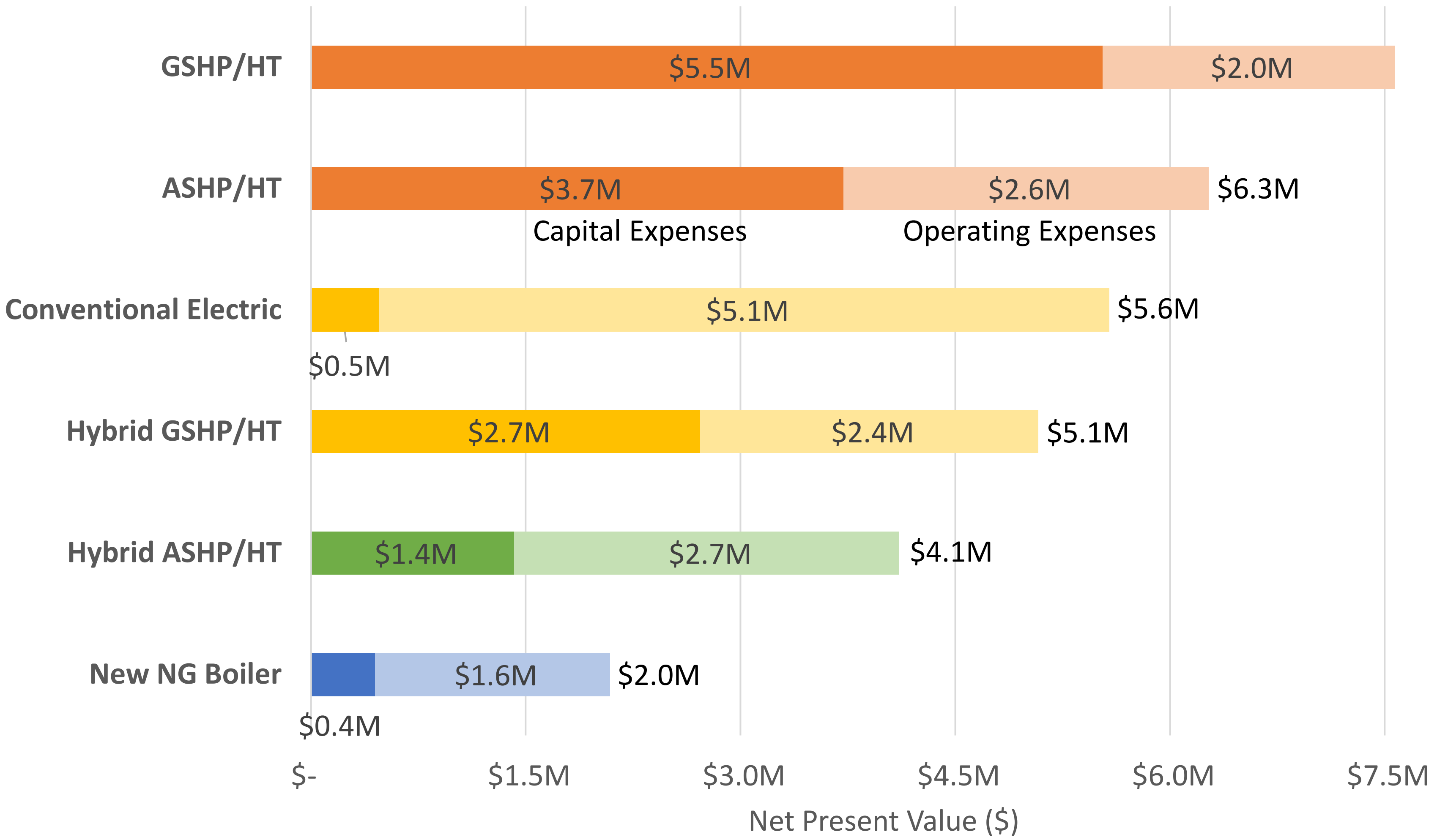


Evaluating Retrofit Options: Questrom

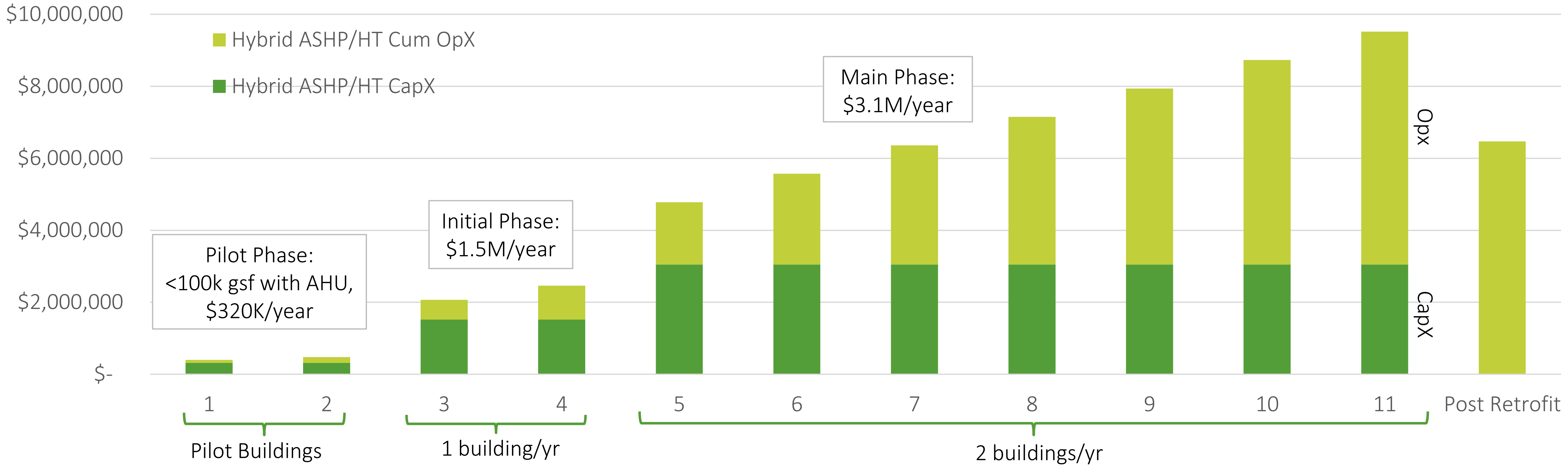
- NPV captures both capital and operating costs
- Hybrid ASHP/HT has 20% lower NPV & 48% lower CapX of GSHP/HT
- Lower CapX enables more projects now



*45-year NPV with 10% Interest Rate

Retrofit Roadmap

- 11-yr plan: Electrify 3.4M GSF, 15 Large Buildings with AHUs
- **Reduce 44% of BU CRC's heating fossil fuel use**
- **CapX: $2.7M/yr ($24M total investment)** | **OpX: $6.3M/yr** (71% premium vs fossil)
- Pilot & initial phases de-risk project for 3rd party investors



Conclusions: Electrifying Large AHU Buildings & Brownstones

- **Large AHU Buildings:** 11-yrs | $24M investment| cut 44% of CRC Heating Fossil Use
- **Brownstones:** 17-yrs | $11.3M investment | cut 8% of CRC Heating Fossil Use |**2.6x more expensive**

1

Hybrid ASHPs/HT are the cheapest electric retrofits for High Temp AHU buildings & Brownstones

Choose Hybrid ASHP/HT

2

Hybrid systems minimize capital expenses & enable more electric retrofits quicker

Hybrid Systems

3

Consider reserving roofs of buildings for ASHPs instead of solar panels

Reserve Roofs for ASHPs

4

GSHPs require the most CapX and disruption. GSHPs' higher COP does not offset its higher CapX.

Don't install GSHPs

Proposed Next Steps

Vision: We want to validate our research findings & scope out Boston University's first electrification retrofits to enable carbon neutrality by 2040.

Goals:

1. Verify key technical and financial analyses with industry experts
2. Reality-check heat pump implementation
   a. benchmark existing projects
   b. quantify maintenance requirements
   c. determine manufacturer landscape
3. Couple energy efficiency technologies with building electrification
4. Design Heating Electrification Retrofit for Existing Steam Systems
   a. Consider electrification of steam loop (steam, high-temp, vs low-temp system)
   b. Consider transition to individual building HVAC
5. Scope out and verify Pilot Electrification Candidates

Acknowledgements

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Valerie Pasquarella	GIS Expert
Robert Kaufmann (NPV analysis for BU)	Founding Partner of First Fuel Software, Earth & Environment Professor
Nalin Kulatilaka (NPV analysis for BU)	Founding Partner of First Fuel Software, Questrom Professor
Robb Dixon	Questrom Professor

Industry Experts

Estimating Costs & Financing Large CapX Projects

Judith Judson	VP of Distributed Energy Systems, Ameresco
Paul Lyons	President, Zapotec Energy Inc
Domenic Armano	President, Guardian Energy Management
Michael Gibbs	Former Deputy Secretary of Climate Action, CalEPA

Understanding Building HVAC Design & Heat Pumps

Jacob Knowles	Director of Sustainable Design, BR+A
Carolyn Meadows	Director of Strategic Initiatives, Boston Arts Academy
James McQueen	Project Manager, Boston Arts Academy
Robert Fisher	VP of Facilities, Roxbury Community College
Bradley Campbell	President, Conservation Law Foundation
Timothy Simpson	AERMEC Product Specialist, Emerson Swan

Geothermal: Heating & District Heating

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T.J. Bernier	Gap Mountain Drilling
Charles Lazin	President, Altren Energy
James O'Hagan	VP of Business Development, Erda Energy
Richa Yadav	Consultant, Buro Happold
Audrey Schulman	Co-Founder, HEET
Zayneb Magavi	Co-Founder, HEET
Wayne Chouinard	City Engineer, Town of Arlington
Peter Ditto	City Engineer, Town of Brookline

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Evaluation of Distributed Ground Source Heat Pump System Across BU's Charles River Campus

1. Technical Geothermal Feasibility
2. Geothermal District Heating Model

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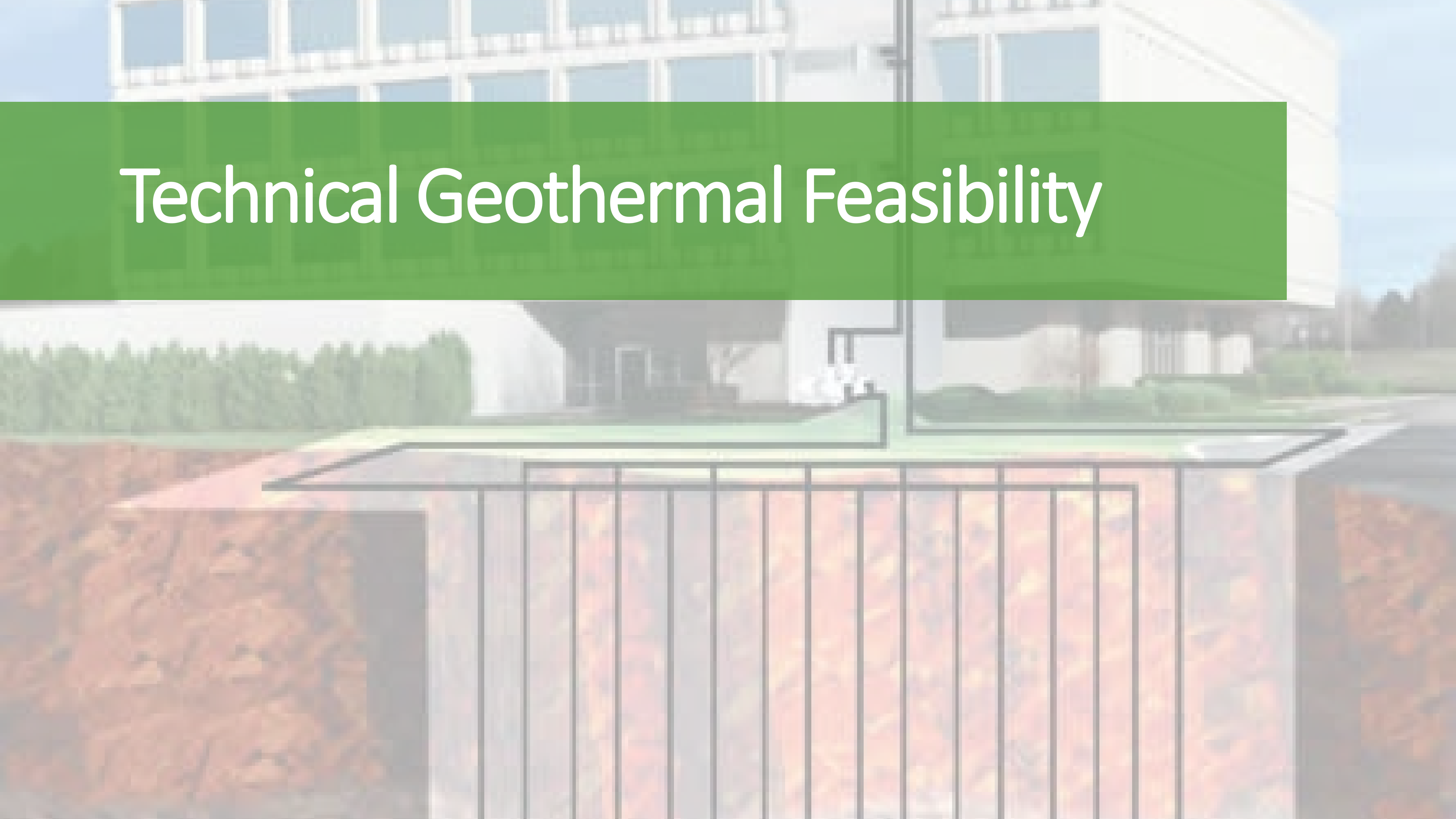
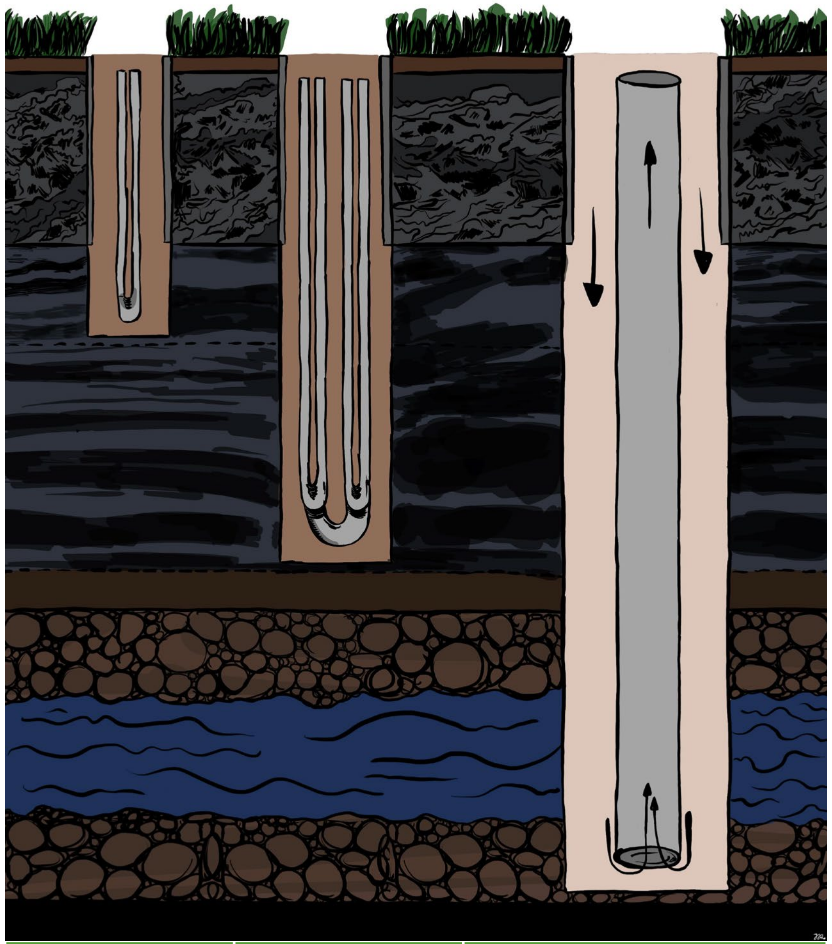
Technical Geothermal Feasibility



Borehole Breakdown

- **Deeper bores = more heating capacity** because the earth gets hotter as you go deeper
- **Cost and tons per well do not increase linearly with depth** because the deeper technologies are more expensive and effective
- **Offset between wells determines the number of wells you can have**



	U-Bend	Quad Loop	Coaxial
Depths	500 ft	900 ft	1,500 ft
Tons per Well	2.5	7.5	11
Total Installed Cost	$20,000	$50,000	$90,000
Offset	20 ft	25 ft	30 ft

* Original Bore Hole Illustration by Jayameena Sundar Rajan

Geothermal Capacity of CRC, 500' Bores

# of Boreholes, Good Drilling Areas	Tons of Heating, Good Drilling Areas
2,188	5,470

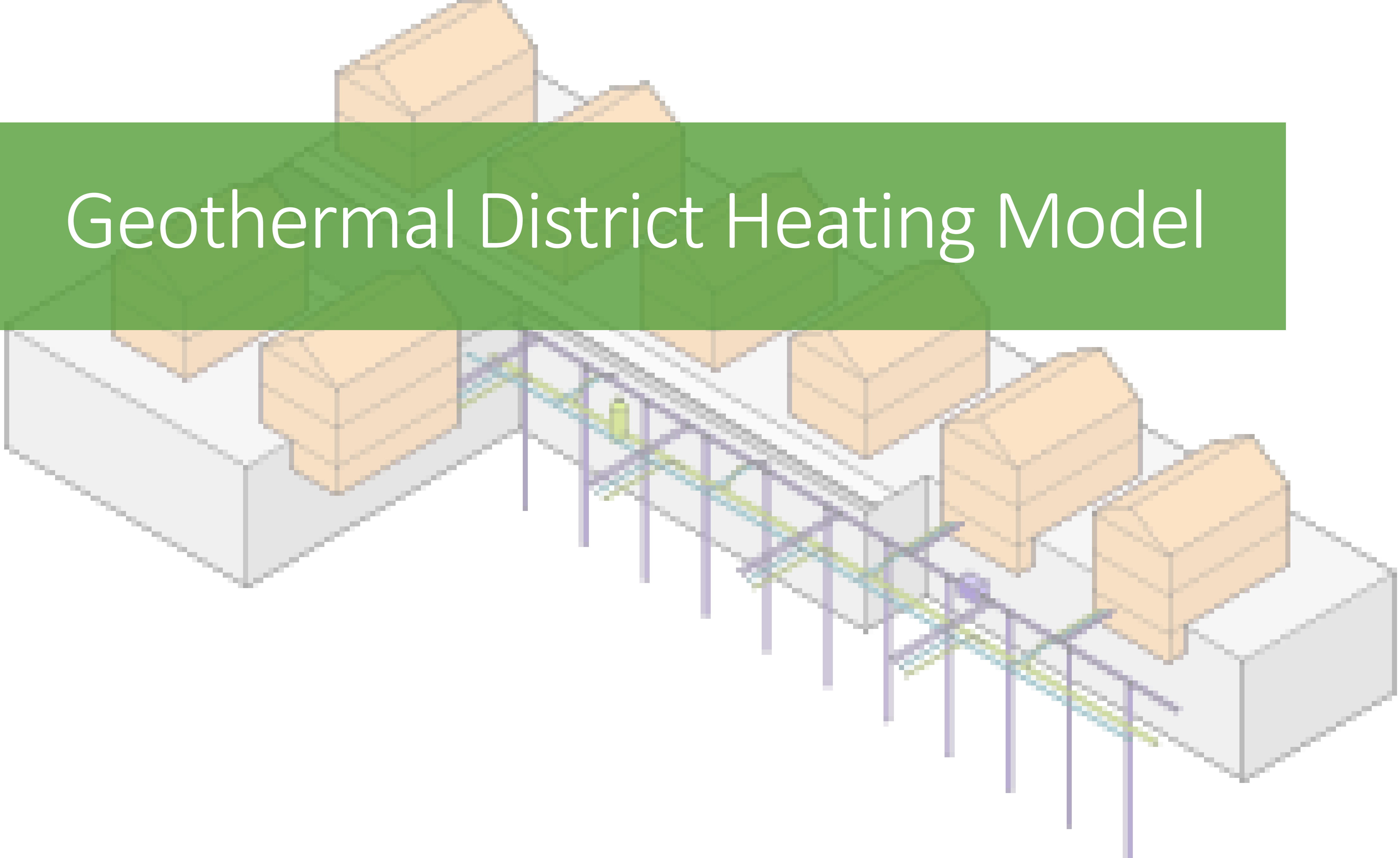
% of Peak Load Met, Initial Buildings, Good Areas	% of 80% Load Met, Initial Buildings, Good Areas
49%	114%

Cummington Mall:
48%
Central Campus
(EPIC Side):
131%

Conclusions: Technical Geothermal Feasibility

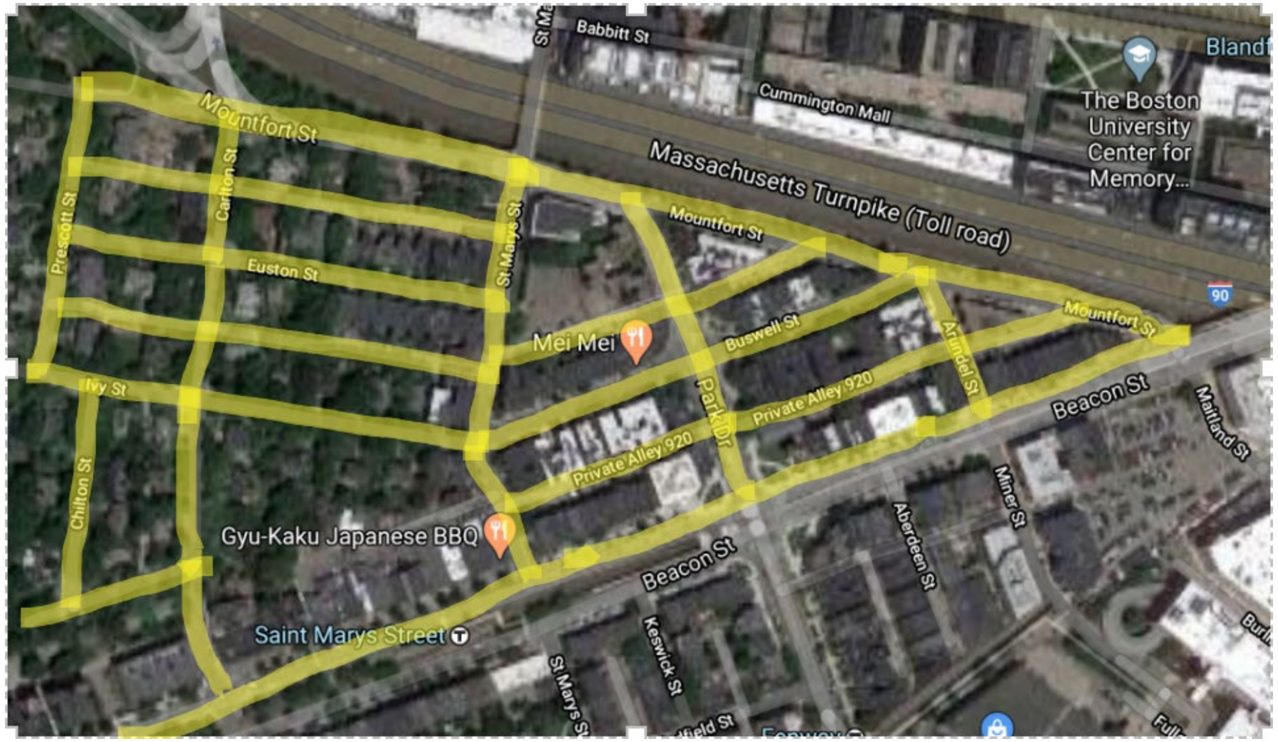
1. Significant technical potential for geothermal on the whole CRC, but the potential differs substantially by campus area
2. Sizing geothermal to meet 80% of load is the most cost effective and technically feasible
3. Geothermal is a feasible solution for some campus sections but not all

Geothermal District Heating Model



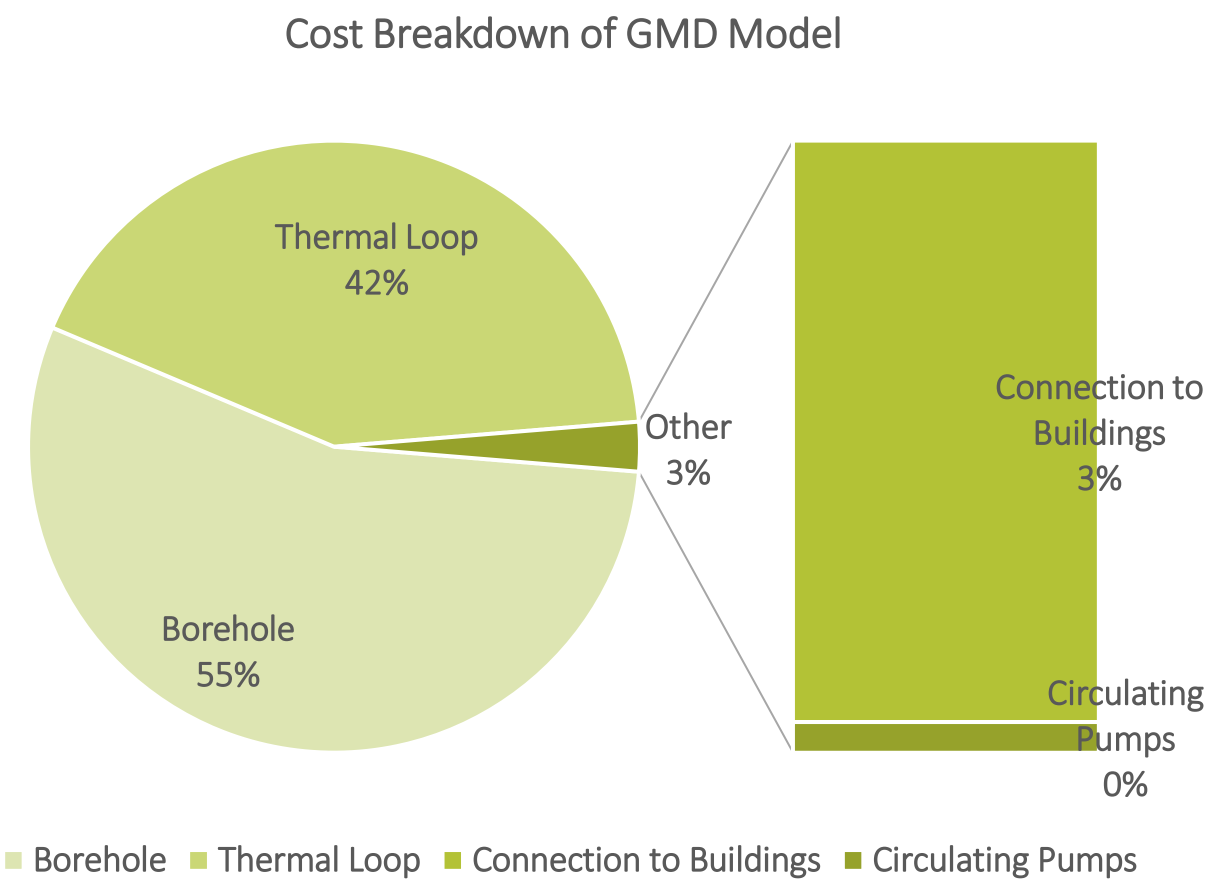
South Campus Model

- Diversity of load and ownership
- BU and beyond
- 18 streets, 2.76 miles, 229 buildings



Cost Breakdown, South Campus Geothermal District Heating Model

Per Ton Cost:	$14,530
Per Building Cost:	$151,195
Per South Campus Model Cost:	$34,623,750



Profit Margin:	9.5%
Total Cost with Profit Margin:	$37,913,006
Capital Recovery Factor (7.5%, 50 years):	0.077
Annual Cost with Capital Recovery Factor:	$2,919,301
Annual Cost for 50 Years, per Ratepayer:	$2,834

District Heating: **10 Ton** Comparison to Norm

I am the owner of a brownstone, and I want to do geothermal heating. What are my options?

	10 Ton Capital Cost			Annual Operating Cost
Independent Geothermal	$80,000, borehole	$30,000, HT GSHP	$3,000, electric boiler	$4,000 per year, electricity

	10 Ton Capital Cost		Annual Operating Cost	
District Heating At Scale	$30,000, HT GSHP	$3,000, electric boiler	$4,000 per year, electricity	$2,800 per year, utility

*discounted, 7.5% interest over 50 years, 10 ton system

Conclusions: Geothermal District Heating Model

1. Geothermal district heating: well suited to South Campus
2. Cost uncertainties: the system itself, how the cost reaches consumer
3. Decreases the upfront capital burden which allows more electrification in a shorter period of time

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