BROWN UNIVERSITY CAMPUS DECARBONIZATION PLAN

Scope 1 Emissions – Phase 1, August 2018

SUNY / PPAA AND NYAPPA SUMMER CONFERENCE
July 16 - 18, 2019 Albany, New York

RAMBOLL Bright ideas. Sustainable change.

BROWN

AGENDA

01 Brown University Plans and Status

02 Decarbonization Plan Objectives

03 Decarb Project Planning Process

04 Goals and Scoring Matrix

05 Energy Supply Scenarios and Modeling Results

06 Implementation Plan and Schedule

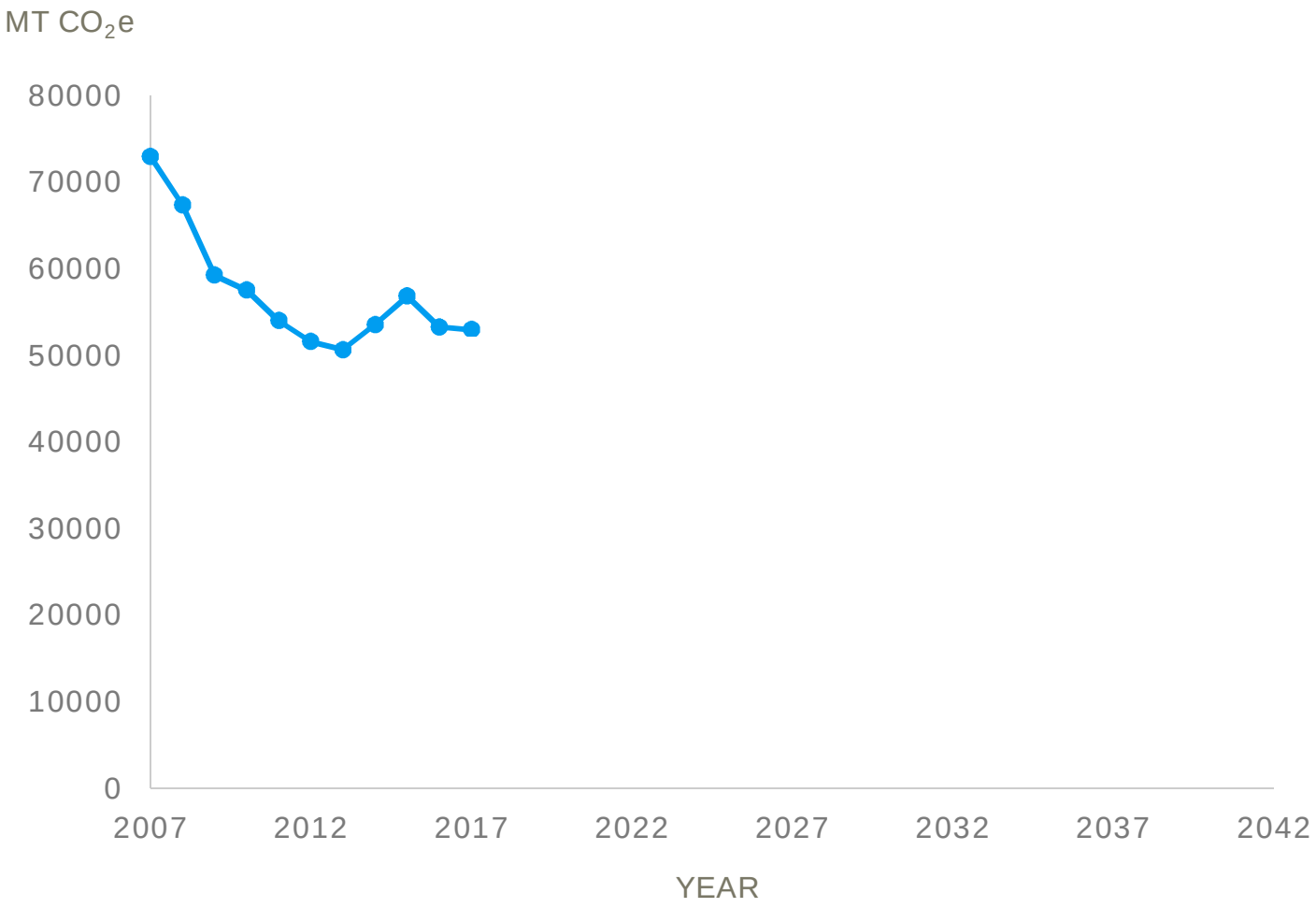
01

BROWN UNIVERSITY PLANS AND STATUS

CURRENT STATUS

PHASE 1	PHASE 2 BY 2022	PHASE 3 BY 2023-2040	PHASE 4 2030-2040
2008 Pledge – 42% below 2007 Levels by 2020 Currently 28% below 2007 levels – *established new baseline of 67% below 2007* 100% Renewable Electricity supply with 40 MW Solar PV and 8 MW Wind Thermal Efficiency Project (TEP) – Remove steam from buildings and lower loop temperature	75% Reduction by 2025 and Carbon Neutral by 2040 Liquid Biofuel conversion for Central Plant boilers	Building renovations and improvements Enable low temperature heating loop	Identify and implement Carbon Neutral energy sources

BROWN'S EMISSIONS TRAJECTORY

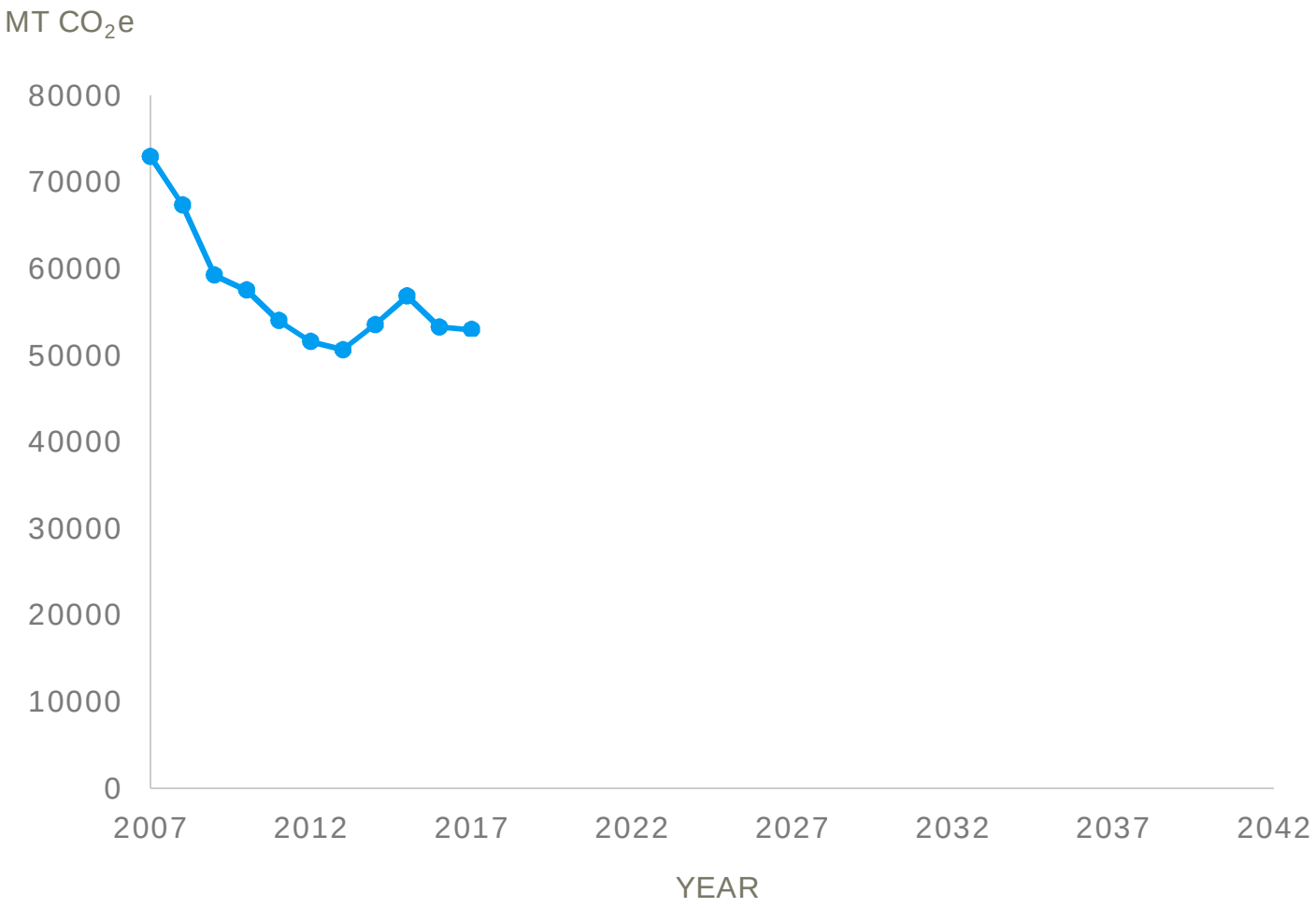


2017-2018

28% Below 2007

- Fuel switching
- Energy Conservation Initiatives

BROWN'S EMISSIONS TRAJECTORY



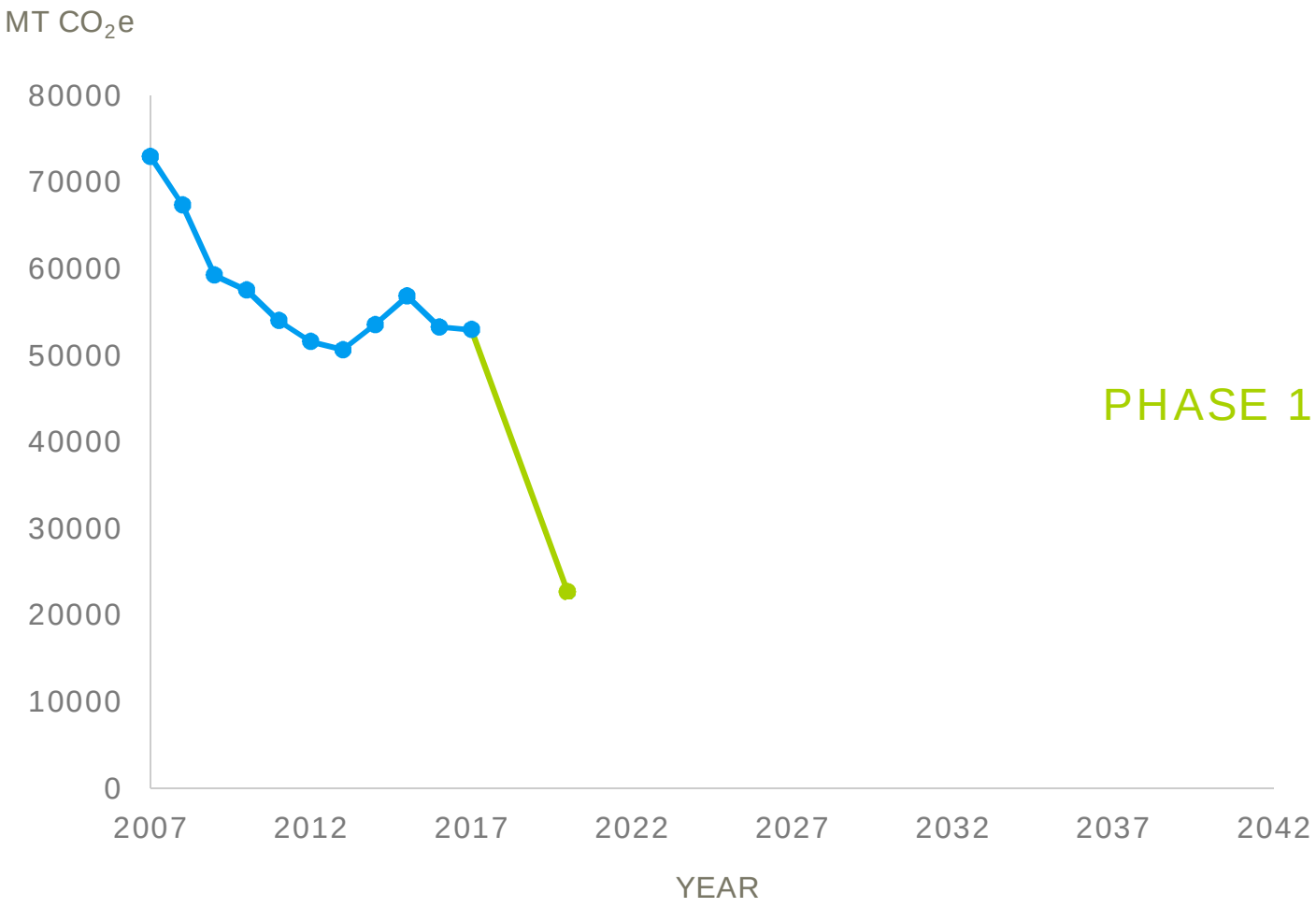
2017-2018

A New Baseline

Remaining Emissions

- Electricity
  26,500 MT
- Central Heat Plant
  16,500 MT
- Off Loop Buildings
  9,500 MT

BROWN'S EMISSIONS TRAJECTORY



PHASE 1

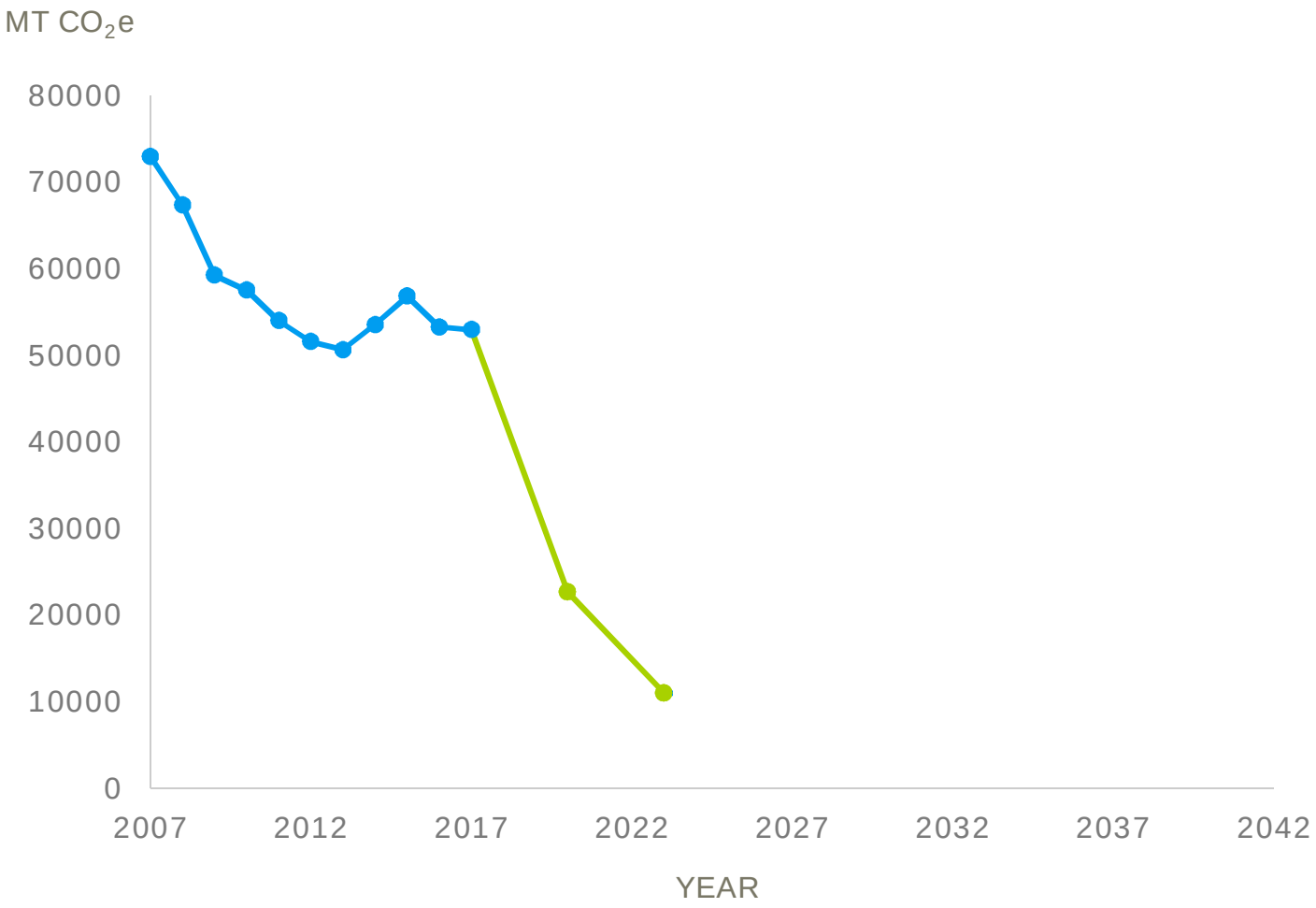
2020

67% Below 2007

50% Below 2017-18

- Thermal Efficiency Project
- 40MW Solar in RI
- 8 MW Wind in Texas

BROWN'S EMISSIONS TRAJECTORY

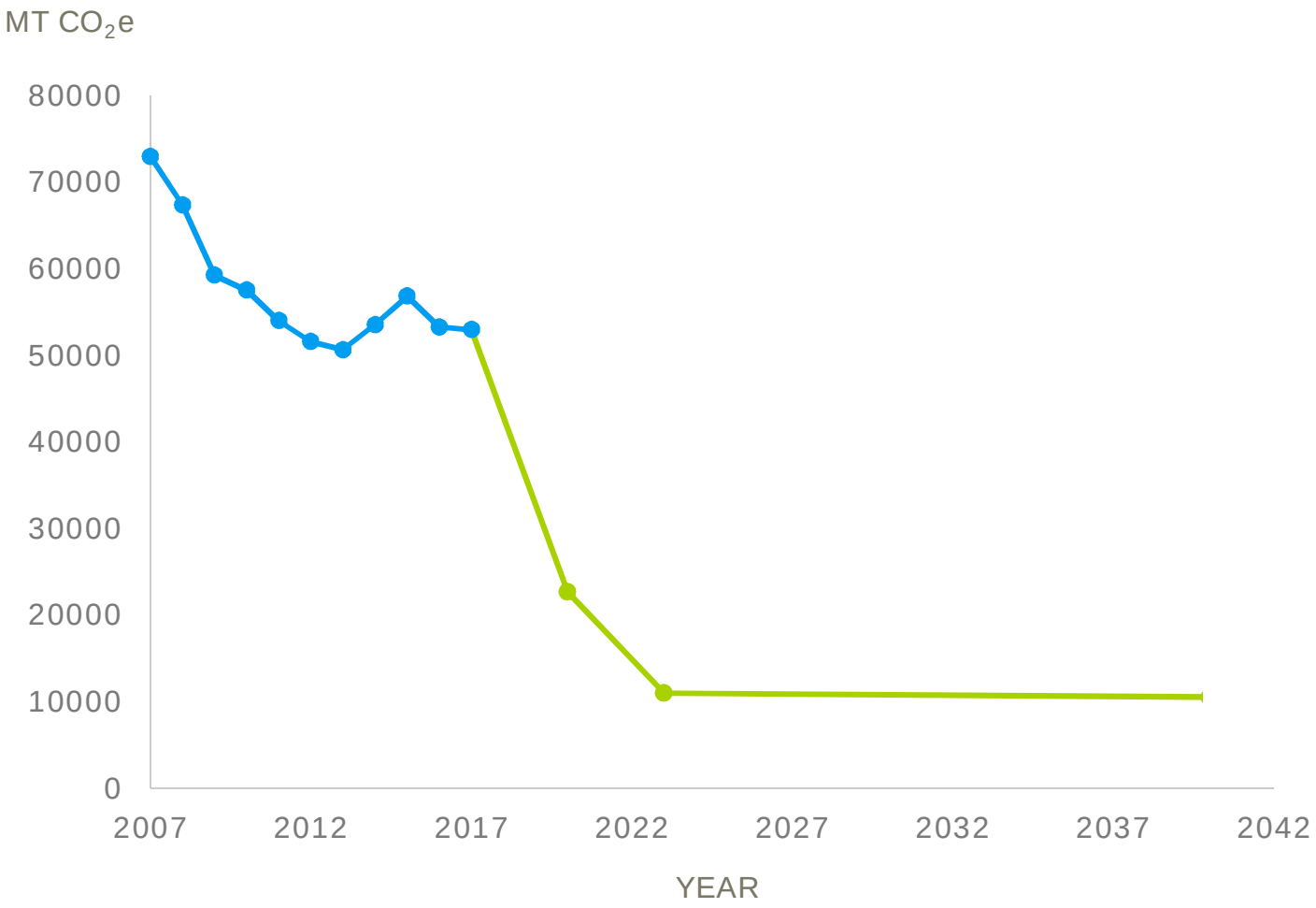


BEYOND 2020

PHASE 2

- Recycled bio-oil for CHP (2023)
- 75% Below 2017-18

BROWN'S EMISSIONS TRAJECTORY

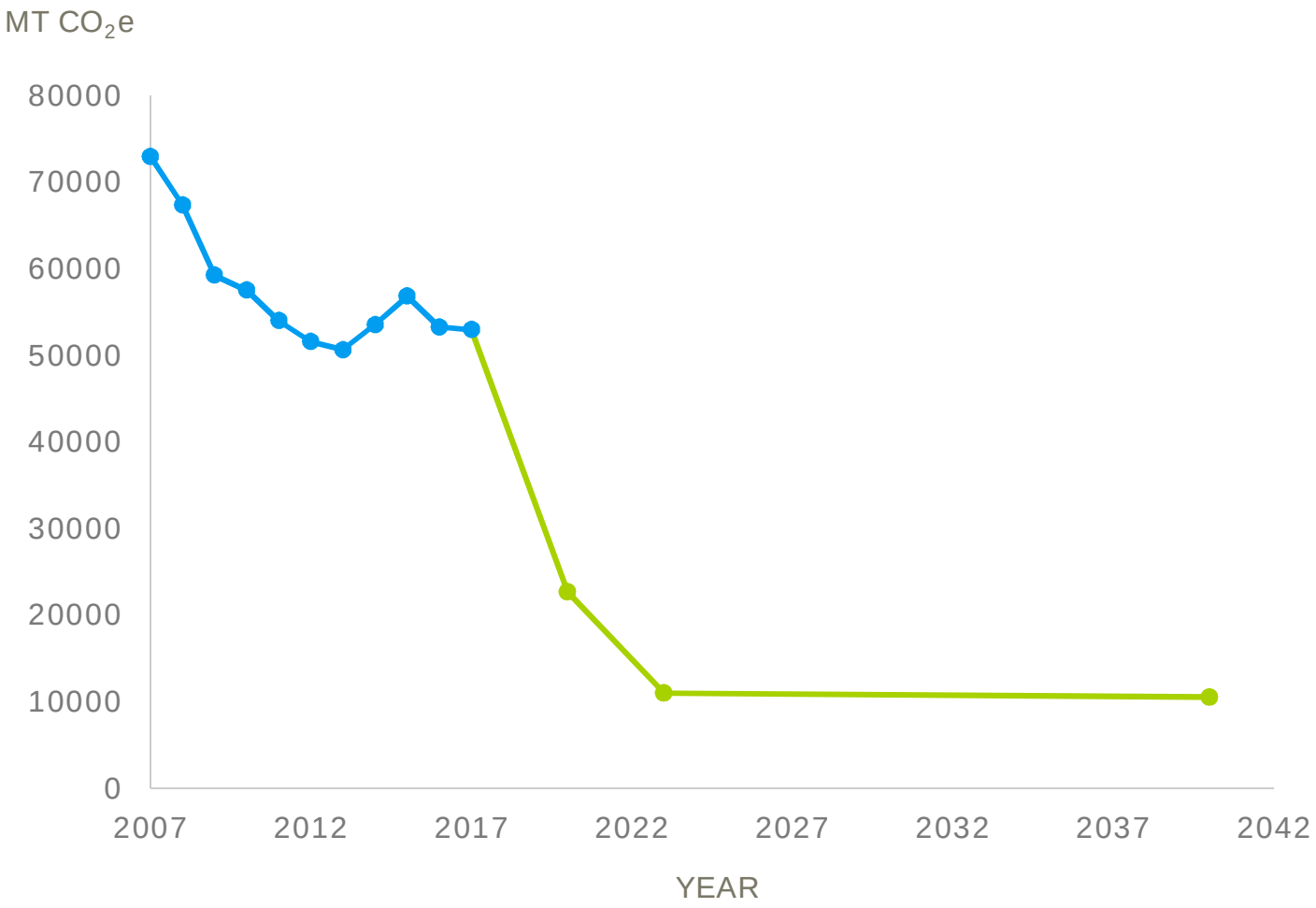


BEYOND 2020

PHASE 3

- Building renovations / loop modifications (2021-2038)
- Lower loop temperature to 185°F

BROWN'S EMISSIONS TRAJECTORY

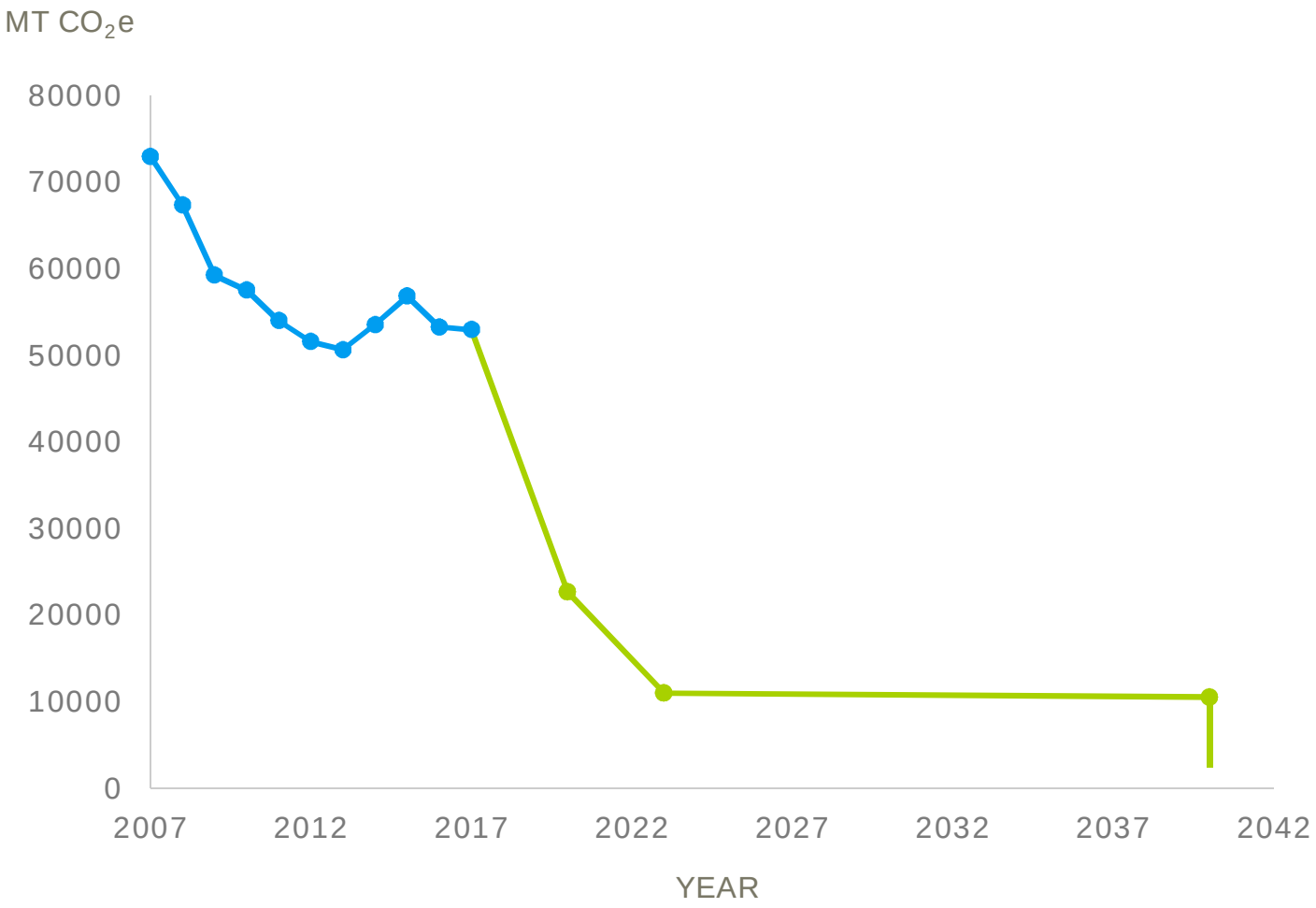


BEYOND 2020

PHASE 4

- 185ºF water opens up heating options
- Installation of Heat Pumps (2040)
- A long term, scalable, sustainable solution

BROWN'S EMISSIONS TRAJECTORY



BEYOND 2020

PATH TO ZERO

- Emissions from off loop buildings offset after 2040

OFF LOOP BUILDINGS

Gradually transition 130 buildings off fossil fuels

- Maintain campus operations
- Incorporate into ongoing building and boiler renewal
- Prioritize larger and higher value buildings
- Explore connecting additional buildings to the loop
- Leverage other renovations

02

DECARBONIZATION PLAN OBJECTIVES

DECARBONIZATION RFP SCOPE OF SERVICES

SCOPE 1 EMISSIONS

- 98 Buildings (4.6M sf) connected to central loop represent 77%
- Remaining 120 off loop buildings (1.9M sf) represent 23%
- 3 Large off loop buildings also included

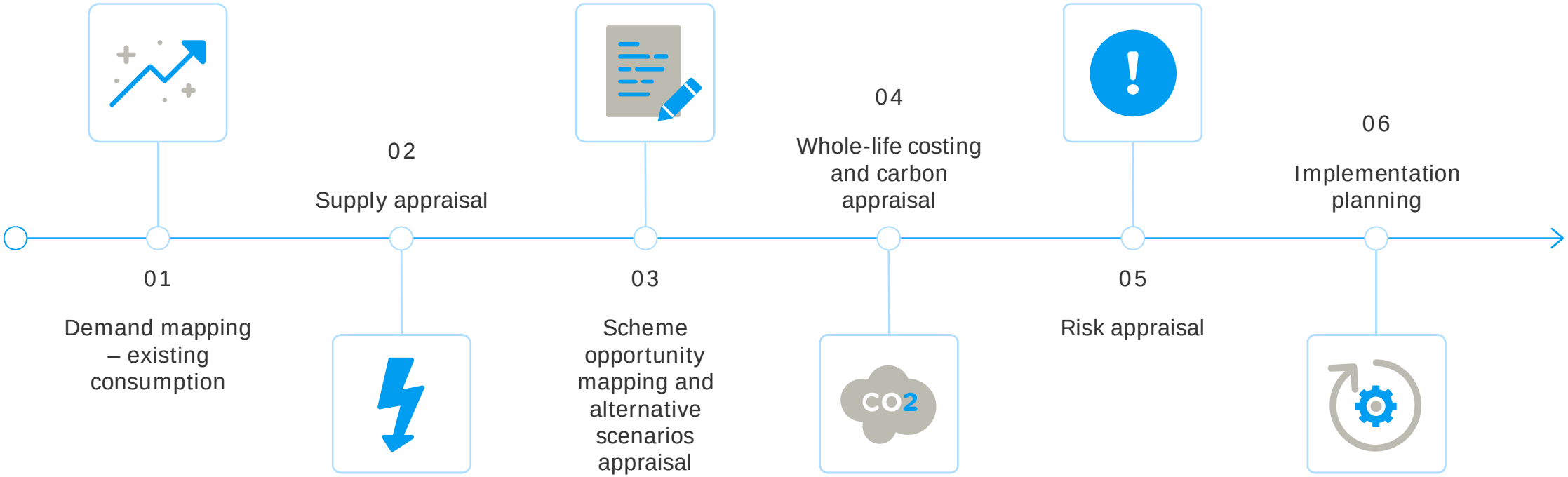
SCOPE OF SERVICES

TASK 1	Work Plan Development - Schedule, approach, goals
TASK 2	Evaluate Existing Conditions
TASK 3	Analysis / Modeling / Conceptual Design
TASK 4	Cost Estimating & Scheduling
TASK 5	Phasing Master Plan
TASK 6	Final Report and Deliverables

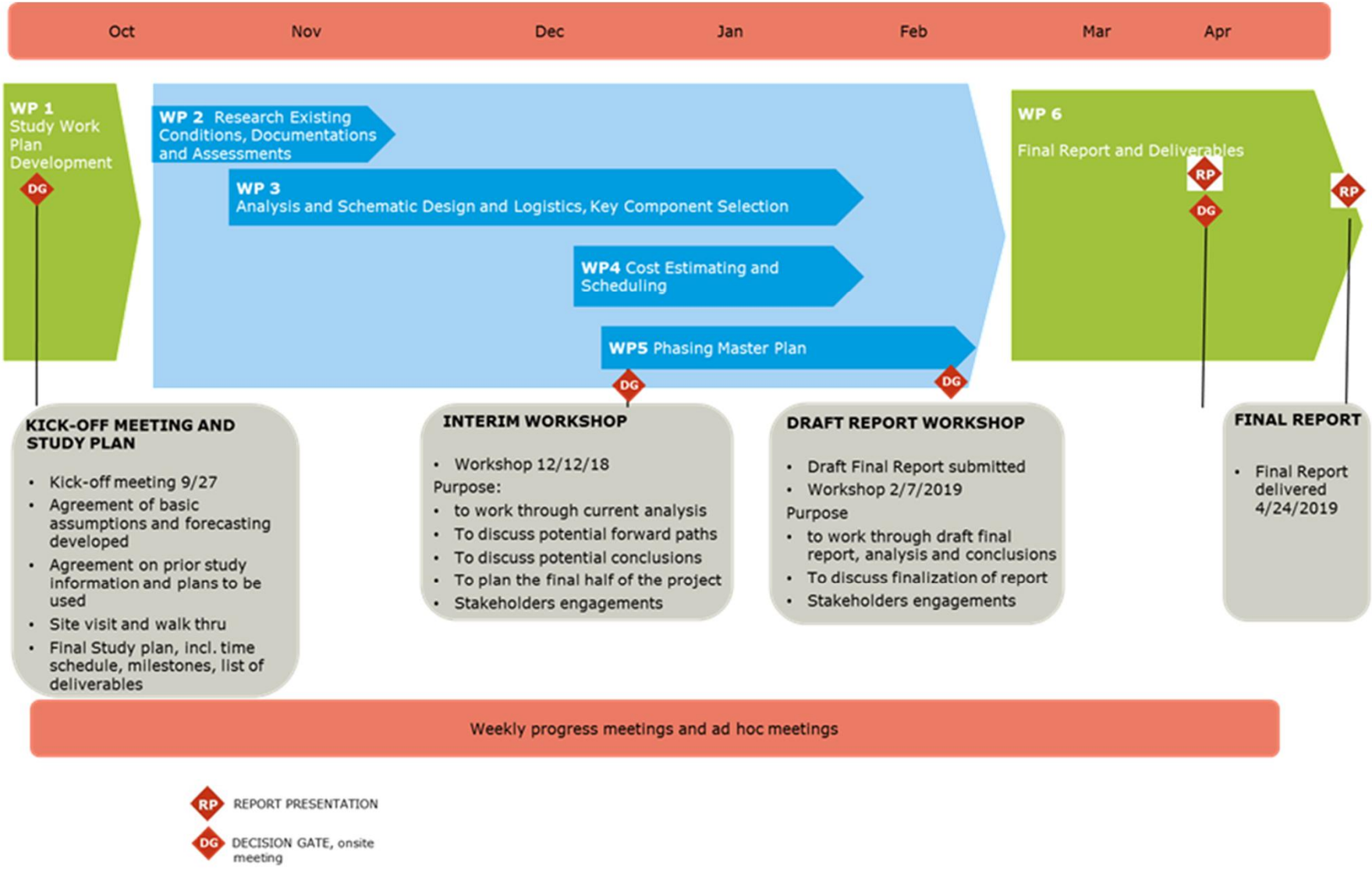
03

PLANNING PROCESS

ENERGY MASTERPLANNING PROCESS



RAMBOLL PLANNING PROCESS



04

GOALS AND SCORING MATRIX

GOALS AND SCORING MATRIX

Weighted Goals and Matrix - Project Evaluation and Scoring						
Top Level		1. Air source heat pumps (ASHP) + peaking boilers (PB)	2. ASHP + Heat recovery chillers (HRC) + peaking boilers	3. ASHP + HRC + river water heat pump + peaking boilers	4. ASHP + HRC + biomass + peaking boilers	5. ASHP + biomass + peaking boilers
Category	% Weight					
Solution Economics	30	19	19	17	22	24
Solution Risk	10	7	7	6	10	10
Environmental Impact	40	37	38	34	36	35
Social Impact	10	6	6	6	6	6
Economic Development	3	2	2	2	3	3
Reputational Impact	7	7	6	5	6	7
	100	78	78	70	83	85

05

ENERGY SUPPLY SCENARIOS AND MODELLING RESULTS

TECHNOLOGIES EVALUATED

Air source heat pumps	
River Water heat pumps	
Ground source heat pumps →	*Eliminated – no viable aquifer or land for district scale system*
Heat recovery chillers including seasonal storage →	*Limited due to chilled water network*
Solar Thermal including seasonal storage →	*Eliminated due to space needed and fractional contribution*
Biomass (heat only, cogeneration will be described)	
Boilers based on bio-oil, green natural gas or natural gas	
Thermal Storage options →	*Should be included in each scenario*
Electric Boilers for Peaking →	*Eliminated due added 9-12 MW of electrical loading during peak periods*
Virtual electricity storage →	*Eliminated due to space needed, high CAPEX, and technology risk*

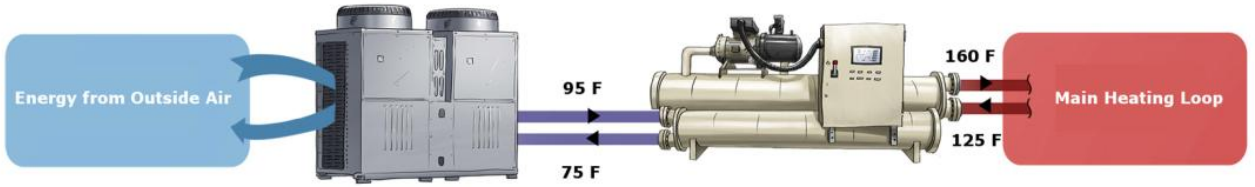
AIR SOURCE HEAT PUMPS

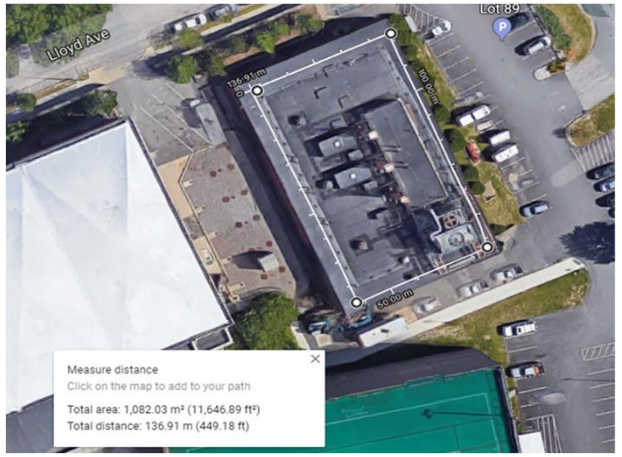
PROS

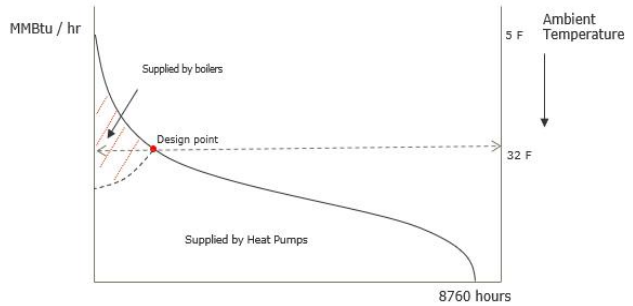
- Easy to install and maintain - scalable
- Should fit within existing CEP area

CONS

- 16,000-30,000 sq ft of space needed (can be split up)
- Noise
- Increased Electrical load 7.5 MW to 22.5 MW peak
- Performance drops off in winter months







RAMBOLL

Scenario	20 MW	15 MW	10 MW
Heating demand (MMBtu/hr)	68	51	34
Electricity consumption (MW)	6.7	5	3.3
Space for Air coolers (ft2)	15,500	11,600	7,800
Space for heat pump building (ft2)	14,000	10,500	7,000

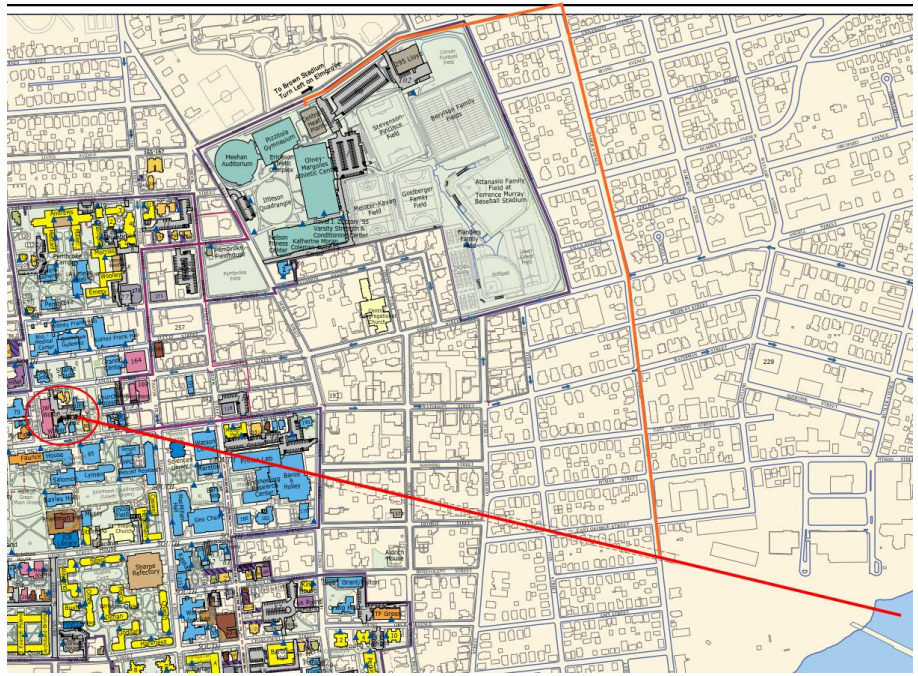
RIVER WATER HEAT PUMPS

PROS

- Improved performance over ASHP
- Less noise & space needed (no coolers)
- Scalable

CONS

- No easy route - “In Street” option in CAPEX
- Below 38° F limits performance and causes Icing – January and February are a concern
- 10% Sea water - corrosive
- Federal 316 a & b permits needed
- (4) State permits needed
- Abandoned Rail Tunnel possibly owned by the State of RI currently



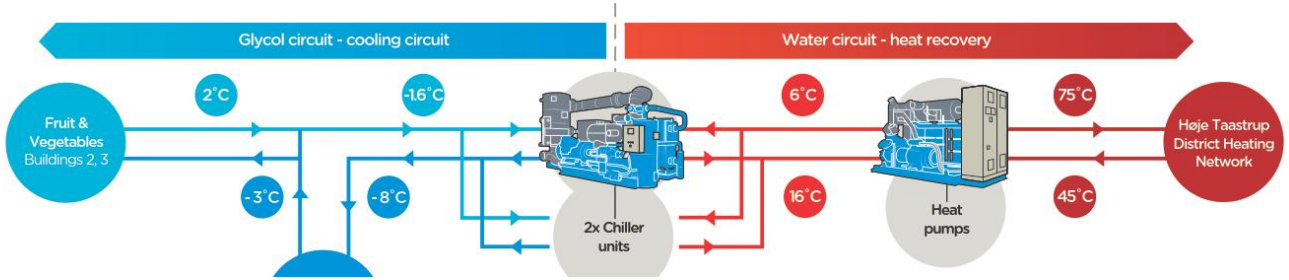
HEAT RECOVERY CHILLERS

PROS

- Leverage existing chilled water system
- Upgrade / Replace Existing Chillers
- Flatter performance curve
- Scalable

CONS

- Existing Chilled Water network limits size and contribution
- Must expand Chilled Water network to increase contribution
- HRC require more maintenance than electric units
- Requires thermal storage



Utilizes waste heat from other process

Couple chilled water system and heating system

- Waste heat from the chiller contributes to heating network
- Cooling effect of heating network helps chilled water system

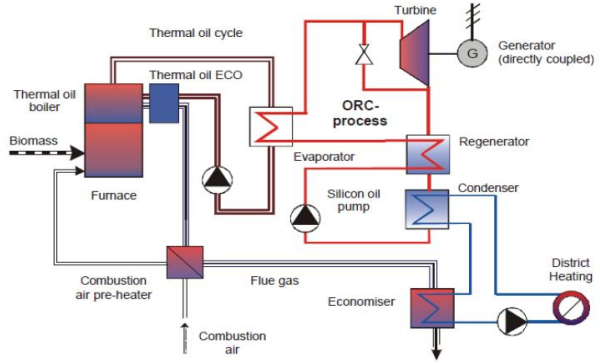
BIOMASS CHP / COGEN

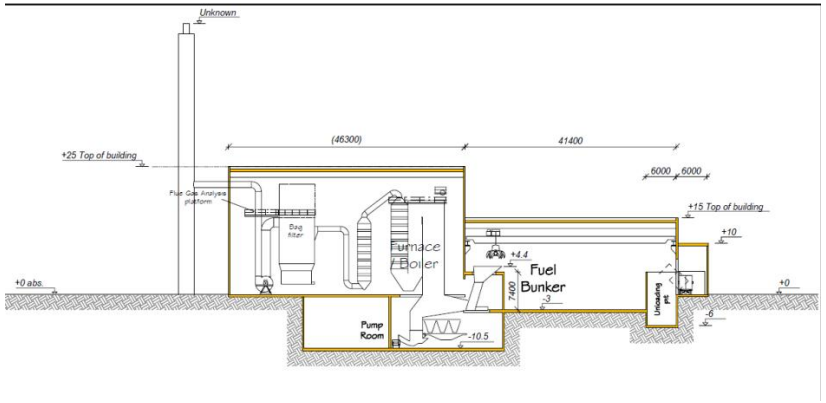
PROS

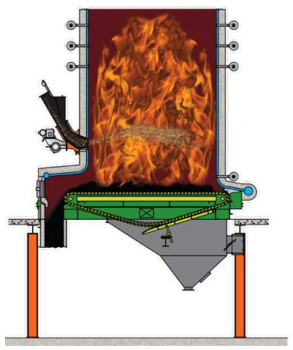
- Carbon neutral fuel
- Onsite Electric production (offsets heat pumps)
- Most cost effective solution
- Electrical distribution system upgrades not required

CONS

- Space requirements and retrofit of existing CEP or new build on new land
- Noise / Dust / Truck traffic (15-20 trucks per day)
- Combustion process and by products
    - Ash
    - Some carbon emissions plus NOx







BIOFUEL (LIQUID) CONVERSION OF CEP BOILERS

PROS

- Timeframe – can be done now and within 2 years
- Carbon neutral depending on source
- Extends time period to evaluate other technologies
- Conversion is not complex

CONS

- Added cost of boiler burner and forwarding system conversion
- Wholesale change for all 3 boilers (redundancy)
- Added truck traffic during peak heating season

Convert existing boilers to burn liquid biofuel

Several biofuels are available in NE

- Post consumer options available

LARGEST CHALLENGE OR IMPACT

HYDRAULIC MODEL – HEATING NETWORK EVALUATION

Network Parameters (current Δ 20° F from ecosystems TEP Model):

Model Result, Central Heat Plant:

- Flow: ~ 5460 gpm
- Power, Thermal: ~ 110,430 MBH
- Pressure, Supply: ~ 270 psi(g)
- Pressure, Return: ~ 14.5 psi(g)
- Temperature, Supply: ~ 185 ºF
- Temperature, Return: ~ 144 ºF

Distribution Network:

- Maximum pressure: ~ 270 psi(g)
- Minimum pressure: ~ 15 psi(g)
- Minimum ΔP: ~ 14.5 psi (Graduate Center E)

- High Flows and supply pressure above 300 psig (equipment limits)
- Pressure gradients in system exceed safety limits due to increased flows

OPTIONS

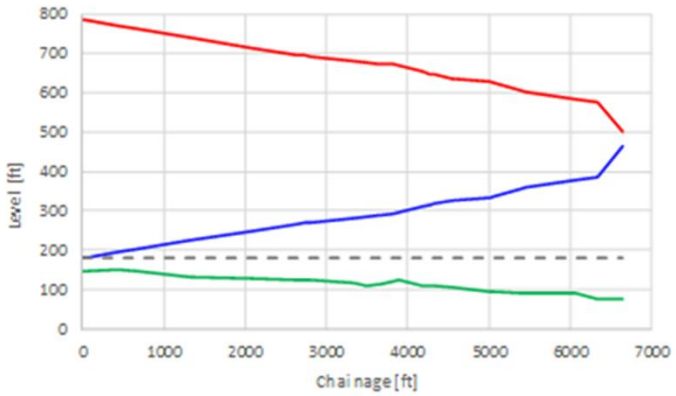
Increase pipe sizes

OR

Increase Delta T in buildings

HYDRAULIC MODEL – HEATING NETWORK EVALUATION

WITH LESS THAN 40°F ΔT

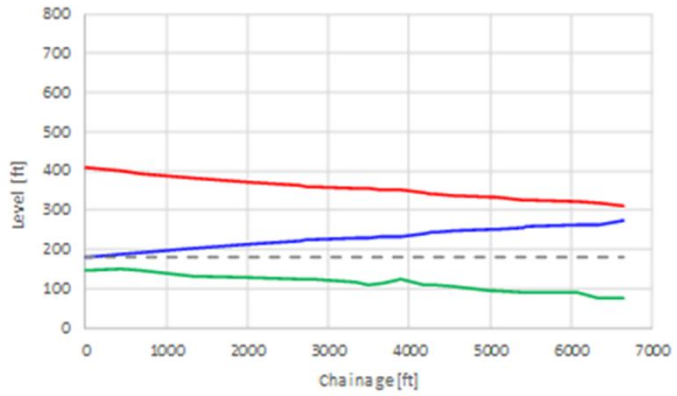


Invest $80-100M in Piping Network Upgrades

Less than less than 40 ° F Δ T - poor performing buildings

Increased pumping and electrical costs

WITH MORE THAN 40°F ΔT



Invest $60-80M in Buildings Upgrades

More Efficient Buildings and Optimized Network

Lower CAPEX and OPEX

Buildings may already be slated for upgrades

HYDRAULIC MODEL – HEATING NETWORK EVALUATION

Increased Building Delta T to 40° F

Model Result, Central Heat Plant:

- Flow: ~ 3836 gpm
- Power, Thermal: ~ 110,370 MBH
- Pressure, Supply: ~ 110 psi(g)
- Pressure, Return: ~ 14.5 psi(g)
- Temperature, Supply: ~ 185 ºF
- Temperature, Return: ~ 127 ºF

Distribution Network:

- Maximum pressure: ~ 110 psi(g)
- Minimum pressure: ~ 15 psi(g)
- Minimum ΔP: ~ 14.5 psi (Graduate Center E)

Buildings with Delta T less than 40 ° F

- Heat exchangers and HVAC
- 54 New Buildings in total
- Included in CAPEX

FAMIS	Building name	Likely MTHW return temp	Resulting DT	BAS Notes related to likely MTHW return temp. Notes are on building that host the hub hardware
100144	ANGELL ST 164	165.00	15.00	Building is under construction. During initial review Brown had requested the EstmmBTU for 164Angell be increased from 3218 to 2963. Please adjust along with Es. MBH
100230	ANNMARY BROWN MEMORIAL LIBRARY	160.00	20.00	
100258	ARCHIBALD-BRONSON: KEENEY QUAD	160.00	20.00	Again hard to get a read on return temps in BAS - only about a 12 degree drop. If it achieves 180 we may only see 168 coming back. TEP revising for 200F supply from Wayland, supply space heating, then cascade through makeup air. Hard to gauge future temps. May be supply of 200 and return of ~160
100278	ARNOLD LAB	145.00	35.00	Andover
100077	BARUS & HOLLEY	150.00	30.00	Barus & Holley: MTHWR-T use 150F. HX-28 has reset of 130-160. During cold weather in January the HWR-T was 140-145 so we can use 145 for that. It appears there may be some radiation return in January of about 150F (dual temp stuff). May want to use 150 for the building unless I can parse that apart.
100143	BLISTEIN HOUSE	145.00	35.00	
100174	BUXTON HOUSE: WRISTON QUAD	160.00	20.00	
100163	CHAPIN HOUSE: WRISTON QUAD	160.00	20.00	
100164	DIMAN HOUSE: WRISTON QUAD	160.00	20.00	
100331	ENGINEERING RESEARCH CENTER	160.00	20.00	Engineering Research Center: MTHWR-T of 160. Running on the boilers. Last January return temps in the mid 160s with supply setpoint at 180. Reset is supposed to be 120-180. However, even at 180 still seeing return at 165. Troubling. Not much for mechanical drawings to know what the coils are rated for. Had to look in progress prints. AHU coils are rated for entering water of 180 and leaving of 160. I think it's 160.

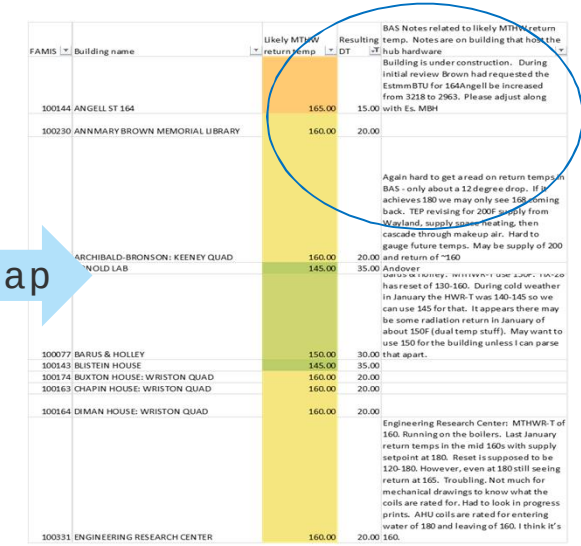
UPGRADES TO BUILDINGS – 2 GROUPS

8 BUILDINGS ON STEAM POST TEP

Buildings not designed for MTHW at or below 180 °F
Alumnae Hall
Andrews House
Caswell Hall
Gardner House
Hegeman Hall
John Hay Library
Maxcy Hall
Sharpe Refectory

4 Buildings Overlap

54 BUILDINGS INCREASE Δ T



FAMIS	Building name	Likely MTHW return temp	Resulting DT	BAS Notes related to likely MTHW return temp. Notes are on building that hosts the hub hardware
100144	ANGELL ST 164	165.00	15.00	Building is under construction. During initial review Brown had requested the EstmmBTU for 164Angell be increased from 3218 to 2963. Please adjust along with Es. MBH
100230	ANNMARY BROWN MEMORIAL LIBRARY	160.00	20.00	
	ARCHIBALD-BRONSON: KEENEY QUAD	160.00	20.00	Again hard to get a read on return temps in BAS - only about a 12 degree drop. If it achieves 180 we may only see 168 coming back. TEP revising for 200F supply from Wayland, supply goes to heating, then cascade through makeup air. Hard to gauge future temps. May be supply of 200 and return of ~160
	NOLD LAB	145.00	35.00	Andover
100077	BARUS & HOLLEY	150.00	30.00	has reset of 130-160. During cold weather in January the HWR-T was 140-145 so we can use 145 for that. It appears there may be some radiation return in January of about 150F (dual temp stuff). May want to use 150 for the building unless I can parse that apart.
100143	BLISTEIN HOUSE	145.00	35.00	
100174	BUXTON HOUSE: WRISTON QUAD	160.00	20.00	
100163	CHAPIN HOUSE: WRISTON QUAD	160.00	20.00	
100164	DIMAN HOUSE: WRISTON QUAD	160.00	20.00	
100331	ENGINEERING RESEARCH CENTER	160.00	20.00	Engineering Research Center: MTHWR-T of 160. Running on the boilers. Last January return temps in the mid 160s with supply setpoint at 180. Reset is supposed to be 120-180. However, even at 180 still seeing return at 165. Troubling. Not much for mechanical drawings to know what the coils are rated for. Had to look in progress prints. AHU coils are rated for entering water of 180 and leaving of 160. I think it's 160.

Good information on existing conditions

B-	Building works (independent of scenario / production technology)		$38.402.220
B1	Hub ETS modifications	24%	$2.932.371
B6	Replacement of shell-and-tube heat exchangers in SMTHW buildings on the Loop	24%	$1.083.099
B2	Production of DHW with MTHW from the Loop	30%	$546.021
B3	Conversion of LPS heated buildings to MTHW	30%	$18.705.310
B4	Increase temp. diff in selected buildings	30%	$15.135.419
B5	Installation of heat pumps in off-loop buildings		$0

COMPARING RESULTS

EMISSIONS COMPARISON – TONS PER YEAR

CARBON NEUTRAL ELECTRIC PPA

Technology	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
ASHP (MMBtu/h)	0	0	0	0	0	0
HRC (assumed)	0	0	0	0	0	0
RWHP	0	0	0	0	0	0
Biomass	0	0	0	644	1.184	1.546
Peaking	146	122	141	111	96	74
TOTAL	146	122	141	755	1.281	1.620

CARBON OF CURRENT ISO NE GRID

Technology	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
ASHP	6.680	5.505	4.594	4.119	2.301	703
HRC (assumed)	0	368	0	0	0	0
RWHP	0	0	1.820	0	0	0
Biomass	0	0	0	644	1.184	1.546
Peaking	146	122	141	111	96	74
TOTAL	**6826**	**5994**	**6554**	**4875**	**3581**	**2323**

ANNUAL OPEX

ANNUAL FUEL COSTS ($)

Can be reduced with Net Metering or new PPA

Technology	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
ASHP (MMBtu/h)	0	0	0	0	0	0
HRC (assumed)	0	0	0	0	0	0
RWHP	0	0	0	0	0	0
Biomass	0	0	0	644	1.184	1.546
Peaking	146	122	141	111	96	74
TOTAL	146	122	141	755	1.281	1.620

VARIABLE OPEX ($)

Technology	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
ASHP	6.680	5.505	4.594	4.119	2.301	703
HRC (assumed)	0	368	0	0	0	0
RWHP	0	0	1.820	0	0	0
Biomass	0	0	0	644	1.184	1.546
Peaking	146	122	141	111	96	74
TOTAL	**6826**	**5994**	**6554**	**4875**	**3581**	**2323**

ELECTRICAL LOAD INCREASE

Maximum electric capacity in the scenarios, in MW								
Electric capacities	ASHP	HRC	RWHP	BIOM	Peaking (oil)	Peaking (elec)	Backup boiler (oil)	Backup Boiler (Elec)
Scenario 1	7.5	0.0	0.0	0.0	0.0	15.0	0.0	30.0
Scenario 2	7.5	0.0	0.0	0.0	0.0	15.0	0.0	30.0
Scenario 3	5.0	0.0	2.3	0.0	0.0	15.0	0.0	30.0
Scenario 4	5.0	0.0	0.0	0.0	0.0	15.0	0.0	30.0
Scenario 5	2.5	0.0	0.0	0.0	0.0	15.0	0.0	30.0

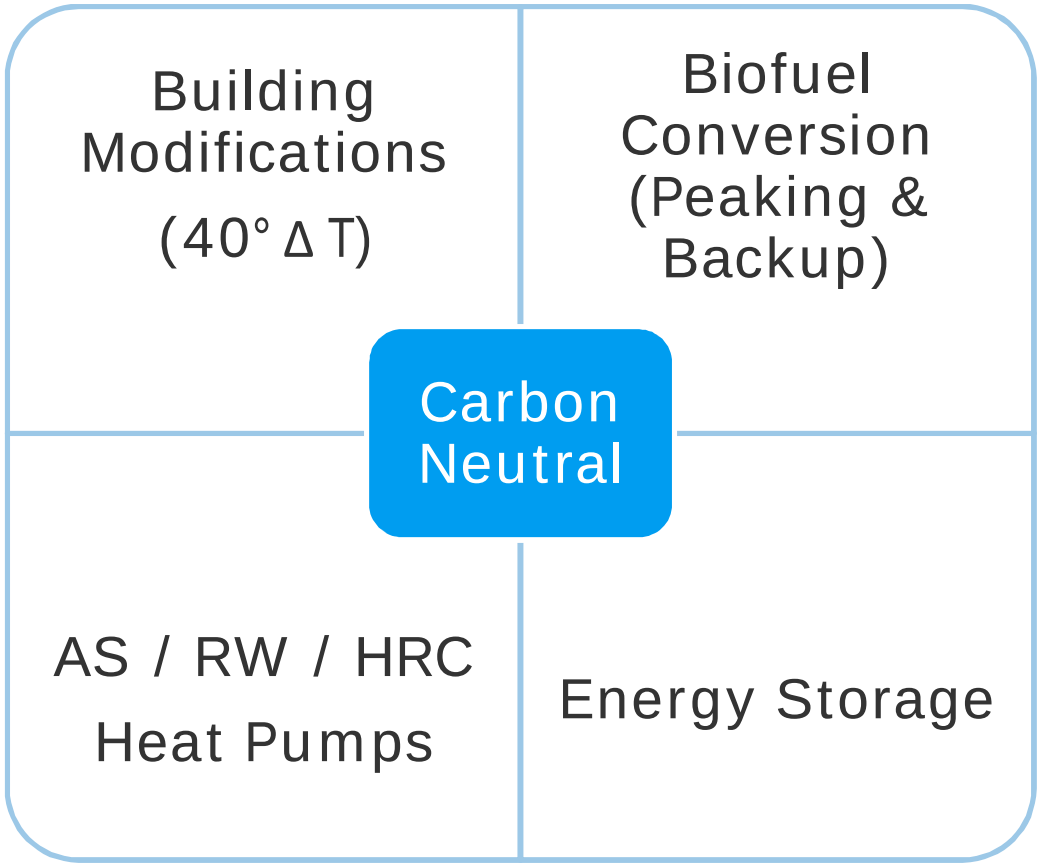
- Over and above current consumption
- Air Source Heat Pumps with Biofuel backup – 7.5 MW Peak
- Air Source Heat Pumps / Biofuel Backup / RWHP – 9.8 MW Peak
- Scenario 6 82% Biomass – less than 2.5 MW
- Electric Boilers for peaking and backup adds 15 MW
- Initial evaluation – new feeder from National Grid required for 7.5 – 10 MW

06

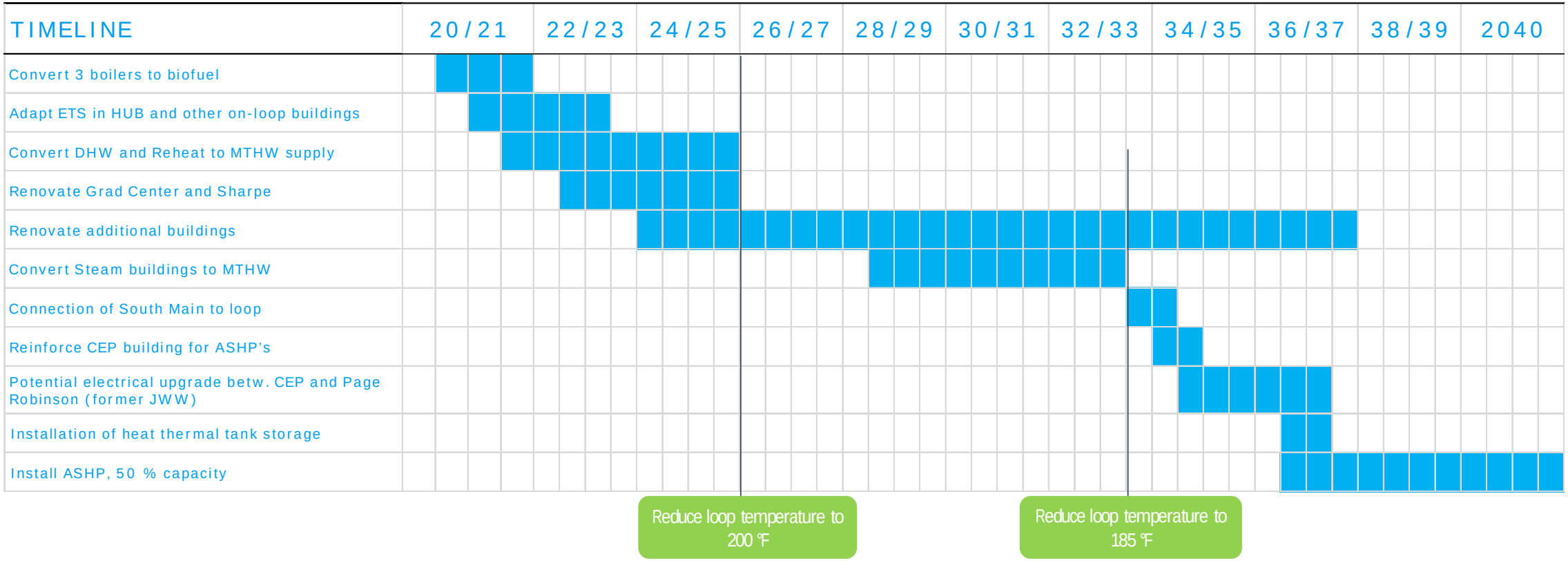
IMPLEMENTATION PLAN

POSSIBLE PHASING & SEQUENCING

- Leverage existing systems
- Reduce cost & carbon while minimizing investment
- Reduce Risk
  - Mitigate technology concerns
  - Test and trial technologies
- Phased in over time



IMPLEMENTATION & PHASING PLAN



THANK YOU

DAVE LARSON
Energy Project Manager, Office of Sustainability
arthur_larson@brown.edu

DANIEL KELLEY
General Manager - Energy Systems N. America
dkelley@ramboll.com

RAMBOLL Bright ideas. Sustainable change.

BROWN

LEARNING OBJECTIVE QUESTIONS

QUESTION 1

Identity the types of projects that Brown University has included in their plan to reduce energy and carbon emissions.

LEARNING OBJECTIVE QUESTIONS

ANSWER

- Thermal efficiency project
- Off-site solar and wind purchase agreements
- Recycled bio-oil for CHP
- Building renovations
- Loop modifications
- Lower temperature loop
- Heat pumps
- Thermal storage

LEARNING OBJECTIVE QUESTIONS

QUESTION 1

What benefits can be realized from utilizing energy scenario planning modeling software?

LEARNING OBJECTIVE QUESTIONS

ANSWER

The modeling software can help assess various carbon reduction scenarios based on technology, life cycle cost, carbon reduction, and interactive impacts.

LEARNING OBJECTIVE QUESTIONS

QUESTION 3

Identify pros and cons of using air source heat pumps.

LEARNING OBJECTIVE QUESTIONS

ANSWER

PROS

- Easy to install and maintain – scalable
- Should fit within existing CEP area

CONS

- 16,000-30,000 sq ft of space needed (can be split up)
- Noise
- Increased Electrical load 7.5 MW to 22.5 MW peak (Scope 2 emissions increase as a result)
- Performance drops off in winter months