Thermal Microgrids: A New Opportunity for Municipalities, Universities, and Corporate Campuses to Reduce Energy Costs and Emissions

May 17, 2018

Funding provided by:

American Public Power Association

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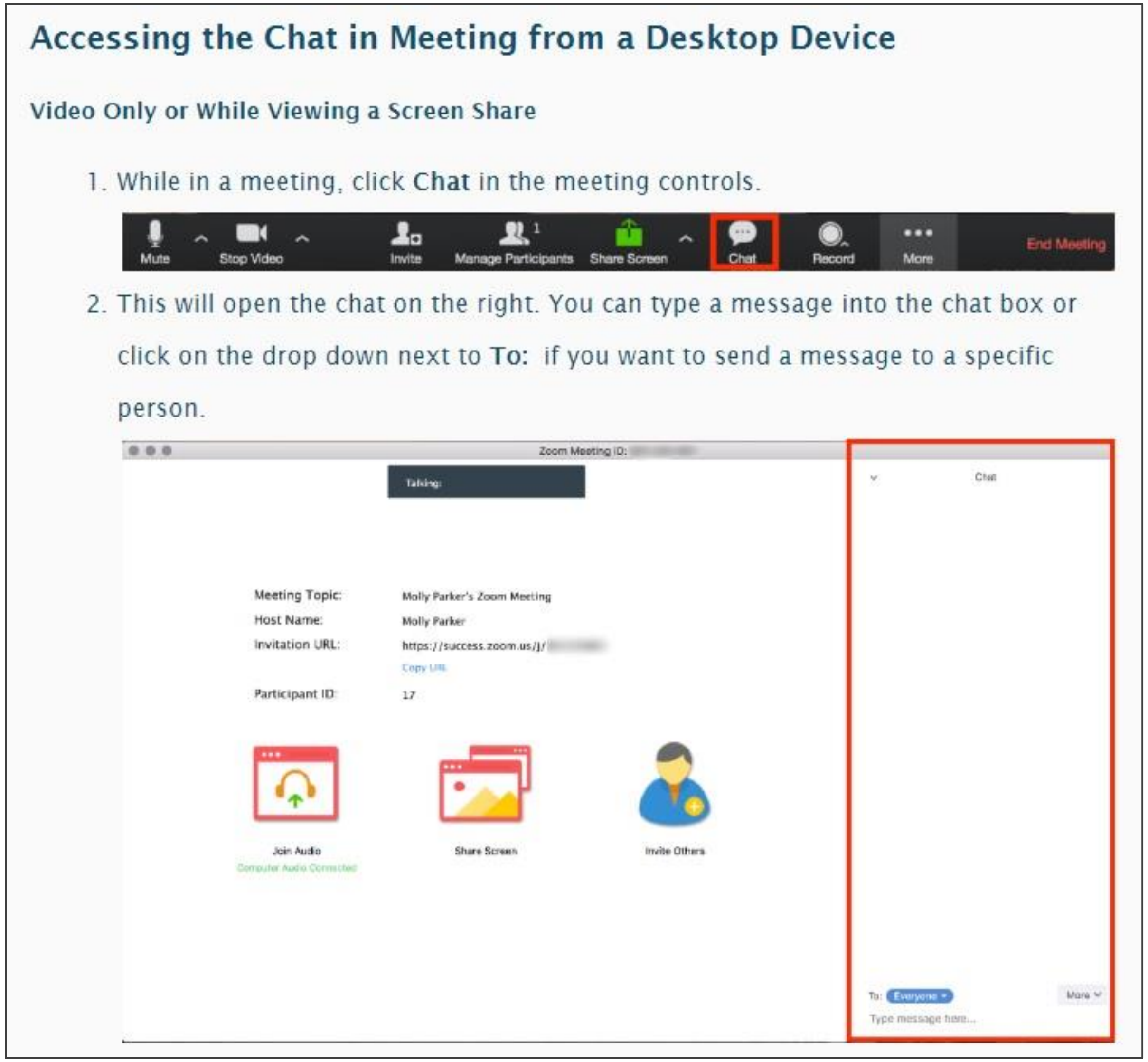

Accessing Chat Function in a Zoom Meeting

EDF Innovation Lab

Today's Webinar

Agenda

Description	Presenter	Duration
Project Introduction & Context	Sonika Choudhary, City of Palo Alto Utilities	5 min
Thermal Microgrids: Technology, Economics & Opportunity	Aimee Bailey, EDF Innovation Lab	20 min
Stanford Case Study	Joe Stagner, Stanford	20 min
Project Next Steps	Aimee Bailey, EDF Innovation Lab	5 min
Q&A		10 min

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Thank you, APPA!

APPA's Demonstration of Energy & Efficiency Developments (DEED) grant to the City of Palo Alto Utilities

"Leveraging Experience from Stanford and EDF to Develop Information and Tools for Thermal Microgrid Feasibility Assessments"

https://www.publicpower.org/periodical/article/palo-alto-utilities-thermal-microgrid-project-funded-through-deed-grant

Project Team Members:

Stanford
Joe Stagner
Jacques Adrian de Chalendar

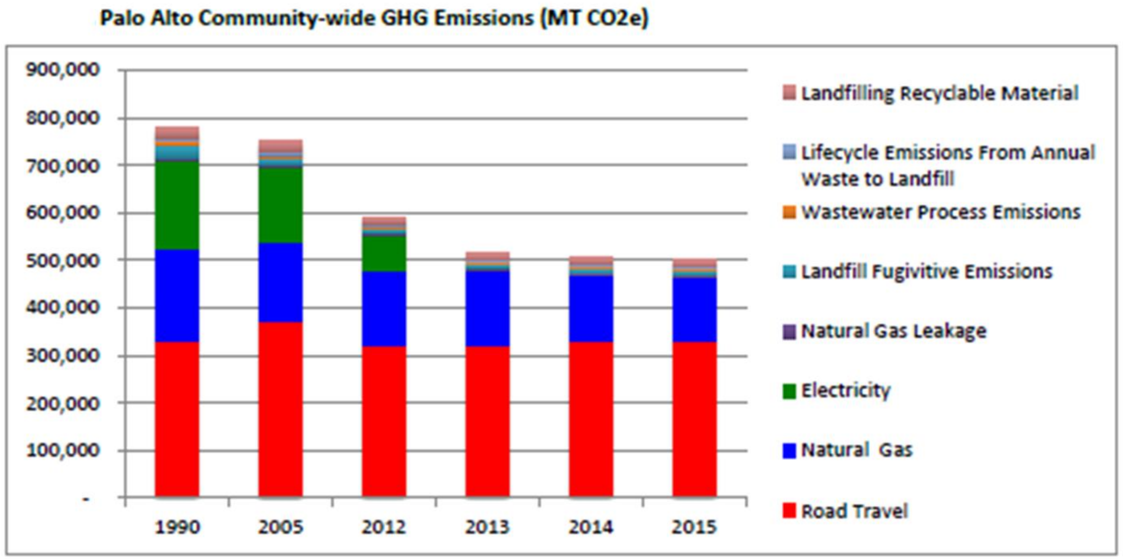
EDF Innovation Lab
Aimee Bailey
Stephanie Jumel

City of Palo Alto Utilities
Sonika Choudhary
Shiva Swaminathan

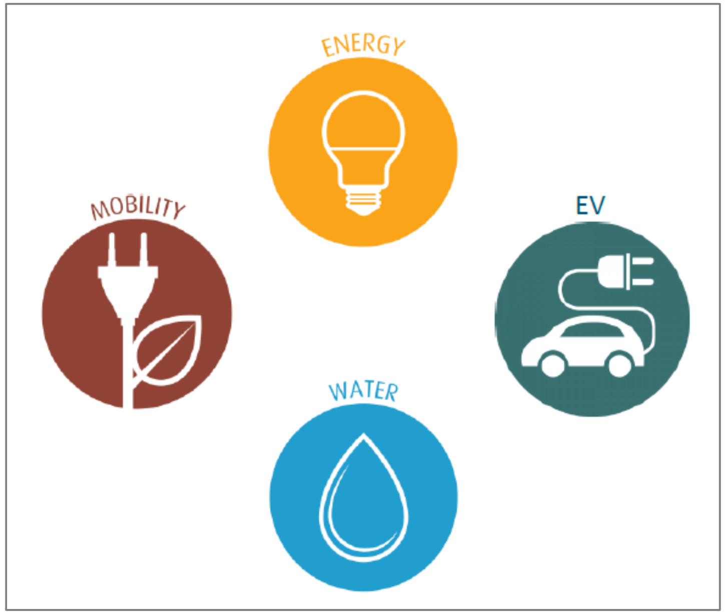
CITY OF PALO ALTO

Palo Alto's Sustainability and Climate Action Plan

Goal of 80% Greenhouse Gas (GHG) reduction by 2030



Sustainability Implementation Plan (2018-2020)



Transportation and building electrification are key focus areas to achieve 2030 goal

CITY OF PALO ALTO

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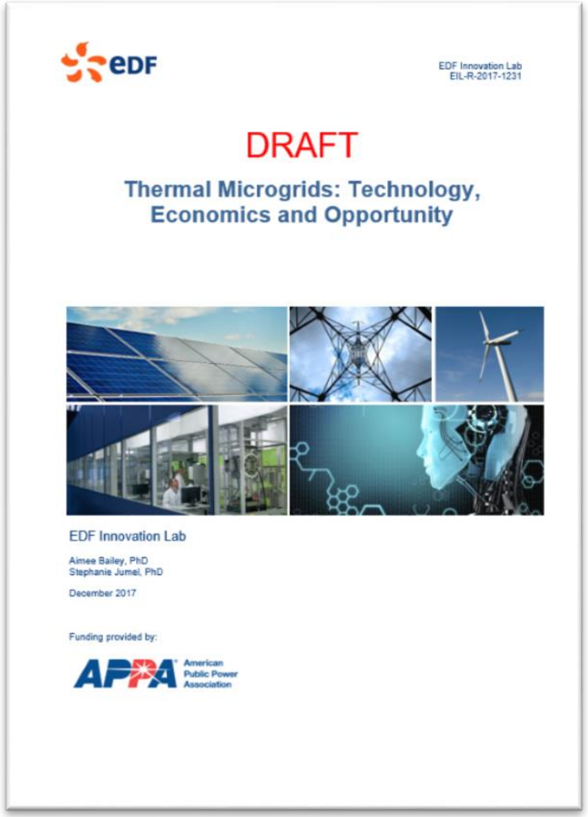
Thermal Microgrids: Technology, Economics & Opportunity

Project Deliverables

Part 1: White paper describing the technology, economics & opportunity
Part 2: Case study describing Stanford Energy System Innovations (SESI)
Part 3: Suite of tools for assessing technical and economic feasibility
Part 4: Municipal case studies carrying out feasibility assessments

Subject of today's webinar



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DRAFT

Thermal Microgrids: Technology, Economics and Opportunity

EDF Innovation Lab

Aimee Bailey, PhD
Stephanie Jumel, PhD

December 2017

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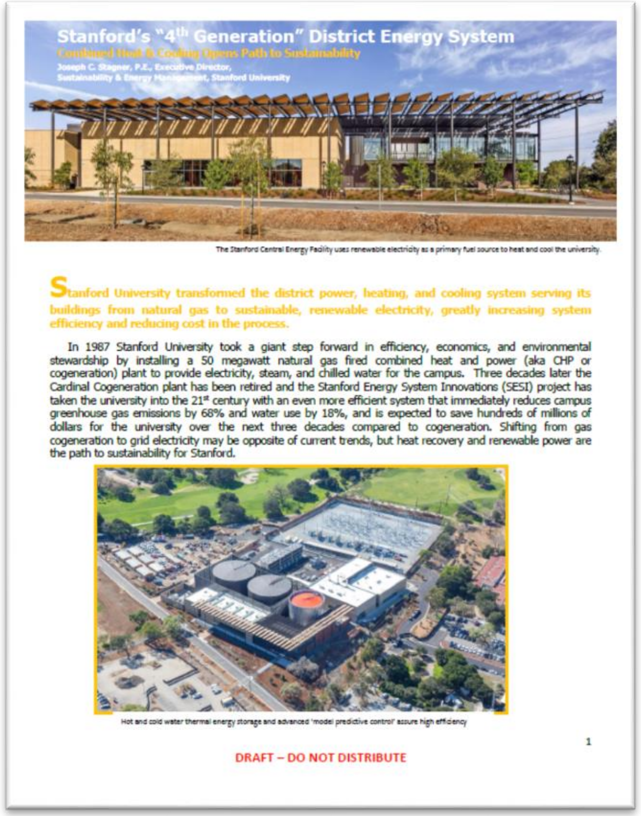

Stanford's "4th Generation" District Energy System

Combined Heat & Cooling Opens Path to Sustainability

Joseph C. Stagner, P.E., Executive Director,
Sustainability & Energy Management, Stanford University

The Stanford Central Energy Facility uses renewable electricity as a primary fuel source to heat and cool the university.

Stanford University transformed the district power, heating, and cooling system serving its buildings from natural gas to sustainable, renewable electricity, greatly increasing system efficiency and reducing cost in the process.

In 1987 Stanford University took a giant step forward in efficiency, economics, and environmental stewardship by installing a 50 megawatt natural gas fired combined heat and power (aka CHP or cogeneration) plant to provide electricity, steam, and chilled water for the campus. Three decades later the Cardinal Cogeneration plant has been retired and the Stanford Energy System Innovations (SESI) project has taken the university into the 21st century with an even more efficient system that immediately reduces campus greenhouse gas emissions by 68% and water use by 18%, and is expected to save hundreds of millions of dollars for the university over the next three decades compared to cogeneration. Shifting from gas cogeneration to grid electricity may be opposite of current trends, but heat recovery and renewable power are the path to sustainability for Stanford.

Hot and cold water thermal energy storage and advanced 'model predictive control' assure high efficiency

1

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Thermal Microgrids: Technology, Economics & Opportunity

Summary of White Paper

Audience: Staff at municipal utilities & similar organizations

Key questions:

1. What is a “thermal microgrid”?
2. What are the advantages and disadvantages of thermal microgrids compared to alternatives?
3. What are the costs, GHG emissions impacts and water usage requirements compared to alternatives?
4. What are the primary feasibility drivers?
5. What is the potential of this technology in the U.S.?
6. What business model structures could a municipal utility use for delivering thermal services via a thermal microgrid?

Peer Reviewers

Thank you to the following industry experts for their peer review:

Jeff Byron, Former California Energy Commissioner

Keith Dennis, Nat’l Rural Electric Cooperative Assoc.

Bertrand Guillemot, Dalkia (EDF Group)

Jerry Schuett, Affiliated Engineers

Robert Turney, Johnson Controls

Joe Vukovich, Natural Resources Defense Council

Thermal Microgrids: Technology, Economics & Opportunity

Energy & Environmental Policy Context

- Within the U.S., buildings are responsible for approximately **40% of energy usage** and **one third of emissions**
- A significant portion is **due to burning natural gas** for space and water heating
- Studies support achieving deep decarbonization requires **fuel switching** in the building sector from fossil fuel to electricity (aka "electrification"), along with continued **energy efficiency** and **electricity decarbonization**
- Electrification policies gaining traction – current focus on **building-level appliance switch-out**
- An alternative approach is to **electrify an entire district**

References: U.S. Energy Information Agency; U.S. Environmental Protection Agency's "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015"; Williams, J.H. et. Al., The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity, Science, Volume 335, January 6, 2012; etc.

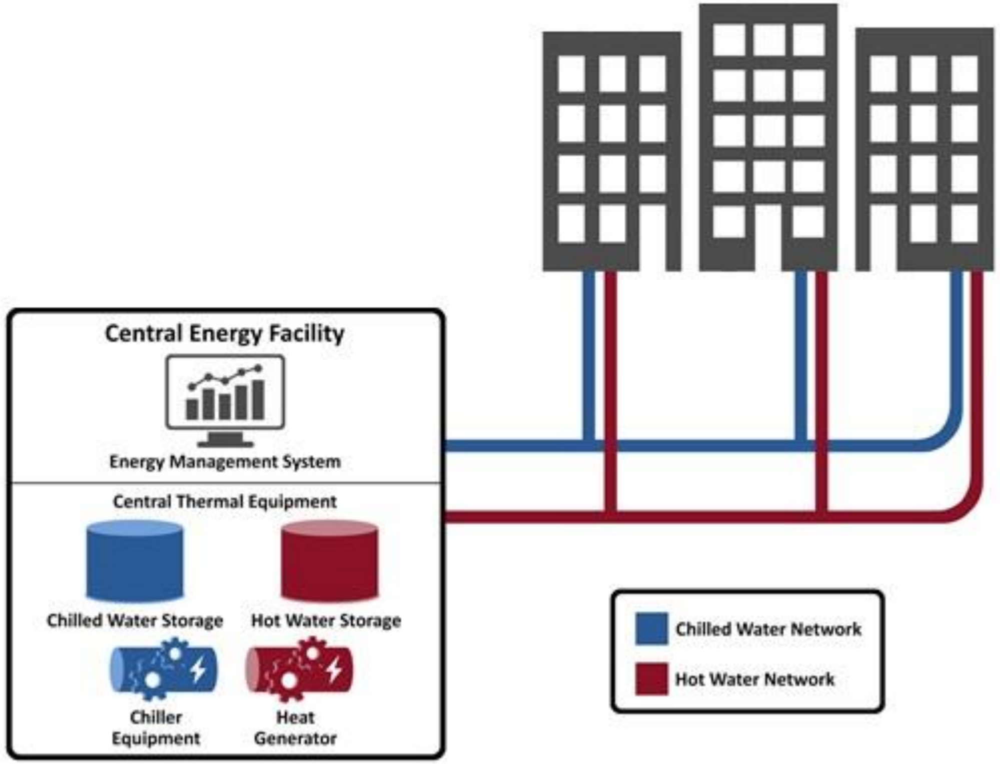
Thermal Microgrids: Technology, Economics & Opportunity

District Energy

District energy systems are networks of underground pipes carrying steam or hot (cold) water used to heat (cool) buildings.

Advantages of a district energy approach include:

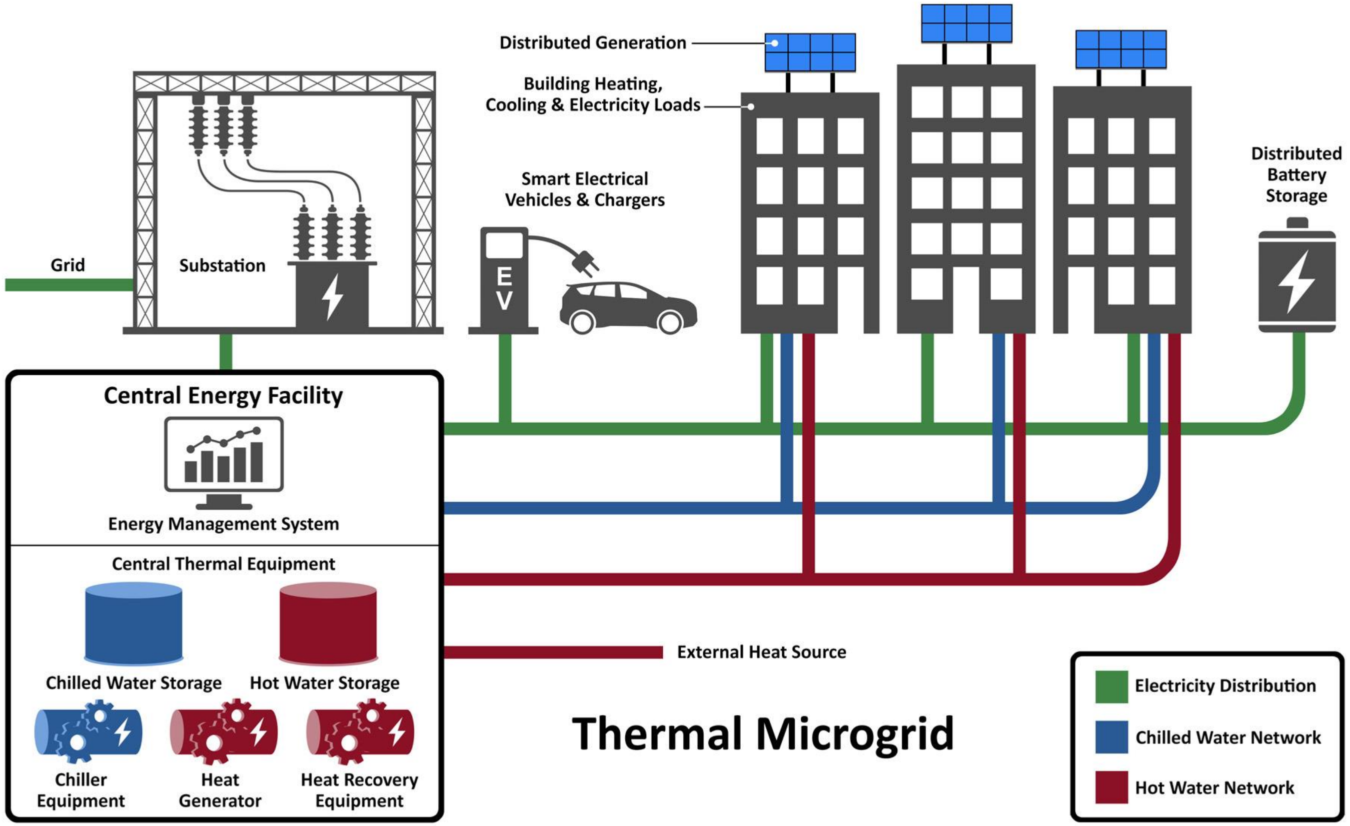
- **Economies of scale** from aggregating a collection of loads from dozens of buildings
- **Waste heat recovery technologies** that are not available or efficient at a building-level
- **Load and resource diversity** enabling optimized central equipment sizing and resultant enhanced efficiency



References: District Heating and Cooling, Svend Frederiksen and Sven Werner (2013)

Thermal Microgrids: Technology, Economics & Opportunity

What Is a “Thermal Microgrid”?



A thermal microgrid utilizes energy efficiency; renewable electricity powered heat recovery; thermal storage; and, advanced analytics and controls to provide co-optimized power and thermal services to a group of interconnected and controllable energy loads within a defined boundary.

Thermal Microgrids: Technology, Economics & Opportunity

Trends Driving Interest in Thermal Microgrids

- The same three trends driving the transformation of the entire energy sector are responsible for increasing interest in thermal microgrids:
  - **Decentralization**. Increasing adoption of behind-the-meter solar, smart thermostats and other building energy management devices enabled by exponentially decreasing costs and novel business/financing structures are leading to a decentralized grid paradigm.
  - **Decarbonization**. Local and state governments across the U.S. have adopted climate goals and corresponding energy policies and regulations to promote decarbonization of the energy sector.
  - **Digitization**. Increased deployment of low-cost sensors, advanced control technologies, and artificial intelligence is fundamentally changing every facet of the energy sector.

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Reference: https://energy.stanford.edu/from-directors/nurturing-innovation-during-strategic-inflection-point-global-energy

Thermal Microgrids: Technology, Economics & Opportunity

Goals & Objectives of Local Energy System Development

- There are typically **several considerations for local energy system deployment**:
  - Economics
  - Environmental Impact
  - Reliance on Fossil Fuel
  - Local Control
  - Reliability & Resiliency
  - Water Usage
  - System Flexibility
  - Local Economic Development
- Stakeholders must first identify and prioritize goals to evaluate a thermal microgrid vs an alternative energy system design

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Thermal Microgrids: Technology, Economics & Opportunity

Opportunity

Public power uniquely positioned to lead thermal microgrid exploration and development:

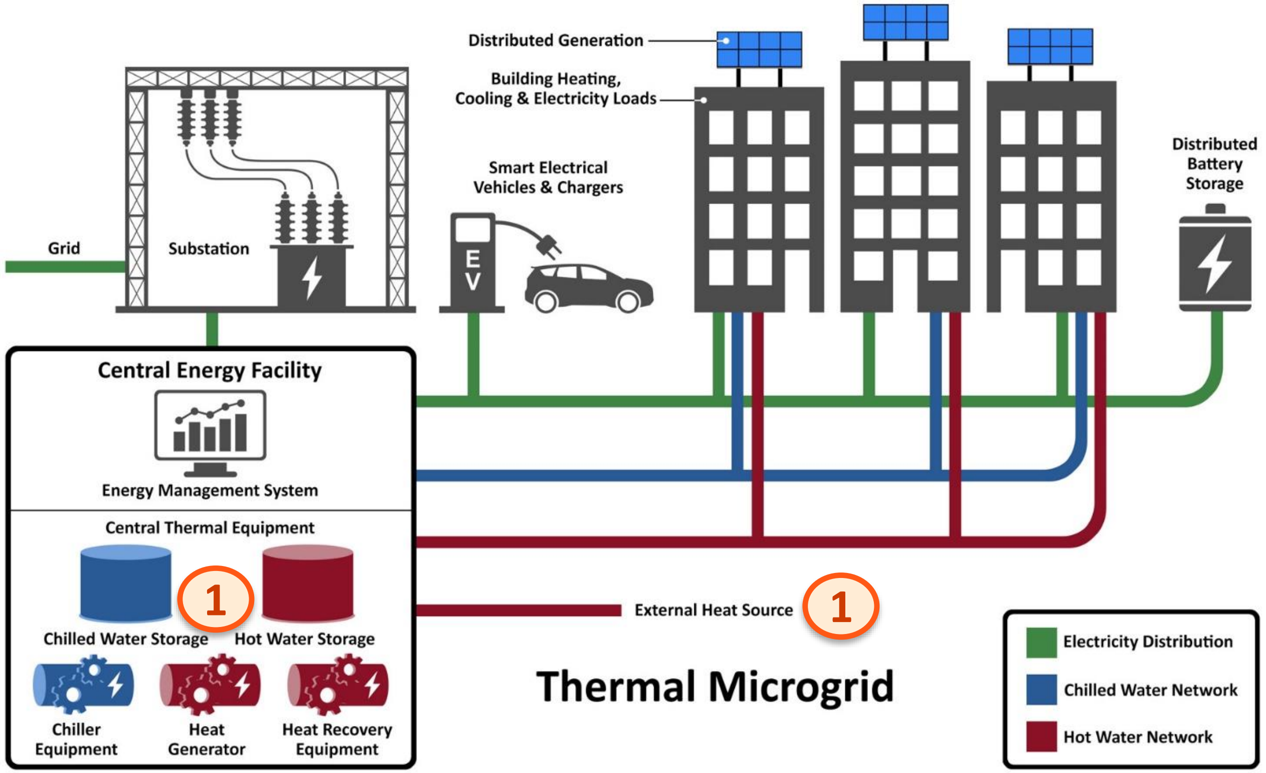
- Local energy system design choices often result in **tradeoffs/synergies with other utility services** & munis often have several, in addition to electric power
- Munis can **standardize interconnection procedures** and develop innovative policies and rate structures to harness value of flexible and controllable load
- Successful deployment **requires ability to navigate complex, multi-stakeholder processes** to achieve community goals – munis have decades of relevant experience
- Historically, munis have shown **leadership on environmental issues** given the direct accountability to communities they serve

Thermal Microgrids: Technology, Economics & Opportunity

Technology Description

Thermal microgrids incorporate several categories of technologies, including:

1. **one or more heat and cooling sources and central equipment**
2. one or more clean power generation systems, either located on-site or remotely
3. a thermal network of pipelines leading to delivery points referred to as substations, with a secondary network of pipes feeding end users
4. building interconnection equipment to couple the thermal network to the heating and cooling systems located at the customer site



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Thermal Microgrids: Technology, Economics & Opportunity

Heat Sources

Low Grade Heat	● **Waste Heat Recovery From Buildings**. Stanford's state-of-the-art system uses the overlap in heating and cooling needs by capturing waste heat from the cooling network return pipe. ● **Waste Heat Recovery from Municipal Wastewater (50-80 °F).** Sewage is a heat source that is available in almost every community. A few degrees of heat can be extracted before or after sewage treatment. ● **Shallow Geothermal (50-80 °F)**. Shallow geothermal (aka *geoexchange*) is the recovery of heat from within several yards of the earth's surface, where the temperature remains relatively constant. Shallow geothermal as a heat source is becoming increasingly common for district energy systems. ● **Other Waste Heat Recovery Opportunities**. There are a variety of other sources of waste heat, a largely untapped potential energy source, including air- and water-source heat.
High Grade Heat	● **Waste Heat Recovery from Industrial Processes (200-1,800 °F).** Waste heat from industrial processes is commonly available, varying in temperature from extremely hot process industry flue gases down to lower temperature refrigeration exhaust. ● **Deep Geothermal (150-350 °F).** Recovering geothermal heat requires deep boring into the ground. When economically feasible, deep geothermal offers a renewable heat source for base load needs. ● **Waste Heat Recovery from Municipal Waste Incineration (130-300 °F).** The combustion of municipal waste to provide electricity and/or heating (aka *waste-to-energy*) has been practiced in Europe for many years. ● **Biomass (130-300 °F).** Biomass can be used as fuel for large boilers or for CHP plants, a common choice for district energy systems. Biomass can also be used within existing fossil-fueled boilers as a co-firing to reduce emissions. ● **Solar Thermal (175-275 °F).** Solar energy can either augment existing heat sources in a thermal network, or feed a stand-alone system incorporating thermal storage to provide thermal heating year-round.

Cooling Sources

- **Heat Recovery Chillers (HRCs) in a Heat Network.** As illustrated by Stanford's system, cooling can be produced from a heat network using large HRCs located at a central plant.
- **Absorption Heat Pumps/Chillers with a Heat Source.** A heat source can be used to produce chilled water using absorption heat pumps/chillers, either located at the building site or at a central plant. Alternatively, a centralized trigeneration system utilizing similar equipment can produce a separate cold supply to serve a district, in addition to power and heat.
- **Surface Water (40-75 °F).** Also known as hydrothermal, lakes, rivers and oceans can be used as cooling source. Some systems use surface water not just as a cooling source, but in a combined scheme to prepare or provide potable water supply.

Thermal Microgrids: Technology, Economics & Opportunity

Thermal Storage

- Central thermal storage enables optimized system operation of a thermal microgrid
- Incorporated into the overall energy system design, thermal storage:
    1. increases the amount of heat recovery potential that can be used
    2. enables electricity load shifting from on-peak to off-peak periods
    3. enhances reliability and resilience by during grid disturbances
    4. reduces chiller capacity requirements
- Hot and chilled water are the most common forms of hot and cold storage, although ice or ice slurry can be used as cold storage

Figure: Stanford's Central Energy Facility, Showing Its Chilled and Hot Water Storage Tanks

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Thermal Microgrids: Technology, Economics & Opportunity

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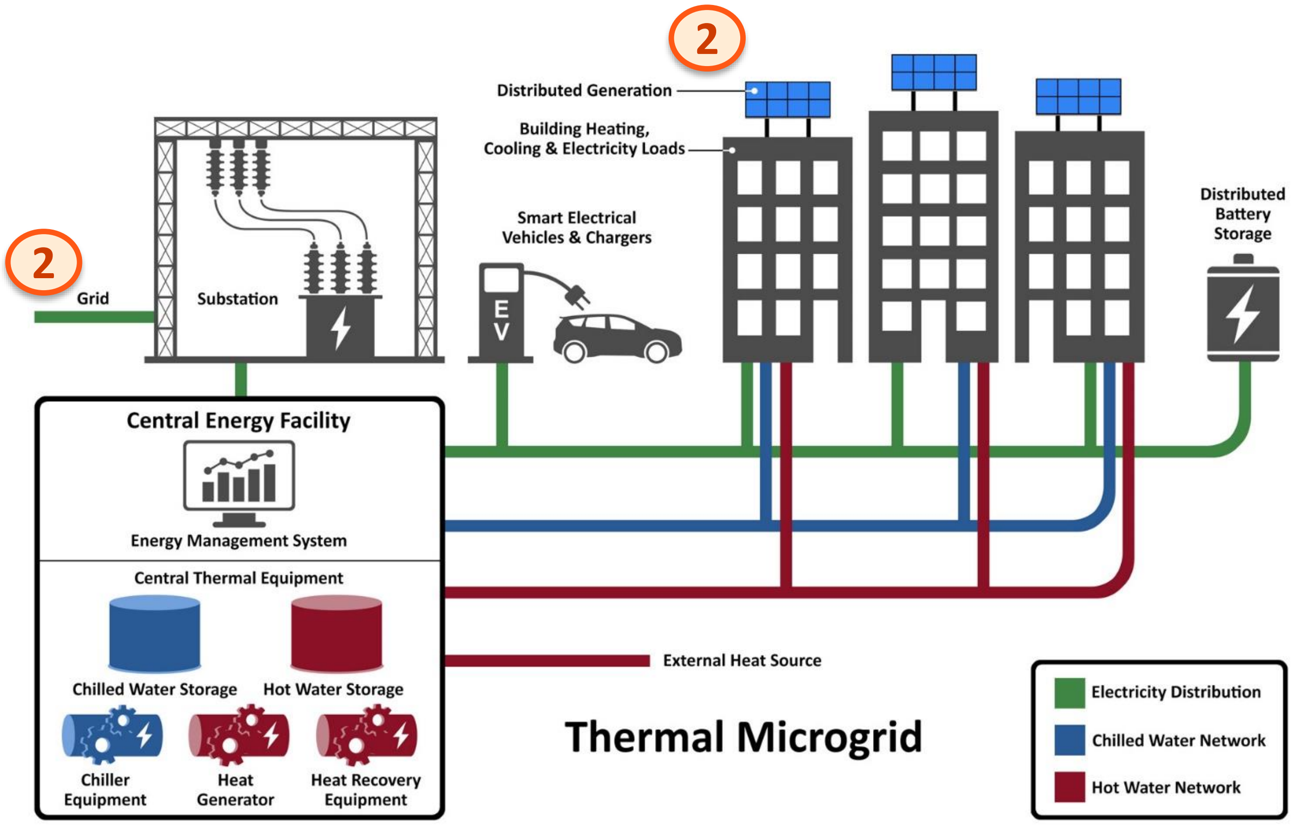

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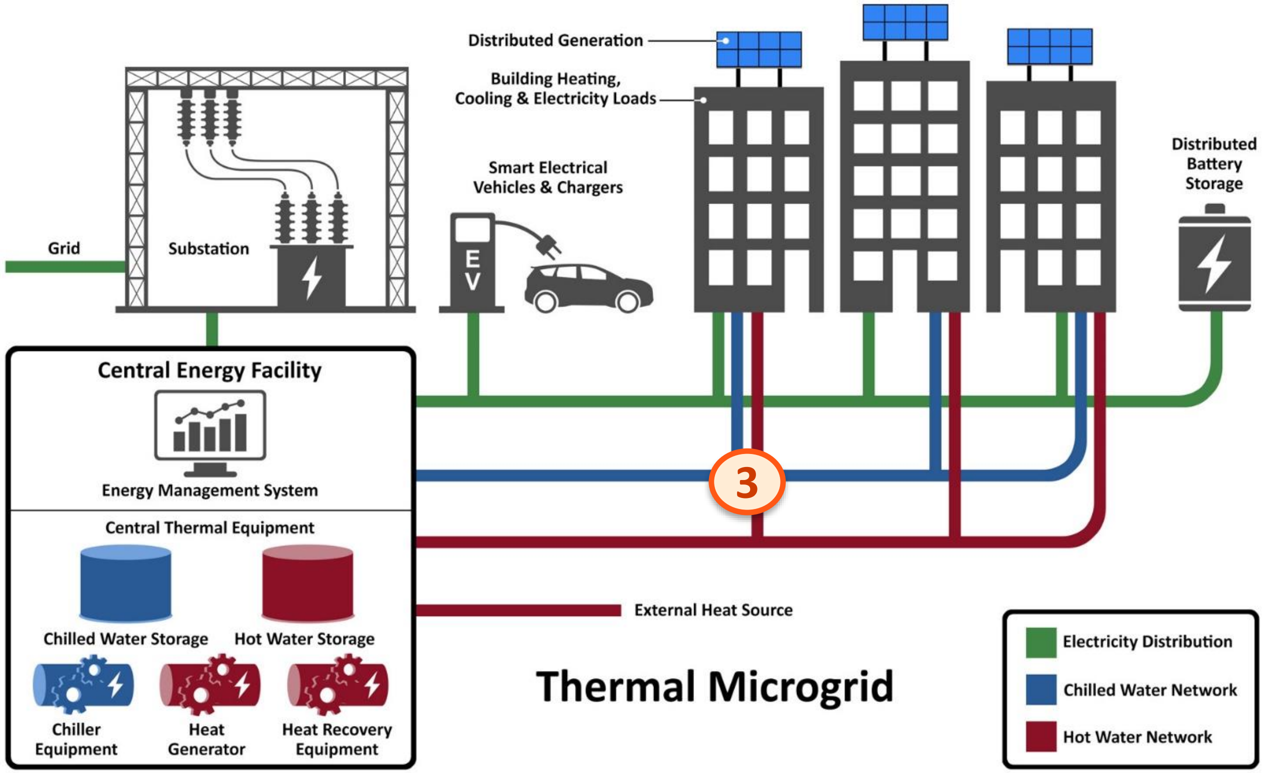

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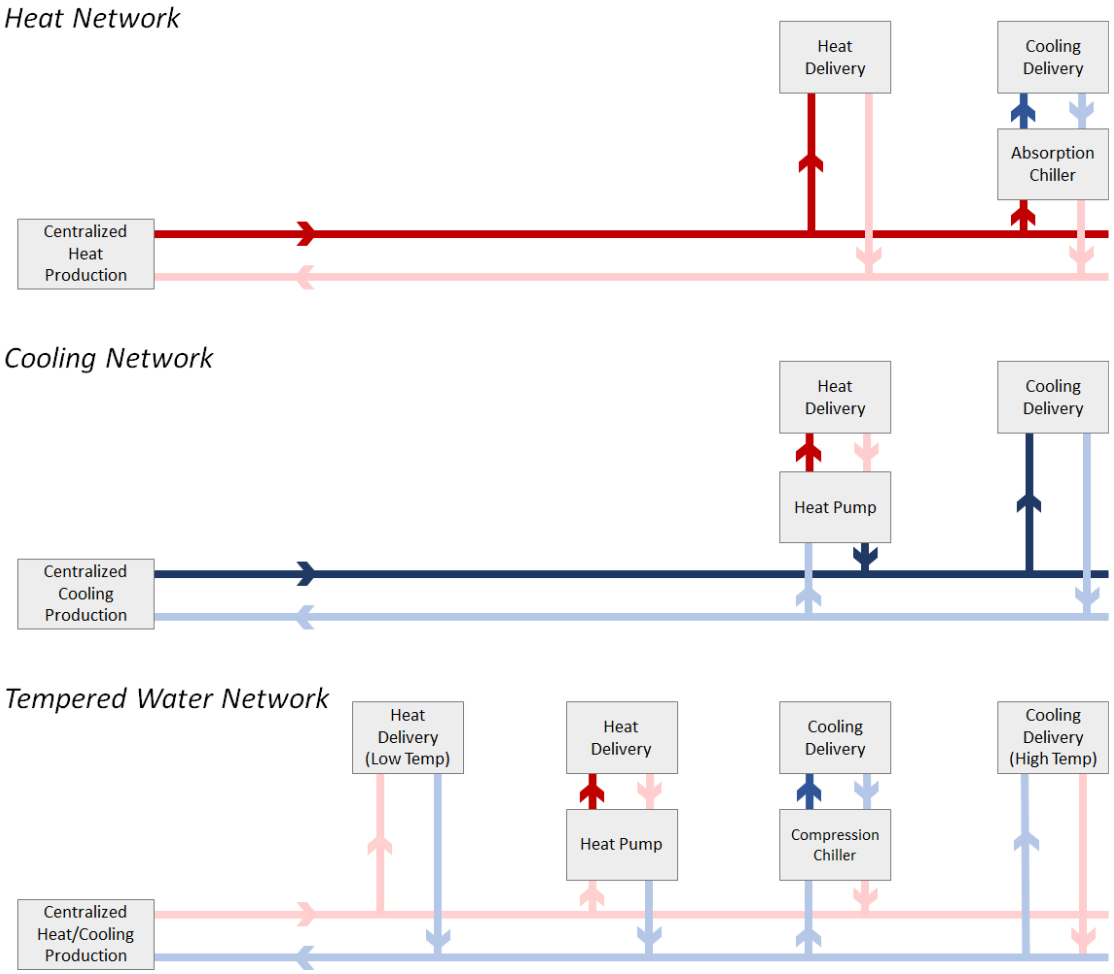
Thermal Microgrids: Technology, Economics & Opportunity

Thermal Network

A thermal network is the distribution network of pipes, substations, valves and controls to deliver steam, hot water or chilled water from a central energy facility to end customers.

- District energy has an advantage over building-level approach when cost savings of the central vs building-level equipment is greater than costs of distribution network
- Three types of thermal networks, shown at right:
    1. A **heat network** supplies required heating and can provide cooling at the building via absorption chillers.
    2. A **cooling network** supplies required cooling and can also provide heat at the building via heat pumps.
    3. A **tempered water system** provides heat or cooling supply directly to the building.
- Like an electricity grid, thermal networks have network operators to control outgoing water temperature and regulate flow to ensure all customer needs are met



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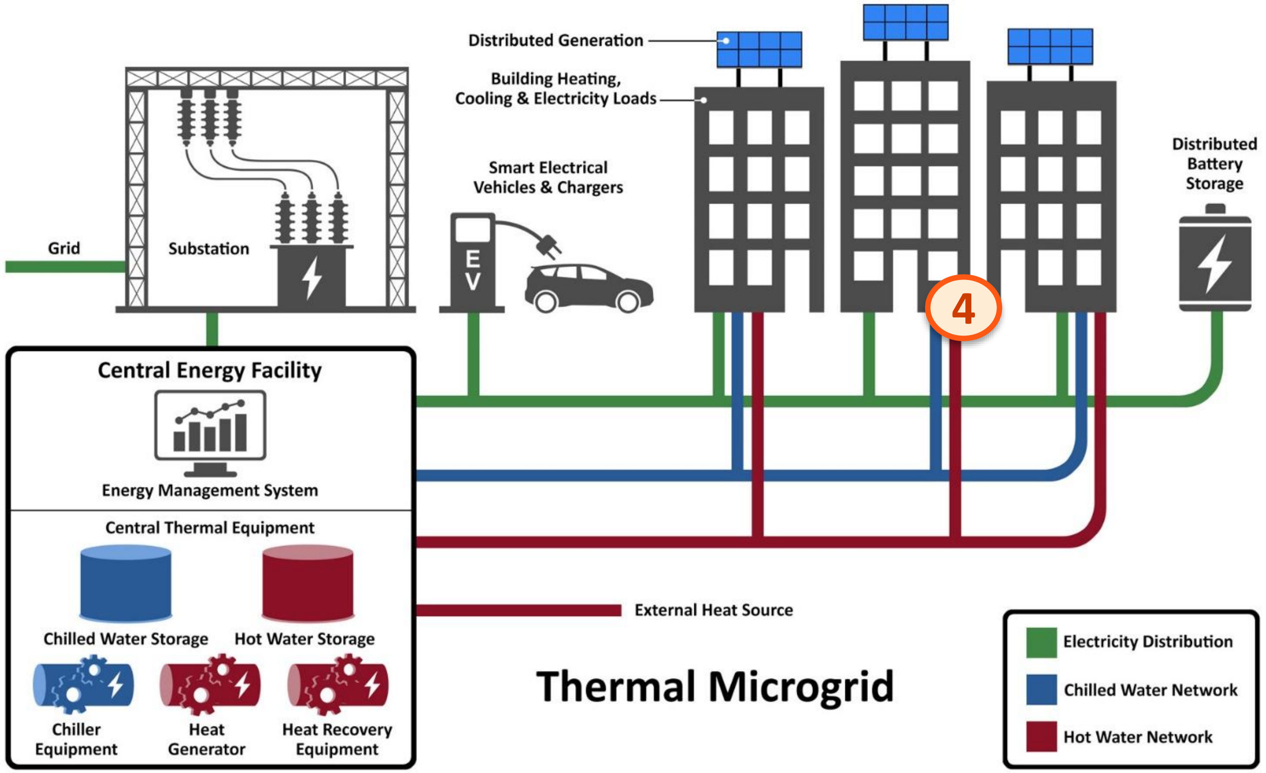

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Thermal Microgrids: Technology, Economics & Opportunity

Building Interconnection Equipment

- The thermal network can interconnect with customer buildings in two ways:
    - **Direct Connection**. The district energy system's supply (i.e. steam, hot water or chilled water) is directly pumped through the customer's building heating and cooling equipment (e.g. radiators).
    - **Indirect Connection**. The district energy system is coupled to the building via heat exchangers used to transfer heat between the supply and the customer's building system, keeping the supply isolated from the building heating and cooling system.
- Controls, heat meters, and isolation valves & filters are installed for network balancing, billing and equipment protection, respectively

Thermal Microgrids: Technology, Economics & Opportunity

Overview of Project Economics

- Thermal microgrids are a major infrastructure project with substantial fixed project costs
- However, they may lead to significant offsets: costs that would have been incurred if maintaining the existing energy system (e.g. expensive electric transmission and distribution system upgrades)
- Costs can be broken down into the following categories:
  - **Primary fixed costs**. Central equipment, thermal network and building interconnection costs
  - **Primary variable costs**. Electricity/fuel and operations & maintenance (O&M)
  - **Other costs**. Project development, customer acquisition, metering, billing, customer service & administration
- Costs depend strongly on local conditions and project details

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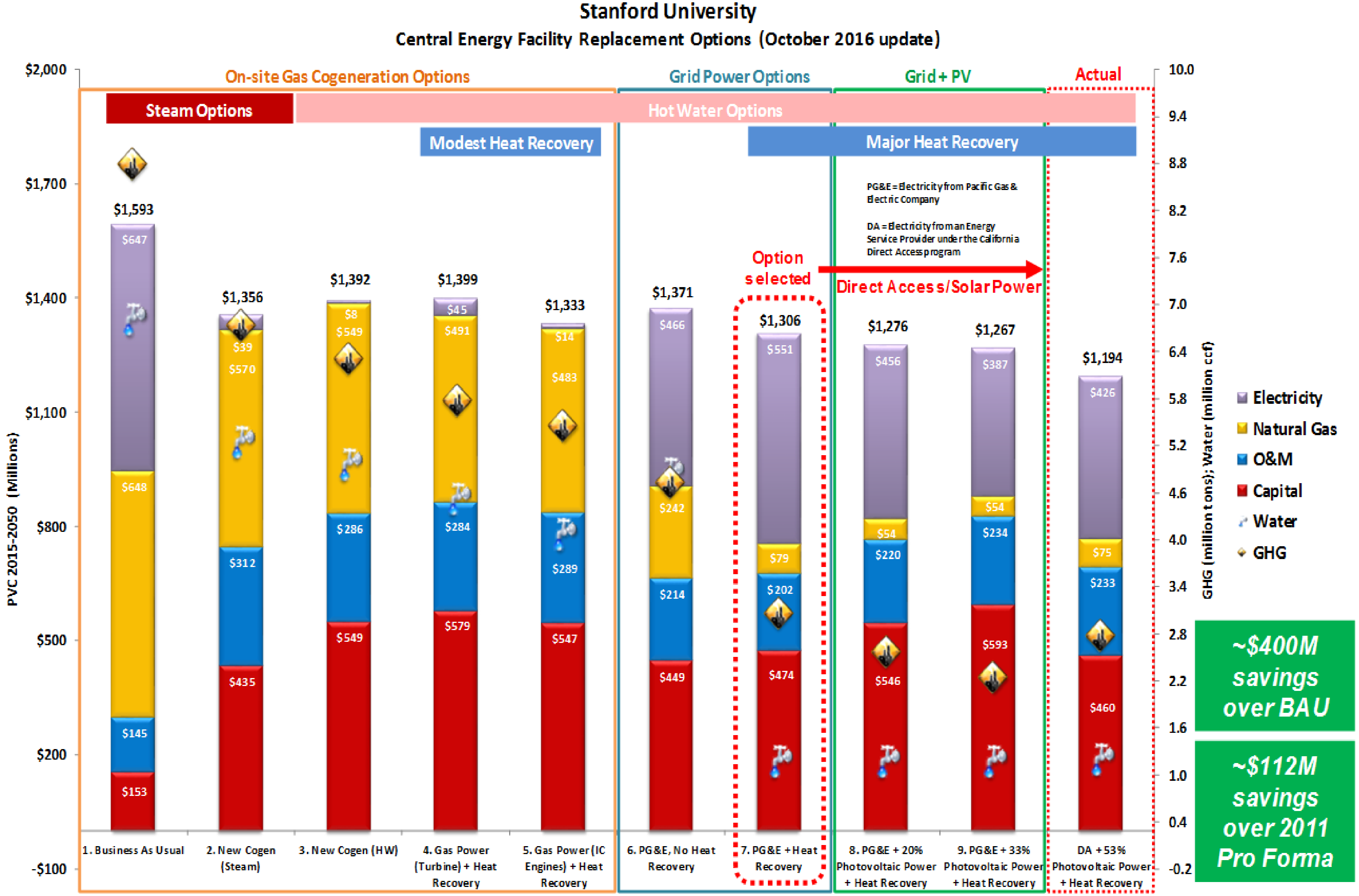
Thermal Microgrids: Technology, Economics & Opportunity

Comparison of Project Economics Across System Design



~$400M savings over BAU

~$112M savings over 2011 Pro Forma

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Thermal Microgrids: Technology, Economics & Opportunity

Drivers of System Feasibility

- Key feasibility drivers include:
  - **Load density**. The thermal network is a major source of project costs: the closer the buildings and the denser the load, the more cost-efficient the thermal network will be. IEA estimates a region can be served economically with district energy if heating load density is >0.93 kWh per square foot.
  - **Cost of heating and cooling supply**. Advanced heat recovery enables low cost source heat for a thermal microgrid design. Regions near data centers or other sources of industrial waste heat could capitalize on this proximity.
  - **Load diversity**. Sizing each individual building for annual peak is more expensive than sizing a cluster of buildings with load diversity. Advanced communications and controls to operate the resources and loads of the thermal microgrid can capitalize on load diversity and further enhance efficiency gains.

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Thermal Microgrids: Technology, Economics & Opportunity

Assessment of Potential in the U.S.

- Many types of regulations would serve to promote thermal microgrids, including carbon tax, cap-and-trade program, energy efficiency targets, and local air quality standards
- Several non-technical barriers that could significantly inhibit thermal microgrid deployment:
  - Lower familiarity with district energy and advanced waste heat recovery in the U.S.
  - Parts of the value chain for district energy are under-developed in U.S.
  - Complex, multi-stakeholder processes for energy infrastructure development
  - Securing large initial investment
  - Timing of building equipment replacement
  - Economic and policy uncertainties over the long project lifetime
  - Etc.
- Comprehensive potential assessment is beyond the scope of the white paper, but the subject of ongoing R&D activity

Thermal Microgrids: Technology, Economics & Opportunity

Utility Business Models for Thermal Services

- District energy systems, like electricity and gas networks, are natural monopolies
- Multiple utility business model choices for thermal services, similar municipal electric utility options
- Ownership & governance examples:
    - Enterprise fund and operational department within a university or local government
    - Special district organizationally independent from existing local governments
    - Community-owned non-profit cooperative
    - Community-owned limited liability corporation
- Metering & billing could be based on square footage or estimation of usage, based on common engineering standards – easiest and most straightforward

Stanford

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DISTRICT ENERGY ST. PAUL™

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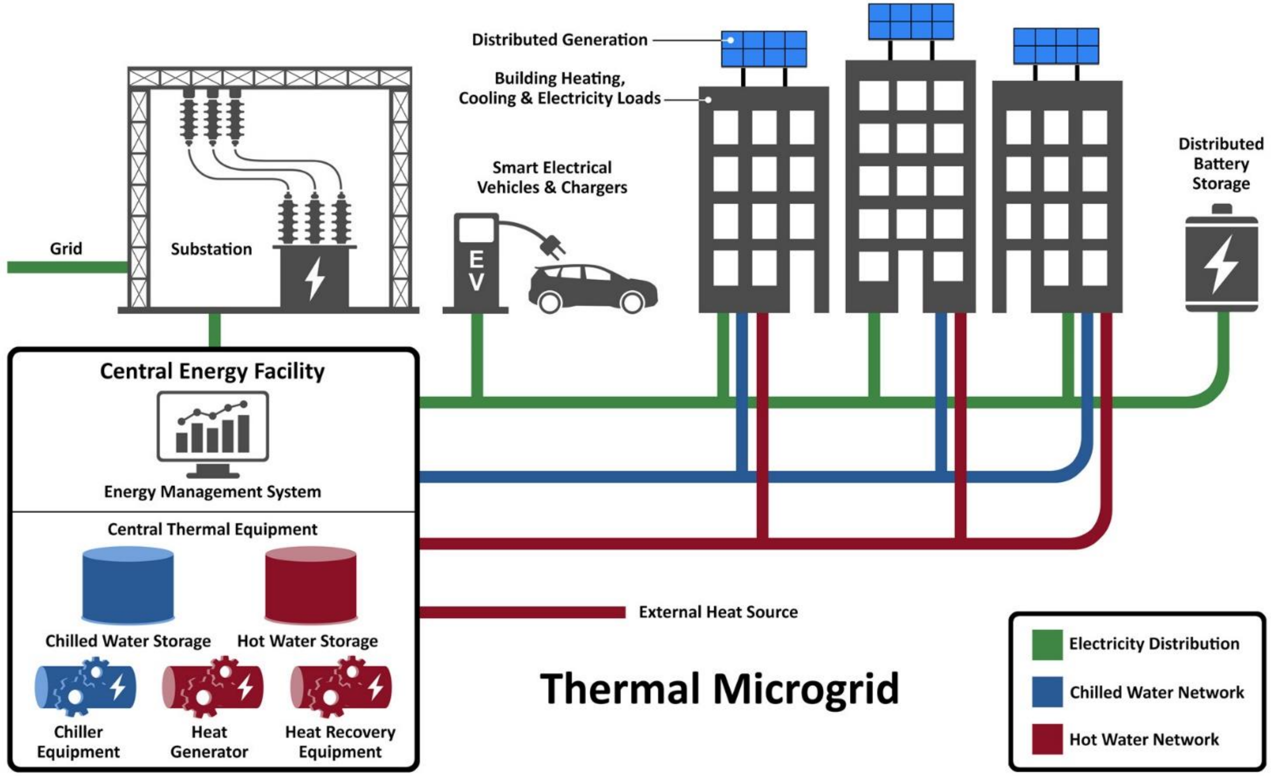
Thermal Microgrids: Technology, Economics & Opportunity

Conclusions

- Decentralization, decarbonization & digitization driving transformation of energy sector
- Same drivers encourage consideration of efficient district electrification
- Stanford’s system demonstrates the potential of thermal microgrids for achieving a decarbonized, cost-effective and resilient local energy system
- Several non-technical barriers challenge market transformation
- Munis are in a unique position to lead



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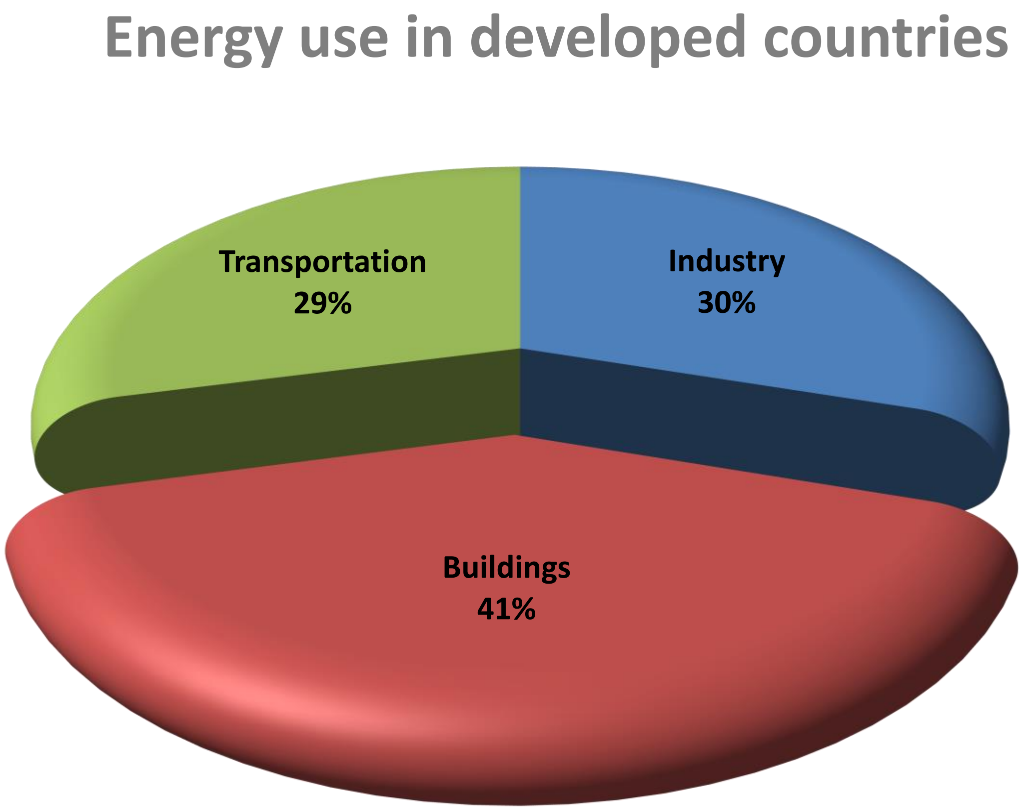
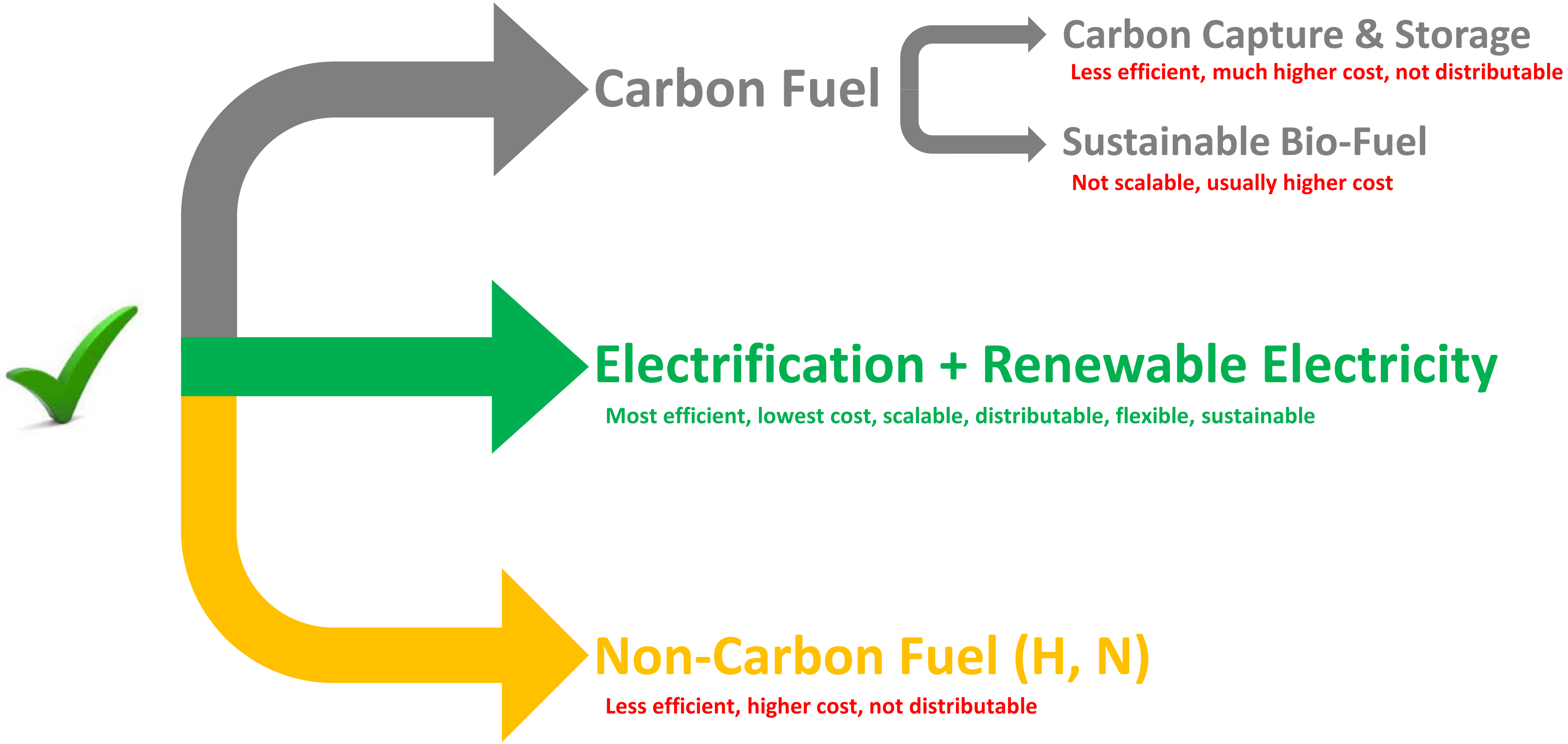
Building Energy- Scale



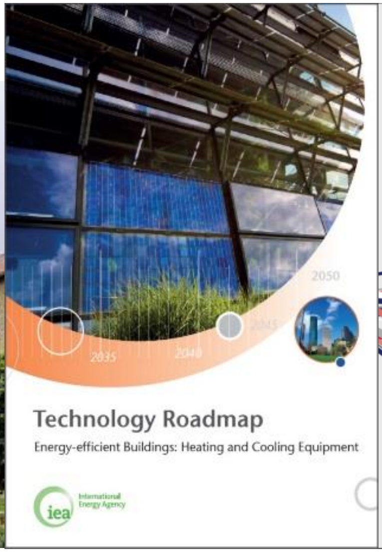
- Electricity, Heating, and Cooling of structures
- 40% of GHG emissions

Pathways for *Sustainable* Building Energy

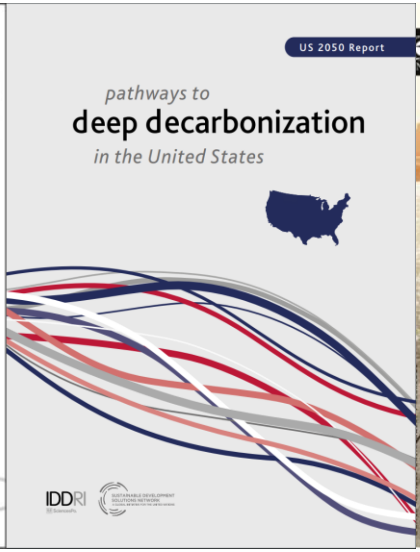


Stanford, IEA, National Labs, UN, SCE, and others agree about the clean electrification pathway:

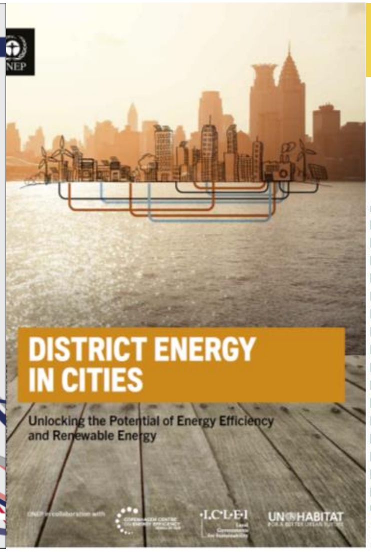
2009



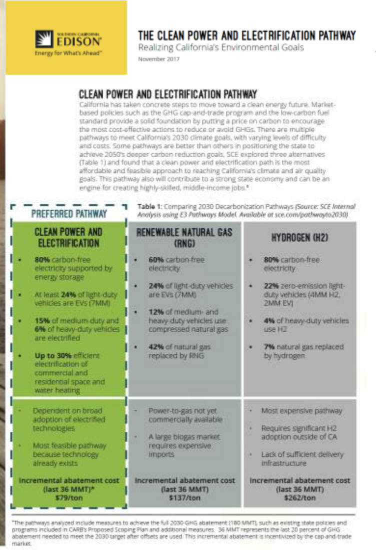
2011



2014



2015



SOUTHERN CALIFORNIA EDISON
Energy for What's Ahead

THE CLEAN POWER AND ELECTRIFICATION PATHWAY
Realizing California's Environmental Goals
November 2017

CLEAN POWER AND ELECTRIFICATION PATHWAY

California has taken concrete steps to move toward a clean energy future. Market-based policies such as the GHG cap-and-trade program and the low-carbon fuel standard provide a solid foundation by putting a price on carbon to encourage the most cost-effective actions to reduce or avoid GHGs. There are multiple pathways to meet California's 2030 climate goals, with varying levels of difficulty and costs. Some pathways are better than others in positioning the state to achieve 2050's deeper carbon reduction goals. SCE explored three alternatives (Table 1) and found that a clean power and electrification path is the most affordable and feasible approach to reaching California's climate and air quality goals. This pathway also will contribute to a strong state economy and can be an engine for creating highly-skilled, middle-income jobs.*

PREFERRED PATHWAY

Table 1: Comparing 2030 Decarbonization Pathways *(Source: SCE Internal Analysis using E3 Pathways Model. Available at sce.com/pathwayto2030)*

CLEAN POWER AND ELECTRIFICATION	RENEWABLE NATURAL GAS (RNG)	HYDROGEN (H2)
• **80%** carbon-free electricity supported by energy storage • At least **24%** of light-duty vehicles are EVs (7MM) • **15%** of medium-duty and **6%** of heavy-duty vehicles are electrified • **Up to 30%** efficient electrification of commercial and residential space and water heating	• **60%** carbon-free electricity • **24%** of light-duty vehicles are EVs (7MM) • **12%** of medium- and heavy-duty vehicles use compressed natural gas • **42%** of natural gas replaced by RNG	• **80%** carbon-free electricity • **22%** zero-emission light-duty vehicles (4MM H2, 2MM EV) • **4%** of heavy-duty vehicles use H2 • **7%** natural gas replaced by hydrogen
- Dependent on broad adoption of electrified technologies - Most feasible pathway because technology already exists	- Power-to-gas not yet commercially available - A large biogas market requires expensive imports	- Most expensive pathway - Requires significant H2 adoption outside of CA - Lack of sufficient delivery infrastructure
Incremental abatement cost (last 36 MMT)* $79/ton	**Incremental abatement cost (last 36 MMT) $137/ton**	**Incremental abatement cost (last 36 MMT) $262/ton**

*The pathways analyzed include measures to achieve the full 2030 GHG abatement (180 MMT), such as existing state policies and programs included in CARB's Proposed Scoping Plan and additional measures. 36 MMT represents the last 20 percent of GHG abatement needed to meet the 2030 target after offsets are used. This incremental abatement is incentivized by the cap-and-trade market.

2017

Heat Pump is Key to Building Electrification

Electric Resistive

6,816 btu of gas = 1 KWH = 3,413 btu of heat
(50% efficient grid gas power plant)

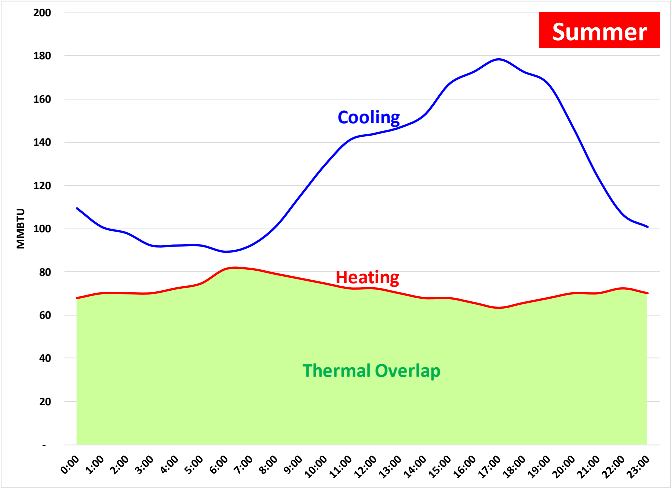
Gas

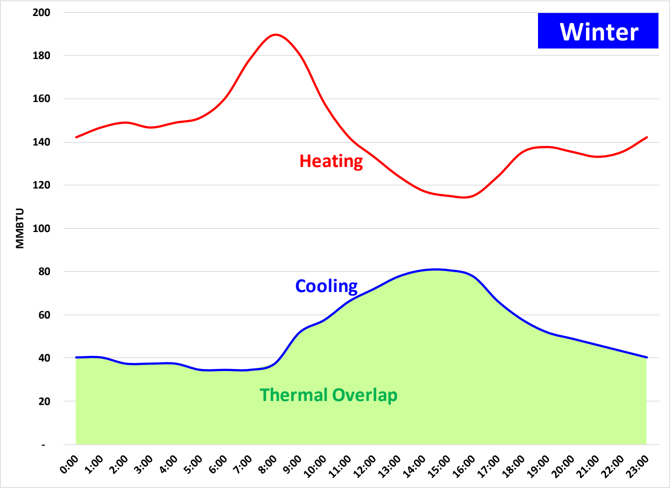
4,000 btu of gas = 3,413 btu of heat
(85% efficient heater)

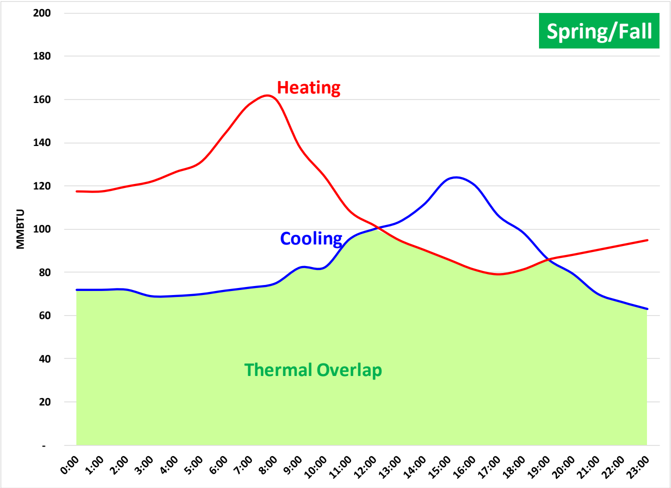
Electric Heat Pump

1,133 to 2,040 btu of gas = .17 (120F) to .3 (160F) KWH
= 3,413 btu of heat
(50% efficient grid gas power plant)

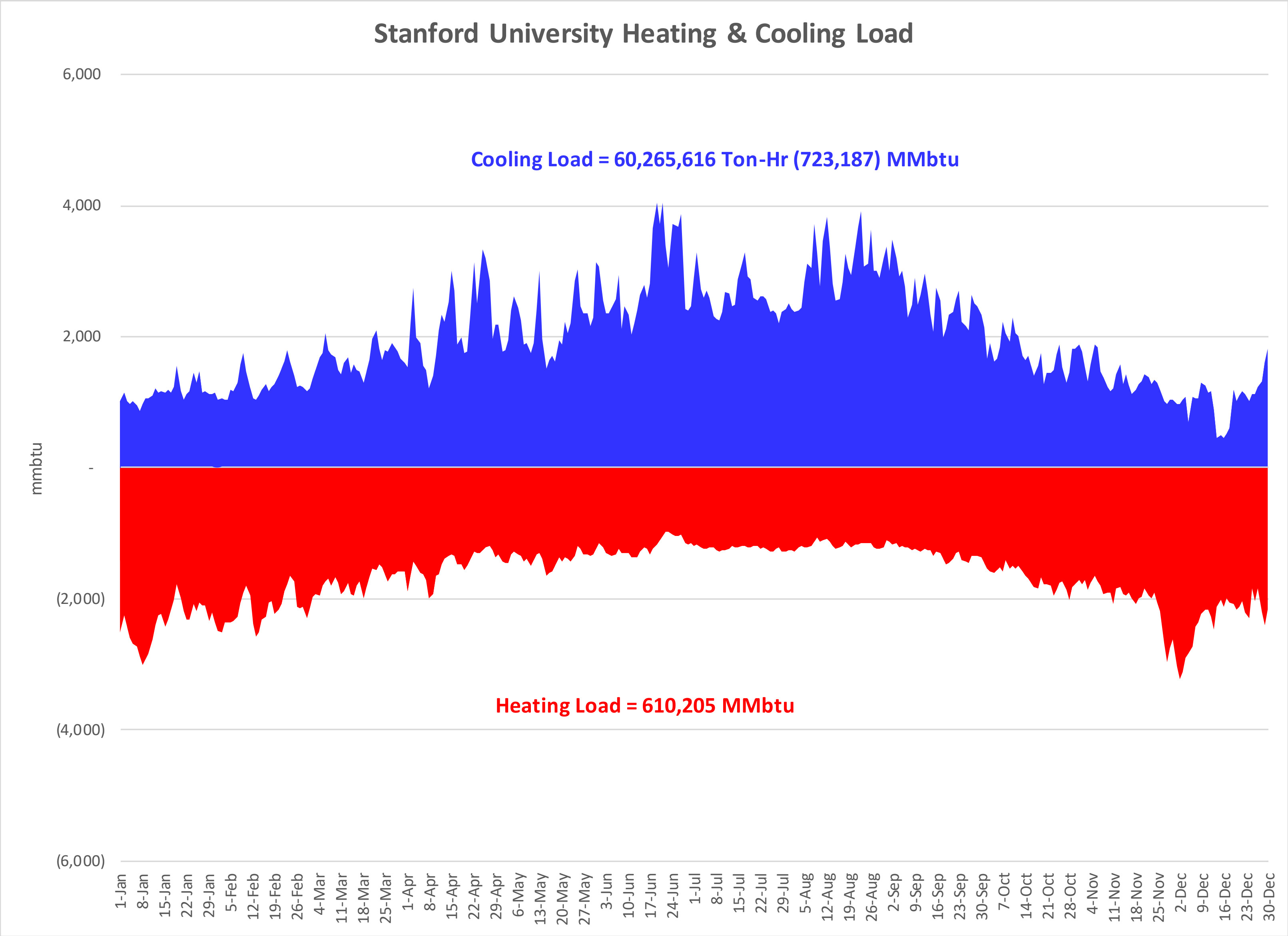
Assessing Heat Recovery Potential- Stanford Example





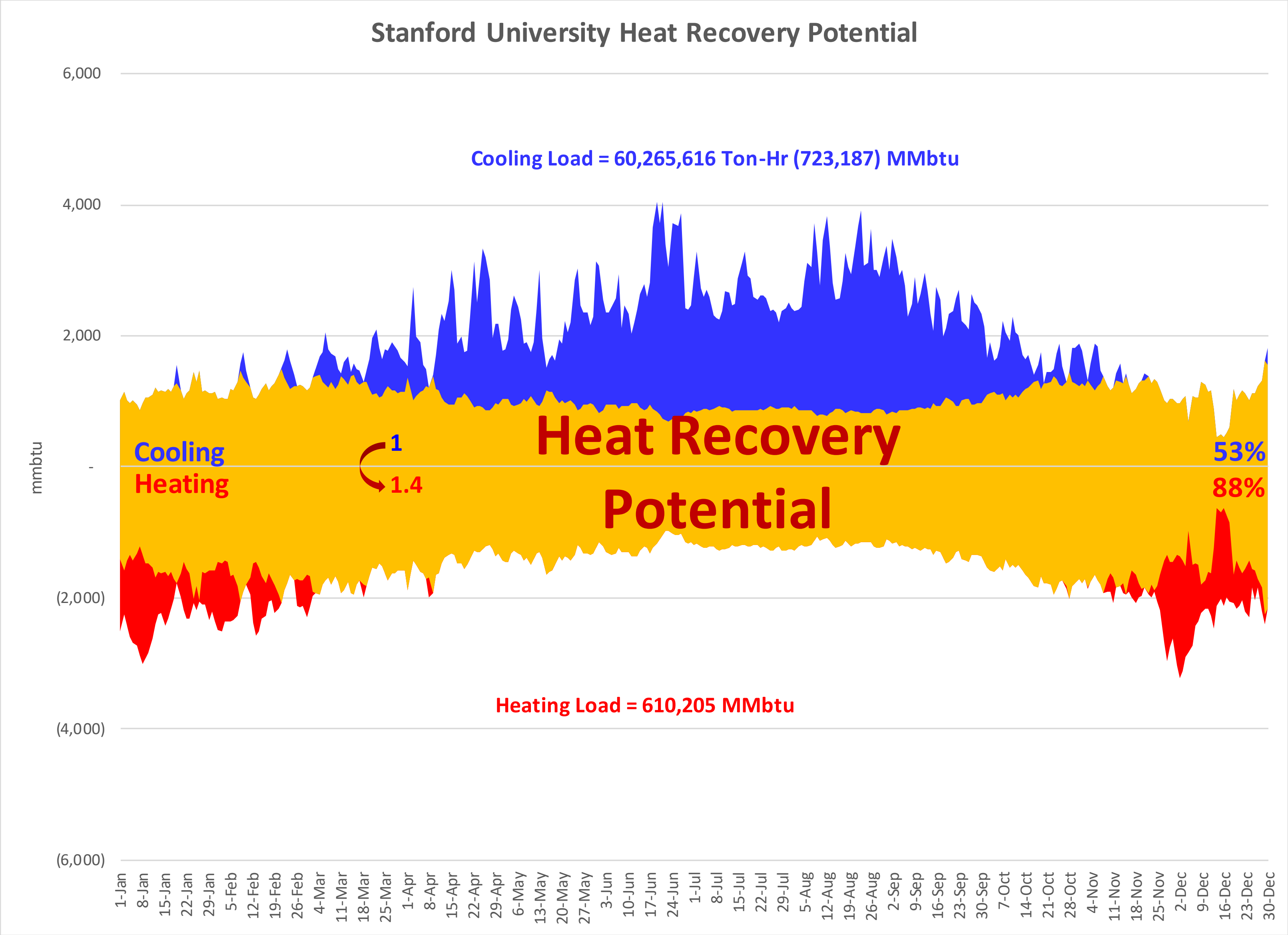


Stanford Heating & Cooling Load

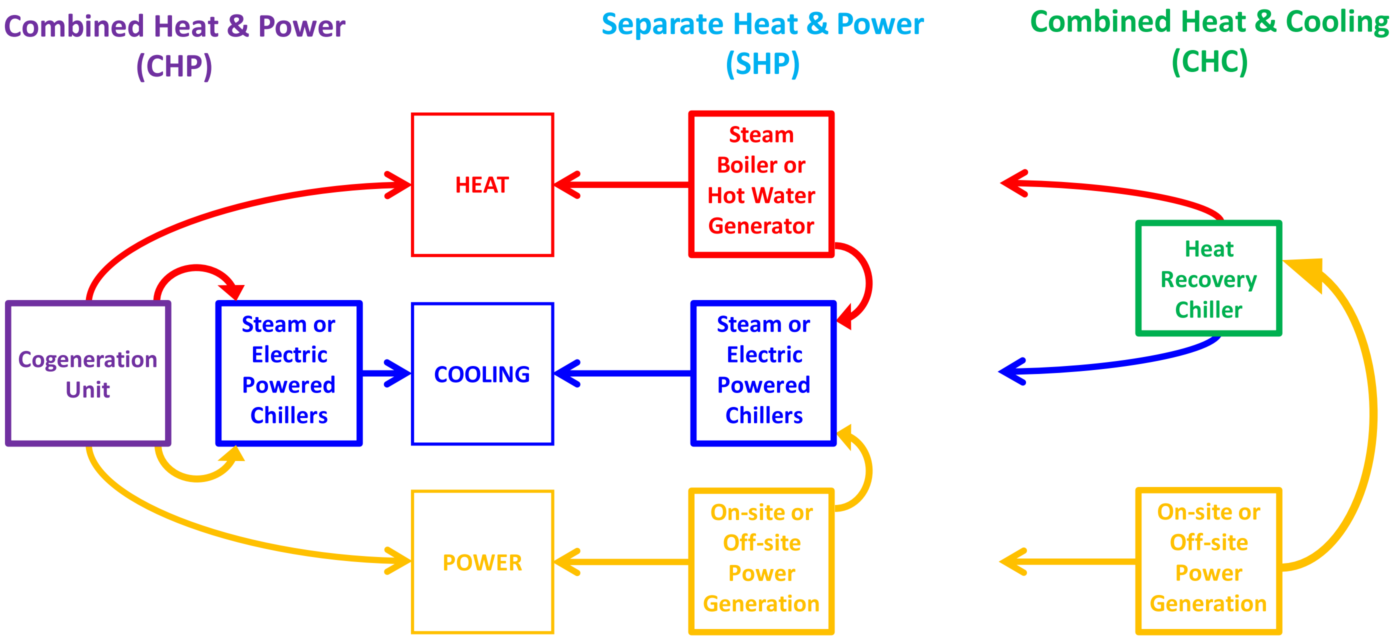


Stanford Heat Recovery Potential

Use Heat Pump first for: 1) Heat Recovery, then 2) Heat Extraction from Ground, Water, or Air



Types of Building Energy Supply Systems



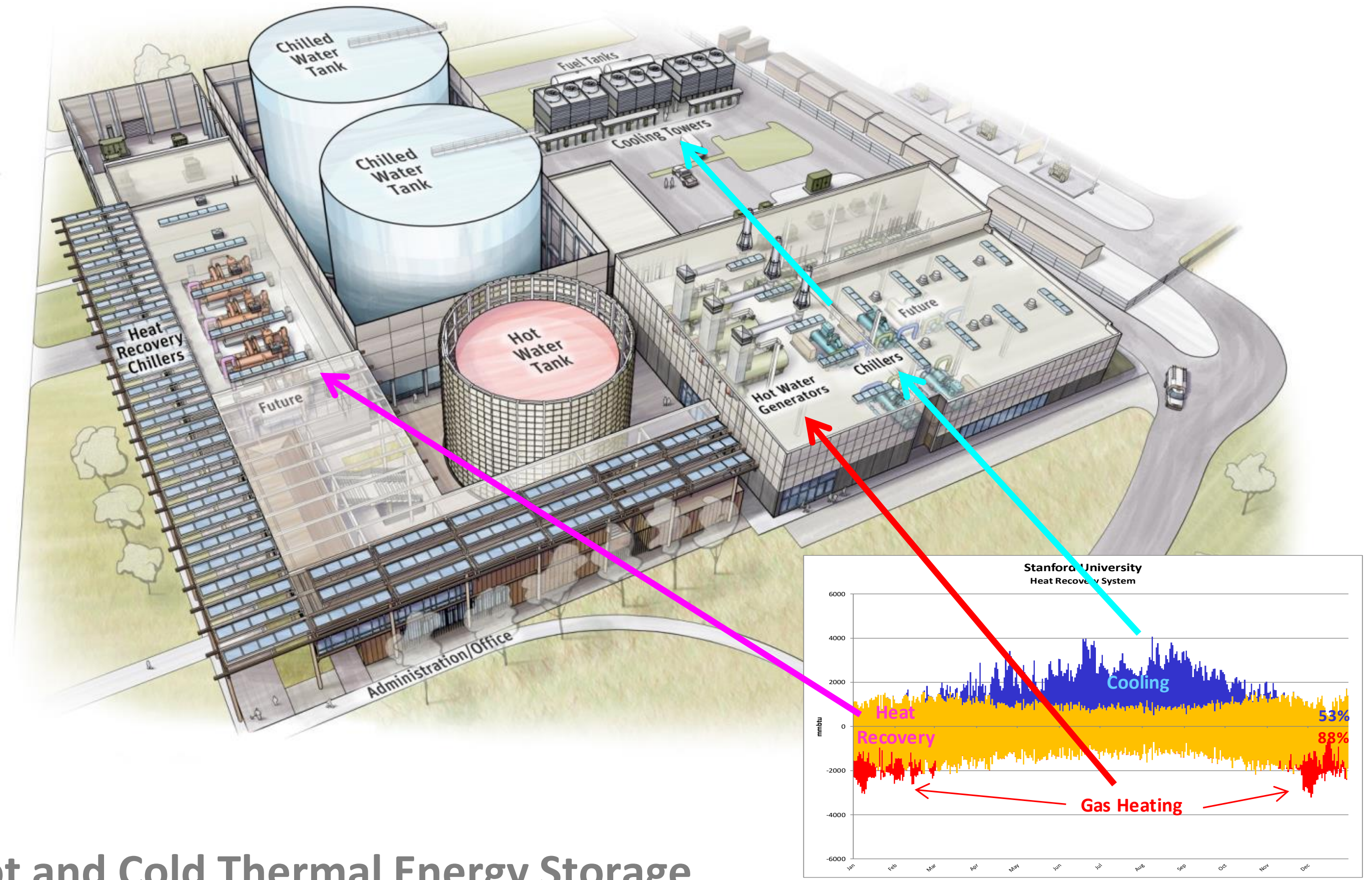
Basic Overall System Components

1. Heat Pump (aka Heat Recovery Chiller)
2. Chiller
3. Boiler/Hot Water Generator

<u>Optional but highly desirable and cost effective</u>

4. Hot thermal energy storage (typically water)
5. Cold thermal energy storage (typically water)
6. Model Predictive Control software for planning, design, and operation

Stanford Central Energy Facility



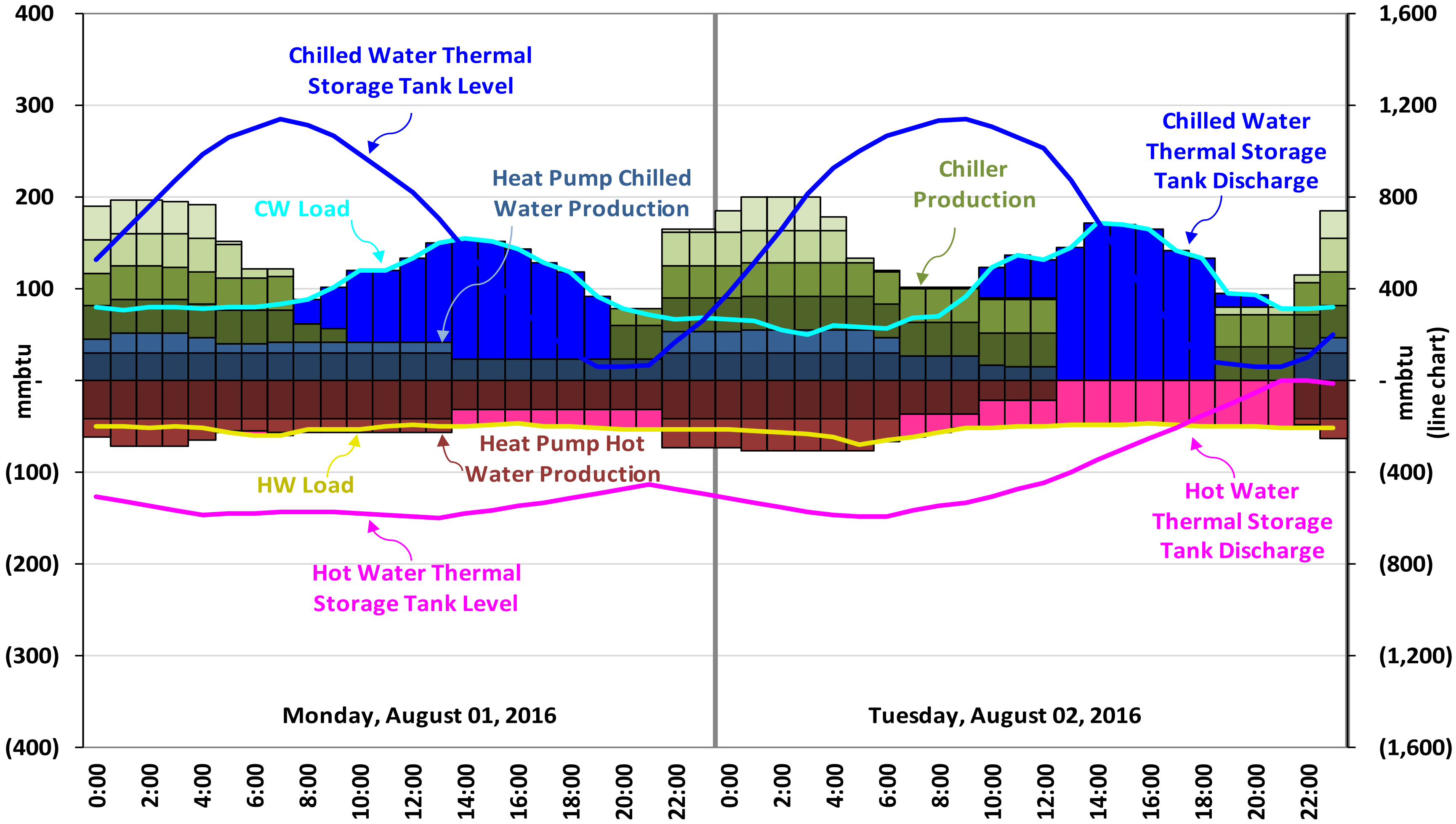
Hot and Cold Thermal Energy Storage

- Reduces Capital & O&M cost
- Increases system efficiency (6% more heat recovery)
- Reduces electricity peak demand by 17% (36 v 43 MW)
- Provides equivalent of 7 MW electricity storage

Model Predictive Control Software

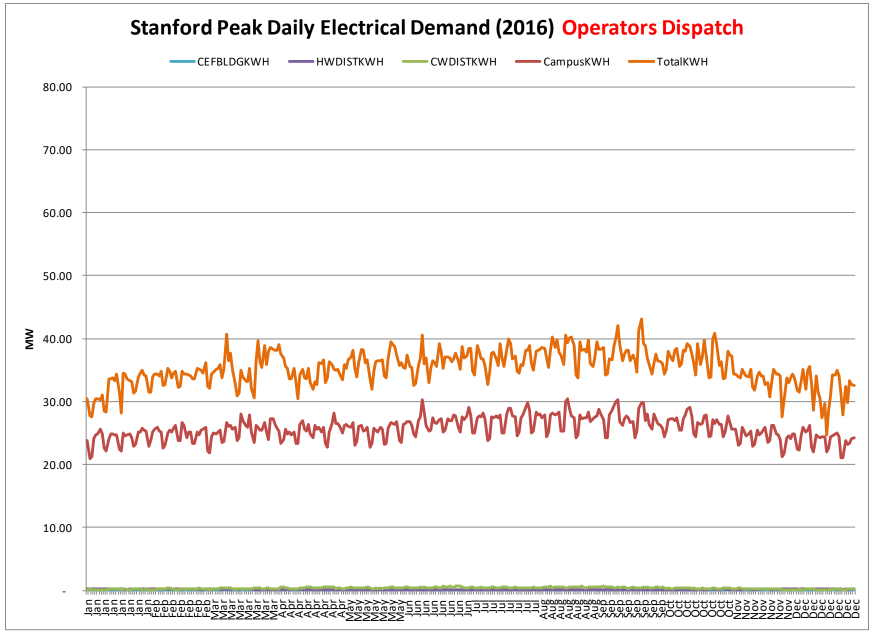
Increases system efficiency

Reduces electricity peak demand and total cost

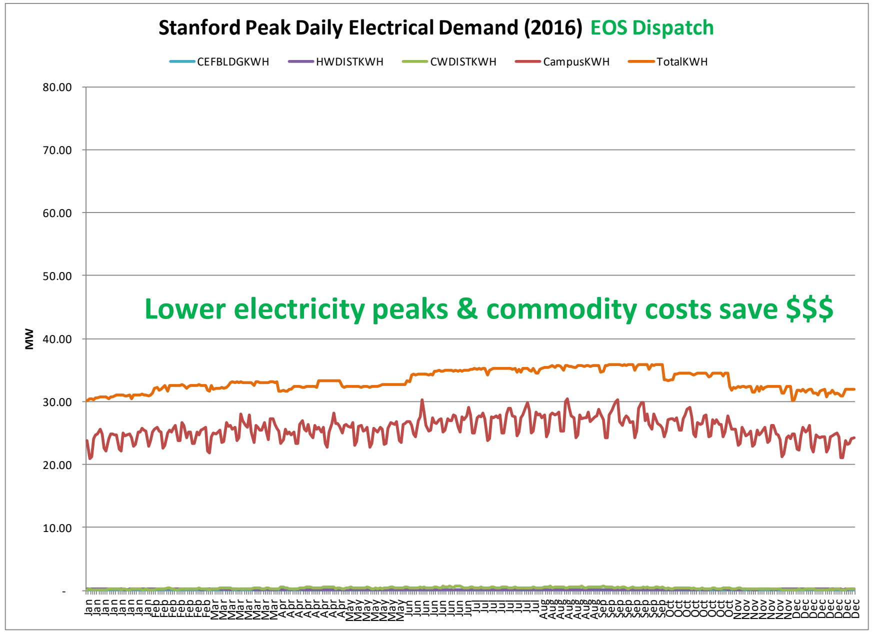


Benefits of Model Predictive Control

Manual Operation



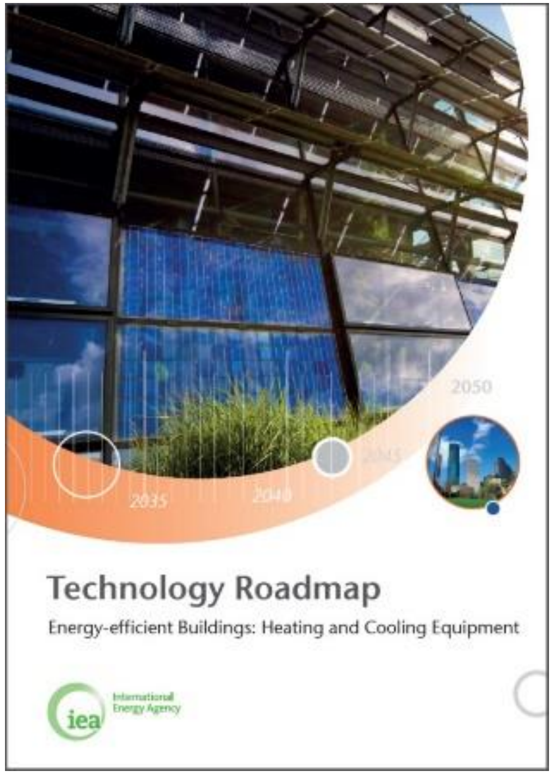
Computer Operation

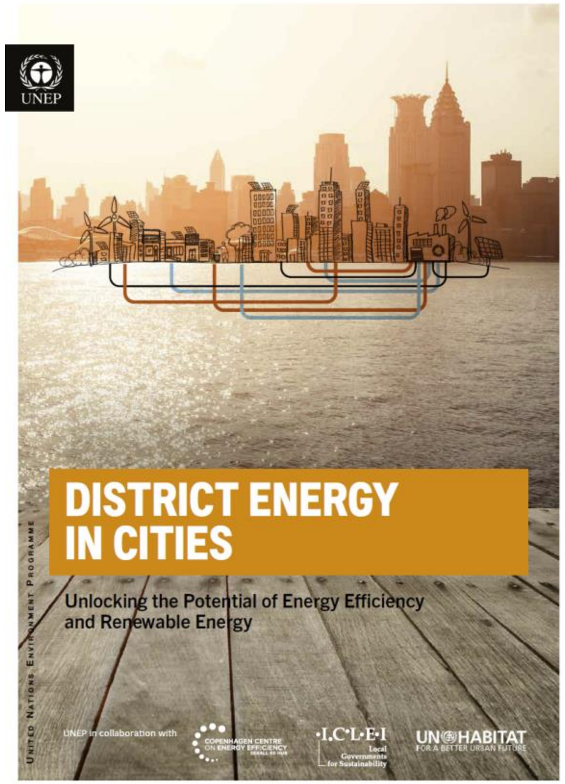


- 2016 full year Operators vs. Computer simulation conducted
- Benefits of computer optimization:
  - Reduces peak demand on grid by 7.3 MW (35.9 MW vs 43.2MW)(17%)
  - Saves $500,000 per year (10%) in CEF electricity cost
  - Functions as ‘autopilot’ to run CEF

Stand Alone vs. District Energy

All concepts work at stand alone building level- residential on up
But application via District Energy even better
Application in new development even easier and more efficient





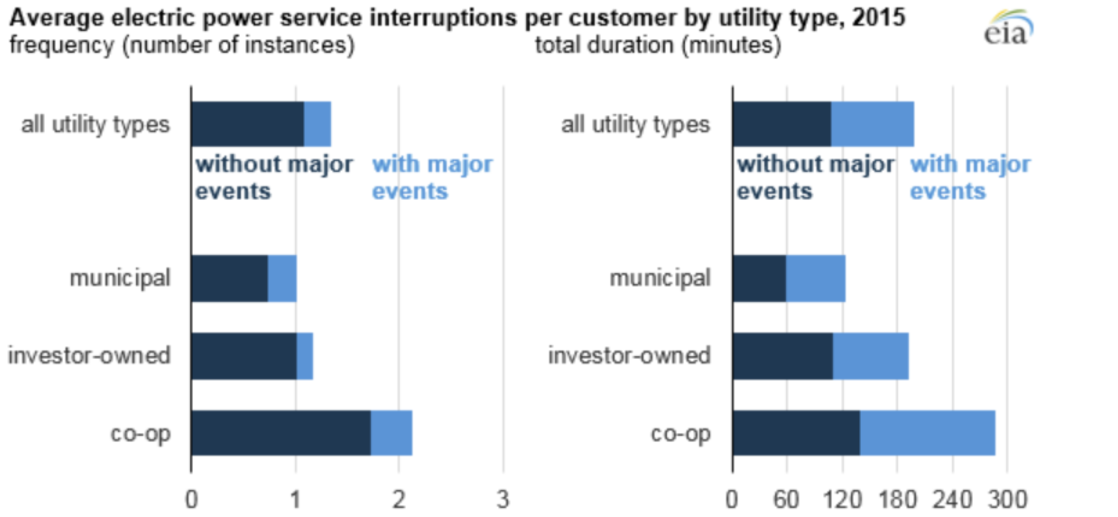
Reliability & Resiliency

"The electrical grid is far more reliable out west than back east…we have outages all the time and can't rely on the grid for something as essential as heating in winter"

"Electrification & Heat Recovery only works in mild climates like Stanford's…it won't work in cold climates like the Midwest or East"

SEPTEMBER 12, 2016

EIA data show average frequency and duration of electric power outages

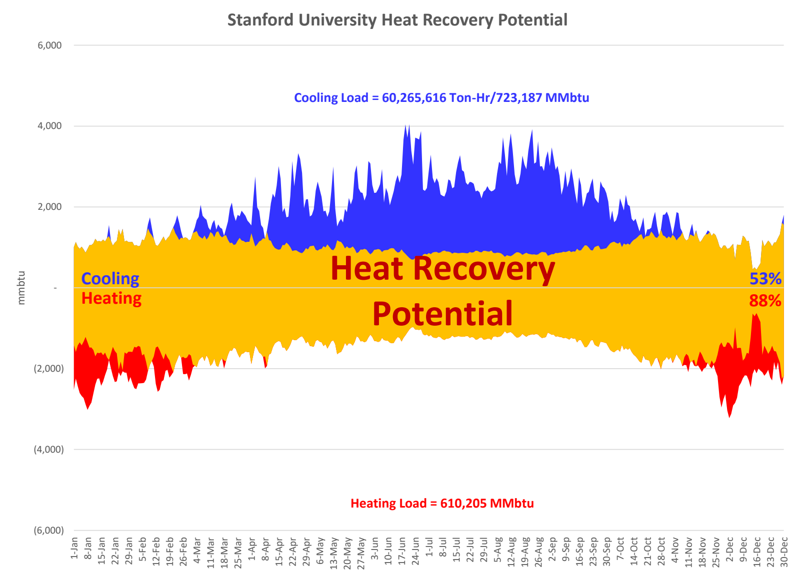


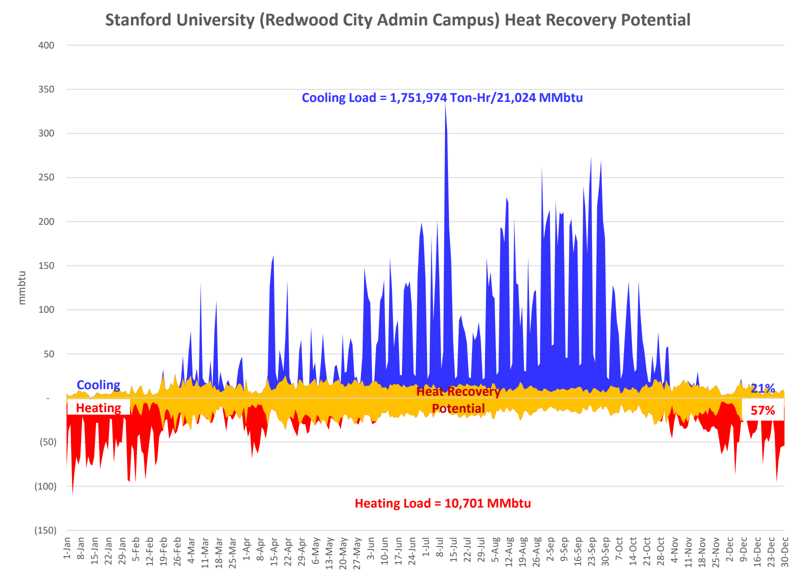
Source: U.S. Energy Information Administration, *Annual Electric Power Industry Report* (EIA-861) 2015 early release

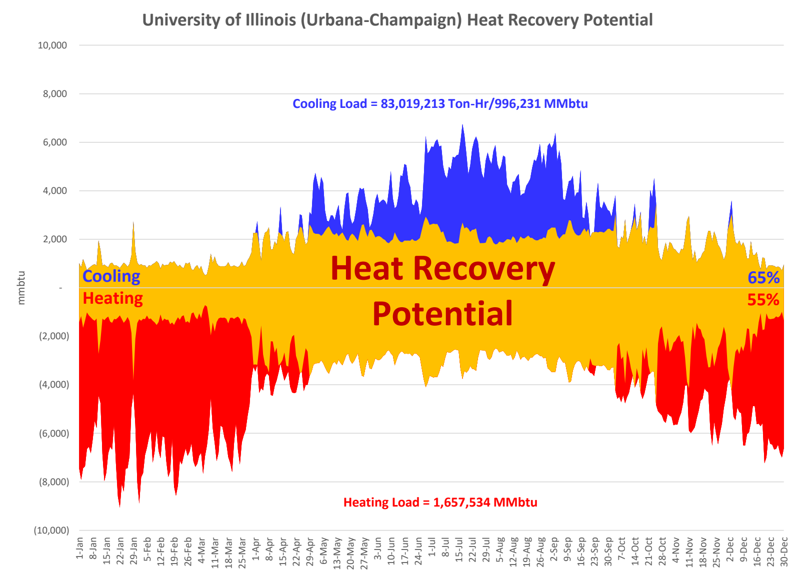
Heat Recovery (CHC) system has 4 sources of winter time heating energy:
1. Electricity (primary)
2. Thermal Storage (backup)
3. Natural Gas (backup)
4. Liquid Fuel (backup)

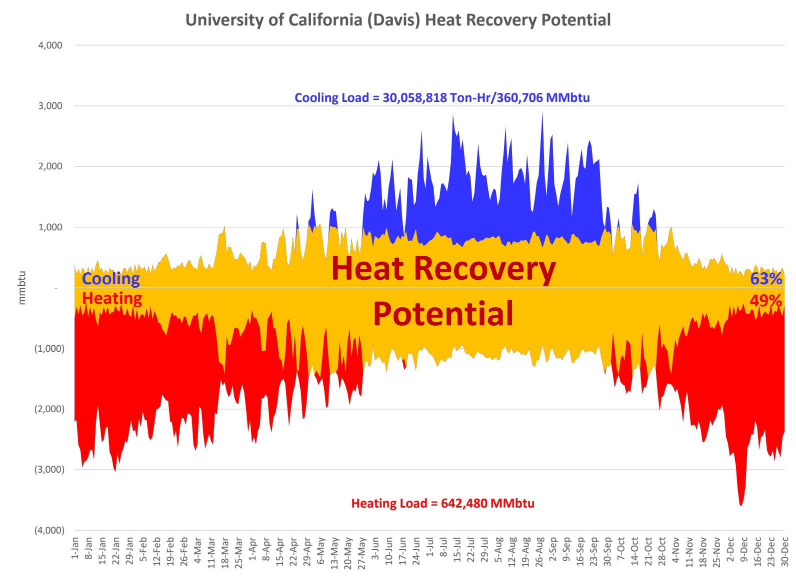
SHP and CHP systems only have 2 sources:
1. Natural Gas (primary)
2. Liquid Fuel (backup)

Electrification makes sense in ***all*** climates

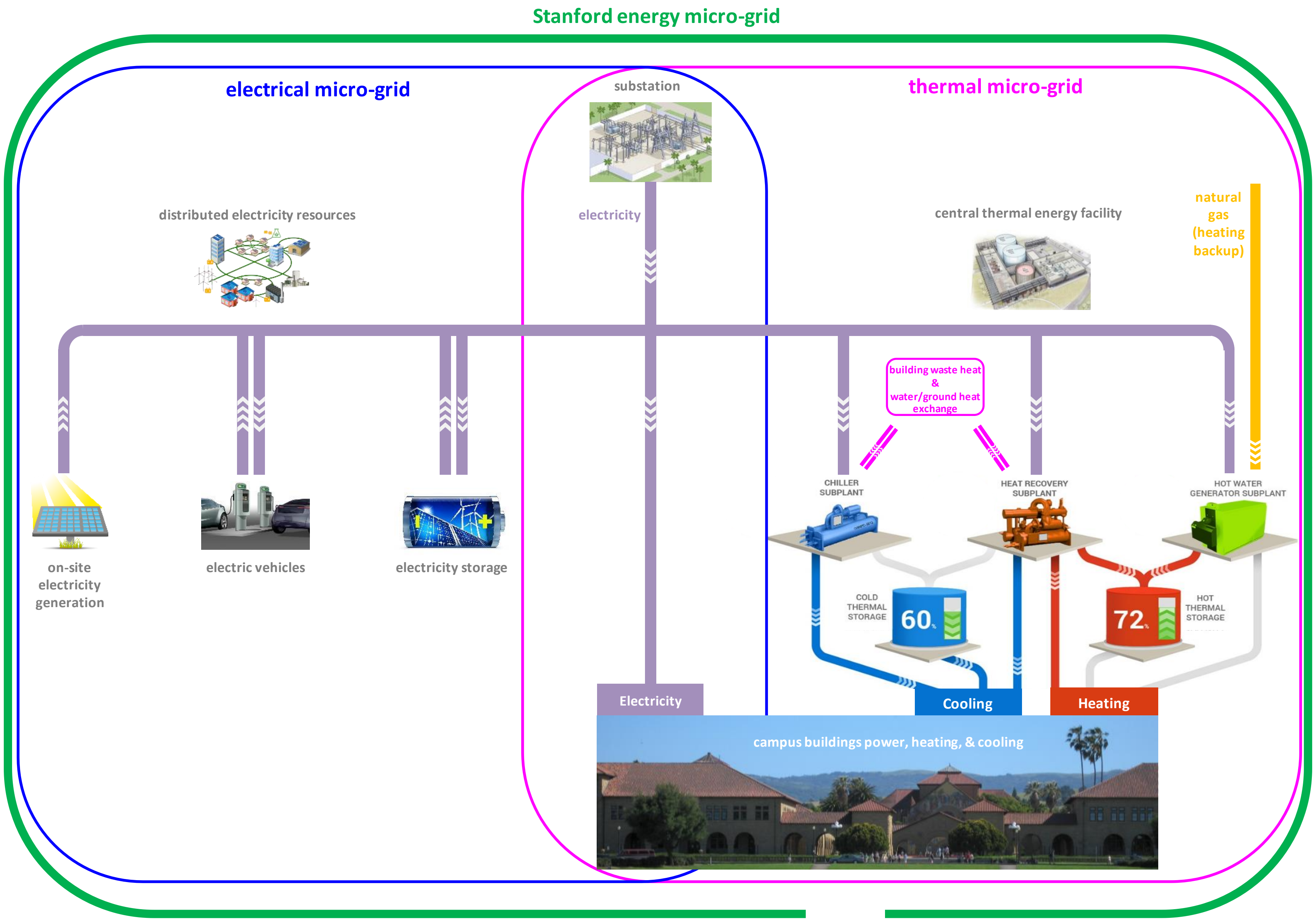








Total Energy Micro-grid…thermal before electric



Today's Webinar

Agenda

Description	Presenter	Duration
Project Introduction & Context	Sonika Choudhary, City of Palo Alto Utilities	5 min
Thermal Microgrids: Technology, Economics & Opportunity	Aimee Bailey, EDF Innovation Lab	20 min
Stanford Case Study	Joe Stagner, Stanford	20 min
Project Next Steps	**Aimee Bailey, EDF Innovation Lab**	**5 min**
Q&A		10 min

Project Next Steps

Project Deliverables

Part 1: White paper describing the technology, economics & opportunity
Part 2: Case study describing Stanford Energy System Innovations (SESI)
Part 3: Suite of tools for assessing technical and economic feasibility
Part 4: Municipal case studies carrying out feasibility assessments

In Progress

- There are two additional parts to the project, shown above
- **If you are a muni and interested in being the subject of the 2nd case study, please contact us**
- A second webinar will be organized in Fall/Winter 2018 covering final results from the project

EDF Innovation Lab

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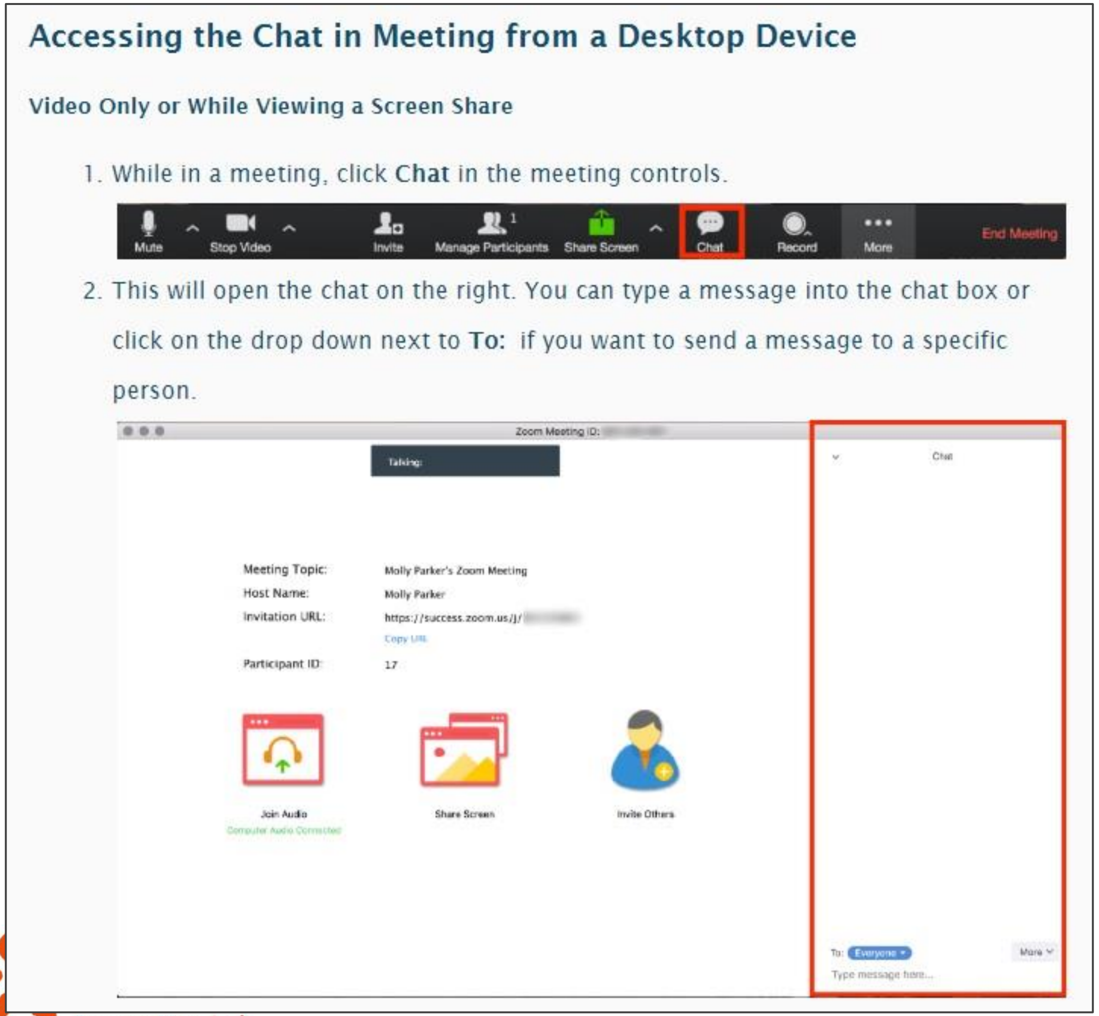
eDF Innovation Lab

Q&A and Contact Information

Q&A

Please type your questions into the chat window.



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CHAMPION OF LOW-CO_2 ENERGY

Thank you!