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A River of Energy Solutions

Central Energy Plants in support of meeting EISA 2007 and NetZero energy goals

Dr. Alexander Zhivov, USACE Engineer R&D Center, Champaign, IL

Outline

- History of District Heating
- Issues with old district heating systems
- CEP Vs Decentralized systems
- Challenges with meeting EISA 2007 goals
- EISA and CHP
- SHW and CEP
- Conclusions

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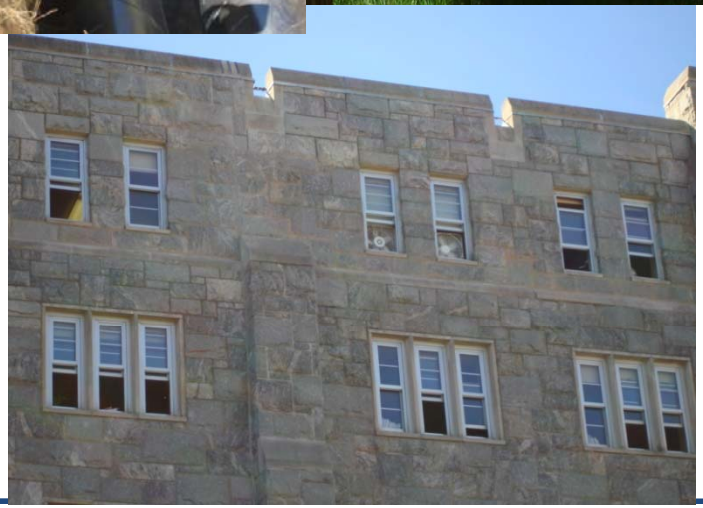
History of District Heating Systems

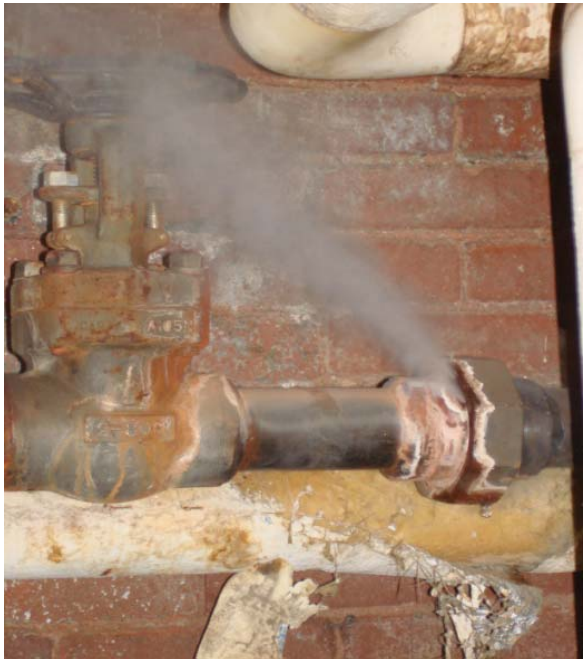
- First district heating systems (DHS) were built in ancient Roman Empire for baths and green houses;
- The oldest still existing was built in 14th century in Chaudes-Aigues Cantal village in France. This system distributed warm water through wooden pipes and it is still in use today
- The first commercial district heating system was created by Birdsill Holly in Lockport, New York in 1877 and consisted of the boiler and a distribution loop with steam pipes, radiators, and a condensate return lines
- Denver's district steam system is in service since November 5, 1880
- Consolidated Edison of New York (Con Ed) operates the New York City steam system, the largest commercial district heating system in the United States built in 1882
- District steam heating systems were created before the invention of electric power distribution system in 1882 by Edison.

Poor Temperature Control with Steam Heating Systems



Steam Leaks from Piping System

The expansion and contraction a steam system experiences as it is started and shut-down can stress the piping components resulting in leaks. Leak in a steam results in a waste of energy and water. Leaks of superheated steam are not visible can be very dangerous.



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Failed Steam Traps

A steam trap is a device that allows condensed steam to pass, but stops steam flow. Over time, the internal parts will fail, which can result in either the trap failing in the closed or open position. If it fails closed, then steam will not flow to the heating device and it will stop heating. If the trap fails in the open position, the heating device will continue to function, but additional steam will be lost through the trap opening or orifice.

Poor Fuel Handling Resulting in Significantly Reduced Efficiency

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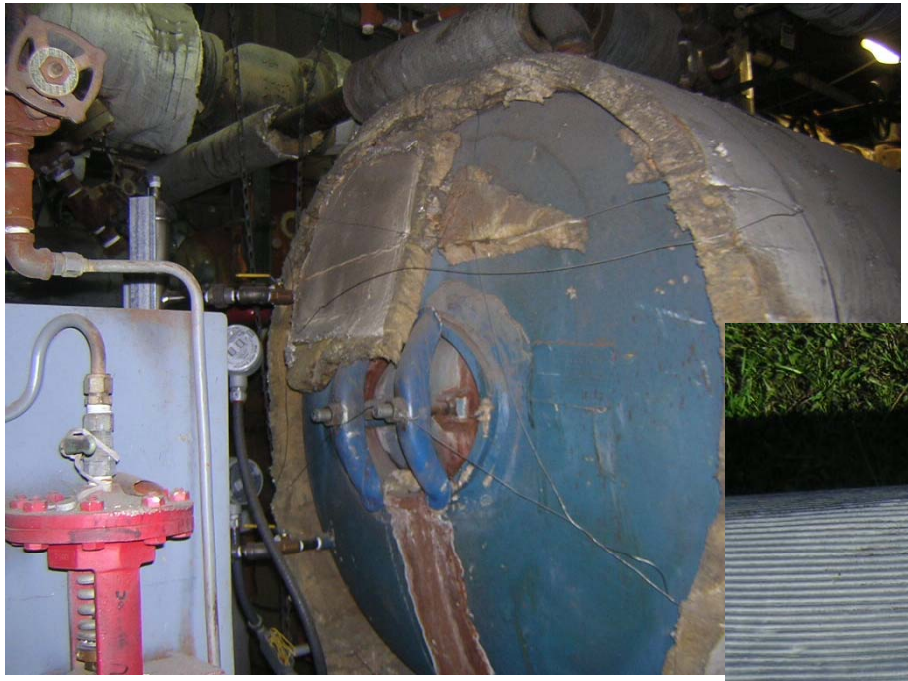
Insufficient or Damaged Insulation



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Flooded Distribution System Resulting in Damaged Insulation

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Poor Water Treatment

Patch on heating pipe is indication of problems with water treatment.

Chemical treatment system typically found in heating plants.

Water treatment is used in heating systems to keep dissolved and suspended solids in solution and to control corrosion. Failure to properly treat the water can shorten the life of the piping system and increase the resistance to heat transfer in heat exchangers

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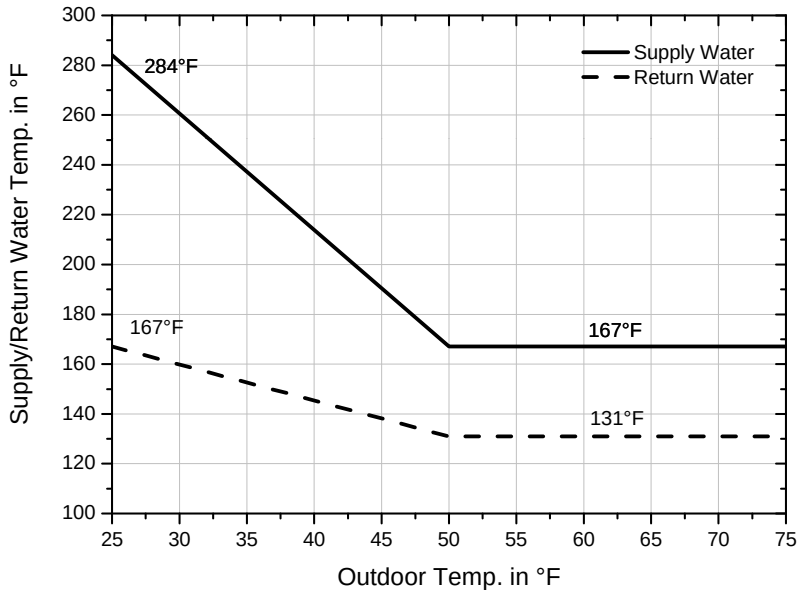
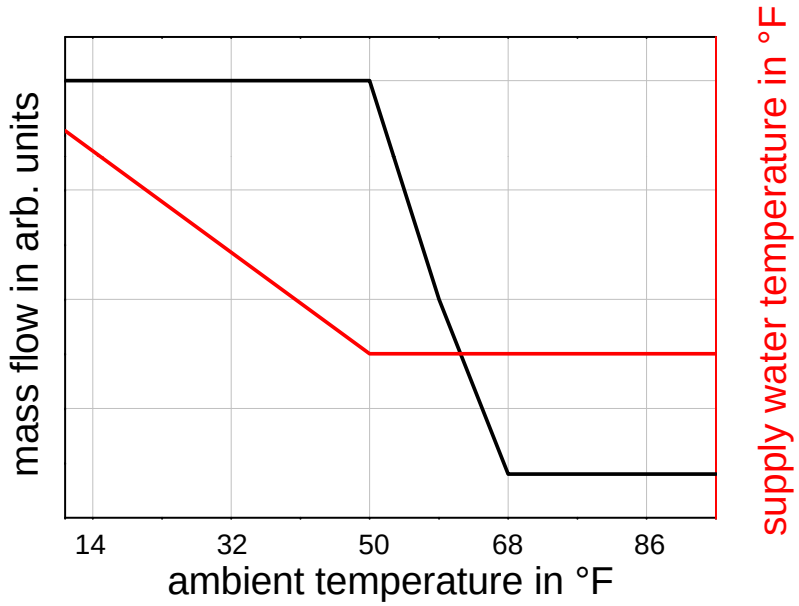
Steam Vs Hot Water Heating System

- Steam system has few moving parts, typically no pump is needed;
- Steam heating method has no or poor temperature control;
- Steam system produces loud noise;
- Steam system requires more expensive (double skin) metal pipes;
- Steam distribution system has higher heat losses;
- Steam heating system require make-up water treatment – when neglected results in corrosion of pipes and significant water losses

Conversion of Steam Heating Systems into Low/Medium Temperature Hot Water Heating Systems

Low and Variable T Hot Water System





District Heating Systems Worldwide

- Denmark: 60% of space heating and DHW is covered by district heating. In 2007, 80.5% of this heat was produced from CHP plants; 20.4% is recovered from waste incineration
- Iceland: 95 % of houses are connected to DHS based on geothermal energy
- Finland: 50% of heating from DHS, 80% from CHP
- Russia: most of heating from CHP
- Sweden: more than 90% of heating and DHW from CHP with a 90% from renewable sources.

Distribution System Replacement with Pre-Insulated Bounded Pipes

Advantages of these Pipes

- Directly buried
- Hardly any manholes
- No concrete needed
- Last installation
- Leak detection system
- Low prices due to batch production
- Up to DN 300 (1ft.) no compensation required
- Less expensive new connections and replacement
- Pre-casted fittings and elbows
- Spot-drilling for connecting new customers under pressure

Limitation

- Max. acceptable temperature is limited to 285°F (expected lifetime of 30 years)
- Reduction of annual average temp. to 195…210°F extends the lifetime twice

Other Pipe Systems

- Steel jacket pipes
- in-situ insulated pipes in dome-shaped ducts
- above ground level pipeline and many more

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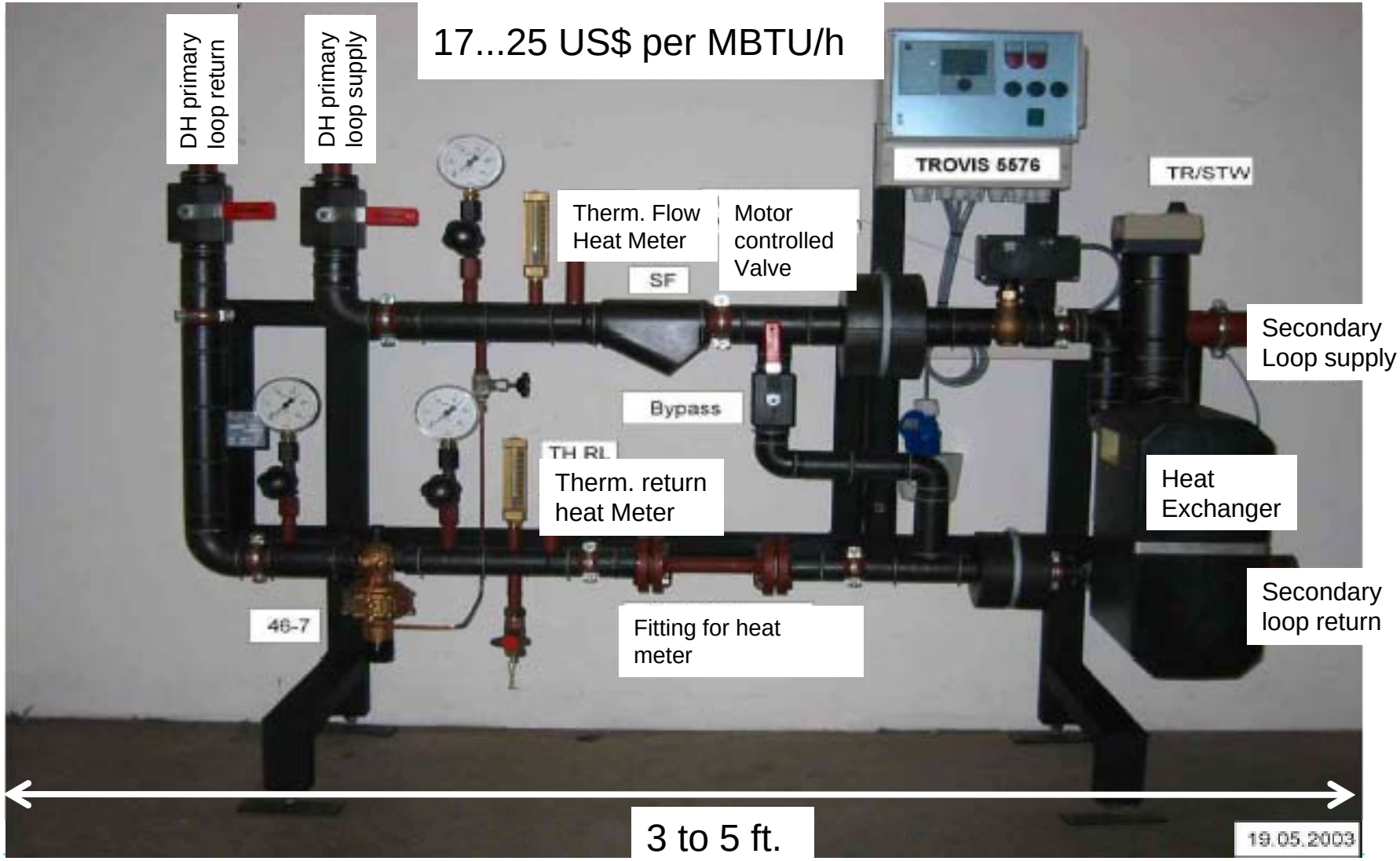
Photo of a modern Compact Station



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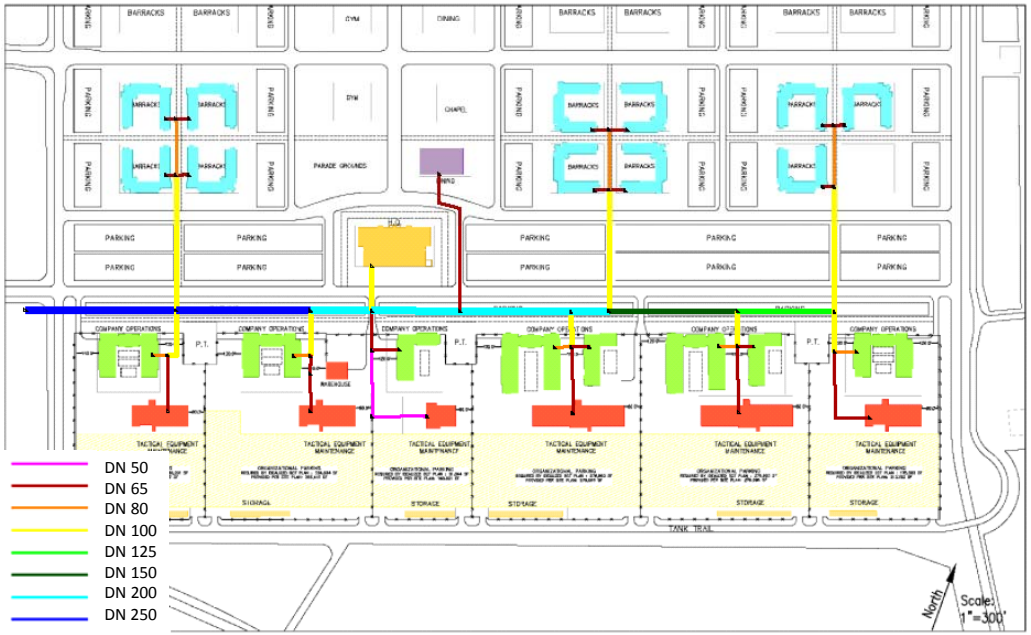
CEP for Brigade Combat Team (BCT), Ft. Bliss



11 Barracks
1 Dining Facility
1 Brigade Headquarter Building
8 Company Operation Facilities
7 Tactical Equipment Maintenance Facilities

(All tier 1 facilities covered by Army standards and USACE standard designs)

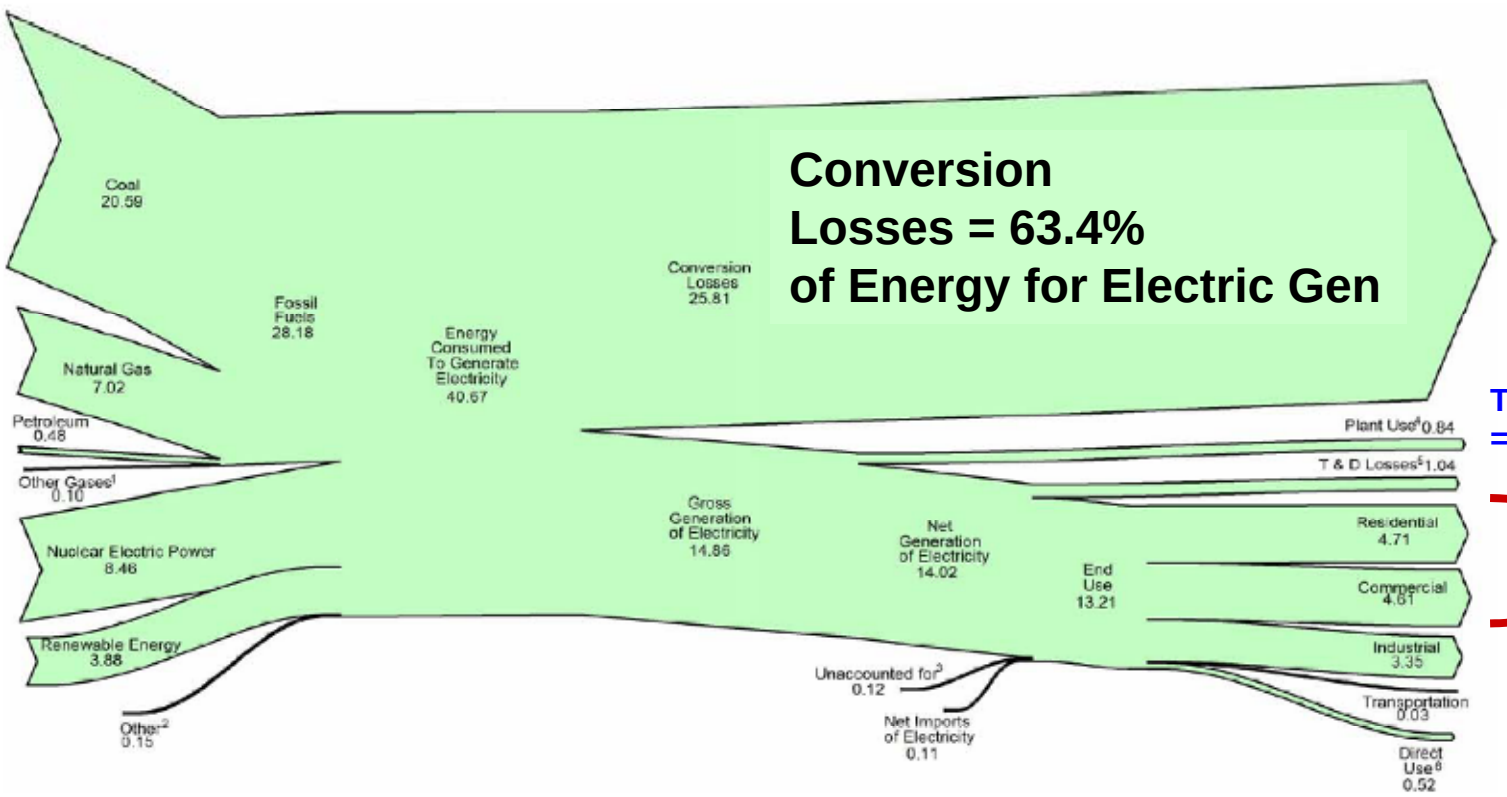
- CEP results in first cost reduction for heating equipment , but also has a first cost increase for cooling equipment
- Annual heating and cooling costs with a CEP are lower
- Central heating plant solution includes co-generation for the base heating load, which results in generation of 4.3 MWh_{el}/a in electricity.
- Higher efficiency of cooling equipment results in electricity use reduction. The total annual electricity savings are 5.7MWh_{el}/yr.
- CEP will reduce 19.3 MWh_t (65.9MBtu) of fossil fuel, or 67 Btu/ft2 for the total BCT4 buildings complex area.
- Central heating and cooling solution has lower O&M costs and will become even more attractive with the energy cost increase and provides a cost effective application of solar water heating when integrated into a central heating/DHW concept.

Pros & Cons for District Heating Vs. Building Individual Heating Equipment

Pros	Cons
Higher efficiencies of boilers due to adapted boiler sizes regarding load profile (benefit from factor of diversion)	Potential for higher 1st cost in case of co-generation and tri-generation
Reduced O&M for reduced number of generation sites and equipment	Buildings have stand alone system and can be operated individually
Reduced 1st costs for security of supply due to N+1 redundancy in DH system	
Opportunity to install dual fuel equipment in a cost efficient way	
Opportunity for co-generation (Combined Heat-Power) and tri-generation (Combined Heat-Power-Chilled Water via Absorption)	
In case of co-generation reduction of back-up generators – reduces 1st costs	
Elimination of oil tanks next to every building – reduces 1st costs	
Replacing fuel source or type of generation equipment at only a small number of sites impacts a greater number of buildings	
Reduced Life Cycle Costs	
Technical Lifetime of central equipment is mostly longer as for decentralized boilers	
Opportunity to combine with renewable sources or use of waste heat from different source	
Opportunity to combine DH with Contracting	
Opportunity to Install the required pipes together with the other utilities – reduces 1st costs	

District Heating and CHP

Electricity Generation & Use in USA
Buildings are ~71% of total



Conversion Losses = 63.4% of Energy for Electric Gen

Trans & Dist Losses = 7.4% Net Gen Elec

Buildings 70.6%

Largest Cause of Greenhouse Gas

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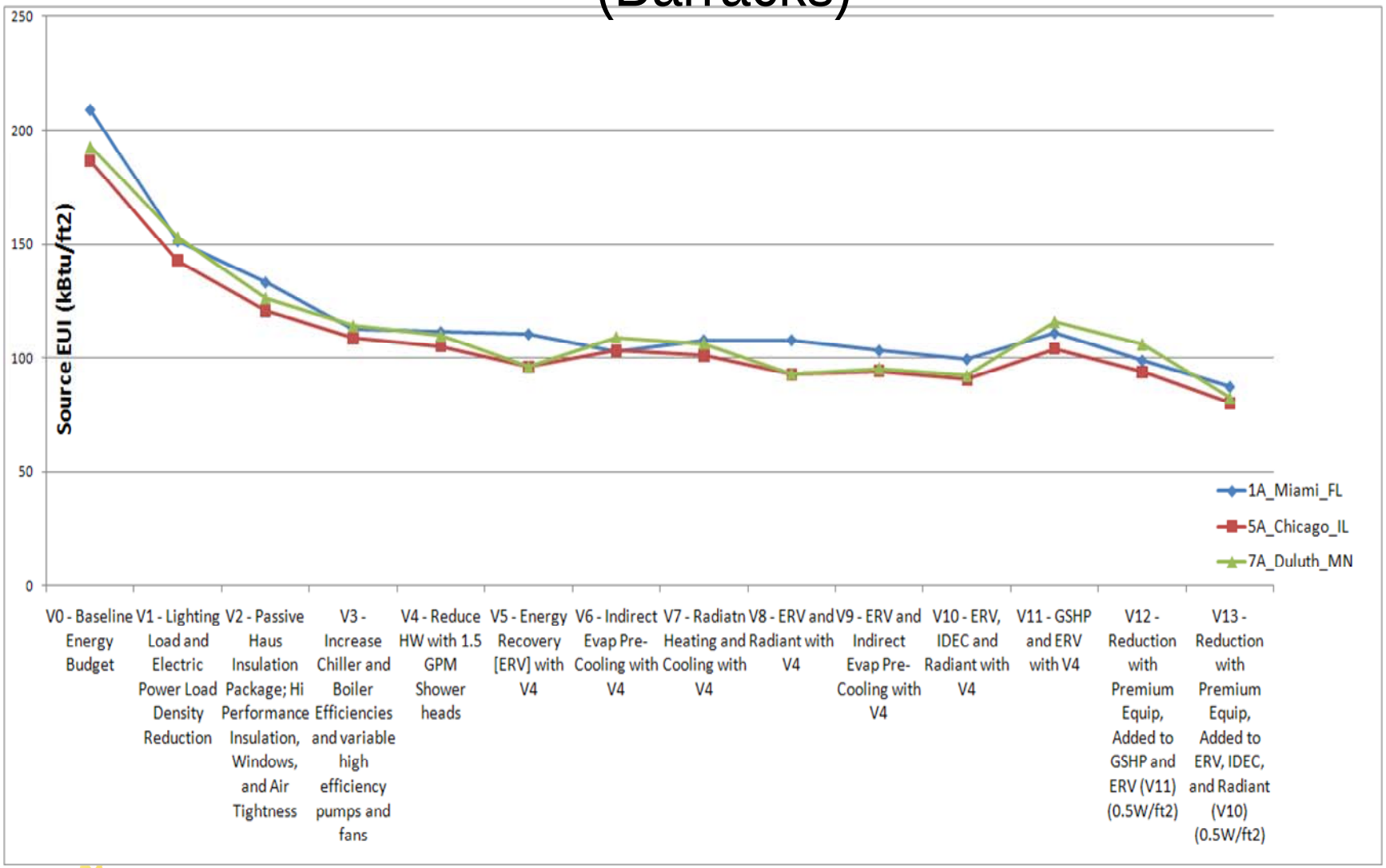
Source: US DoE EIA 2008

Effect of Different EEM on Source Energy Use Reduction (Barracks)



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Barracks Building EUI (Source) Vs CBECs 2003

Climate Zone	Based on building only EEM Vs. CBECs, %	Based on building EEM w/co-generation Vs. CBECs, %
1A	42%	78
2A	43%	77
2B	37%	80
3A	41%	74
3B	40%	77
3C	39%	72
4A	48%	74
4B	26%	74
4C	35%	72
5A	48%	74
5B	44%	74
6A	56%	76
6B	46%	75
7	53%	75
8	60%	75

Barracks - Example CHP Theoretical Limit
(Electrical Tracking)

	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)		(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)	(kBtu/ft2)
					Electric Tracking of DHW; Assume sale of thermal to adjoining building or the theoretical limit of CHP						Assume 100% Solar-Thermal for DHW; Theoretical Solar Thermal Limit			
Weather Region	Site 2003 CBECS Dormitory/ fraternity/ sorority	Site Target Energy Budget	Source 2003 CBECS Dormitory/ fraternity/ sorority	Source Target Energy Budget	Site Purch Elec	Site Purch Nat Gas	Excess Thermal or Heat	Tot Site EUI	Tot Source EUI	% Source Energy Reductio	Site Purch Elec	Site Purch Nat Gas	Tot Site EUI	Tot Source EUI
1A_Miami_FL	68	24	208	73	0	97	43	55	57	72%	24	0	24	81
2A_Houston_TX	69	24	194	68	0	89	36	53	56	71%	22	0	23	75
2B_Phoenix_AZ	67	23	195	68	0	77	32	46	48	76%	19	0	19	64
3A_Memphis_TN	68	24	176	62	0	83	31	52	55	69%	21	1	22	70
3B_ElPaso_TX	64	22	172	60	0	75	28	47	49	72%	19	0	19	63
3C_SanFrancisco_C	58	20	150	52	0	73	25	48	51	66%	18	1	19	62
4A_Baltimore_MD	75	26	178	62	0	78	26	52	55	69%	20	2	21	67
4B_Albuquerque_NM	66	23	164	57	0	73	25	48	50	69%	18	0	19	61
4C_Seattle_WA	68	24	159	56	0	72	22	50	52	67%	18	1	20	62
5A_Chicago_IL	84	29	185	65	0	76	23	54	57	69%	19	3	22	67
5B_ColoradoSprings_	73	26	167	59	0	72	22	50	53	69%	18	1	19	61
6A_Burlington_VT	97	34	203	71	0	74	20	54	57	72%	19	3	22	65
6B_Helena_MT	86	30	182	64	0	72	20	52	55	70%	18	2	20	62
7A_Duluth_MN	105	37	206	72	0	73	16	57	60	71%	18	5	23	66
8A_Fairbanks_AK	135	47	237	83	0	71	7	65	68	71%	18	11	29	71

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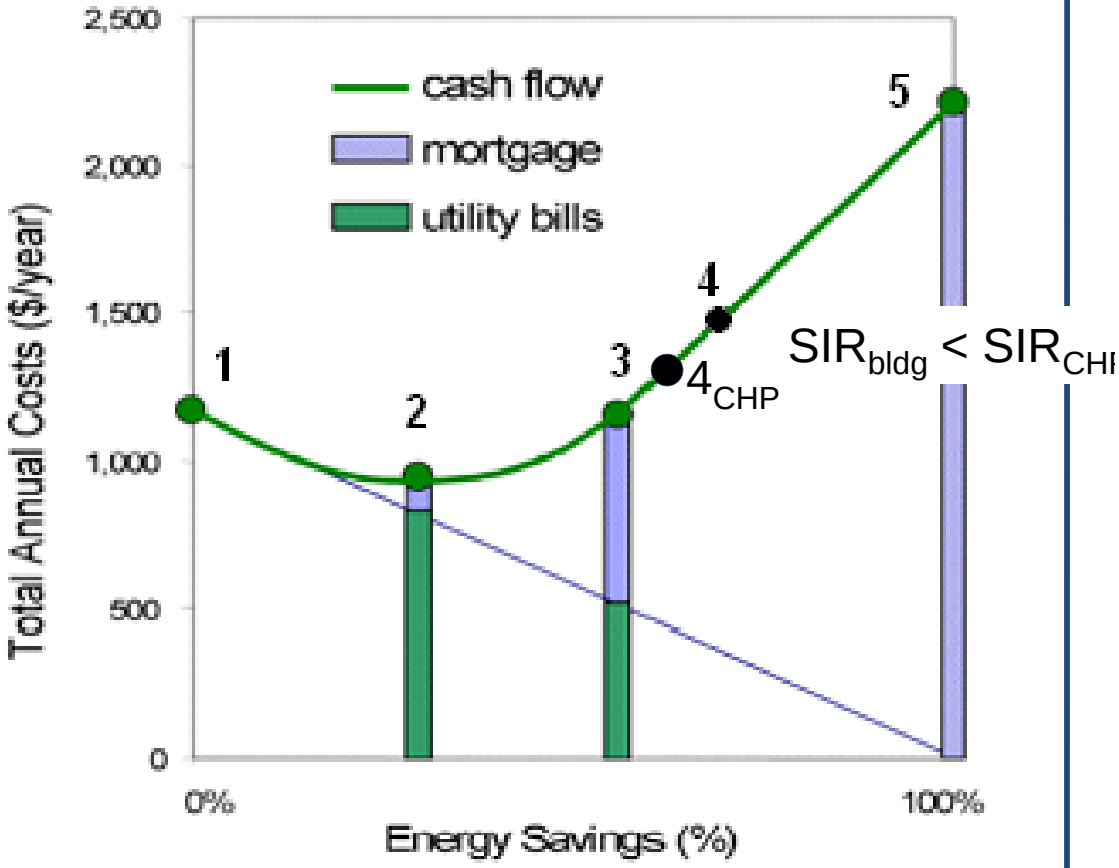
Cost-Optimizing for Low Energy Buildings

Integrating EEM's with Combined Heat and Power (CHP) plant

- Building-only analysis sub-optimizes
- Relook at building EEMS
- Clustering changes the economi
- Stop adding EEMs when the inc
  $SIR_{bldg} < SIR_{CHP.}$
- This example assumes combine
  more optimal.



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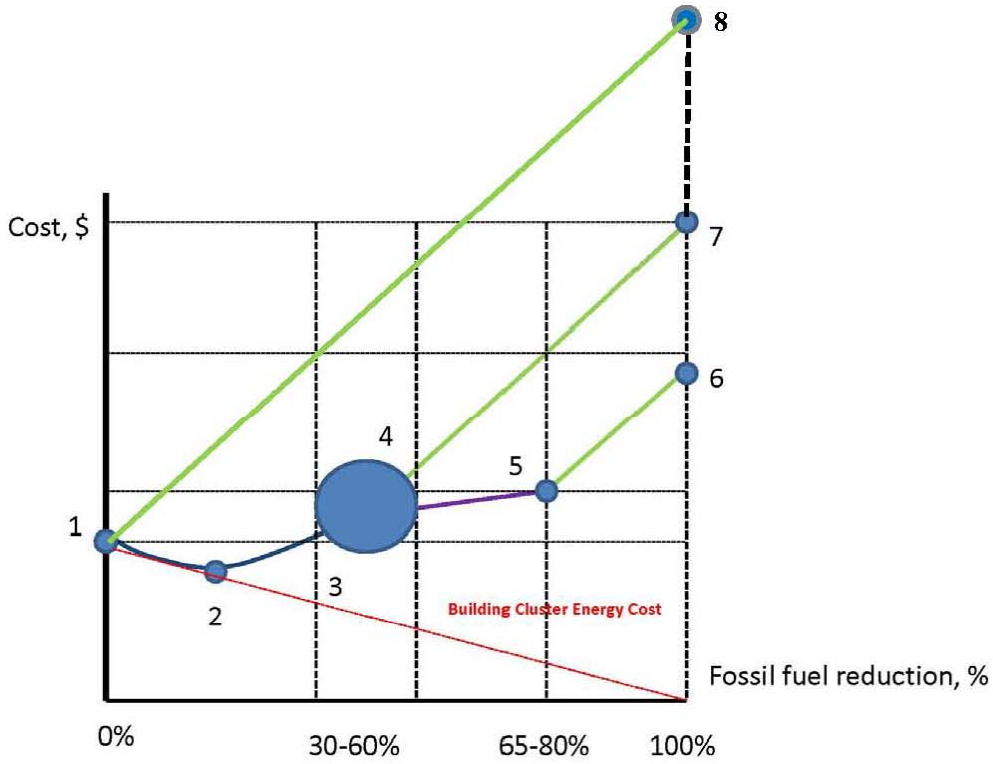
Building Cluster Fossil Fuel Optimization Process



1 – Building prior to retrofit
2 - Building after retrofit with Business As Usual (BAU)
3 - Building after retrofit option to maintain the same annualized cost
4 - Building after maximum building site energy reduction retrofit
4-5 Building fossil fuel reduction due to Central Energy Plant (CEP) with co-generation
6 - NZE building connected to CEP with co-generation and a renewable energy source
7 - NZE building connected to a renewable energy source
8 - Building prior to retrofit connected to a renewable energy source

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Toward NetZero: CHP with Syngas produced from Biomass

Small-Scale Turnkey Heat & Power Systems

- Thermal steam & hot water systems (20 – 120 MMBtu/hr)
- Direct-fired thermal systems to convert boilers from fossil fuel to syngas
- Steam power or steam CHP systems (2 –10 MW)
- Syngas to internal combustion engine CHP systems (2 – 10 MW)
- Fuels – wood (commercial); biosolids (development)

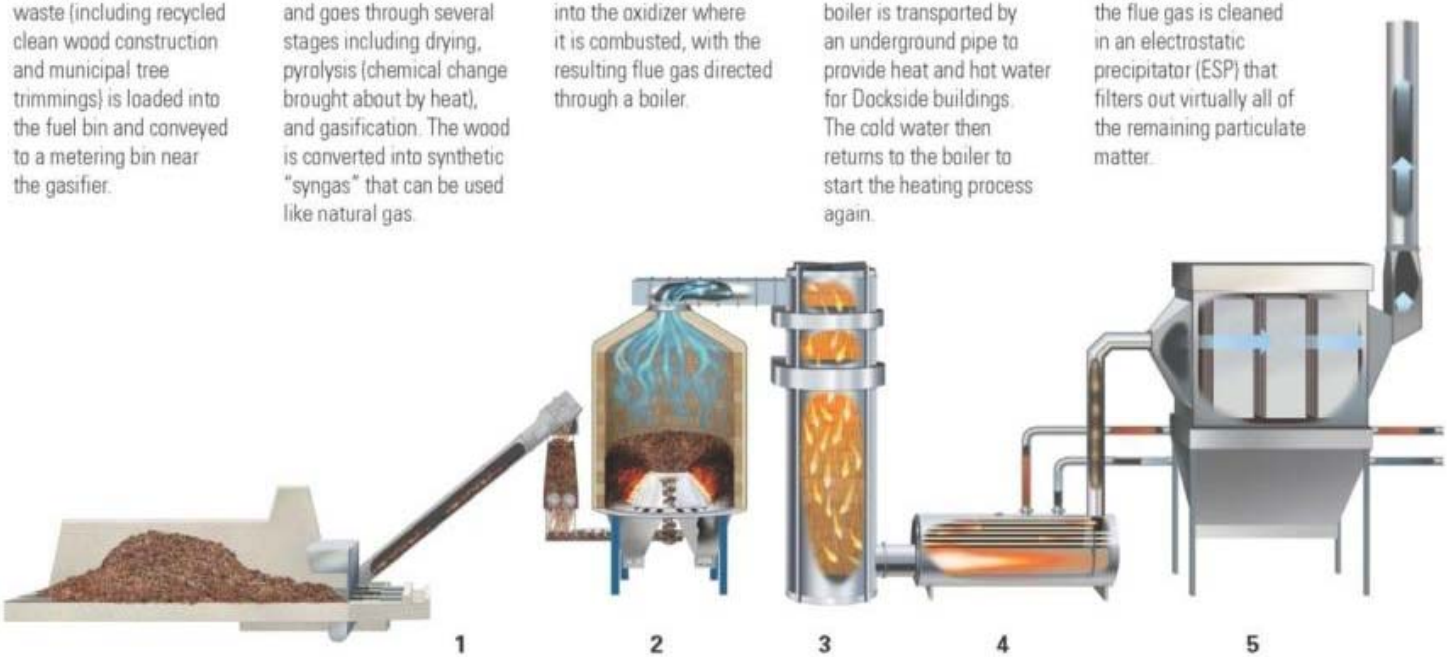
1. Fuel In-Feed
Locally sourced wood waste (including recycled clean wood construction and municipal tree trimmings) is loaded into the fuel bin and conveyed to a metering bin near the gasifier.

2. Gasifier
Fuel enters the gasifier and goes through several stages including drying, pyrolysis (chemical change brought about by heat), and gasification. The wood is converted into synthetic "syngas" that can be used like natural gas.

3. Oxidizer
The syngas is conveyed into the oxidizer where it is combusted, with the resulting flue gas directed through a boiler.

4. Boiler
Hot water from the boiler is transported by an underground pipe to provide heat and hot water for Dockside buildings. The cold water then returns to the boiler to start the heating process again.

5. ESP
After exiting the boiler, the flue gas is cleaned in an electrostatic precipitator (ESP) that filters out virtually all of the remaining particulate matter.



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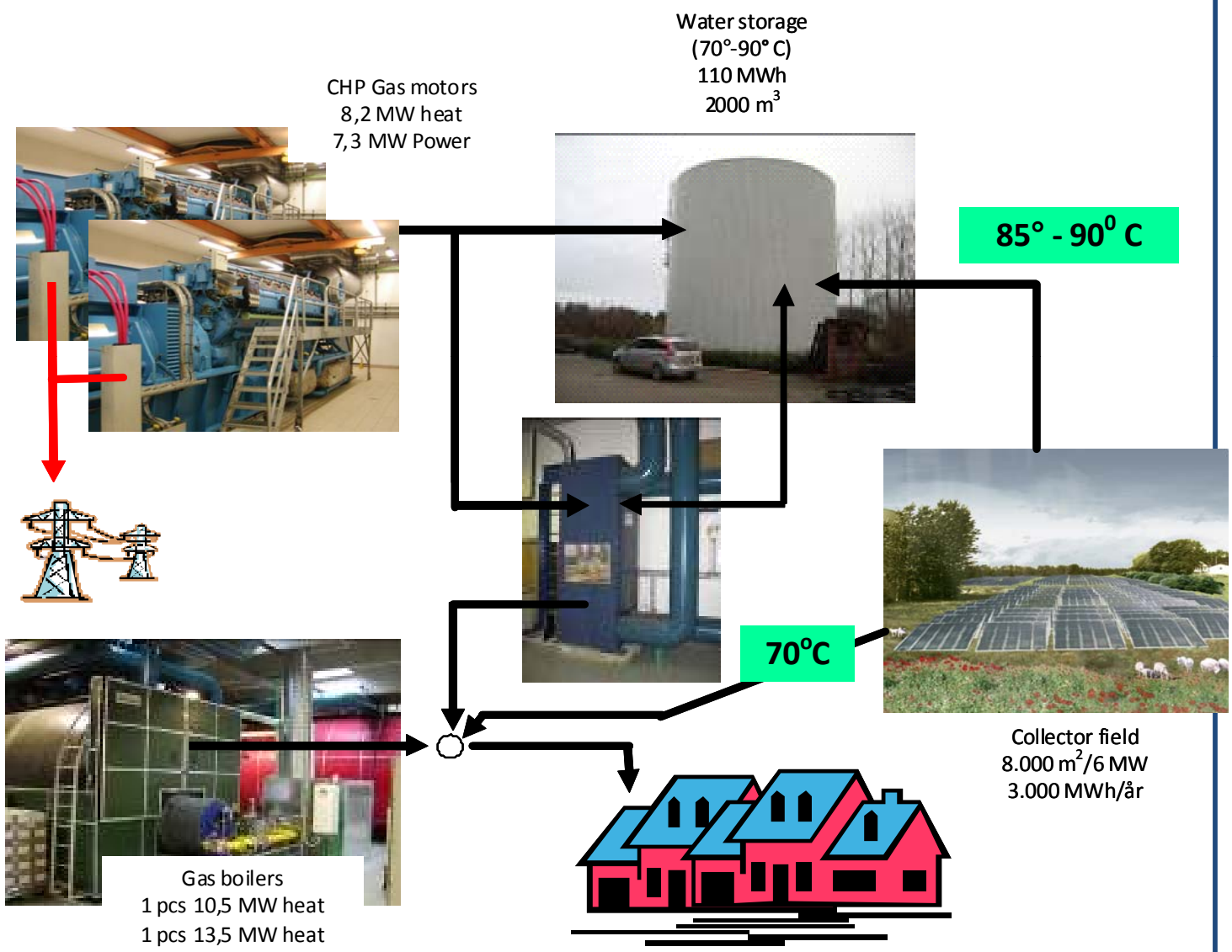
District Heating and Solar Water Heating

Solar Water Heating connected to District Heating System Concept



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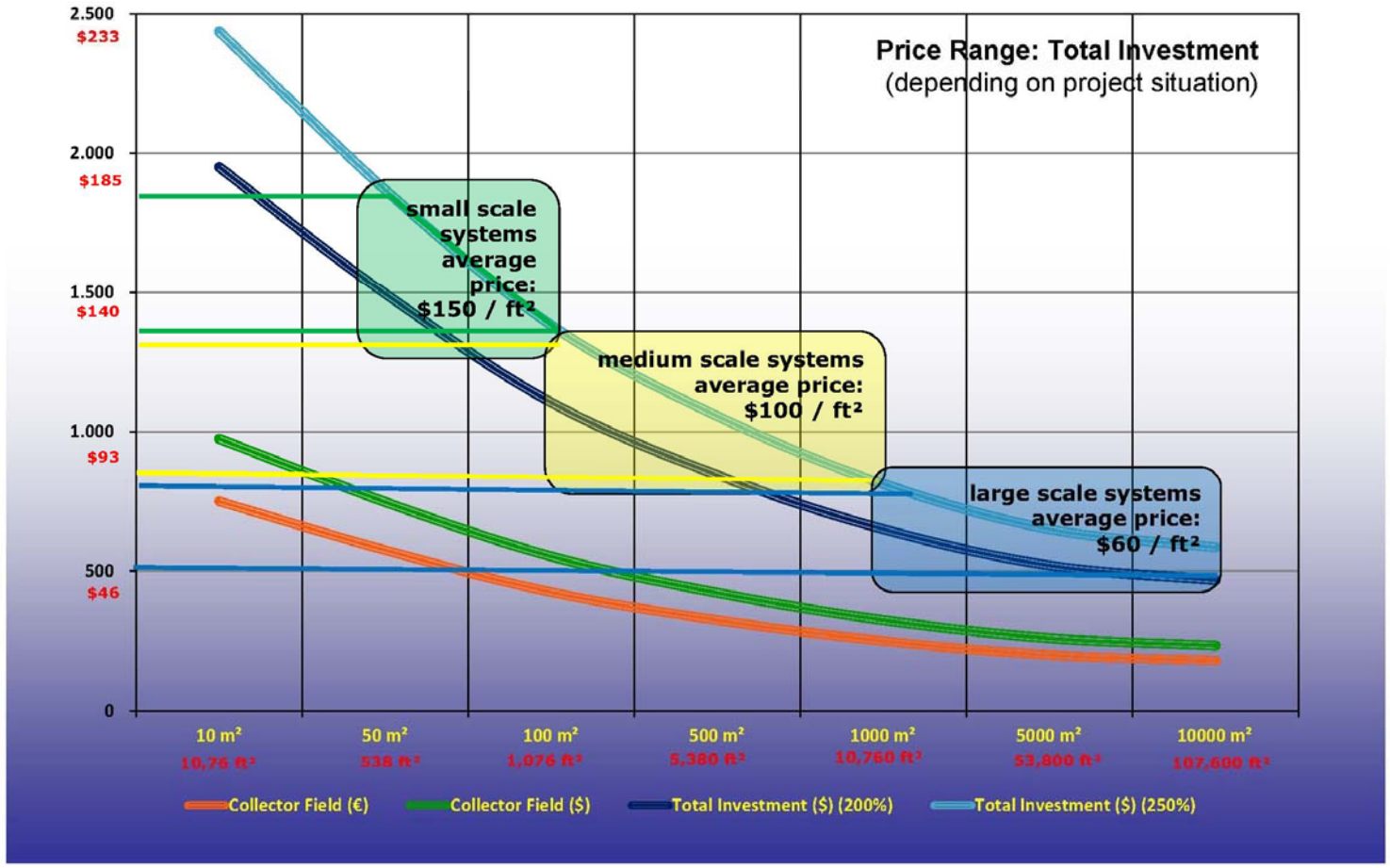
SWH System Scale

SWH System cost Vs. System Size



Energy price based on 3% interest rate and 500 kWh/m^2 annually
All prices are excluding subsidy / grants

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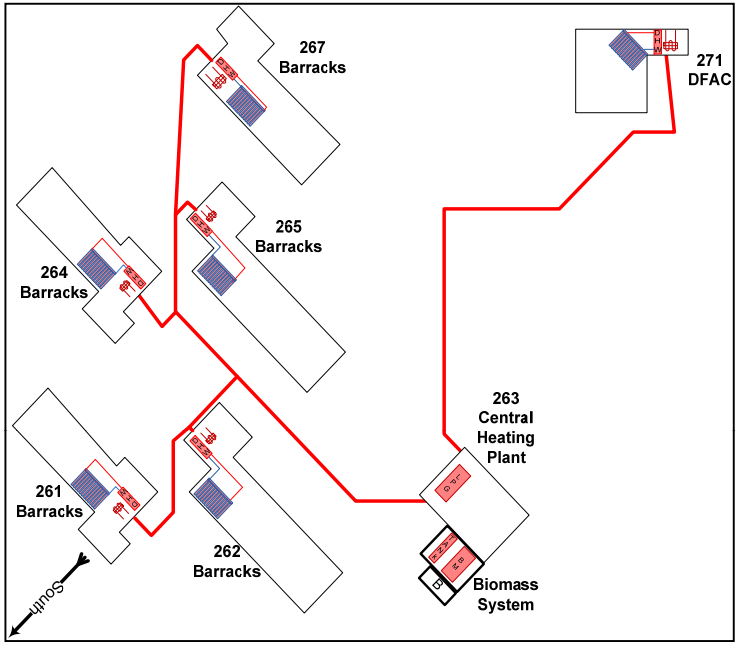
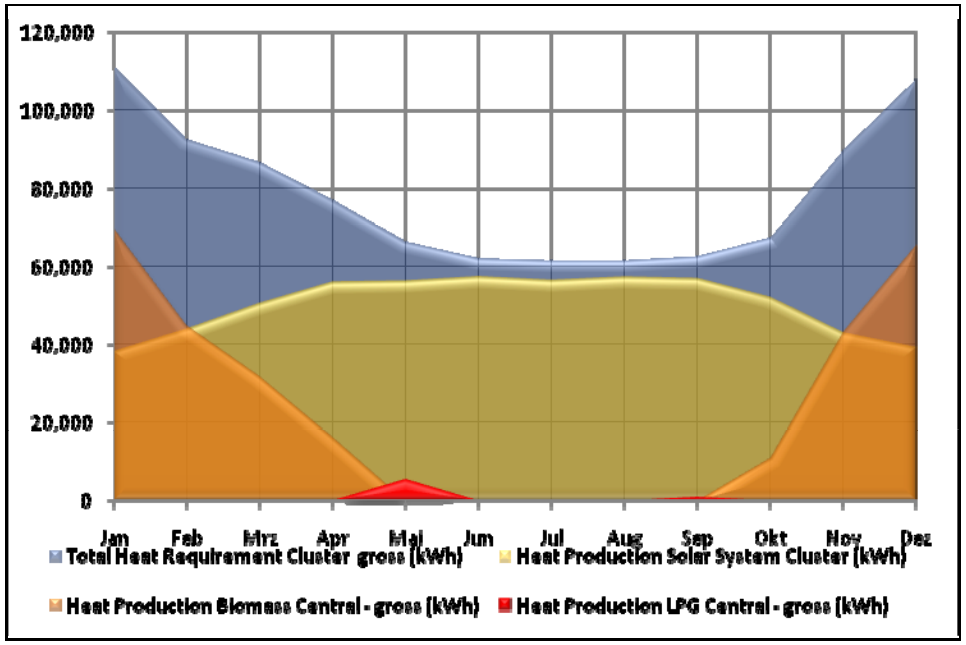
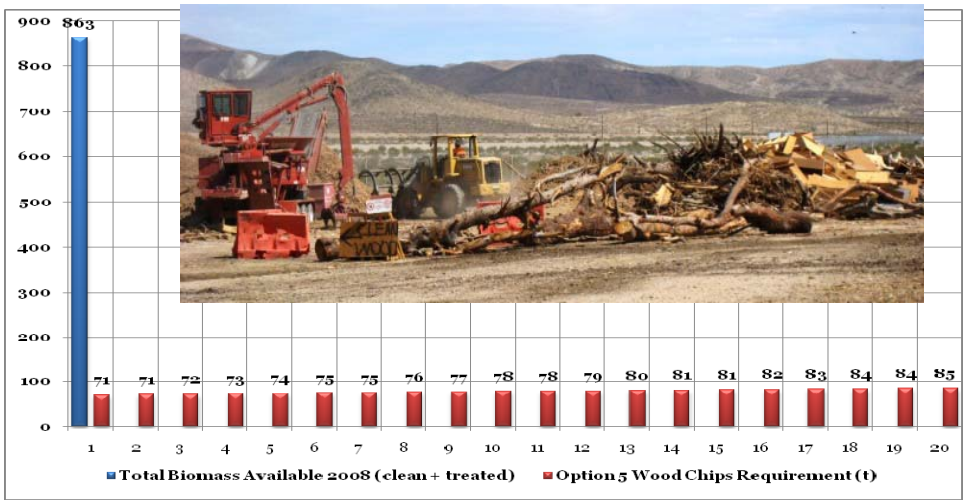
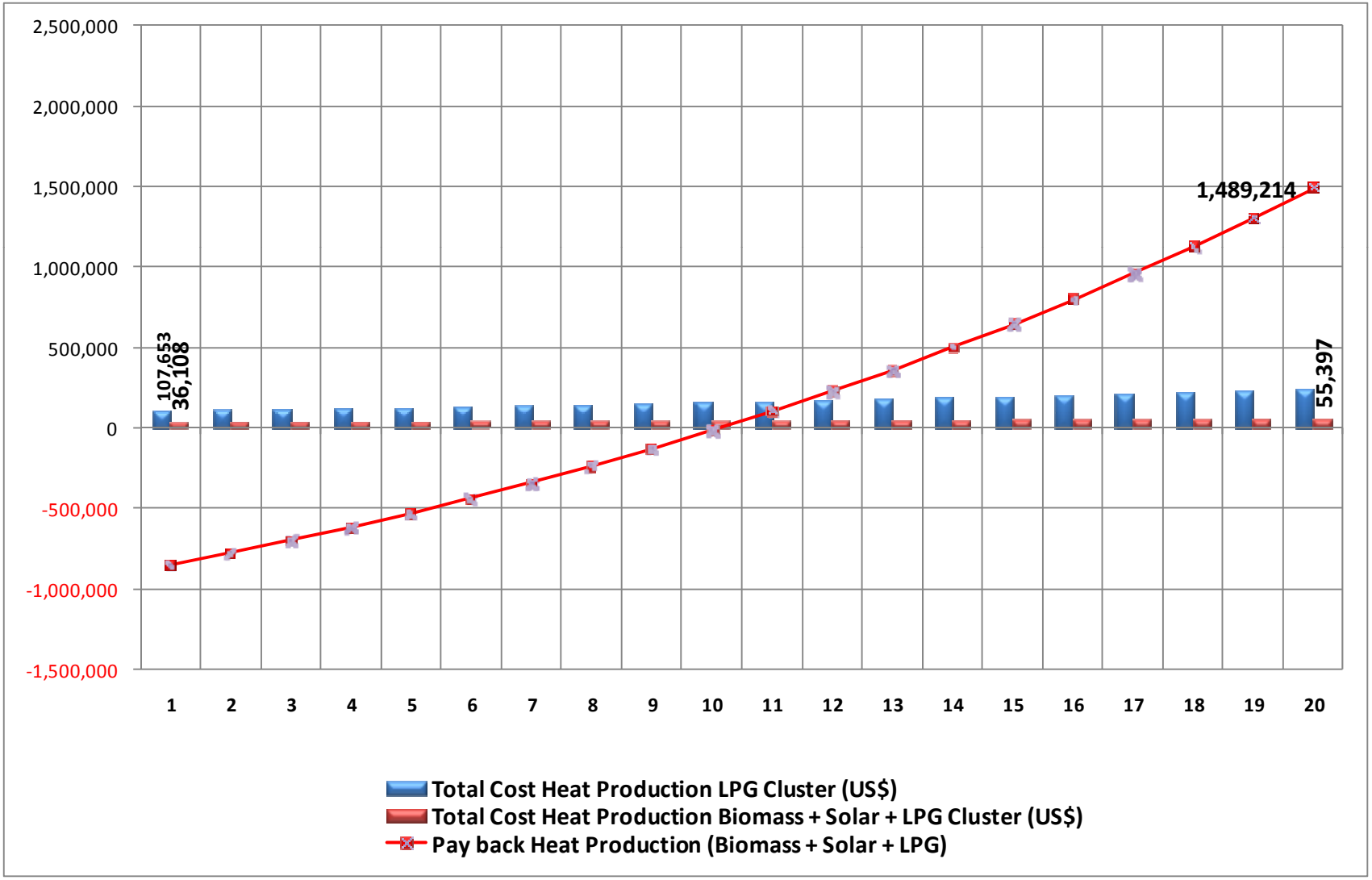
Bldg Upgrade with Radiant cooling, DOAS & EC (Dir & Indir) LPG vs. Bldg Upgrade with Radiant cooling, DOAS & EC (Dir & Indir) Biomass + Solar Thermal Systems + LPG



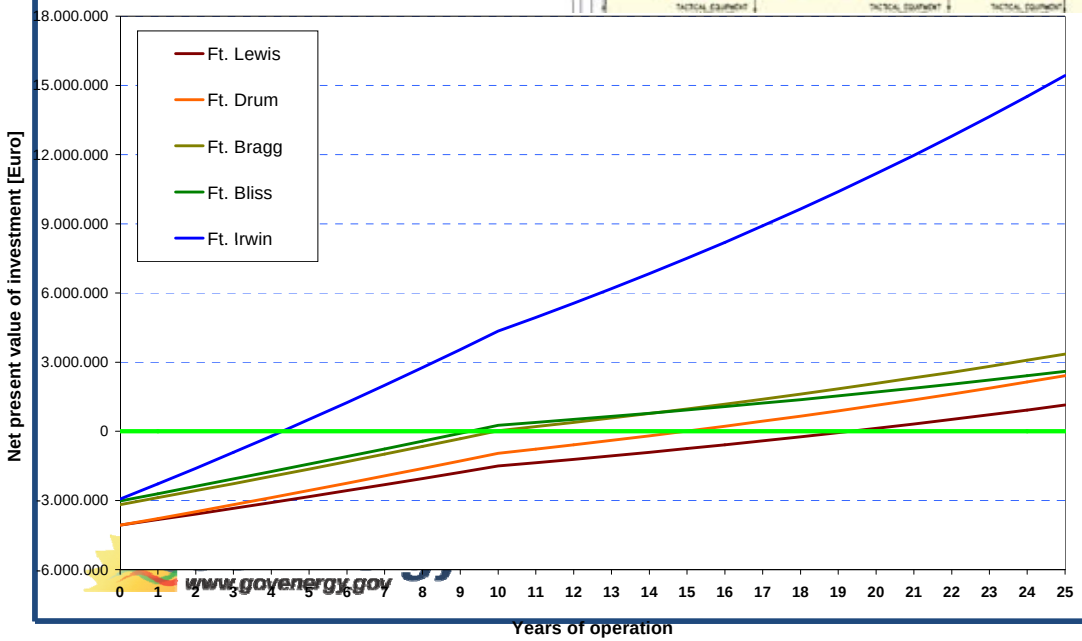




Bldg Upgrade with Radiant cooling, DOAS & EC (Dir & Indir) LPG vs. Bldg Upgrade with Radiant cooling, DOAS & EC (Dir & Indir) Biomass + Solar Thermal Systems + LPG



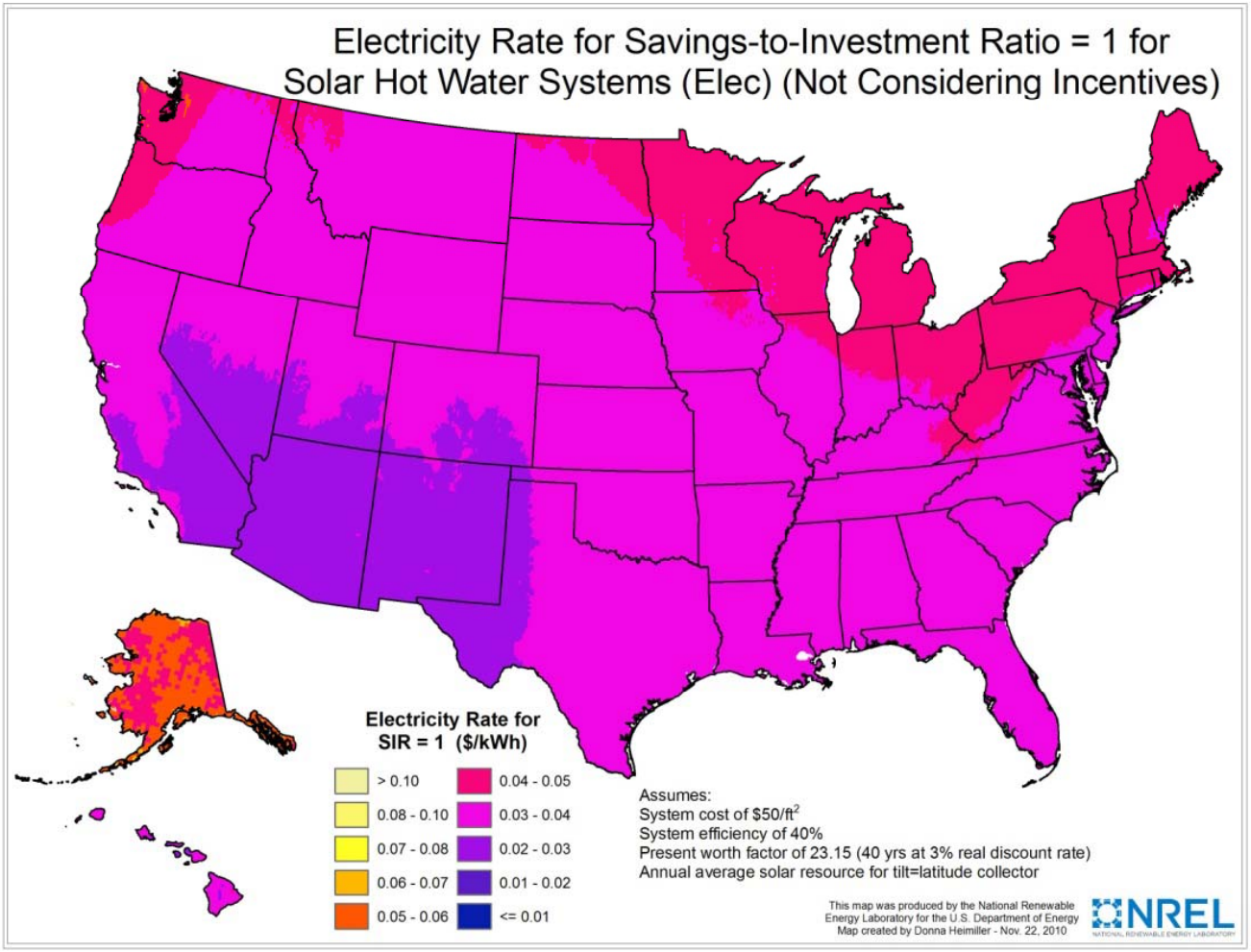
SWH Collector Field Arrangement Options for BCT



NPV of investment considering a discount rate of 0 %

Ft Irwin
Ft Bliss
Ft Bragg
Ft Drum
Ft Lewis

Cost effectiveness of solar hot water systems priced at $50/ft^2 (replacing electrical heating use)



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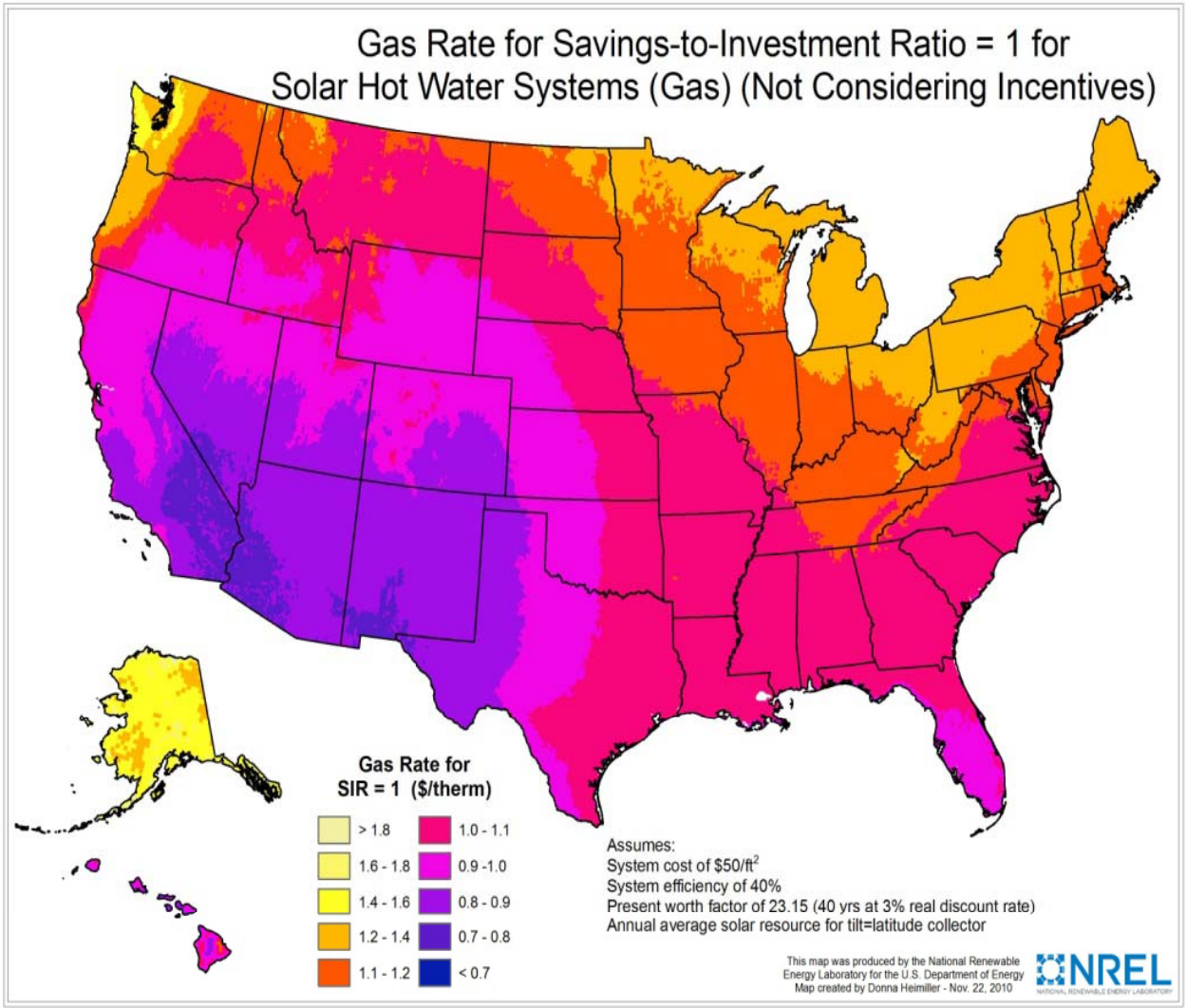
Cost effectiveness of solar hot water systems priced at $50/ft^2 (replacing gas-fired heating use)



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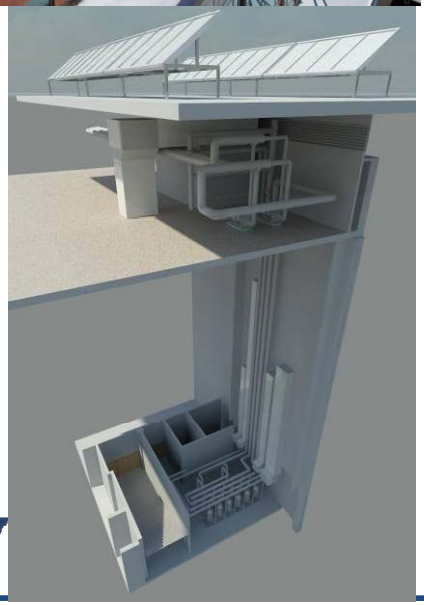
District Energy St Paul, MN

TKDA
ENGINEERING • ARCHITECTURE • PLANNING
The right time. The right people. The right company.

Completion:
March 2011
Project Cost:
$2,000,000



Solar Water Heating system with 144 collectors 20 ft by 8 ft) having 1MW peak capacity are producing hot water for space heating and domestic hot water usage primarily for the St Paul River Centre and sending excess energy to the District Energy heating network. District Energy heats more than 185 buildings and 300 single -family homes (31.1 M ft2) and cools more than 95 buildings (18.8 M ft2) in downtown Saint Paul, MN and adjacent areas. Heating network is connected to a CHP plant fueled by wood chips producing 25 MW of electricity and 65 MW of thermal energy.

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Conclusions

- Problems with aging district steam heating systems: significant O&M costs, energy and water losses, poor temperature control;
- Steam heating systems can either be decentralized or be replaced with variable temperature-variable flow water heating systems;
- District water heating and cooling systems have lower LCC compared to decentralized solutions;
- CHP systems increase efficiency of electricity generation with a waste heat used for heating and cooling;
- Large scale SWH systems connected to district heating systems make SWH systems LCC effective almost everywhere in CONUS and in Hawaii;
- CHP systems can be fuel flexible and can turn the community into NZE when biomass or syngas are used as a fuel.

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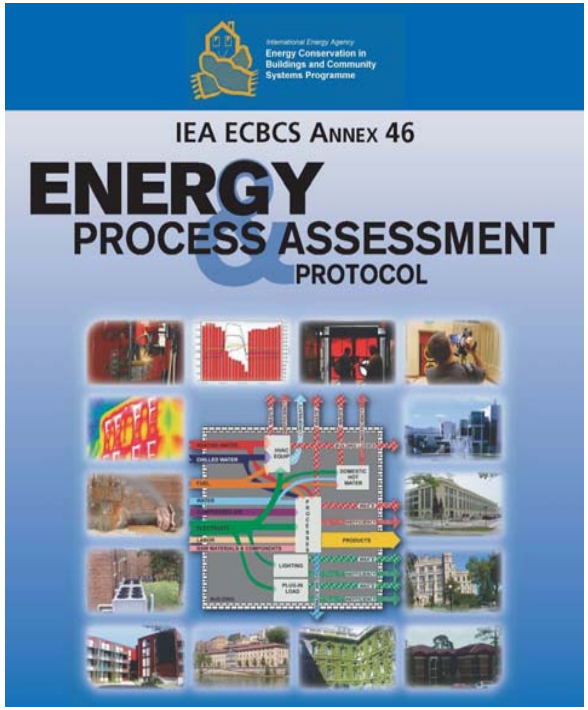
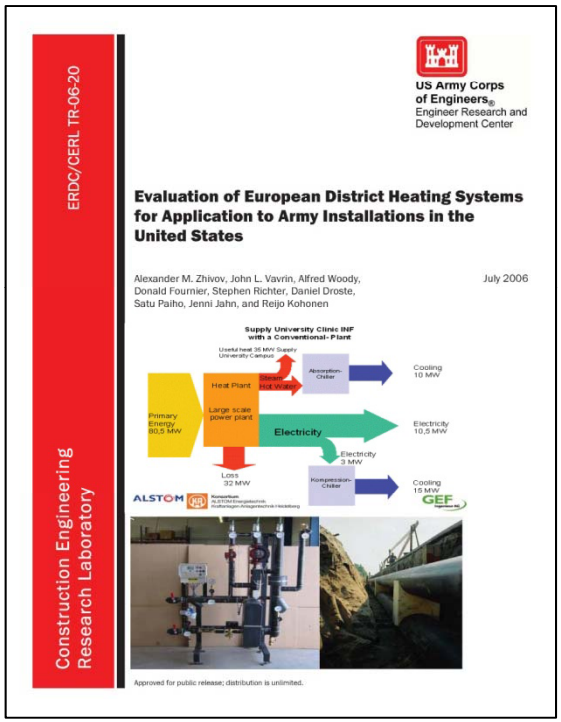
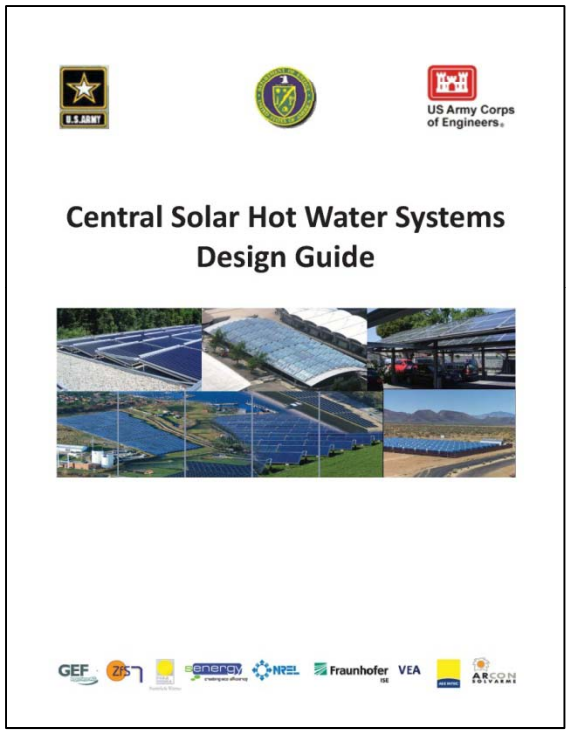
Some References







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Thank you for your attention

Questions??

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