Harvesting Waste Energy and District Energy Systems Under EPA CAA 111.d
EPA Pending Rule CAA, Section 111d

What it Could Mean for Ground Source Heat Pump Systems and Distributed Energy Systems
For our purposes today, to simplify the concepts:

**Exergy** – The energy available at the source vs what gets to the site. (In thermodynamics, the *exergy* of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.)

**Negawatts** – Avoided generation in watts. (e.g. cooling)

**Negabtu** – Avoided generation in BTUs. (e.g. heating energy-switch gas to electric)

**Negaenergy** – Speaking of Negawatts and Negabtus in the same breath.

**GCHP, GLHP, etc.** – our bread and butter

**GSDES** – Ground source distributed energy systems

**WER** – Waste energy recovery.
On June 2, 2014, the U.S. Environmental Protection Agency, under President Obama’s Climate Action Plan, proposed a common sense plan to cut carbon pollution from power plants.

- Nationwide mandate to cut Carbon (CO$_2$) emissions by 30 percent from 2005 levels by 2030.
- The EPA’s target is the generating industry but places the burden for implementation on the states.
The original reaction of a significant number of States and Legislators was:

1. The US could lose (up to) 200,000 jobs.
2. Compliance would cost the industry in excess of $50 billion.

Fortunately, there is a way to make lemonade out of these lemons.
Although the target is the generating industry and, in particular, inefficient coal fired plants, the plan places the burden of action on the States or group of States.

The metric:
- pounds of carbon (CO$_2$) per megawatt hour (#/MWh)
- or –
- pounds CO$_2$ per kilowatt hour (#/kWh)
The EPA believes that by focusing on Carbon, all other related pollutants will also be reduced, including pm 2.5 emissions.

For example:
The national average for CO$_2$ emissions is 1.44 #CO$_2$/kWh.

Utah is one of the dirtier states (#19) with a 2012 metric of 1.874 # CO$_2$/kWh.

Utah’s target for 2030 is 1.322 # CO$_2$/kWh.
The EPA, in an unprecedented move, gave the States the flexibility to meet the CO$_2$ reduction goal:

- States get to decide when individual power plants must make reductions.
- States can choose to participate in multi-state programs that already exist or may create new ones.
- States that have already invested in energy efficiency (EE) programs and Renewable Energy will be able to build on these programs to help make progress toward meeting their target. (Building Block #3)
AND:

Building Block #3 – Recognizes the capture and use of Renewable Energy.

Building Block #4 of the new Rule….

States can reduce emission rates by including avoided generation that results from projected energy efficiency (EE) improvements.

These improvements are called “demand side” improvements.
Some of the measures states can choose to rely on in their plans include, but are not limited to:

- renewable energy standards
- expanding renewables
- demand-side energy efficiency programs
- energy storage technology
- energy conservation programs
- market-based trading programs

A perfect fit for GSHP and GCHP based distributed energy systems (GC-DES)?
What does that mean for what ASHRAE calls “The Built Environment”?

ASHRAE Fundamentals Handbook Chapter 34, Nonrenewable and Renewable Energy Resources: (Building Block #3)

“Geothermal energy for heating and cooling buildings is a renewable resource. To quantify this source of renewable energy, one must measure or calculate the electric or thermal energy that is either generated from, or avoided by, use of the geothermal resource. ... Geothermal heat pumps (GHPs) also utilize these sources albeit in a more complex, indirect fashion... (quantification may be required for renewable portfolio standards, utility programs, etc.)”

AND

Recognizes Waste Energy Recovery (WER) as a valuable tool to increase SYSTEM efficiency.
The Elusive “Negawatt”

**Negawatt Power** (Lovins 1989) -
• A theoretical unit of power representing an amount of energy (measured in watts) saved as a direct result of energy conservation or increased energy efficiency.

**Negawatt Market** –
• A negawatt market is a secondary market in which saved energy is allocated from one consumer to another consumer.

• **Negawatts could be traded as a commodity across time and space.**
Avoided Generation:

- A method of calculation that permits the quantification of avoided emissions at a point source or the site.

- The quantity of energy, expressed in BTUs or power (kW), that is not needed...

Reduced combustion in BTUs, by virtue of the avoided emissions, may be converted to kW or other units of energy.
Conventional Throw-away Energy
“Negawatts” from Waste Energy Recovery

• Energy recovered and reused in the process of heating and cooling buildings that the user would normally discard.

• Calculated in Kilowatt hours (kWh) or British Thermal Units (BTU)

• An estimate may be made of:
  • resource consumption avoided (e.g. electricity, hydrocarbon fuel, water)
  • emissions avoided (CO$_2$, PM 2.5)

• ASHRAE research proposal – Quantify renewable energy of GSHP in Cooling and develop a standard methodology to quantify WER.
What this means to the GX Industry

**Heat Pump** – A device used to move energy in an HVAC system.

**Ground Source Heat Pump** – a device used in an HVAC system to move energy and utilize energy stored in the ground.

**Vertical and Horizontal Closed Loop System** – GX systems that enable the recovery and storage of energy in and from the ground.

**GSHP System** – An HVAC system that permits recovery of native ground energy and the storage and recovery waste energy stored in the ground.

**Ground Coupled District Energy System (GCDES)** – An HVAC system that permits the movement and storage of energy from building to building using the earth as a battery or capacitor and enabling the sharing of waste energy.

GSHP systems and GCDES are perhaps the most effective and most efficient systems to implement in any State-initiated Building Block #4 Program under EPA Rule 111d.
Heat Pumps, WER, and Air Quality

Heat Pump / WER systems Improve Air Quality by reducing and/or eliminating…

- Site combustion for heating
- Emissions from generation and transmission losses
- Site evaporated water
- Cooling tower emissions (drift, pm 2.5/10)
- Reusing/storing thermal energy reduces “thermal emissions” / “heat island”

Large, diverse WER systems maximize SYSTEM EFFICIENCIES.

Higher SYSTEM EFFICIENCIES (COPs) magnify these Air Quality benefits.
Heat Pumps, WER, and Water

On Site

• 1/3 of site water is often consumed by the cooling tower(s)
  • FYI: In our climate a small high school will consume 600 gallons per hour when the tower is running.
• Balanced WER / GSHP-thermal storage systems can eliminate cooling tower water
• Even hybrid systems can reduce cooling water by 70%

At The Power Plant

• 41% of U.S. freshwater use is power plant cooling (USGS)
• Reductions in demand, & generation/transmission losses reduce power plant cooling water.

• DYK?: 3X flow of Niagara Falls is consumed by U.S. power plants - per minute!

-Union of Concerned Scientists
The water loop connects all the heat pumps in a building, and connects buildings to each other.

Heat pumps “cooling” add energy to the loop.

Heat pumps “heating” remove energy from the loop.

Energy can be harvested, moved, and reused!
Geothermal District Energy System
Operational Strategy

Stage 1: Heat Pumps – Share energy within each building
Stage 2: Central Loop – Shares energy among buildings
Stage 3: Ground Loop – Balance energy to/from the Earth
Stage 4: Hybrid – Utilize boilers / fluid coolers / solar thermal

We call this the “Least Energy Path”
Stage 1: Heat Pumps
Share Energy Within Each Building

With heat pumps, “loads” become a resource.

*Harvest, Move, Reuse!*
Stage 2: Central Loop
Shares Energy Between Buildings

Buried piping connects buildings.

Variable speed pumps adapt to loads via temperature controls.

Circulate Central Loop, to/from buildings, borefields as needed.
Diversity maximizes utility of shared resources:

- Building uses – residential, office, commercial, etc.
- Occupancy schedule
- Heating vs. cooling dominant buildings
- Domestic hot water
- Tie in non-HVAC loads – ice making, refrigeration, pools

Campuses, military bases, mixed use developments, industrial, co-located facilities, cities...
Balancing Energy Sources / Sinks
Stage 3: Geo Borefields
Balance Energy To/From the Earth

As GHEX $\Delta T$ increases, heat moves to or from the surrounding earth.

**Summer - Cooling**

**Winter - Heating**
Stage 4: Hybrid
Utilize Conventional Components For Peaks

Boilers add heat to the loop.

Cooling Towers or fluid coolers reject heat from the loop.

*Amount of hybrid use is a design choice, often 5-10% of annual hours.*
Stage 1 – building moves energy internally using building pumps.

Thermal/Energy Storage

Stage 3 – Central Loop calls Borefield (hot or cold).

<50F or >85F

Stage 1 & 2 represent WER

Central Loop 50F to 85F

Stage 2 – building(s) move energy to or from the central loop.

Stage 4 – Central Loop calls Boiler or Fluid Cooler (hot or cold).

LAST RESORT: Throw-away energy

<40F or >90F
Now let’s introduce a way to start to quantify the magnitude of the contribution of WER.

SYSTEM COP is the most valid way to compare competing systems.

Consider two systems operating at their respective peaks.
### HVAC System Cooling Efficiency Calculator (Reference: HVAC Simplified, ASHRAE, 2006)

#### Item

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Enter Data by Clicking Here</th>
<th>Enter Data in Cells Below OR Enter Compressor Below</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Chiller or Compressors</td>
<td><a href="https://example.com">Click Here for Explanation</a></td>
<td>Enter Chiller Data in Cells Below</td>
</tr>
<tr>
<td>Qty.</td>
<td>kW/ton</td>
<td>Tons</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>500</td>
</tr>
</tbody>
</table>

| 2a Air Handling Unit Fans (1.0 hp and larger) | [Click Here](https://example.com) | --- |
| Air Flow (cfm) | TP (in. wtr) | η fan (%) | η mtr. (%) | η VSD (%) | kW-each | kW-total | kBtu/ton | tons |
| 5 | 40000 | 5 | 75.0% | 92.0% | 100.0% | 41.99 | 34.05 | 170.3 | -580.9 |

| 2b DX Coil, Water Coil, or VAV Fans (<1.0 hp) | [Click Here](https://example.com) | --- |
| Air Flow (cfm) | TP (in. wtr) | η fan (%) | η mtr. (%) | η VSD (%) | kW-each | kW-total | kBtu/ton | tons |
| 200 | --- | --- | --- | 75.0% | 100.0% | 0.2 | 0.25 | 49.7 | -169.7 |

| 3 Return Air Fans | | --- |
| Air Flow (cfm) | TP (in. wtr) | η fan (%) | η mtr. (%) | η VSD (%) |
| 5 | 35000 | 2 | 75.0% | 92.0% | 100.0% | 14.7 | 11.92 | 59.6 | -203.3 |

| 4 Chilled Water Pumps | | --- |
| Wtr. Flow (gpm) | ΔH (ft. wtr) | η pump (%) | η mtr. (%) | η VSD (%) |
| 2 | 600 | 100 | 75.0% | 90.0% | 100.0% | 20.2 | 16.75 | 33.3 | -114.2 |

| 5 Condenser (Ground loop) Water Pump | | --- |
| Wtr. Flow (gpm) | ΔH (ft. wtr) | η pump (%) | η mtr. (%) | η VSD (%) | --- | --- | --- | Click Here |
| 2 | 75 | 100 | 75.0% | 90.0% | 100.0% | 25.2 | 20.93 | 41.9 | --- |

| 6 Condenser (or Fluid Cooler/Cooling Tower) Fan | | --- |
| Air Flow (cfm) | TP (in. wtr) | η fan (%) | η mtr. (%) | η VSD (%) | kW-each | kW-total | kBtu/ton | tons |
| 0 | --- | --- | --- | 75.0% | 100.0% | 0.00 | 0.00 | 0.00 | 0.00 |

### System Totals

- kW/ton: 1.47
- EER: 8.2
- Btu/W-h: 411.0
- COP: 2.39

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Calculate system COP:
Measuring System Efficiency under Rule 111d

- **Box** COP and EER are very poor ways to measure efficiency.
- **Box** COP/EER lead to a false sense of accomplishment and may not stand up under EPA scrutiny.

We Suggest: Calculate **System** COP/EER to accurately measure the energy efficiency of a building.

Thanks to: Nina Baird, Adjunct Assistant Professor, Carnegie Mellon University—PhD candidate: Building performance and Diagnostics
The proposed rule requires that state plans submitted to EPA demonstrate that emission performance standards are “quantifiable, non-duplicative, permanent, verifiable, and enforceable.”

Carbon intensity is going to be a key factor in determining the value of WER.

The WER component of this system is the “least cost” and highest benefit because only an addition of pumping energy could magnify the thermal efficiency of the system by several hundred percent.

Adding a ground loop permits this energy to be used at a time determined by the system manager.
**SYSTEM EFFICIENCY**

Two *Independent* Buildings 500 tons each

Office Building – Chiller/Tower

Hot Water Load - Boiler

Maximum Cooling Load

- Perimeter Units
- Core Units
- Pump On
- Boiler Off
- Cooling Tower On

Maximum Heating Load

- Perimeter Units
- Core Units
- Pump On
- Boiler On
- Cooling Tower Off

**kW/ton** = 3.0  
**EER** = 4.0 Btu/W-h  
**COP** = 1.17
SYSTEM EFFICIENCY
District Energy System - Two Buildings 500 tons each
Coincidental Connected Loads

Office Building - WSHP

Maximum Cooling Load

Hot water load - WSHP

Maximum Heating Load

kW/ton = 0.71  EER = 16.9 Btu/W-h  COP = 4.96
Shed 100 kW and 7.14MM BTU/h NG
7.14 decatherms/h = 293 kWh
SYSTEM EFFICIENCY
District Energy System - Two Buildings 500 Tons Each
Non-Coincidental Connected Loads

Add Ground Heat Exchanger / Thermal Storage

Office Building - GSHP
Maximum Cooling Load

Hot water load - GSHP
Maximum Heating Load

kW/ton = 0.75  EER = 16.0 Btu/W-h  COP = 4.68
Reduces peak savings slightly but increases WER hours per year.
In short:

1. GX should always have a lower carbon footprint than ASHPs.
2. The more efficient a system, the lower the carbon footprint.
Heating is a bit more complicated because we actually increase the use of electricity. The higher the average System COP, the more states in which a GSHP has a lower Carbon footprint than a 90% AFUE gas furnace.
Waste Energy Recovery – Heat Pump Alchemy
Heat Pumps vs 90% AFUE Natural Gas

- 14 EER or 4.5 COP
- 14,666 BTU/h Heat of rejection
- 12,000 BTU/h Cooling

Input energy + work for DHW:
14,666 BTU/h + 4,889 BTU/h = 19,555 BTU/h

NG Input Energy – HP Work =
21,728 BTU/h – 4,889 BTU/h = 16,839 BTU/h WER or Negabtu/h or 4,935 Negawatts/h

Input NG Energy:
19,555 BTU/h / .9 AFUE = 21,728 BTU/h
Natural Gas: The Exergy Story Revised 2014

Input NG Energy
19,555 BTU / .9 AFUE
= 21,728 BTU

Is this the correct amount to calculate CO₂ emissions? What’s missing?

The EXERGY part of the equation.

“…there is such a glut of shale gas that a lot of it is being flared off…

Methane, the main component of natural gas, is an atmospheric nightmare. Its potency for global warming is estimated to be at least 20 times greater than carbon dioxide's…” Globe Advisor, The Glaring Threat From Shale 1-31-2014

“In the PHMSA database, which lists more than 1,400 gas companies, 72 companies reported lost and unaccounted for rates of 10 percent or higher. Two-hundred-and-seventy-five companies had a rate between 3 and 9.9 percent.” This does not account for NG lost at the production site or un-burned and "up-the-stack”. Scientific American, “How Much Gas Leaks?”, August 1, 2013

Natural Gas Leaking:

2 – 3% at the wellhead
2-4% transmission loss
1 – 2% at the boiler stack
2% - ? Flared (burned) at the production location

10% loss is considered appropriate but the jury is still out!
Lost Natural Gas - CO$_2$ and CO$_2$ Equivalent

- The national average of electricity CO$_2$ emission is 1.44# CO$_2$/kWh (EXERGY) Congressional Research Service, Proposed Rule 111.d

- 1MM BTU of Natural Gas combustion = 117# of CO$_2$

- The lost NG (Methane) is the ugly part

Pound for pound, Methane is 21 times more damaging than # CO$_2$.
- 10% wellhead loss is 4.17# of METHANE/MM BTU or 87.6 #-equivalent # CO$_2$.

To deliver 1MM BTU of NG to the site is 204 # equivalent # CO$_2$
Remember:
1. 90% AFUE Furnace (alternative system) net cost is 21,728 BTU/h
2. Energy Needed to Use the waste energy is 4,889 BTU/h or 1.43 kWh

WER
Carbon Emission penalty for our WER system is:
1.44# CO₂/kWh x 1.43 kWh = 2.06 # CO₂/kWh

The (EXERGY) CO₂ emission penalty of the 90% AFUE natural gas furnace is:
Fuel burned on site + the 10% METHANE leakage.
21,728 BTU\text{site-use} = 4.43 # CO₂/kWh equivalent

53% lower
CO₂ EMISSIONS COMPARISON - 2000 SF HOME GAS CO₂ TO WELL (COMBINED HEATING & COOLING)

Assumptions:
- Avg. local COP & EER (Climate)
- State carbon intensity (#CO₂/kWh)
- EWT 32-90°F
- Tight construction

State Carbon Intensity:

- SEATTLE: 1.831#/kWh, 3.9 COP, 18.9 EER
- LAS VEGAS: 0.988#/kWh, 4.1 COP, 16.7 EER
- SALT LAKE CITY: 0.736#/kWh, 3.8 COP, 19.3 EER
- JACKSON HOLE: 2.115#/kWh, 3.7 COP, 16.7 EER
Gas emissions calculated back to the wellhead.

COP = 3
How Does All of This Effect Us As Designers?

- The loopfield gives us the ability to store waste energy and use it at a different time.

- **SYSTEM efficiency** will most likely be the metric used to value the actual value of waste energy recovered.

- Accurate measurement and verification will be the key to getting credit for avoided generation thus the Carbon reduction.

- The EPA’s State Carbon Intensity will dictate minimum system COP necessary to count Nega-Energy.
“The fourth building block reduces state emission rates by including avoided electricity generation that results from projected demand-side energy efficiency (EE) improvements.”

This is the Door For GSHP and GCWER Systems. Ground coupled Waste Energy Recovery offers huge potential to help address CAA 111d targets.

Call to Action.

1. Include GSHP in the State plan
2. Include WER in your State plan.
3. Help level the playing field with alternate fuels.
   Watch for more on potential EPA action on methane emissions from natural gas and be ready if action is needed.

GET INVOLVED WITH THE DEVELOPMENT OF YOUR STATE’s PLAN.
You also may want to caution the audience about the proposed rule facing legal challenges and potential congressional challenge, but that state action may be moving forward anyway just because of the timeframe so better to be proactive and get with your state.

Expected final rule in mid-2015 with state plans due as follows:
• June 30, 2016 – Initial plan or complete plan due
• June 30, 2017 – Complete individual plan due if state is eligible for a one-year extension
• June 30, 2018 – Complete multi-state plan due if state is eligible for two-year extension (with progress report due June 30, 2017)

BTW: See page 50 of State Plan Considerations Technical Support Document where they talk about avoided transmission and distribution losses related to electricity.

Also, EPA may go after methane losses at wellheads and through distribution system, but I think they are weighing their options and legal authority.
Sound Geothermal Corporation
801-942-6100
www.soundgt.com

Cary Smith
dcsmith@soundgt.com

Questions?

www.epa.gov
http://www.pnas.org/content/109/17/6435.full

http://www.edf.org/methaneleakage


http://www.edf.org/sites/default/files/AWMA-EM-airPollutionFromOilAndGas.pdf

Additional Information:
Google:
• Methane emissions
• Environmental impact of methane
Cornell University, Howarth Study