Putting CO₂ to Work

Charlie Stephens
Northwest Energy Efficiency Alliance
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Going forward, HFC emissions are projected to grow by nearly 140% between 2005 and 2020 as demands for refrigeration continue to grow and as more ozone-depleting substances are replaced.

HFC Refrigerants Matter

Overall, fluorinated gas emissions in the United States have increased by about 73% between 1990 and 2013. This increase has been driven by a 250% increase in emissions of hydrofluorocarbons (HFCs) since 1990.
Phase-outs are Imminent

- Europe is phasing out HFC refrigerants now
  • Depending on end use, phase-out will occur from 2017 through 2022.
  • Many manufacturers (automotive, commercial refrigeration) are choosing CO$_2$ and/or propane as their new refrigerant.

- U.S. is a couple of years behind Europe
  • But some markets are moving now (e.g. CARB proposal for R-410a phase-out by 2022, Whole Foods).
Refrigerant GWPs

- **R-410a** (small hvac, HPWH): 2,030
- **R-134a** (auto AC, ref/frzrs, HPWH): 1,430
- **R-404a** (groc. & conv. store refriger.): 3,920
- **R-507a** (commercial refrigeration): 3,990
- **R-32** (proposed replacement for R-410a): 675
- **R-290** (Propane): 3
- **R-744** (CO₂; auto AC, hvac, refriger., HPWH): 1
Relevant End Use Equipment

- Water heating/chilling (air-to-water heat pump, R-744 / R-290)
- Space heating/cooling (air-to-water heat pump, R-744 / R-290)
- Grocery store refrigeration (packaged and rack-based; R-290, R-744, cascade systems using more than one refrigerant, including ammonia)
- Vending machines (R-744, R-290, R-600a)
# CO₂ as an Alternative

## Heating

### CO₂ Heat Pump Warm Water Room Heater Specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>Form</th>
<th>EDS-C110A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase/Voltage/Hz</td>
<td>-</td>
<td>200V 50/60Hz</td>
</tr>
<tr>
<td>Design Heating Capacity (1)</td>
<td></td>
<td>3.5kW</td>
</tr>
<tr>
<td>Power Consumption (1)</td>
<td></td>
<td>0.80kW</td>
</tr>
<tr>
<td>Energy Efficiency (1)</td>
<td>-</td>
<td>COP 4.3</td>
</tr>
<tr>
<td>Heating Capacity (2)</td>
<td></td>
<td>11.0kW</td>
</tr>
<tr>
<td>Max Power Capacity (2)</td>
<td>-</td>
<td>4.0kW</td>
</tr>
<tr>
<td>Drainage Prevention Heater</td>
<td></td>
<td>0.1kW</td>
</tr>
<tr>
<td>Operating Noise</td>
<td></td>
<td>47dB</td>
</tr>
<tr>
<td>External Dimensions</td>
<td></td>
<td>1280×828×283mm (excluding fin)</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>98kg</td>
</tr>
<tr>
<td>Refrigerant</td>
<td></td>
<td>R744 (CO₂)</td>
</tr>
<tr>
<td>Design Water Temp.</td>
<td></td>
<td>45°C to 70°C in 3 steps (variable)</td>
</tr>
<tr>
<td>Dim Water Connection Fitting</td>
<td></td>
<td>R3/4</td>
</tr>
</tbody>
</table>

※1. Outdoor temp: 20°C / Indoor temp: 20°C / Water temp: 20°C
※2. Outdoor temp: 5°C / Indoor temp: 5°C / Water temp: 20°C

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## Refrigeration

![Hillphoenix Ramps Up Critical Production](image)
Natural Refrigerant Energy Savings

**Heating (CO₂)**
- High COPs (4.0 – 6.0)
- Cold-climate capable (down to -25F OAT)
- Can make very hot water (up to 195 F)
- Split system, so no impact on indoor environment
- High system pressures (~1,450 psi)
- Energy storage

**Cooling (R-290)**
- Modestly to much better efficiency (20-30% better than HFC-based systems)
- Non-transcritical CO₂ systems not so capable at very high ambient air temperatures (above 80F); R-290 should fill this gap
- Typically packaged systems
- More modest system pressures (~400 psi for propane and non-transcritical CO₂)
Climate-Responsive Space & Water Heating
Work in Which NEEA is a Partner

- Extensive lab testing of packaged and split CO$_2$ DHW systems (2013 – 2014)
- Field tests of 4 split CO$_2$ DHW systems (late 2013 to present; one 8,800 DD site in Montana)
- Field tests of 9 combined space & water heating systems (CO$_2$ split systems, late 2014 to present)
- Lab & field tests of new 11 kW (35 kBtu/hr) combined space & water heating systems (2016/17)
- Investigation of grocery refrigeration system conversion (Whole Foods, Target) (2016/17)
HPWH Performance

kWh per 100 gallons water delivered

Note: Performance for CO₂ sites is for cold weather months only; other sites are annual.
Efficiency

![Graph showing efficiency of different systems](image-url)
Performance vs. Temperature

- Linear fit of EF to temperature
- Use TMY temperature bins to calculate an annual EF:

<table>
<thead>
<tr>
<th>Outside Air Temperature (F)</th>
<th>Energy Factor (EF)</th>
<th>COP</th>
<th>Output Capacity (kW)</th>
<th>Input Power (kW)</th>
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</thead>
<tbody>
<tr>
<td>17</td>
<td>1.74</td>
<td>2.1</td>
<td>4.0</td>
<td>1.9</td>
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<tr>
<td>35</td>
<td>2.21</td>
<td>2.75</td>
<td>3.6</td>
<td>1.3</td>
</tr>
<tr>
<td>50</td>
<td>3.11</td>
<td>3.7</td>
<td>4.0</td>
<td>1.1</td>
</tr>
<tr>
<td>67</td>
<td>3.35</td>
<td>4.2</td>
<td>4.1</td>
<td>0.97</td>
</tr>
<tr>
<td>95</td>
<td>4.3</td>
<td>5.0</td>
<td>4.6</td>
<td>0.93</td>
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</table>

y = 0.0331x + 1.1958

<table>
<thead>
<tr>
<th>Climate</th>
<th>Annual EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boise</td>
<td>2.9</td>
</tr>
<tr>
<td>Kalispell</td>
<td>2.6</td>
</tr>
<tr>
<td>Portland</td>
<td>3.0</td>
</tr>
<tr>
<td>Seattle</td>
<td>2.9</td>
</tr>
<tr>
<td>Spokane</td>
<td>2.8</td>
</tr>
</tbody>
</table>
1.25-ton SanCO$_2$

- UL-listed
- Two tank sizes (40-, 80-gal)
- Became available July 2016

$\ast$

- Can be used in a combined space & water heating system, but heating loads must be small

* Now eligible for utility incentives in the PNW!
3-ton Eco Runo

- Completed lab-testing phase
- Configured for space heating
- Can do sidearm water heating
Combined System Configuration

Hydraulic Separator

Sanden Outdoor Unit

DHW

Hot DHW to House

Cold Water Supply to DHW

Hydronic AHU
Field Performance – 1.25-ton

Click and drag in the plot area to zoom in.
Field Performance – 3-ton
Controls
Next Steps

- Install 6 forced air combined systems & monitor for 15 months
- Complete new test & rating procedures
- Acquire 4-ton systems for combined heating, cooling & DHW
  - Low-pressure stage likely to use R-290 (chilled water and first stage hot water)
- Develop a program for replacing electric forced air and electric resistance water heating in existing homes
Thank you!

Charlie Stephens
cstephens@neea.org