

Heat Pumps and Climate Change

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|---|------|
| Best case carbon savings by changing from propane furnace to efficient heat pump | 18% |
| Carbon savings by changing from propane furnace to small heat pump | -36% |
| Carbon savings by changing from oil furnace to heat pump with no fugitive emissions | 40% |
| Carbon savings by changing from oil furnace to heat pump with fugitive emissions | |

| Item | Value |
|------|-------|
|------|-------|

Annual Emissions from Most Efficient Size of Single Zone Heat Pump

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|---|--------------|
| Single Zone Heat Pump Efficiency | 7.53 - 12.47 |
| Heat Pump Efficiency (efficient single zone heat pump) | 7.53 |
| Heat Pump Efficiency (less efficient single zone heat pump) | 12.47 |
| Heat Pump Annual Electricity Consumption | 3.78 |
| Marginal Emissions Rate of ISO-NE | 905.00 |
| Annual CO ₂ Emissions from One Heat Pump | 3420.90 |
| MMBtu delivered annually | 28.47 |
| Fugitive emissions of methane | 1.4% |

Annual Emissions from Oil Furnace producing Same Heat

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|---|---------|
| BTUs per gallon #2 heating oil | 138,500 |
| Furnace efficiency | 80% |
| Gallons per year of oil to provide same BTUs as heat pump | 256.92 |
| Heating Oil carbon content | 161.30 |
| Heating Oil Emissions is used instead of heat pump | 5739.66 |
| Heat Pump direct emissions savings | 40% |

Annual Emissions from Propane Furnace producing Same Heat

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|--|--------|
| CO ₂ emissions from propane | 139.05 |
|--|--------|

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|---|----------|
| Propane furnace efficiency | 95% |
| Annual CO ₂ emissions from propane furnace equal to heat pump | 4,166.67 |
| Carbon savings by converting from propane furnace to most efficient heat pump | 18% |
| Annual CO ₂ emissions from less efficient heat pump | 5,664.44 |
| Carbon savings by converting from propane furnace to less efficient heat pump | -36% |

Statewide Energy Calculations

Distillate Fuel Oil

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|---|------------|
| Residential sales of distillate fuel oil 2020 | 79,600,000 |
| MMBTUs in VT distillate fuel oil sales | 11,024,600 |
| MMBTUs delivered | 8,819,680 |
| Heat pumps to displace distillate oil | 309,821 |
| Energy required | 1.17 |

Natural Gas

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|--|------------|
| Natural gas consumption 2020 | 13,056 |
| BTUs per cubic foot of natural gas | 1,037 |
| MMBTUs in VT natural gas consumption 2020 | 13,539,072 |
| MMBTUs delivered | 12,862,118 |
| Heat pumps to displace natural gas consumption | 475,606 |
| Energy required | 1.80 |

EVs

| | |
|-------------------------------------|------|
| Miles driven in Vermont | 7.42 |
| Miles per kWh | 4.00 |
| kWh needed for current miles driven | 1.86 |
| TWh needed for current miles driven | 1.80 |

Most Efficient Combined Cycle Natural Gas Plant

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|---|-----------|
| Best CC heat rate for natural gas per kWh | 6,654 |
| Best CC heat rate for natural gas per MWh | 6,654,000 |
| Natural gas energy | 1,037,000 |
| MCF natural gas per MWh | 6.42 |
| CO ₂ emissions natural gas | 121 |
| Lbs CO ₂ per MWh natural gas | 776.41 |

| | |
|--|-----|
| Best case natural gas plant compared to ISO-NE marginal emissions rate | 86% |
|--|-----|

ISO-New England

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|---|---------|
| Net Energy for Load (2020) | 116,859 |
| Fossil Generation in New England | 46.70% |
| Fossil generation to be replaced | 54,573 |
| Wind installations required to displace New England fossil generation | 12.46 |

| | |
|-----------------------------|-------|
| VT need | 5 |
| Solar needed | 4.2 |
| Solar per year for 20 years | 208.3 |
| Acres per MW | 5 |
| Acres required | 1042 |

Natural Gas

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|---|---------|
| BTUs per therm | 100,000 |
| Average carbon coefficient of pipeline natural gas burned in 2018 | 14.43 |
| Fraction oxidized to CO2 | 100% |
| Molecular weight of CO2 to molecular weight of C | 3.67 |
| CO2 content per MMBTU | 52.91 |
| Lbs per KG | |
| MMBTU per MWh most efficient combined cycle plant | 6.65 |
| CO2 per MWh most efficient combined cycle plant | 352.06 |
| CO2 per MWh most efficient combined cycle plant | 774.54 |
| Price | \$5.00 |
| Fuel cost per kWh most efficient plant | 3.33 |

| Units | Notes | Source |
|----------------------------|--|---|
| MMBtu/MWh | Least efficient 6,000 BTU nameplate capacity, most efficient 24,000 BTU nameplate capacity | CO2 Cost Ef |
| MMBtu/MWh | Select most efficient as conservative calculation | CO2 Cost Ef |
| MMBtu/MWh MWh | Less efficient single zone heat pump | CO2 Cost Ef |
| lbs CO ₂ /MWh | | Calculated i |
| lbs CO ₂ | | |
| MMBtu | | Agrees with |
| | | EIA ?? |
| BTUs | | https://www.assumptions.com |
| lbs CO ₂ /MMBtu | | Assumption |
| lbs CO ₂ | | D12 * 1,000 |
| | | CO2 Cost Ef |
| | | 1 - (D11 / D |
| lbs CO ₂ /MMBtu | | CO2 Cost Ef |

| | |
|---------------------|--------------|
| lbs CO ₂ | D13 * D33 , |
| | 1 - (D12 / D |
| lbs CO ₂ | D35 * (D9 / |
| | 1 - (D37 / D |

| | |
|----------------------|---------------------------------------|
| Gallons | https://www |
| MMBTUs | D48 * (D28 |
| MMBTUs | D50 * D29 |
| Number of heat pumps | 24,000 BTU |
| TWh | (D52 * D16 |

| | |
|-----------------------|---------------------------------------|
| Million cubic feet | https://www |
| BTU / ft ³ | |
| MMBTUs | D61 * D62 |
| | D63 * D42 |
| | 24,000 BTU |
| | (D65 * D16 |

| | |
|---|---|
| Billion miles | https://vtra |
| High estimate (conservative for energy calculation) | |
| Billion kWh | D63 / D64 |
| TWh | D65 / 1,000 |

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|--|---------------------------------------|
| BTUs/kWh | https://evc |
| BTUs/MWh | D66 * 1000 |
| BTUs/MCF (1000 ft ³) | https://www |
| MCF/MWh | D67 / D68 |
| Lbs CO ₂ /MCF (1000 ft ³) | https://www |
| Lbs CO ₂ per MWh | |

D71 / D20

GWh
Percent fossil generation for New England load
GWh
GW installations

<https://www>

TWh
GW solar
MW per year

Acres per year

BTUs/therm
KG carbon per MMBTU

44/12
KG per MMBTU

<https://www>
<https://www>
<https://www>
Molecular \
Calculation

MMBTU
KG CO2 per MWh
Lbs CO2 per MWh

Cents per kWh

1 CO2 Cost Effectiveness Model DRAFT Higher RES 30Dec2020, Cold-Climate Heat Pump tab, cell D18 if 24.

<https://www.vermont.gov/sites/aot/files/planning/documents/planning/The%20Vermont%20Transportation%20Er>

[Energy%20Profile_2019_Final.pdf, page 6. Note that label on Table is incorrect; it is billion miles, not milli](#)

ion miles (which would be 10 miles per person per year). Also see <https://www.bts.dot.gov/sites/bts.do>

[t.gov/files/states2020/Vermont.pdf](https://www.t.gov/files/states2020/Vermont.pdf), page 2.