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### Title

Solar district heating with underground thermal energy storage: Pathways to commercial viability in North America

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Abstract: Underground Thermal Energy Storage (UTES) has emerged in both  
specific applications and within energy policy literature as a promising  
technology for meeting thermal loads with locally collected and stored  
solar energy, as well as several other potential applications, such as  
time-shifting of grid-based wind and solar power to better align variable  
generation with loads. In Europe, UTES systems have experienced  
increased deployment in connection with district heating systems. But  
despite this academic attention and several demonstration projects, the  
commercial market viability of UTES systems has yet to be established in  
North America, and the finance world uses different conceptions of  
viability than engineering or academic studies. This study explores,  
through the conventions of finance and risk-mitigation, what capital  
costs North American UTES systems would need to exhibit to achieve market  
viability; which is to say, the up-front cost at which a UTES system  
represents an attractive investment when compared with natural gas-based  
systems for the provision of residential space heating.

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10/12/2017

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Cover Letter: Renewable Energy

Dear Referees,

Please accept this manuscript, entitled “Solar District Heating with Underground Thermal Energy Storage: Pathways to Commercial Viability in North America,” for your consideration for publication in *Renewable Energy*. The research in this manuscript is funded by the United States National Science Foundation’s Sustainable Energy Pathways program, grant number 1230237. The authors report no conflicts of interest.

Thank you for your consideration,

Adam L. Reed

## Highlights

- Our model develops 10,000 scenarios for the lifetime costs of both underground thermal energy storage for solar district heating (UTES-SDH) systems and non-weatherized gas furnace (NWGF) systems, based upon historical gas prices and heating degree days in each of the 15 states, under both historical conditions and the Representative Concentration Pathway (RCP) 8.5 climate change scenario of the Climate Model Intercomparison Project.
- As the model spans a significant time-scale, it also considers the effects of inflation and discounts the future costs of both systems into today's dollars using discounted cash flow (DCF) analysis. This captures the value of the UTES-SDH system as a financial hedge against fuel price uncertainty.
- We estimate greenhouse gas emissions savings attributable to the UTES-SDH system under both the RCP8.5 and historical climates, utilizing EPA estimates for CO<sub>2</sub> emitted per thousand ft<sup>2</sup> of natural gas burned by NWGFs.
- The model's calculated discounted savings per home represents the per-unit breakeven cost of a UTES-SDH system as compared to NWGF systems under prevailing methods of financial analysis: the capital expense at which a rational investor would be indifferent between the two systems. This figure estimates a target "cost to beat" in order for the technology to compete economically with NWGF systems in the 15 states examined, presuming no additional subsidies are provided and presuming a lack of a price on greenhouse gas emissions. This target cost result ranges from ~\$36,000 per home in Massachusetts, if funded through municipal bonds, and presuming low impacts to heating demand from climate change, to ~\$17,500 per home in Idaho, if funded through a private residential cooperative, presuming significant effects of climate change on heating demand.
- Massachusetts, in particular, stands out as uniquely positioned to drive prospects for UTES-SDH, as the state exhibits high heating demands, above-average retail natural gas prices, and a high Mcf NG/HDD proxy suggesting an average of less thermally efficient buildings than in other states we examined. Utah, to a lesser extent, also exhibits favorable market conditions.

DRAFT

1 **Solar District Heating with Underground Thermal Energy Storage: Pathways to Commercial**  
2 **Viability in North America**

3

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5

6 **Abstract**

7

8 Underground Thermal Energy Storage (UTES) has emerged in both specific applications and  
9 within energy policy literature as a promising technology for meeting thermal loads with locally  
10 collected and stored solar energy, as well as several other potential applications, such as time-  
11 shifting of grid-based wind and solar power to better align variable generation with loads. In  
12 Europe, UTES systems have experienced increased deployment in connection with district  
13 heating systems. But despite this academic attention and several demonstration projects, the  
14 commercial market viability of UTES systems has yet to be established in North America, and  
15 the finance world uses different conceptions of viability than engineering or academic studies.  
16 This study explores, through the conventions of finance and risk-mitigation, what capital costs  
17 North American UTES systems would need to exhibit to achieve market viability; which is to say,  
18 the up-front cost at which a UTES system represents an attractive investment when compared  
19 with natural gas-based systems for the provision of residential space heating.

20

21 Keywords: solar thermal energy; solar district heating, underground thermal energy storage,  
22 borehole thermal energy storage, financial viability, risk mitigation.

23

24 **Introduction**

25

26 The intermittency of renewable energy resources is one of the primary challenges to their  
27 effective and wide scale deployment. Stated broadly, the problem involves how to make  
28 renewable energy available contemporaneously with energy demand. Experts have proposed a  
29 variety of approaches, including geographically-larger and more efficient transmission systems  
30 which reduce aggregate variability and allow a wider range of time zones for matching  
31 generation with loads (MacDonald et al. 2016), electrical energy storage and electro-chemical  
32 storage to hold charge for several hours at a time (Dunn et al. 2011, Alotto et al. 2014), and  
33 thermal storage approaches (geothermal borehole arrays, paraffin-based systems, hydrated  
34 salts) for longer-term energy storage and reduction of aggregate electrical load magnitude and  
35 variability (Jacobson et al. 2015b, Farid et al. 2004).

36

37 Underground thermal energy storage (UTES) systems used for solar district heating (SDH), as  
38 demonstrated at the 1.6 MW<sub>th</sub> Drake Landing Solar Community in Okotoks, Canada, can shift  
39 peak-intensive space heating loads away from grid-based electricity or natural gas delivery  
40 systems (McClenahan et al. 2006; Sibbitt et al. 2012). If widely deployed, coupled UTES-SDH  
41 systems could thus contribute to reduced electric load variability and smaller electric power  
42 system peaks where they displace electric resistance heating. Jacobson et al. (2015b) also  
43 envision UTES systems as potentially providing storage of thermal energy collected from utility-  
44 scale wind, solar, and hydropower systems for months or even years, though this usage is  
45 theoretical at present and outside the scope of our inquiry.

46

47 The importance of the Drake Landing Solar Community project in generating attention and  
48 enthusiasm for UTES-SDH systems cannot be understated, but it is important to note that it is a

49 publicly-funded demonstration project and not a commercial viability study. UTES-SDH systems  
50 in North America have yet to empirically demonstrate economic viability through robust real-  
51 world deployment. And while some larger UTES-SDH systems in Northern Europe have done  
52 so, they experience fundamentally different infrastructural and market conditions than those  
53 that North American UTES systems are likely to face, and so are an imperfect analogue (Reed  
54 and McCartney 2015).<sup>1</sup>

55  
56 In this study, we examine the financial prospects for future North American UTES-SDH systems  
57 by considering the decision-processes of investors with available capital and a variety of  
58 competing options from which to choose. We have thus created a financial breakeven model  
59 that calculates the potential energy and cost savings of a residential community-scale UTES-SDH  
60 system deployed in lieu of natural gas furnaces over the entire estimated 60-year life of the  
61 system. To do so, the model integrates location-specific residential heating demand forecasts  
62 with a forward-looking retail natural gas pricing simulation for each of the top 15 heating  
63 demand states (North Dakota, Minnesota, Wyoming, Montana, Wisconsin, South Dakota,  
64 Colorado, Iowa, Michigan, Idaho, Utah, Massachusetts, Nebraska, Illinois, and New York) and  
65 performs a run-cost calculation for natural gas furnaces in each state over a 60-year period (the  
66 expected lifetime of a UTES system) including fuel, maintenance, and regular replacement  
67 costs. It then discounts those costs back to present value, which allows side-by-side  
68 comparison to the up-front investment cost of UTES-SDH systems. The result is a target break-  
69 even capital cost for UTES-SDH systems at which rational investors would consider them  
70 equivalent to conventional natural gas furnaces in each of the 15 states. Critical to this  
71 approach is the framing of the UTES-SDH system as a financial instrument: a hedge for the  
72 system owner against fluctuations in natural gas prices that would otherwise cause uncertainty  
73 in future space-heating costs.

74  
75 **Background**

76  
77 UTES-SDH systems combine solar thermal collection technologies with long-term thermal  
78 energy storage methods, often in the form of closed-loop soil borehole heat exchangers. Unlike  
79 batteries and other short-term energy storage, UTES is capable of storing thermal energy for  
80 months or years, and dispatching it on-demand to users irrespective of ambient temperatures  
81 or the present availability of sunlight (Reed and McCartney 2015, McCartney et al. 2013, Zhang  
82 et al. 2012; Nussbicker 2012, Baser et al. 2016).

83  
84 The Drake Landing Solar Community in Okotoks, Canada is illustrative of the typical system  
85 design principles for UTES as envisioned in recent literature. 800 roof-mounted solar panels  
86 absorb energy from the sun to heat a water-glycol solution circulating through an insulated  
87 collector system connecting all of the panels. Heat is transferred from the glycol-water solution  
88 to water storage tanks in a central maintenance facility. These tanks provide short-term

---

<sup>1</sup> Specifically, European SDH systems often benefit from legacy district heating infrastructures that used to be served by natural gas cogeneration, waste incineration, or other sources, and so do not require the higher capital cost outlays that are associated with brand-new SDH systems.



89 thermal energy storage on a diurnal basis. In the warmer months of the year, a separate closed-  
90 loop system is used to extract heat from the water-filled tanks by circulating a water glycol  
91 solution through an array of 144 37-meter-deep boreholes installed beneath a small park in the  
92 center of the neighborhood. By the end of the summer, the circulation of heated water  
93 through the borehole array leads to an increase in ground temperature to approximately 80 °C.  
94 In the wintertime, when sunlight is scarce and the panels do not collect much heat, the heat  
95 flow in the borehole array is reversed and distributed to a third district heating loop that  
96 distributes the thermal energy to the 52 homes in the community (Sibbitt et al. 2012, Sibbitt et  
97 al. 2015). The system has been providing approximately 90% of the annual space heating needs  
98 of the highly-efficient homes in the community, which normally experience 9,027 heating  
99 degree days per year. The efficiency of heat storage has been improving over several seasons  
100 (Zhang et al. 2012; Sibbitt et al. 2012; Catolico et al. 2016). The remaining heat is provided by a  
101 centralized natural gas boiler system that also serves the district heating loop.

102  
103 Though SDH systems are rare in North America, they have expanded rapidly in Northern Europe  
104 in the last decade. A number of these systems have coupled SDH systems with UTES systems,  
105 including a 13 MW<sub>th</sub> system in Braedstrup, Denmark; a 5.1 MW<sub>th</sub> system in Crailsheim,  
106 Germany; a 4 MW<sub>th</sub> system in Neckarsulm, Germany; a 1.7 MW<sub>th</sub> system in Groningen, The  
107 Netherlands; a 1.7 MW<sub>th</sub> system in Anneberg, Sweden; and a 0.8 MW<sub>th</sub> system in Kerava,  
108 Finland (Solar District Heating 2016). The rapid expansion is due in part to high fossil fuel  
109 prices, preexisting district heating infrastructures, clean energy subsidies, and related energy  
110 policies and market conditions (Chittum and Østergaard 2014, Reed and McCartney 2015).  
111 These conditions are notably different from North America, where subsidies are lower  
112 (Wüstenhagen and Menichetti 2012), natural gas is inexpensive (Wang et al. 2014), and there is  
113 a general absence of pre-existing district heating infrastructure other than the remnants of  
114 century-old downtown steam systems (Ulloa 2007).

115  
116 Capital costs for installed SDH systems in Northern Europe range from 400 to 800 USD/m<sup>2</sup> of  
117 installed solar collectors (Dalenbäck and Werner 2012). But these figures are not sufficient for  
118 estimating UTES-SDH system capital costs in the US because of pre-existing district heating  
119 infrastructures in Northern Europe that were initially run using natural-gas-fired combined-  
120 heat-and-power plants. SDH systems in Europe thus rarely need to build distribution or storage  
121 capacity from scratch, and can connect solar thermal collectors directly to the existing heat  
122 distribution system. The Drake Landing system, which had to construct both storage and  
123 distribution infrastructure from scratch, achieved capital costs of approximately 1,100 USD/m<sup>2</sup>  
124 of installed solar collectors (Sibbitt et al. 2012, Sibbitt et al. 2015).

125  
126 The relatively high initial cost of UTES-SDH systems may be balanced by their longevity and  
127 minimal operational costs when compared to conventional natural gas furnaces, which require  
128 fuel to operate and must be replaced approximately every 20 years (Petro 2016).  
129 Manufacturers claim that UTES ground loop components typically last well over 50 years  
130 (Geothermal Genius 2014) and solar thermal panels last approximately 30 years (YouGen 2011).  
131 Critical to the successful deployment at scale of UTES-SDH systems is confidence among  
132 investors that they will provide substantial fuel, maintenance, and replacement cost savings

133 over the life of the system under a variety of potential scenarios for heating demand and  
134 natural gas prices. We have thus attempted in this study to quantify cost savings in terms of  
135 net present value for potential UTES-SDH systems in each of the 15 U.S. states with the highest  
136 number of annual heating degree days.

137

## 138 **Methodology**

139

140 UTES-SDH and non-weatherized gas furnace (NWGF) systems realize their respective costs over  
141 different time-horizons: UTES-SDH systems require significant upfront costs, but have minimal  
142 operating expenses and long lifespans – approximately 60 years<sup>2</sup>; gas furnaces have lower  
143 upfront costs, but shorter lifespans and higher operating expenses due to maintenance and fuel  
144 costs (DOE 2015). Moreover, the highly predictable costs of the UTES-SDH system have their  
145 own financial value as a hedge against uncertainty compared to historically volatile fuel costs.  
146 In order to compare the two investment options on the basis of net present value (NPV), we  
147 have constructed an uncertainty-driven system lifetime-cost model<sup>3</sup> that compares capital and  
148 operating costs between UTES-SDH and NWGF systems for a 50 home development, over a 60-  
149 year time horizon, on a state-by-state basis, discounted to present value. The central feature of  
150 the model is its forecasting of annual prices for residentially-delivered natural gas through a  
151 probabilistic simulation that performs 10,000 independent iterations based on historical price  
152 inflation and volatility.<sup>4</sup> In the language of finance, this approach conceptualizes the UTES-SDH  
153 system as a long-term investment wherein returns are realized through hedging against  
154 difficult-to-predict fluctuations in fossil fuel prices. Thus the model aims to capture not only the  
155 value of potential savings under 10,000 separate fossil-fuel price scenarios in the future, but the  
156 value today of being insulated from price uncertainty over the given time period.

157

158 The practical goal of the model is to quantify the maximum up-front expenditure for a UTES-  
159 SDH system that would satisfy a breakeven NPV against an alternative investment in NWGFs. In  
160 other words, the model calculates the initial capital expenditure equivalent to the value of the  
161 system's hedge against uncertainty—a point where the life-time cost for the UTES-SDH and the  
162 comparable costs associated with NWGF systems for the same period are equivalent. This  
163 value may then serve as a target capital cost for future efforts at commercializing UTES-SDH  
164 systems in North America. Our model considers unique environmental and market conditions  
165 for 15 states: Colorado, Idaho, Illinois, Iowa, Massachusetts, Michigan, Minnesota, Montana,  
166 Nebraska, New York, North Dakota, South Dakota, Utah, Wisconsin, and Wyoming. These

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<sup>2</sup> Empirical data on the lifespan of a modern, commercially-installed UTES loop system is not yet solidified. We have decided on 60 years as a reasonable estimate, but this may require revisiting in subsequent studies as more data is available.

<sup>3</sup> Our model utilizes Analytic Solver Platform for Education (ASPE), a commercially-available platform that facilitates the construction of uncertainty-driven models.

<sup>4</sup> We have elected to model future natural gas prices in this mechanics-agnostic fashion so as to match the practices of the business/finance community, as opposed to the energy forecasting community. As such, the model reflects a desire to hedge risk broadly rather than an attempt to forecast prices or theorize about the drivers of natural gas price movements.

167 states were chosen due to their cold climates<sup>5</sup> (NOAA 2016), as well as their primary utilization  
 168 of natural gas for residential space heating (US Census Bureau 2016).

169  
 170 The model develops 10,000 scenarios for the lifetime costs of both UTES-SDH and NWGF  
 171 systems, based upon historical gas prices and heating degree days in each of the 15 states,  
 172 under both historical conditions and the Representative Concentration Pathway (RCP) 8.5  
 173 climate change scenario of the Climate Model Intercomparison Project (Petri and Caldeira  
 174 2015). Historical and projected heating degree days for all 15 states are listed in Table 1 (all  
 175 tables are located in the appendix). The NWGF system's costs include the initial purchase and  
 176 installation of the gas furnaces for each of the 50 homes, as well as annual maintenance and  
 177 replacement after their useful lives are complete (DOE 2015).<sup>6</sup> DOE estimates the average  
 178 annual maintenance cost for NWGFs at \$62.30 and expected lifespan at 21.5 years, with  
 179 significant volatility in useful life estimates.<sup>7</sup> We assume that our homes incur the average cost  
 180 of purchase and installation of NWGFs at \$3,894 (Home Advisor 2016).<sup>8</sup> The time of  
 181 replacement for the NWGFs is simulated using the above distribution of useful lives. The cost  
 182 model for the UTES-SDH incorporates system-wide operating and maintenance costs, along  
 183 with the expected lifespan of the system's back-up heat-generation system.<sup>9</sup>

184  
 185 The model constructs residentially-delivered natural gas prices over the next 60 years as a  
 186 product of average annual price inflation  $\mu$  and standard deviation of annual price inflation  $\sigma$   
 187 over the past 30 years for each state (EIA, 2016a), displayed in Table 2. The annualized  
 188 continuously compounding inflation rate for natural gas was derived from EIA data for each of  
 189 the 15 states through the equation

190  
 191 
$$\text{Annual Inflation} = \ln \left( \frac{RP_t}{RP_{t+1}} \right)$$

192  
 193 where  $RP_t$  is the real price of gas in the base year and  $RP_{t+1}$  is the real price of gas in the  
 194 following year for the state. Averages and standard deviations of historical price inflation were  
 195 calculated from these thirty data points, and assigned unique values of  $\mu$  and  $\sigma$ , respectively,  
 196 for each state.

197

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<sup>5</sup> As measured by annual heating degree days (HDDs)

<sup>6</sup> Electricity costs are assumed to be negligible in this iteration of the model (NYSERDA 2013).

<sup>7</sup> Here, assumed to be normally distributed with standard deviation 3 years.

<sup>8</sup> We break with DOE estimates of these costs, as they differ with the Air-Conditioning, Heating, and Refrigeration Institute (AHRI 2015).

<sup>9</sup> While robust data sets exist for the expected lifespans and maintenance costs for single-home gas furnaces, data for the costs and lifespans of both industrial boilers and solar thermal collectors (STCs) are more difficult to access. Currently, we do not take into account the 30-year lifespan of STCs (NREL 2016), and assume that the UTES-SDH system would require a \$10,000 industrial boiler that faces the same expected lifespan as single-home furnaces. We have arbitrarily assumed \$500 per year in other maintenance costs for the UTES-SDH system.

198 Using this data, the model runs 10,000 possible future scenarios for the price of residentially-  
 199 delivered natural gas for all 15 states. Simulated, state-specific price increases were modelled  
 200 for 60 years and were calculated through the equation

201

$$202 \quad MP_{t+1} = MP_t * e^x$$

203

204 where  $MP_t$  is the modeled price of gas in year  $t$ ,  $x$  is a normally-distributed random variable  
 205 with mean  $\mu$  and standard deviation  $\sigma$ , and  $MP_0$  is equal to the cost of the state's residentially  
 206 delivered natural gas as of February, 2016 (EIA 2016b). Representative data from the  
 207 Wisconsin and Massachusetts simulations are displayed in Table 3.

208

209 These annual prices are then translated into the model housing development's estimated  
 210 annual space heating costs using a proxy variable for the amount of natural gas used as a  
 211 function on the cold experienced by the home. This proxy variable translates the HDDs  
 212 experienced by the home over the course of a year into the amount of natural gas used by the  
 213 average NWGF-heated home. The proxy variable was constructed on a state-by-state basis by  
 214 cross-referencing the average consumption of natural gas in homes heated by natural-gas  
 215 furnaces in 2009 (EIA 2013) with the actual HDDs those homes experienced in 2009.<sup>10</sup> The  
 216 state-specific proxy variables were calculated using the equation

217

$$218 \quad P = \frac{N\mu}{H}$$

219

220 where  $P$  is the proxy variable for each state,  $N\mu$  is the average amount of natural gas used by  
 221 homes with natural gas furnaces in the state in 2009, and  $H$  is the amount of heating degree  
 222 days experienced by the state during 2009.<sup>11</sup> These proxy variables, listed for each state in  
 223 Table 4, provide an approximation of the amount of natural gas used by the average home in  
 224 each state as a function of the cold weather the home experienced. The proxy variable is then  
 225 multiplied by NOAA's normalized HDDs for each state (NOAA 2016) and the modelled  
 226 residentially-delivered natural gas prices in order to forecast space heating costs per unit for  
 227 the NWGF system over the entire 60-year period, displayed in Tables 5 and 6. As demonstrated  
 228 by the Drake Landing Solar Community, a UTES-SDH system can reduce district-wide natural gas  
 229 consumption by 94% (McClenahan et al. 2006, Sibbitt et al. 2015), which allows for a projection  
 230 of life-time savings in natural gas costs of the UTES-SDH system as compared to NWGFs.

231

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<sup>10</sup> At present, the non-RCP 8.5 scenario assumes that the development will experience the NOAA's normalized HDDs for each state over the entirety of the 60 year study period, but we intend for future iterations of this study to better incorporate the effects of climate change and weather uncertainty under a variety of scenarios.

<sup>11</sup> Our present model only uses data from 2009 to construct the proxy variable, as previous EIA residential gas usage surveys only offer regional data, while the 2009 survey gives state-by-state information. In the future, we will refine our data as further insights are furnished by the EIA.

232 The natural gas consumed by both systems is modelled as a linear product of the amount of  
 233 cold experienced by the home, so the model estimates space heating costs using both the  
 234 normalized historical HDDs experienced by each state (Table 4), and the expected HDDs under  
 235 the Representative Concentration Pathway (RCP) 8.5<sup>12</sup> climate change scenario of the Climate  
 236 Model Intercomparison Project (CMIP5) (Petri and Caldeira 2015) (Table 5). A graphical  
 237 comparison of the 15-State average of simulated space heating costs under no-climate-change  
 238 and RCP 8.5 scenarios is displayed in Figure 1. Under the RCP 8.5 scenario, we linearly model  
 239 the decrease in HDDs in each state across the 60-year evaluation period. Using the equation  
 240

$$241 \quad HDD_t = HDD_0 * \frac{t}{60} * \Delta_{HDD}$$

242  
 243 Where  $HDD_t$  is the modeled heating degree days experienced by the specific state in year  $t$ , the  
 244 number of years after the system's installation in 2016,  $HDD_0$  is the state's normalized heating  
 245 degree days, and  $\Delta_{HDD}$  is the expected change in HDDs experienced by each state, as modelled  
 246 by the RCP8.5 scenario.  
 247

248 As the model spans a significant time-scale, it also considers the effects of inflation and  
 249 discounts the future costs of both systems into today's dollars using discounted cash flow<sup>13</sup>  
 250 (DCF) analysis. We assume that the future prices incurred for repairs, maintenance, and  
 251 replacement of system components can be calculated by applying the annualized inflation rate  
 252 for the last 30 years, 2.74% (BLS 2016). We have run the model with two different discount  
 253 rates to reflect two possible financing schema for a project of this scale. The first scheme  
 254 considers municipal funding for the initial capital expenditure and an issuance of a 20 year, AAA  
 255 municipal bond. These results are displayed in Tables 7 and 9. We used current AAA municipal  
 256 bond yields (Yahoo Finance 2016) and the 30-year interest rate swap rate (Board of Governors  
 257 of the Federal Reserve System 2016),<sup>14</sup> to develop a low-risk discount rate of 4.78%. The

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<sup>12</sup> The RCP8.5 scenario represents the CMIP5's unmitigated high emission scenario, which presumes that no significant action is undertaken to curb greenhouse gas emissions over the course of the 21<sup>st</sup> Century. As the UTES-SDH systems conceptualized here are heating systems, the RCP8.5 scenario presents the most unfavorable investment case with respect to heating demand, as projected heating degree days under the scenario decline in all 15 states.

<sup>13</sup> DCF is the standard financial modeling tool to find the present value of cash flows in the future. The discounted value of the cash flows (DCF) of this project is calculated by taking the annual cash flows  $CF_1, CF_2, \dots, CF_{60}$ , which represent the raw costs of energy heating, and discounting them by the discount rate ( $r$ )

$$DCF = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_{60}}{(1+r)^{60}}$$

<sup>14</sup> Interest rate swaps allow interest-bearing debtors to exchange floating-rate interest payments for a fixed rate. Functionally, this allows us to model the future yields of AAA municipal bonds with zero uncertainty. A 30-year swap over-estimates the cost of utilizing this financial instrument as the proposed bond matures in 20 years, but data on the market rates for 20-year swaps is not readily available.

258 second scheme considers a higher-risk debtor undertaking, such as a private residential co-  
259 operative, with a discount rate set arbitrarily at 6%.<sup>15</sup> These results are displayed in Tables 8  
260 and 10.

261  
262 Finally, we estimate greenhouse gas emissions savings attributable to the UTES-SDH system  
263 under both the RCP8.5 and historical climates, utilizing EPA estimates for CO<sub>2</sub> emitted per  
264 thousand ft<sup>2</sup> of natural gas burned by NWGFs (EPA 1998). This calculation is a conservative  
265 estimate of the emissions savings of the UTES-SDH system, as most NWGFs burn less than 95%  
266 of all natural gas drawn and there are significant inefficiencies and leakages in natural gas  
267 production and distribution that lead to emissions of methane, which has roughly 20 times the  
268 global warming potential of CO<sub>2</sub> (Howarth et al. 2011, Cathles 2012a, Cathles 2012b).<sup>16</sup> These  
269 results are displayed in the final column of Tables 7-10.

270

## 271 **Results and Discussion**

272

273 The model's calculated discounted savings per home represents the per-unit breakeven cost of  
274 a UTES-SDH system as compared to NWGF systems under prevailing methods of financial  
275 analysis: the capital expense at which a rational investor would be indifferent between the two  
276 systems. This figure estimates a target "cost to beat" in order for the technology to compete  
277 economically with NWGF systems in the 15 states examined, presuming no additional subsidies  
278 are provided and presuming a lack of a price on greenhouse gas emissions. This target cost  
279 result ranges from ~\$36,000 per home in Massachusetts, if funded through municipal bonds,  
280 and presuming low impacts to heating demand from climate change, to ~\$17,500 per home in  
281 Idaho, if funded through a private residential cooperative, presuming significant effects of  
282 climate change on heating demand.

283

284 The discounted savings per home figure is sensitive to several factors: climatic conditions in the  
285 state, differences in retail gas prices between states, differences in the energy efficiency of the  
286 built environment (as represented by our Mcf NG/HDD proxy), the type of funding utilized (and  
287 thus the presumed discount rate applied), and the extent of future climate change and its  
288 effects on future heating demand.

289

## 290 **Conclusions and Policy Implications**

291

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<sup>15</sup> We use an arbitrary discount rate here because there are scant examples of district-level infrastructure not funded through municipal bonds. This number is a 33% premium on current average interest rates offered to homeowners for NWGF upgrades (DOE 2015).

<sup>16</sup> Both the global warming potential of methane and the leakage rates from the gas sector are debated. Howarth et al. (2011) and Cathles et al. (2012a, 2012b), among others, spar over the appropriate time horizon for considering global warming impacts of methane in the atmosphere. Leakage rates for the natural gas supply system span a large range of uncertainty, from 1% to 10% (Allen 2014).

292 By utilizing concepts from financial analysis and fuel-price risk hedging in the assessment of  
293 commercial viability for UTES-SDH systems, we have attempted to explore macro-economic  
294 prospects for wide-scale deployment through micro-economic, investor-specific considerations.  
295 The range of target system costs represented by the discounted savings per home figures may  
296 provide useful guidance to developers and policymakers interested in the prospects of UTES-  
297 SDH systems. The government-funded Drake Landing demonstration project, for example,  
298 developed a UTES-SDH system for 52 homes at a subsidized capital cost of approximately 2.6  
299 million USD (Sibbitt et al. 2012, 2015). This per-home cost of \$50,000 is above the highest  
300 target costs produced by our model, and suggests that capital costs for Drake Landing-like  
301 projects must come down by ~28% to compete in the most attractive market conditions we  
302 modeled, and ~65% to compete in the most challenging market conditions we modeled.

303  
304 These cost reductions are not insubstantial, but neither are they insurmountable, given that  
305 Drake Landing was the first project of its kind in North America, and that we can expect capital  
306 costs to decline as deployment rates increase, as has been observed in countless other markets  
307 for clean energy. A 28% reduction in Drake Landing's \$1100/m<sup>2</sup> of collector area capital cost  
308 figure would bring the capital cost to \$792/m<sup>2</sup>, comparable to the high range of European SDH  
309 systems in Austria. Getting to 65% reductions, on the other hand, is more daunting, as this  
310 would bring capital costs below those enjoyed by the low end (\$400/m<sup>2</sup>) of Danish systems,  
311 which have the tremendous advantage of using pre-existing district heating infrastructure  
312 coupled with dense Scandinavian community designs.

313  
314 Massachusetts, in particular, stands out as uniquely positioned to drive prospects for UTES-  
315 SDH, as the state exhibits high heating demands, above-average retail natural gas prices, and a  
316 high Mcf NG/HDD proxy suggesting an average of less thermally efficient buildings than in other  
317 states we examined. Utah, to a lesser extent, also exhibits favorable market conditions.  
318 Previous work by Reed and McCartney (2015) identified states (among the top 10 states for  
319 solar energy installations) with favorable utility regulatory schemas for UTES-SDH system  
320 deployments, where the systems would likely not face charges of illegal competition with  
321 existing electric or gas utilities. Notably, Massachusetts, New York, and Colorado all exhibited  
322 such open regulatory environments, allowing heat provision to the public through UTES  
323 systems without subjecting them to cost-of-service rate regulation. Reed and McCartney 2015  
324 did not examine regulatory environments in Idaho, Illinois, Iowa, Michigan, Minnesota,  
325 Montana, Nebraska, North Dakota, South Dakota, Utah, Wisconsin, and Wyoming, and future  
326 legal and regulatory research should examine those states.

327  
328 State policies providing subsidized support to UTES-SDH system deployment, particularly those  
329 aimed at retrofits for older, less efficient housing, may both provide a scaffolding for system  
330 costs to decline to competitive levels in these low-hanging-fruit markets, while also addressing  
331 high heating costs and uncertainties that may disproportionately affect low-income  
332 populations. State policies that support or enable municipally-funded UTES-SDH projects are  
333 also recommended at this early stage, as the lower interest rates associated with municipal  
334 bonds provide greater headroom for systems to realize savings for residents than higher-  
335 interest private debt, and municipal governments are well-suited to the management of long-

336 lived infrastructures that last for over half a century. Numerous exogenous factors complicate  
337 these decisions, however. We have not, for example, modeled the availability of UTES  
338 components and transport costs on a state-by-state basis. States with thriving geothermal heat  
339 pump markets, for example, might exhibit cheaper materials costs for UTES loop fields. Nor  
340 have we taken into consideration differences in soil composition and hydrogeology, which can  
341 impact both construction costs (if the soil is particularly rocky, for example) and borehole field  
342 design (if, for example, an underground water flow causes heat leakage from the field and  
343 necessitates the addition of a thermal barrier). Nevertheless, this analysis aims to provide  
344 useful markers for the contours of a future potential UTES-SDH industry with respect to target  
345 system costs and likely regions for favorable deployment.

346

#### 347 **Declaration of Interest**

348

349 Conflicts of interest: none.

350

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**APPENDIX: Data Tables and Charts**

**Table 1: Heating Degree Days by State: Historical and Projected**

<i>State</i>	<b>Historical Average (1981-2010)</b>	<b>RCP8.5 Climate Change Scenario (2080)</b>
<i>Colorado</i>	6947	4797
<i>Idaho</i>	6787	3987
<i>Illinois</i>	6168	4059
<i>Iowa</i>	6815	5065
<i>Massachusetts</i>	6369	4369
<i>Michigan</i>	6792	4992
<i>Minnesota</i>	8471	5471
<i>Montana</i>	7853	5753
<i>Nebraska</i>	6314	4414
<i>New York</i>	6147	3897
<i>North Dakota</i>	9103	6103
<i>South Dakota</i>	7466	5466
<i>Utah</i>	6442	4492
<i>Wisconsin</i>	7504	5504
<i>Wyoming</i>	7911	5711

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**Table 2: Price of Natural Gas Delivered to Residential Consumers by State (\$/Mcf)**

	CO	ID	IL	IA	MA	MI	MN	MT	NE	NY	ND	SD	UT	WI	WY
<b>1986</b>	5.01	6.02	5.07	5.12	7.41	5.74	5.28	4.45	4.59	7.46	5.29	5.26	4.64	6.2	4.93
<b>1987</b>	4.74	5.5	4.81	4.75	6.64	5.46	4.58	4.41	4.36	6.88	5.47	4.87	4.97	5.99	4.7
<b>1988</b>	4.42	5.49	4.6	4.79	6.47	5.34	4.64	4.3	4.46	6.5	5.15	4.91	5.11	5.89	4.48
<b>1989</b>	4.63	5.05	4.92	4.7	7.16	5.19	4.57	4.37	4.48	7.22	4.68	4.85	5.14	5.64	4.71
<b>1990</b>	4.57	5.05	5.06	4.99	7.82	5.02	4.63	4.59	4.6	7.4	4.7	5.14	5.28	5.74	4.84
<b>1991</b>	4.59	5.19	4.95	4.81	8.11	5.07	4.52	4.52	4.64	7.35	4.82	4.94	5.44	5.61	4.74
<b>1992</b>	4.56	5.23	5.09	5.23	7.92	5.06	4.86	4.8	4.82	7.58	5	5.15	5.44	5.87	4.72
<b>1993</b>	4.52	5.38	5.52	5.48	8.33	5.04	5.31	4.92	4.96	8.15	5.23	5.3	5.13	6.34	4.77
<b>1994</b>	4.92	5.29	5.5	5.4	8.94	4.98	5.18	5.23	5.01	8.75	5.19	5.27	4.96	6.28	5.1
<b>1995</b>	4.8	5.59	4.66	5.09	9.04	4.72	4.8	5.15	4.83	8.42	4.66	5.05	4.74	5.82	4.83
<b>1996</b>	4.39	5.2	5.28	5.49	8.88	4.96	5.46	4.86	4.88	8.9	4.54	5.25	4.47	6.04	4.26
<b>1997</b>	4.81	5.12	5.95	6.17	9.43	5.2	5.76	5.05	5.69	9.73	4.99	5.75	5.13	6.43	4.58
<b>1998</b>	5.22	5.33	5.47	5.96	9.42	5.17	5.48	5.25	5.13	9.59	5.16	5.59	5.57	6.15	5.19
<b>1999</b>	5.38	5.42	5.5	6.1	9.25	5.13	5.56	5.16	5.06	9.12	5.32	5.83	5.37	6.17	5.11
<b>2000</b>	6.14	6.28	7.33	7.81	9.91	5.11	7.13	6.03	6.43	9.86	6.37	7.34	6.2	7.55	6.11
<b>2001</b>	8.37	8.48	9.04	8.9	12.8	5.77	8.74	7.26	8.71	11.75	7.68	8.57	8.09	8.76	8.45
<b>2002</b>	5.62	8.41	6.41	7.08	10.05	6.32	6.61	5.3	6.18	9.85	5.14	6.93	6.39	7.35	6.08
<b>2003</b>	6.61	7.59	8.65	9.14	12.52	7.31	8.58	7.08	7.83	11.59	7.25	8.49	7.33	9.27	7.14
<b>2004</b>	8.47	9.04	9.41	10.14	14.41	8.52	9.5	9.19	9.06	12.5	9.03	9.52	8.12	10.16	8.65
<b>2005</b>	10.29	10.59	11.62	12.3	15.43	10.55	11.21	10.7	10.68	14.89	11.4	11.68	9.71	11.93	10.53
<b>2006</b>	10.45	12.25	11.18	12.42	17.66	11.97	11.67	11.26	11.3	15.35	10.8	11.11	11.02	12.17	11.6
<b>2007</b>	8.84	11.47	10.76	11.76	16.99	11.06	11.14	9.91	11.15	15.73	9.13	10.49	9.44	12.02	8.84
<b>2008</b>	9.77	11.07	12.07	11.91	17.18	11.93	11.29	11.45	11.11	16.78	10.34	11.32	9	12.81	10.16
<b>2009</b>	8.8	10.54	8.97	9.83	14.85	11.27	8.99	9.5	9.34	15.05	8.46	9.14	8.95	10.76	9.39
<b>2010</b>	8.13	8.95	9.39	9.57	14.53	11.32	8.76	8.64	8.95	14.04	8.08	8.77	8.22	10.34	8.58
<b>2011</b>	8.25	8.8	8.78	9.54	13.81	10.47	8.85	8.8	8.84	13.71	8.1	8.59	8.44	9.77	8.72
<b>2012</b>	8.28	8.26	8.26	9.46	13.22	9.95	7.99	8.05	8.68	12.97	7.43	8.39	8.7	9.27	8.42
<b>2013</b>	7.85	8.12	8.2	8.99	13.49	9.09	8.19	8.19	8.39	12.49	7.43	8.23	8.55	8.65	8.27
<b>2014</b>	8.89	8.54	9.59	10.02	14.5	9.33	9.89	9.11	8.77	12.54	8.86	9.27	9.48	10.52	9.34
<b>2015</b>	9.56*	8.62	7.95	8.49	12.91*	8.78	8.84	8.21	8.94	11.2	10.15*	8.21	9.72	10.09*	9.19
<b>Average Inflation</b>	2.23%	1.24%	1.55%	1.74%	1.92%	1.47%	1.78%	2.11%	2.30%	1.40%	2.25%	1.54%	2.55%	1.68%	2.15%

<b><i>Inflation Std. Dev.</i></b>	13.43%	9.71%	15.07%	11.38%	10.36%	7.85%	12.77%	12.71%	12.51%	8.73%	14.91%	10.83%	10.29%	10.11%	13.63%
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521 \*Data for Full Year 2015 unavailable at last running of simulation for CO, MA, ND, & WI. 2015 numbers for these states are average prices for residentially  
 522 delivered natural gas for each state for the year of 2015 through 6/30/2015

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**Table 3: Simulated NG Prices over UTES-SDH Lifetime for Wisconsin and Massachusetts<sup>23</sup> (\$/Mcf)**

Year	Wisconsin			Massachusetts		
	Simulation Min	Simulation Max	Expected	Simulation Min	Simulation Max	Expected
0	7.24	7.24	7.24	12.02	12.02	12.02
1	4.96	11.43	7.36	7.99	18.06	12.25
2	4.56	12.38	7.49	7.09	22.81	12.48
3	3.73	14.49	7.61	6.91	26.01	12.72
4	3.72	18.23	7.74	6.19	29.42	12.97
5	3.52	18.04	7.87	5.60	32.71	13.22
6	3.19	19.26	8.00	5.41	35.81	13.47
7	2.91	21.55	8.14	4.95	41.42	13.73
8	2.83	24.32	8.27	4.87	45.48	13.99
9	2.95	25.37	8.41	4.90	47.86	14.26
10	3.03	25.83	8.55	4.29	51.84	14.53
11	2.71	30.81	8.70	4.38	59.53	14.81
12	2.53	33.25	8.84	3.84	62.11	15.09
13	2.39	31.46	8.99	3.98	62.77	15.38
14	2.15	41.39	9.14	3.79	70.98	15.68
15	2.18	44.96	9.30	3.56	61.28	15.98
16	2.14	53.48	9.45	3.50	67.61	16.28
17	2.07	54.65	9.61	3.16	75.09	16.60
18	1.96	50.29	9.77	3.31	77.16	16.91
19	1.85	60.84	9.94	3.20	81.81	17.24
20	1.77	63.46	10.10	3.00	87.71	17.57
21	1.80	73.02	10.27	3.25	109.00	17.90
22	1.46	74.09	10.45	3.01	105.80	18.25
23	1.24	94.71	10.62	2.83	108.13	18.60
24	1.46	94.23	10.80	2.94	117.07	18.95
25	1.46	88.11	10.98	3.27	116.31	19.32
26	1.31	109.51	11.17	3.01	131.67	19.68
27	1.49	112.30	11.35	2.98	126.45	20.06
28	1.58	111.09	11.54	2.96	132.30	20.45
29	1.63	113.83	11.74	3.03	139.47	20.84
30	1.68	109.99	11.94	2.75	147.91	21.24
31	1.44	120.58	12.14	2.52	163.79	21.64
32	1.35	124.49	12.34	2.41	184.01	22.06
33	1.25	136.48	12.55	2.39	229.95	22.48
34	1.25	138.23	12.76	2.50	219.27	22.91

<sup>23</sup> These are provided for illustrative purposes. Simulated NG price data for other states is available upon request.

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<b>35</b>	1.33	136.27	12.97		2.23	210.04	23.35
<b>36</b>	1.27	141.84	13.19		1.82	226.57	23.80
<b>37</b>	1.35	149.71	13.41		1.76	241.27	24.25
<b>38</b>	1.43	166.53	13.64		1.62	246.80	24.72
<b>39</b>	1.39	187.98	13.87		1.67	278.67	25.19
<b>40</b>	1.23	192.68	14.10		2.01	263.10	25.67
<b>41</b>	1.08	206.25	14.34		1.80	273.00	26.17
<b>42</b>	1.11	226.32	14.58		1.87	267.96	26.67
<b>43</b>	1.02	208.33	14.82		1.91	295.40	27.18
<b>44</b>	1.04	225.73	15.07		1.73	344.61	27.70
<b>45</b>	1.02	208.75	15.32		1.94	416.12	28.23
<b>46</b>	1.10	209.27	15.58		1.87	443.24	28.77
<b>47</b>	1.17	220.04	15.84		1.76	434.37	29.32
<b>48</b>	1.16	233.84	16.11		2.06	417.25	29.88
<b>49</b>	0.92	243.69	16.38		2.02	503.47	30.45
<b>50</b>	0.97	235.12	16.66		1.82	524.12	31.04
<b>51</b>	1.05	263.99	16.94		2.16	508.17	31.63
<b>52</b>	1.12	352.48	17.22		1.83	510.25	32.24
<b>53</b>	1.00	366.31	17.51		2.08	520.67	32.86
<b>54</b>	0.94	428.29	17.80		2.22	531.89	33.48
<b>55</b>	0.77	475.81	18.10		2.20	567.93	34.13
<b>56</b>	0.70	433.26	18.41		2.12	724.35	34.78
<b>57</b>	0.77	464.94	18.72		1.97	614.85	35.45
<b>58</b>	0.75	456.31	19.03		1.90	630.95	36.12
<b>59</b>	0.83	493.82	19.35		1.85	677.75	36.82
<b>60</b>	0.94	684.68	19.68		1.84	818.50	37.52

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**Table 4: State-Specific Natural Gas Consumption Proxy Variables**

<i>State</i>	<b>State-wide HDDs in 2009</b>	<b>Average thousand cubic feet (Mcf) of NG used for space heat by residential homes with NWGFs in 2009</b>	<b>Proxy Variable (Mcf NG used per HDD)</b>
<i>Colorado</i>	6953	60.07	0.0086
<i>Idaho*</i>	7145	55.99	0.0078
<i>Illinois</i>	6319	70.70	0.0112
<i>Iowa*</i>	7104	65.62	0.0092
<i>Massachusetts</i>	6472	64.84	0.0100
<i>Michigan</i>	7005	70.70	0.0101
<i>Minnesota*</i>	8909	65.62	0.0074
<i>Montana*</i>	8143	55.99	0.0069
<i>Nebraska*</i>	6712	54.80	0.0082
<i>New York*</i>	6368	59.18	0.0093
<i>North Dakota*</i>	9674	65.62	0.0068
<i>South Dakota*</i>	7985	65.62	0.0082
<i>Utah*</i>	6607	55.99	0.0085
<i>Wisconsin</i>	7747	70.670	0.0091
<i>Wyoming*</i>	8078	55.99	0.0069

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**Table 5: Average Simulated Space Heating costs per unit with NWGFs without Climate Change (\$s)**

<b>Year</b>	<b>CO</b>	<b>ID</b>	<b>IL</b>	<b>IA</b>	<b>MA</b>	<b>MI</b>	<b>MN</b>	<b>MT</b>	<b>NE</b>	<b>NY</b>	<b>ND</b>	<b>SD</b>	<b>UT</b>	<b>WI</b>	<b>WY</b>
<b>0</b>	386.52	436.08	434.05	409.17	767.02	519.58	432.38	372.01	338.12	539.80	347.01	403.10	479.83	495.78	392.57
<b>1</b>	398.81	443.61	445.87	419.07	786.06	528.88	443.74	383.03	348.70	549.50	358.86	411.74	494.84	506.77	404.83
<b>2</b>	411.56	451.23	458.11	429.14	805.65	538.30	455.26	394.29	359.67	559.30	371.18	420.55	510.25	518.03	417.58
<b>3</b>	424.76	458.96	470.29	439.46	825.59	547.93	467.38	405.91	370.99	569.45	383.89	429.58	526.17	529.38	430.81
<b>4</b>	438.31	466.96	483.08	450.01	846.18	557.75	479.55	417.87	382.66	579.74	396.92	438.85	542.47	541.33	444.36
<b>5</b>	452.17	474.95	496.51	460.82	867.38	567.85	492.06	430.29	394.66	590.15	410.69	448.29	559.33	553.36	458.18
<b>6</b>	466.48	483.16	510.10	471.82	889.15	578.02	505.24	442.99	406.93	600.82	424.36	457.91	577.03	565.59	472.62
<b>7</b>	481.25	491.50	524.03	483.05	911.00	588.32	518.41	456.04	419.46	611.52	438.86	467.66	595.08	578.33	487.52
<b>8</b>	496.34	500.01	537.87	494.72	933.65	598.76	532.48	469.42	432.89	622.53	453.80	477.78	613.91	590.83	502.53
<b>9</b>	512.29	508.67	552.43	506.72	957.11	609.57	546.07	483.29	446.44	633.66	469.18	487.83	633.19	603.73	518.11
<b>10</b>	527.93	517.43	567.20	519.30	980.40	620.63	560.09	497.60	460.28	645.24	485.63	498.69	653.50	617.04	534.10
<b>11</b>	544.73	526.43	582.53	531.67	1004.82	631.85	574.97	512.09	474.55	656.82	502.30	509.50	674.00	630.45	550.46
<b>12</b>	561.69	535.79	598.66	544.37	1029.24	643.05	590.31	526.95	488.91	668.74	519.55	520.36	695.21	644.30	567.72
<b>13</b>	579.62	544.94	615.50	557.25	1054.42	654.37	605.81	542.42	504.19	680.48	537.30	531.89	717.43	658.47	585.90
<b>14</b>	597.62	554.52	632.34	570.83	1079.90	665.99	621.80	558.97	520.55	692.34	556.39	543.48	739.80	673.15	604.21
<b>15</b>	617.21	563.84	649.13	584.74	1106.69	677.96	637.83	575.44	536.78	704.71	575.73	555.07	762.83	687.89	623.07
<b>16</b>	637.51	573.72	666.58	599.00	1133.91	690.39	655.02	592.42	552.90	717.37	596.07	567.53	786.33	703.11	642.85
<b>17</b>	657.41	583.46	685.30	613.31	1160.97	702.77	672.58	609.85	569.86	730.69	616.43	580.22	810.80	718.70	663.99
<b>18</b>	678.31	593.73	704.16	628.02	1190.25	715.56	690.49	627.90	587.06	743.62	637.98	592.40	836.28	734.56	683.96
<b>19</b>	698.86	603.80	723.73	642.60	1219.28	728.43	707.41	647.25	605.21	756.63	659.37	605.09	863.27	751.09	705.75
<b>20</b>	720.60	613.82	743.28	658.23	1249.43	741.42	725.67	667.11	623.90	770.38	680.92	618.06	890.15	768.31	728.50
<b>21</b>	743.16	624.34	764.59	673.76	1280.66	755.02	743.95	686.62	643.16	784.44	705.21	631.23	918.13	784.85	750.76
<b>22</b>	767.78	635.21	783.71	689.89	1313.03	768.45	763.80	706.30	663.63	798.91	729.70	644.94	946.92	802.42	775.31
<b>23</b>	792.59	646.09	803.74	705.88	1345.78	782.26	783.44	726.64	684.34	813.01	756.77	658.71	976.31	820.15	798.93
<b>24</b>	817.89	657.30	825.33	723.02	1379.80	795.77	804.42	748.82	705.83	827.57	783.78	671.86	1006.24	838.21	823.50
<b>25</b>	845.11	668.83	845.89	739.54	1414.24	809.74	825.76	770.18	728.66	842.75	810.78	686.80	1037.29	857.03	850.76
<b>26</b>	871.92	680.15	868.37	757.87	1449.39	823.65	847.68	793.42	750.40	858.00	838.75	700.88	1070.20	876.18	877.65
<b>27</b>	899.59	692.40	890.46	776.68	1486.74	838.23	868.90	815.84	773.45	873.16	867.42	716.19	1103.57	895.54	902.80
<b>28</b>	927.92	704.30	913.83	796.10	1522.93	853.41	891.68	841.09	798.37	888.49	898.48	731.51	1138.60	915.55	930.64
<b>29</b>	956.89	716.26	939.96	815.21	1561.79	868.93	915.48	865.14	823.16	904.26	928.49	747.29	1174.90	937.04	959.05
<b>30</b>	985.94	727.96	965.17	834.52	1601.02	884.49	939.26	889.51	848.73	920.48	961.57	762.56	1213.10	957.99	987.59

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31	1014.87	740.54	994.69	855.29	1639.27	900.39	963.61	917.52	875.83	937.88	993.69	779.40	1251.77	979.61	1019.06
32	1045.92	753.21	1019.53	874.90	1681.33	916.51	987.37	944.92	902.73	954.69	1030.91	796.60	1289.57	1001.69	1050.48
33	1078.27	765.71	1044.14	895.49	1722.02	932.81	1014.21	973.95	930.75	971.77	1068.15	814.74	1328.28	1023.14	1082.27
34	1112.37	778.85	1070.19	917.83	1762.41	948.82	1041.41	1002.79	960.89	989.18	1106.05	833.26	1370.63	1046.65	1114.26
35	1147.44	792.32	1098.36	940.47	1805.85	965.66	1069.81	1030.94	991.59	1007.08	1149.90	851.20	1413.91	1069.37	1148.05
36	1184.27	806.08	1127.15	964.01	1850.49	982.98	1097.78	1062.74	1021.96	1025.84	1190.22	868.42	1458.80	1094.32	1186.63
37	1221.07	818.75	1156.28	986.51	1894.65	1000.99	1124.14	1093.56	1054.16	1043.23	1236.61	886.80	1504.83	1119.99	1224.30
38	1259.37	832.68	1187.14	1009.96	1942.39	1018.68	1154.34	1124.69	1088.01	1061.94	1281.79	904.02	1551.75	1145.30	1261.43
39	1298.14	847.22	1219.97	1033.77	1991.45	1036.59	1184.02	1157.17	1121.97	1081.57	1323.36	922.90	1600.54	1171.18	1299.89
40	1337.61	861.67	1255.28	1059.46	2043.02	1055.47	1215.45	1191.31	1157.26	1101.37	1361.40	944.55	1647.87	1196.70	1337.89
41	1380.93	876.43	1286.54	1085.79	2094.47	1073.98	1246.12	1227.71	1192.87	1121.92	1406.47	964.79	1697.93	1223.04	1380.79
42	1426.82	892.02	1320.70	1114.14	2146.55	1093.83	1281.86	1264.94	1227.78	1141.83	1450.93	985.72	1751.93	1251.04	1421.39
43	1475.96	908.02	1358.40	1140.56	2200.50	1114.31	1314.27	1305.14	1268.51	1162.39	1505.45	1006.18	1803.23	1279.53	1464.39
44	1524.81	923.94	1388.78	1167.24	2253.14	1134.30	1349.08	1340.63	1309.20	1183.71	1555.15	1027.00	1859.84	1308.95	1509.12
45	1573.65	939.93	1429.81	1195.45	2312.06	1155.57	1381.99	1381.64	1350.85	1205.38	1607.96	1047.26	1917.93	1337.71	1555.83
46	1622.18	955.77	1473.85	1225.85	2366.79	1176.63	1418.65	1422.71	1393.54	1226.88	1671.15	1070.22	1973.45	1366.71	1603.36
47	1673.58	972.44	1513.07	1255.19	2424.54	1197.90	1455.79	1465.69	1437.60	1249.15	1732.99	1092.15	2034.95	1397.72	1653.27
48	1729.45	987.61	1557.36	1284.62	2480.98	1219.85	1489.87	1511.88	1481.08	1272.94	1788.19	1118.03	2100.42	1426.72	1707.41
49	1782.91	1004.12	1600.79	1313.97	2543.91	1242.03	1529.11	1556.95	1528.15	1296.27	1855.21	1140.53	2164.37	1458.32	1758.07
50	1842.67	1021.88	1639.25	1343.57	2607.69	1264.21	1569.99	1602.63	1576.21	1320.50	1925.08	1163.53	2232.86	1490.33	1819.36
51	1903.13	1040.53	1689.70	1374.18	2668.41	1286.78	1613.39	1646.68	1620.59	1343.89	1984.27	1189.47	2301.95	1524.21	1870.13
52	1961.32	1058.41	1738.70	1406.74	2736.72	1310.12	1657.42	1695.15	1672.53	1368.41	2050.39	1214.20	2374.99	1558.91	1930.23
53	2025.69	1077.53	1785.59	1442.70	2801.26	1332.89	1701.13	1741.06	1723.95	1392.68	2130.48	1238.86	2453.92	1595.06	1989.44
54	2091.61	1097.30	1828.64	1478.44	2866.64	1356.61	1747.32	1791.23	1774.23	1417.10	2206.74	1266.66	2527.33	1629.87	2053.98
55	2162.51	1115.87	1879.75	1513.10	2934.85	1380.33	1796.80	1849.14	1836.11	1442.92	2282.96	1294.57	2607.89	1666.19	2117.99
56	2229.14	1135.57	1933.58	1549.25	3009.29	1406.43	1848.18	1906.67	1895.75	1468.50	2371.33	1320.28	2695.68	1699.43	2180.99
57	2291.68	1154.27	1991.72	1589.25	3082.71	1431.30	1897.42	1965.46	1949.30	1494.23	2458.79	1347.42	2781.21	1735.93	2247.24
58	2370.90	1175.12	2046.95	1631.22	3157.70	1456.19	1943.77	2019.58	2009.98	1521.09	2535.43	1375.00	2870.04	1777.18	2323.74
59	2440.07	1197.40	2103.03	1671.31	3238.85	1482.17	1993.80	2077.66	2068.10	1547.44	2618.13	1401.89	2959.67	1814.34	2392.13
60	2518.75	1217.03	2157.43	1712.04	3320.45	1510.80	2045.00	2131.96	2128.27	1575.90	2704.15	1432.05	3051.16	1854.34	2468.30

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**Table 6: Average Simulated Space Heating costs per unit with NWGFs with Climate Change (\$s)**

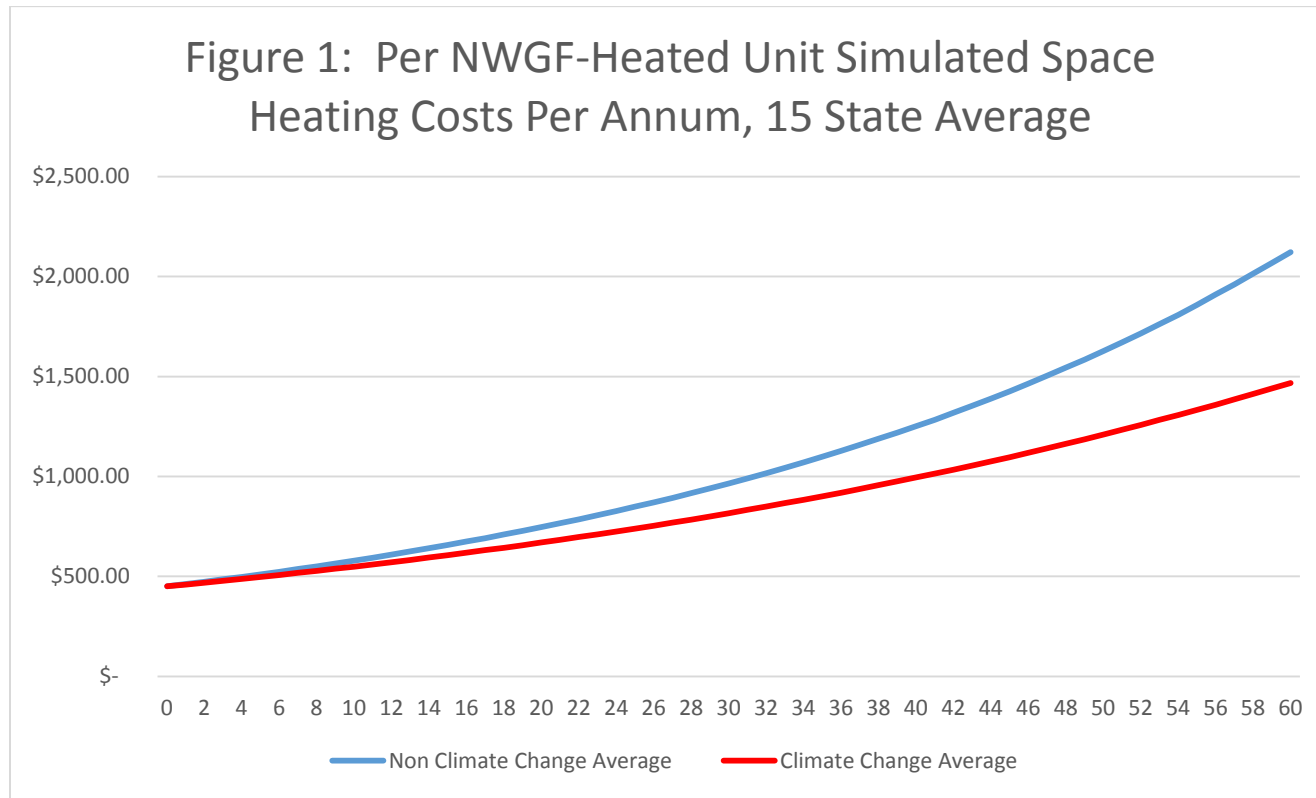
Year	CO	ID	IL	IA	MA	MI	MN	MT	NE	NY	ND	SD	UT	WI	WY
0	386.52	436.08	434.05	409.17	767.02	519.58	432.38	372.01	338.12	539.80	347.01	403.10	479.83	495.78	392.57
1	396.75	440.55	443.33	417.28	781.95	526.54	441.12	381.32	346.95	546.15	356.90	409.90	492.33	504.51	402.96
2	407.16	444.93	452.70	425.59	797.13	533.57	450.09	390.82	355.90	552.58	367.09	416.78	505.22	513.34	413.62
3	418.04	449.38	462.34	434.06	812.96	540.60	459.24	400.44	365.23	559.15	377.43	423.93	518.41	522.39	424.39
4	429.14	453.95	472.19	442.81	828.50	547.78	468.58	410.53	374.72	565.69	388.02	431.12	531.77	531.63	435.57
5	440.24	458.59	482.52	451.74	844.33	554.99	477.80	420.72	384.20	572.14	398.92	438.18	545.65	541.15	447.35
6	451.67	463.21	492.73	460.63	860.32	562.40	487.52	431.23	394.20	578.73	410.07	445.52	559.95	550.52	459.22
7	463.56	467.95	502.81	469.52	877.09	569.84	497.45	441.99	404.49	585.52	421.80	453.06	574.50	560.00	471.24
8	475.95	472.49	513.75	478.60	893.87	577.38	507.16	452.55	414.70	592.16	433.53	460.53	589.45	569.82	484.01
9	488.92	476.96	524.62	488.35	911.35	584.95	517.38	463.68	425.41	598.97	445.94	468.20	604.25	579.59	496.74
10	501.61	481.83	535.01	497.97	928.82	592.35	527.76	475.48	436.45	605.80	458.19	476.07	619.68	589.72	509.74
11	515.07	486.15	546.30	507.55	946.81	600.07	538.35	487.16	447.93	612.84	470.69	484.07	635.66	600.27	522.98
12	528.01	490.69	557.64	517.85	965.34	607.96	549.12	499.87	459.81	619.63	483.85	491.78	652.36	610.76	536.89
13	541.92	495.26	569.56	528.21	983.44	615.96	560.61	512.48	471.72	626.62	497.77	499.83	668.43	621.62	550.44
14	555.78	499.78	581.22	538.72	1002.13	623.95	571.28	525.38	484.11	633.58	511.06	508.10	685.70	631.93	564.68
15	570.63	504.71	593.13	549.43	1021.13	632.10	582.40	538.23	496.51	640.76	525.38	516.49	703.36	643.21	580.05
16	585.09	509.43	605.79	560.22	1040.06	640.19	594.27	551.45	509.28	647.80	539.93	525.00	721.25	654.26	595.13
17	600.08	514.50	619.00	571.44	1059.40	648.63	606.50	565.00	522.43	655.19	554.86	533.92	739.23	665.50	611.76
18	614.95	519.35	632.56	582.74	1079.54	656.85	617.17	579.57	535.56	662.33	570.38	542.85	758.10	676.69	626.65
19	631.19	524.08	645.71	593.51	1099.33	665.52	628.83	594.15	549.22	669.76	586.77	551.43	777.61	687.73	642.38
20	648.27	528.91	659.83	605.11	1120.18	674.30	640.88	608.20	563.68	676.97	604.02	559.85	797.05	699.59	659.60
21	665.33	533.79	674.31	616.50	1142.51	682.86	652.95	622.96	577.30	684.32	620.64	569.87	817.63	711.53	676.02
22	682.33	538.40	687.93	627.89	1165.16	691.45	665.61	637.54	591.97	692.05	636.65	578.76	838.21	723.76	692.43
23	700.47	543.26	703.12	640.12	1186.51	700.33	678.10	653.58	607.08	699.47	653.69	588.14	859.16	736.09	709.66
24	718.75	548.22	716.70	652.06	1208.50	709.31	690.77	669.65	623.08	706.73	672.21	597.80	880.72	748.42	726.67
25	738.38	553.11	729.79	664.09	1230.60	718.46	704.19	686.66	638.64	714.80	691.04	607.82	903.00	761.85	744.32
26	756.96	558.43	743.90	676.86	1253.31	727.69	717.79	702.56	654.67	722.25	710.36	618.25	926.43	774.48	765.00
27	777.24	563.48	758.43	689.97	1276.42	737.09	732.18	720.41	670.43	729.88	730.44	628.32	950.32	788.14	784.73
28	795.85	568.23	773.01	703.68	1301.40	746.70	745.65	737.57	686.85	738.00	751.13	638.13	974.03	801.90	805.66
29	816.78	573.03	789.03	718.34	1325.25	755.80	759.87	756.25	704.80	746.05	771.91	648.75	998.59	816.75	827.99
30	836.69	577.80	805.38	731.85	1349.87	765.55	775.23	773.68	723.72	753.81	792.28	659.73	1024.02	829.97	850.23

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<b>31</b>	858.90	582.43	823.74	746.18	1375.07	775.10	789.43	791.64	740.06	762.11	815.63	669.46	1049.56	843.80	870.92
<b>32</b>	881.81	587.43	841.25	760.89	1399.30	784.29	803.58	812.93	758.22	769.62	838.30	679.43	1075.44	857.57	891.74
<b>33</b>	902.85	592.66	858.02	775.17	1423.87	794.27	819.65	832.58	776.64	777.71	863.34	690.38	1103.07	871.23	914.00
<b>34</b>	926.33	597.42	874.14	790.01	1450.32	804.33	834.01	854.95	797.32	785.19	885.36	700.73	1131.19	886.18	934.37
<b>35</b>	949.50	602.10	893.39	804.89	1476.00	814.44	850.32	876.30	817.48	792.33	910.31	711.56	1160.07	899.70	958.11
<b>36</b>	971.20	606.76	911.00	819.78	1503.96	824.52	867.74	898.04	837.81	800.91	934.34	722.93	1188.61	915.19	982.68
<b>37</b>	998.49	612.40	929.56	835.24	1532.11	834.68	883.81	919.80	859.48	808.21	959.31	735.12	1218.83	930.31	1007.19
<b>38</b>	1022.59	617.52	946.41	853.67	1561.31	845.28	900.74	940.86	881.33	815.83	986.71	747.37	1250.03	946.20	1030.42
<b>39</b>	1050.44	622.31	962.64	868.45	1588.41	855.22	917.97	963.65	903.13	823.50	1016.02	759.82	1280.86	962.21	1055.93
<b>40</b>	1075.54	626.57	979.78	886.73	1616.23	865.73	932.84	986.01	925.91	831.84	1044.02	772.27	1312.14	977.67	1082.24
<b>41</b>	1103.64	631.19	997.14	903.64	1644.88	876.39	948.65	1006.64	950.24	840.38	1075.07	783.72	1345.29	994.72	1110.42
<b>42</b>	1129.71	636.87	1016.64	920.36	1675.15	887.13	966.72	1030.14	973.27	848.49	1104.40	796.34	1379.18	1010.85	1136.62
<b>43</b>	1159.96	641.37	1037.57	937.92	1703.73	898.25	984.57	1052.66	997.76	857.06	1130.71	807.88	1412.99	1027.34	1165.34
<b>44</b>	1186.55	645.59	1057.02	955.37	1733.76	909.30	1003.20	1077.63	1021.63	865.41	1163.75	821.22	1448.19	1044.79	1196.72
<b>45</b>	1216.63	649.97	1076.19	972.43	1765.39	920.60	1021.26	1101.83	1047.27	874.12	1196.63	833.61	1482.72	1061.92	1227.59
<b>46</b>	1245.82	654.21	1095.38	990.16	1797.64	931.99	1036.68	1128.56	1074.48	881.69	1229.77	847.75	1518.88	1079.31	1263.17
<b>47</b>	1276.63	658.82	1117.48	1009.12	1831.15	943.65	1054.52	1155.21	1100.68	889.45	1259.81	860.87	1556.14	1097.33	1296.14
<b>48</b>	1311.95	663.51	1141.09	1026.56	1863.70	954.97	1071.48	1182.07	1128.92	897.84	1294.16	875.09	1594.10	1114.88	1327.41
<b>49</b>	1345.90	667.46	1165.30	1045.04	1898.91	967.12	1091.83	1210.16	1155.40	905.71	1329.76	889.20	1631.94	1132.79	1357.87
<b>50</b>	1378.69	671.93	1187.51	1063.49	1932.03	978.74	1110.80	1238.21	1183.96	914.66	1361.60	903.54	1671.24	1150.46	1390.55
<b>51</b>	1414.00	676.17	1210.48	1083.35	1965.81	990.21	1130.33	1268.19	1213.64	923.56	1395.12	919.36	1714.50	1169.30	1426.61
<b>52</b>	1450.30	680.98	1230.20	1105.51	1998.26	1002.99	1150.55	1298.02	1246.51	930.96	1432.16	933.99	1759.19	1187.14	1463.71
<b>53</b>	1483.55	685.04	1252.51	1126.34	2032.46	1015.00	1170.44	1327.01	1280.37	939.04	1474.68	949.07	1800.20	1205.59	1501.22
<b>54</b>	1522.67	689.80	1273.05	1148.94	2068.49	1026.93	1190.06	1357.59	1309.71	946.34	1513.41	964.72	1844.13	1224.80	1538.04
<b>55</b>	1560.17	693.75	1298.21	1169.44	2103.20	1038.96	1211.75	1389.45	1338.97	954.50	1547.42	979.48	1887.05	1244.33	1577.08
<b>56</b>	1598.96	697.63	1322.82	1191.83	2138.83	1051.48	1232.24	1420.48	1370.53	962.87	1586.45	994.21	1931.56	1263.84	1617.04
<b>57</b>	1633.46	701.43	1352.03	1212.85	2173.24	1064.08	1253.44	1451.41	1403.82	970.69	1628.32	1009.37	1980.26	1285.10	1655.52
<b>58</b>	1669.14	705.11	1374.65	1235.63	2212.34	1076.04	1275.54	1486.76	1435.44	978.39	1676.50	1025.54	2030.41	1306.61	1698.85
<b>59</b>	1708.16	709.63	1396.77	1259.82	2246.63	1088.62	1300.85	1522.80	1470.27	987.03	1722.93	1041.29	2076.69	1326.86	1738.77
<b>60</b>	1753.29	713.21	1422.97	1281.88	2283.48	1100.57	1320.98	1559.70	1508.47	995.40	1768.50	1056.82	2124.13	1349.67	1780.73

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**Table 7: Funding: Municipal Bonds, No Climate Change**

<i>State</i>	<b>Total Average Savings of UTES</b>	Total Average Savings per Home	<b>Discounted Average Savings</b>	Discounted Savings per Home	<b>Metric Tons CO<sub>2</sub> Saved</b>	Metric Tons CO <sub>2</sub> Saved per Home
<i>Colorado</i>	\$ 6,015,267	\$ 120,305	\$ 1,302,426	\$ 26,049	<b>9.37</b>	0.19
<i>Idaho</i>	\$ 4,904,416	\$ 98,088	\$ 1,163,871	\$ 23,277	<b>8.30</b>	0.17
<i>Illinois</i>	\$ 5,825,176	\$ 116,504	\$ 1,305,053	\$ 26,101	<b>10.77</b>	0.22
<i>Iowa</i>	\$ 5,336,291	\$ 106,726	\$ 1,217,034	\$ 24,341	<b>9.82</b>	0.20
<i>Massachusetts</i>	\$ 7,720,625	\$ 154,412	\$ 1,791,244	\$ 35,825	<b>9.96</b>	0.20
<i>Michigan</i>	\$ 5,376,963	\$ 107,539	\$ 1,285,059	\$ 25,701	<b>10.70</b>	0.21
<i>Minnesota</i>	\$ 5,729,043	\$ 114,581	\$ 1,289,871	\$ 25,797	<b>9.74</b>	0.19
<i>Montana</i>	\$ 5,637,627	\$ 112,753	\$ 1,238,656	\$ 24,773	<b>8.43</b>	0.17
<i>Nebraska</i>	\$ 5,529,871	\$ 110,597	\$ 1,200,315	\$ 24,006	<b>8.04</b>	0.16
<i>New York</i>	\$ 5,491,818	\$ 109,836	\$ 1,314,404	\$ 26,288	<b>8.91</b>	0.18
<i>North Dakota</i>	\$ 5,928,003	\$ 118,560	\$ 1,263,024	\$ 25,260	<b>9.64</b>	0.19
<i>South Dakota</i>	\$ 5,052,026	\$ 101,041	\$ 1,169,045	\$ 23,381	<b>9.57</b>	0.19
<i>Utah</i>	\$ 6,719,967	\$ 134,399	\$ 1,464,502	\$ 29,290	<b>8.52</b>	0.17
<i>Wisconsin</i>	\$ 5,678,315	\$ 113,566	\$ 1,319,001	\$ 26,380	<b>10.69</b>	0.21
<i>Wyoming</i>	\$ 6,001,354	\$ 120,027	\$ 1,304,019	\$ 26,080	<b>8.56</b>	0.17

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**Table 8: Funding: Residential COOP, No Climate Change**

<i>State</i>	<b>Total Average Savings of UTES</b>	Total Average Savings per Home	<b>Discounted Average Savings</b>	Discounted Savings per Home	<b>Metric Tons CO<sub>2</sub> Saved</b>	Metric Tons CO <sub>2</sub> Saved per Home
<i>Colorado</i>	\$ 6,010,143	\$ 120,203	\$ 1,011,814	\$ 20,236	<b>9.37</b>	0.19
<i>Idaho</i>	\$ 4,897,841	\$ 97,957	\$ 927,407	\$ 18,548	<b>8.30</b>	0.17
<i>Illinois</i>	\$ 5,823,194	\$ 116,464	\$ 1,022,979	\$ 20,460	<b>10.77</b>	0.22
<i>Iowa</i>	\$ 5,348,632	\$ 106,973	\$ 961,028	\$ 19,221	<b>9.82</b>	0.20
<i>Massachusetts</i>	\$ 7,732,262	\$ 154,645	\$ 1,407,415	\$ 28,148	<b>9.96</b>	0.20
<i>Michigan</i>	\$ 5,376,833	\$ 107,537	\$ 1,023,758	\$ 20,475	<b>10.70</b>	0.21
<i>Minnesota</i>	\$ 5,719,982	\$ 114,400	\$ 1,012,150	\$ 20,243	<b>9.74</b>	0.19
<i>Montana</i>	\$ 5,621,637	\$ 112,433	\$ 966,097	\$ 19,322	<b>8.43</b>	0.17
<i>Nebraska</i>	\$ 5,513,118	\$ 110,262	\$ 936,635	\$ 18,733	<b>8.04</b>	0.16
<i>New York</i>	\$ 5,490,209	\$ 109,804	\$ 1,046,776	\$ 20,936	<b>8.91</b>	0.18
<i>North Dakota</i>	\$ 5,946,414	\$ 118,928	\$ 981,103	\$ 19,622	<b>9.64</b>	0.19
<i>South Dakota</i>	\$ 5,056,415	\$ 101,128	\$ 928,057	\$ 18,561	<b>9.57</b>	0.19
<i>Utah</i>	\$ 6,718,120	\$ 134,362	\$ 1,138,177	\$ 22,764	<b>8.52</b>	0.17
<i>Wisconsin</i>	\$ 5,673,152	\$ 113,463	\$ 1,043,017	\$ 20,860	<b>10.69</b>	0.21
<i>Wyoming</i>	\$ 6,004,617	\$ 120,092	\$ 1,015,371	\$ 20,307	<b>8.56</b>	0.17

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**Table 9: Funding: Municipal Bonds, Climate Change**

<i>State</i>	<b>Total Average Savings of UTES</b>	<b>Total Average Savings per Home</b>	<b>Discounted Average Savings</b>	<b>Discounted Savings per Home</b>	<b>Metric Tons CO<sub>2</sub> Saved</b>	<b>Metric Tons CO<sub>2</sub> Saved per Home</b>
<i>Colorado</i>	\$ 5,320,325	\$ 106,407	\$ 1,203,927	\$ 24,079	<b>7.92</b>	0.16
<i>Idaho</i>	\$ 4,368,606	\$ 87,372	\$ 1,076,958	\$ 21,539	<b>6.59</b>	0.13
<i>Illinois</i>	\$ 5,143,519	\$ 102,870	\$ 1,204,186	\$ 24,084	<b>8.93</b>	0.18
<i>Iowa</i>	\$ 4,925,854	\$ 98,517	\$ 1,154,417	\$ 23,088	<b>8.56</b>	0.17
<i>Massachusetts</i>	\$ 6,760,273	\$ 135,205	\$ 1,645,329	\$ 32,907	<b>8.39</b>	0.17
<i>Michigan</i>	\$ 4,960,343	\$ 99,207	\$ 1,217,973	\$ 24,359	<b>9.28</b>	0.19
<i>Minnesota</i>	\$ 5,066,382	\$ 101,328	\$ 1,190,126	\$ 23,803	<b>8.01</b>	0.16
<i>Montana</i>	\$ 5,132,233	\$ 102,645	\$ 1,164,589	\$ 23,292	<b>7.30</b>	0.15
<i>Nebraska</i>	\$ 4,993,161	\$ 99,863	\$ 1,124,167	\$ 22,483	<b>6.83</b>	0.14
<i>New York</i>	\$ 4,891,601	\$ 97,832	\$ 1,217,504	\$ 24,350	<b>7.28</b>	0.15
<i>North Dakota</i>	\$ 5,235,588	\$ 104,712	\$ 1,166,433	\$ 23,329	<b>8.05</b>	0.16
<i>South Dakota</i>	\$ 4,680,289	\$ 93,606	\$ 1,111,330	\$ 22,227	<b>8.29</b>	0.17
<i>Utah</i>	\$ 5,937,544	\$ 118,751	\$ 1,352,602	\$ 27,052	<b>7.23</b>	0.14
<i>Wisconsin</i>	\$ 5,179,301	\$ 103,586	\$ 1,242,824	\$ 24,856	<b>9.26</b>	0.19
<i>Wyoming</i>	\$ 5,377,907	\$ 107,558	\$ 1,216,103	\$ 24,322	<b>7.37</b>	0.15

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**Table 10: Funding: Residential COOP, Climate Change**

<i>State</i>	<b>Total Average Savings of UTES</b>	<b>Total Average Savings per Home</b>	<b>Discounted Average Savings</b>	<b>Discounted Savings per Home</b>	<b>Metric Tons CO<sub>2</sub> Saved</b>	<b>Metric Tons CO<sub>2</sub> Saved per Home</b>
<i>Colorado</i>	\$ 5,339,586	\$ 106,792	\$ 949,631	\$ 18,993	<b>7.92</b>	0.16
<i>Idaho</i>	\$ 4,370,799	\$ 87,416	\$ 868,523	\$ 17,370	<b>6.59</b>	0.13
<i>Illinois</i>	\$ 5,160,415	\$ 103,208	\$ 955,839	\$ 19,117	<b>8.93</b>	0.18
<i>Iowa</i>	\$ 4,908,211	\$ 98,164	\$ 915,985	\$ 18,320	<b>8.56</b>	0.17
<i>Massachusetts</i>	\$ 6,756,487	\$ 135,130	\$ 1,307,848	\$ 26,157	<b>8.39</b>	0.17
<i>Michigan</i>	\$ 4,963,019	\$ 99,260	\$ 977,595	\$ 19,552	<b>9.28</b>	0.19
<i>Minnesota</i>	\$ 5,034,578	\$ 100,692	\$ 943,275	\$ 18,866	<b>8.01</b>	0.16
<i>Montana</i>	\$ 5,138,821	\$ 102,776	\$ 920,185	\$ 18,404	<b>7.30</b>	0.15
<i>Nebraska</i>	\$ 4,983,265	\$ 99,665	\$ 884,929	\$ 17,699	<b>6.83</b>	0.14
<i>New York</i>	\$ 4,883,334	\$ 97,667	\$ 979,319	\$ 19,586	<b>7.28</b>	0.15
<i>North Dakota</i>	\$ 5,218,077	\$ 104,362	\$ 914,614	\$ 18,292	<b>8.05</b>	0.16
<i>South Dakota</i>	\$ 4,668,370	\$ 93,367	\$ 886,055	\$ 17,721	<b>8.29</b>	0.17
<i>Utah</i>	\$ 5,935,454	\$ 118,709	\$ 1,063,389	\$ 21,268	<b>7.23</b>	0.14
<i>Wisconsin</i>	\$ 5,196,317	\$ 103,926	\$ 992,653	\$ 19,853	<b>9.26</b>	0.19
<i>Wyoming</i>	\$ 5,382,144	\$ 107,643	\$ 956,854	\$ 19,137	<b>7.37</b>	0.15

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