CARBON EMISSIONS REDUCTION STRATEGIES FOR UTAH HOUSEHOLDS OPERATING UNDER A BUDGET CONSTRAINT

by

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ABSTRACT

This thesis presents actions that households can take to reduce carbon dioxide emissions associated with day-to-day activities. Average annual estimates of the carbon output associated with home energy use, transportation, and dietary choices are provided for both Utah and U.S. households. It is estimated that the average Utah household produces 81,808 pounds (lbs) of carbon dioxide annually from these three categories, while the average U.S. household contributes 71,561 lbs per year. The research concludes that significant carbon dioxide emissions reductions of 32.2% for Utah households and 32.4% for national households are accessible by employing a mix of strategies. Furthermore, it is found that these strategies are available at a net financial savings to the household.

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INTRODUCTION

The topic of climate change mitigation encompasses a wide variety of participants and a large number of institutions with potential remedies to support the basic need of reducing greenhouse gas (GHG) emissions. This thesis will aim to address this same basic need, but on a much more elementary level than carbon taxes, greenhouse gas trading markets, feed-in tariff programs, or similar policy initiatives. The research will focus on individual households and day-to-day choices that can be made in order to reduce climate change impact, all while operating under a reasonable budget constraint. This thesis will relate the majority of the carbon dioxide (CO_2) reduction methods and costs to a typical Utah household while simultaneously providing national estimates, where available.

Research highlighted here will mainly focus on carbon dioxide emissions, the primary GHG driver of anthropogenic climate change according to the Intergovernmental Panel on Climate Change (IPCC, 2007). While it is important to note that other GHGs impose a measurable and significant impact on the Earth's climate, carbon dioxide is focused on throughout this thesis due to the ability to translate daily household activities and their emissions equivalent into CO_2 figures and CO_2's central role in the issue of climate change. The ability to calculate CO_2 emission intensities, and their reduction counterparts, is currently available within a great deal of literature on the topic. Where CO_2-specific estimates are not available, the thesis will utilize research that aggregates a wider range of GHG emissions, or offsets, of an activity and introduces them in a CO_2-equivalent (CO_2e) metric.

In addition to climate change mitigation, this thesis acknowledges the essential role household budget constraints play in emissions reduction decision making. A goal of the thesis is to explore whether carbon reduction strategies are feasible, or even financially advantageous, for the common household. Where available, the estimated costs of activities contributing to CO_2 emissions are provided along with the financial implications of emissions reduction methods. The financial aspects of this thesis are translated in Utah-relevant figures along with national approximations.

The next section of the thesis will contain details on carbon footprint estimates for Utah and national households and describe the methodologies and reasoning behind how these projections were obtained. In most cases, the related financial costs behind these footprints will be included. After obtaining carbon footprint estimates, the research will focus on strategies households can employ to reduce their carbon emissions along with the microeconomic costs and benefits for these suggestions. Finally, the aggregates of emissions and reduction data will be discussed and then be followed by the conclusion.

ESTIMATING THE ECONOMIC PROFILE AND CARBON FOOTPRINT OF A TYPICAL HOUSEHOLD

Economic Profile

Considering the wide variety in incomes, expenses and other contributing factors to a household's economic profile, compiling a guide which is representative of a significant portion of Utah households is a challenging task. A similar difficulty exists when attempting to analyze carbon dioxide reduction statistics and make them relevant to large portions of the population. Given the challenges inherent in constructing universally-relevant profile data and emissions reduction strategies, this thesis will rely heavily on statistical averages. The observations and suggestions here would need to be tailored to a specific household's situation if the model were to be directly applied. However, the statistics and possibilities recounted here can serve as an adjustable baseline for what is realistically relevant and achievable.

According to research from the U.S. Census Bureau (2006), there were 791,929 households in Utah in 2005 with an average of 3.07 people in each household. National figures estimate 111,090,617 households in the U.S. in 2005 containing an average of 2.60 people in each (U.S. Census Bureau, 2006). Utah households earned a median income of $47,224 in 2004, slightly above the national median of $44,334 for that same year (U.S. Census Bureau, 2005). These figures will be used later on in the thesis to determine the household impact of certain carbon emitting activities. The median incomes can also provide the reader some context for the percentage costs and savings of carbon mitigation techniques.

This thesis will not assess the general expenses (e.g., mortgage payment, rent, education costs, etc.) incurred by a household in any given year. Also, the scope of the thesis will not include assessments of additional discretionary income, or debt, attributed to an average Utah or national household. Rather, the focus will remain on the financial implications of the carbon emitting and carbon prevention activities presented.

Home Energy Use Emissions

The first core component of a household's carbon footprint presented here relates to home energy use. This includes the electricity and natural gas, along with other less prominent energy sources, directly consumed within an average Utah home.

The total electricity consumed by Utah households in 2005 was 7.567 billion kilowatt hours (kWh), or 9,555 kWh per household. These figures were calculated by combining Energy Information Administration (EIA, 2008a) data reported in 2008 along with the U.S. Census Bureau household estimates for 2005 (2006) mentioned earlier:

$$7{,}567{,}000{,}000 \text{ kWh per year} / 791{,}929 \text{ households} = 9{,}555 \text{ kWh per household per year} \quad (1)$$

The CO_2 output associated with this electricity consumption was derived using a carbon intensity estimate for electricity provided by the U.S. Environmental Protection Agency (U.S. EPA, 2002). This carbon intensity estimate accounted for the carbon footprint of electricity produced from 1998 – 2000 and the details were provided for a regional, state and national level. Furthermore, the EPA detailed the output of other prominent GHGs including methane and nitrous oxide. For the scope of this thesis, only the CO_2 emissions are taken into account, but there is a clear correlation between higher CO_2 and other GHG emissions. This fact means that both the electricity emissions footprints and related reduction strategies have a more significant impact on climate change than expressed in this research.

The EPA estimated the carbon coefficient for electricity produced for the state of Utah between 1998 and 2000 was 1.93 pounds (lbs) of CO_2 per kWh (2002). The national average during this same time period was 1.34 lbs of CO_2 per kWh generated (U.S. EPA, 2002). The larger carbon coefficient associated with Utah's electricity, 44% higher than the U.S. mean, is related to a higher reliance on coal for electricity in this state (EIA, 2009a). Given this carbon coefficient and the average amount of electricity consumed in a Utah household, an average of 18,441.2 lbs of CO_2 are created via electricity usage by a typical Utah household per year:

$$9{,}555 \text{ kWh per household per year X } 1.93 \text{ lbs of } CO_2 \text{ per kWh} = 18{,}441.2 \text{ lbs of } CO_2 \text{ per year} \quad (2)$$

Along with the environmental toll of electricity consumption, there is an associated financial cost for each household. In June of 2008, the average residential electricity price in Utah was \$0.0868 per kWh (EIA, 2008b). The average national residential price was 24.7% higher at \$0.108 during this same time period (EIA, 2008b). The price of electricity for Utah residents translates into an average of \$829.37 in electricity costs per year:

$$9{,}555 \text{ kWh per household/year X } \$0.0868/\text{kWh} = \$829.37 \text{ in electricity costs per household per year} \quad (3)$$

The second major producer of CO_2 emissions from home energy use for a Utah household is natural gas consumption. According to EIA figures, Utah consumed 58 billion cubic feet (ft^3) of natural gas in 2005 (2008a), or 73,238 cubic feet per household:

$$58{,}000{,}000{,}000 \text{ ft}^3 \text{ of natural gas per year / } 791{,}929 \text{ households} = 73{,}238 \text{ ft}^3 \text{ of natural gas per household per year} \quad (4)$$

The CO_2 output associated with this natural gas usage can be acquired using the EPA's estimated average carbon coefficient for natural gas of 0.12012 lbs of CO_2 per cubic foot (2007a):

$$73{,}238 \text{ ft}^3 \text{ of natural gas per household per year X } 0.12012 \text{ lbs of } CO_2 \text{ per ft}^3 = 8{,}797.3 \text{ lbs of } CO_2 \text{ per household per year} \quad (5)$$

Natural gas prices in Utah are currently considerably lower than the national average. In June of 2008 Utah residents paid an average of $8.66 per thousand cubic feet of natural gas, this is much less than the $18.33 per thousand cubic feet rate paid by the average U.S. consumer during this time period (EIA, 2008c). Given this relatively low rate, the average Utah household spends roughly $634.24 annually on natural gas per residence:

$$73{,}238 \text{ ft}^3 \text{ natural gas per household per year X \$8.66 per thousand ft}^3 = \$634.24 \text{ in natural gas costs per household per year} \quad (6)$$

The EIA also provides details on the consumption of other, much less prominent, sources of energy for at home use. Liquefied petroleum gas (LPG) is the third largest component of home energy usage in Utah with 1.19 barrels consumed per Utah household in 2005 (EIA, 2008a):

$$943{,}000 \text{ barrels of LPG / } 791{,}929 \text{ households} = 1.19 \text{ barrels of LPG per household per year} \quad (7)$$

The EPA estimates that 510.18 lbs of CO_2 are produced per barrel of LPG (2007a) which leads to an average of 607.1 lbs of CO_2 attributable to LPG for a Utah household each year:

$$1.19 \text{ barrels of LPG X } 510.18 \text{ lbs of } CO_2 \text{ per barrel} = 607.1 \text{ lbs of } CO_2 \text{ per household per year} \quad (8)$$

The fourth, and final, component of home energy usage which creates a notable carbon impact is distillate fuel oil. Utah residents consumed roughly 26,000 barrels of distillate fuel oil in 2005 (EIA, 2008a), or .03 barrels per household:

$$26{,}000 \text{ barrels of distillate fuel oil / } 791{,}929 \text{ households} = .03 \text{ barrels of distillate fuel oil per household per year} \quad (9)$$

Distillate fuel oil contributes an estimated 1,016.62 lbs of CO_2 per barrel, according to the EPA (2007a), leading to an average impact of 30.5 lbs of CO_2 per Utah household each year:

.03 barrels of distillate fuel oil X 1,016.62 lbs of CO_2 per barrel = 30.5 lbs of CO_2 per household per year (10)

While the carbon footprints for LPG and distillate fuel oil are included in this analysis, the financial impacts will be excluded due to a lack of consolidated pricing data. Additionally, there is a relatively small imprint of these energy sources on a Utah household's total energy usage. These fuels are more commonly used in rural areas and thus are not necessary to create an accurate snapshot of financial costs related to residential energy consumption for the average Utah household.

The national CO_2 output figures presented in this thesis for home energy use were calculated using 2005 figures provided by the EIA (2007) which detailed residential emissions from each of the mentioned energy sources. These figures from the original EIA source were converted to lbs of CO_2 and then divided by the number of U.S. households in 2005 (U.S. Census Bureau, 2006) to obtain the average amount of CO_2 emitted per energy source:

(Millions of metric tons of CO_2 X 2204.6 lbs of CO_2 per metric ton) / 111,090,617 households = Annual CO_2 output per U.S. household by energy source (11)

Aggregating all of the preceding information results in an average annual home energy footprint of 27,876.1 lbs of CO_2 for Utah households and 24,905.6 lbs of CO_2

nationally in 2005. For Utah households, there is an associated financial cost of $1,463.62 for home electricity and natural gas usage which is approximately 3.10% of the median Utah income reported earlier in this thesis. Table 1 includes a summary of CO_2 output for Utah and national households per home energy source, while Figure 1 breaks down CO_2 output by energy source for Utah households.

Transportation Emissions

Personal transportation accounts for another major component of a Utah household's CO_2 footprint. The research here will focus on two primary modes of transportation for the average Utah household, personal vehicle transport and commercial air transport, and provide CO_2 emissions data for each. There are certainly emissions associated with other forms of personal transportation; however, this thesis will highlight the two most prominent sources that shape an average household's climate change

Table 1

Average Annual CO_2 Emissions From Various Home Energy Sources

Home Energy Source	Annual CO_2 Output per Utah Household (lbs)	Annual CO_2 Output per U.S. Household (lbs)
Electricity	18,441.2	17,664.1
Natural gas	8,797.3	5,223.2
Liquefied Petroleum Gas (LPG)	607.1	639.0
Distillate fuel oil	30.5	1,240.3
Kerosene	NA[a]	121.1
Household Coal	NA	17.9
Wood	NA	NA
Average Annual CO_2 Output (2005)	27,876.1	24,905.6

Note. The data in Table 1 were calculated based on information from the following sources: EIA (2007); EIA (2008a); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2007a).

[a]'NA' values indicate CO_2 footprints which were so small they were deemed insignificant or incalculable.

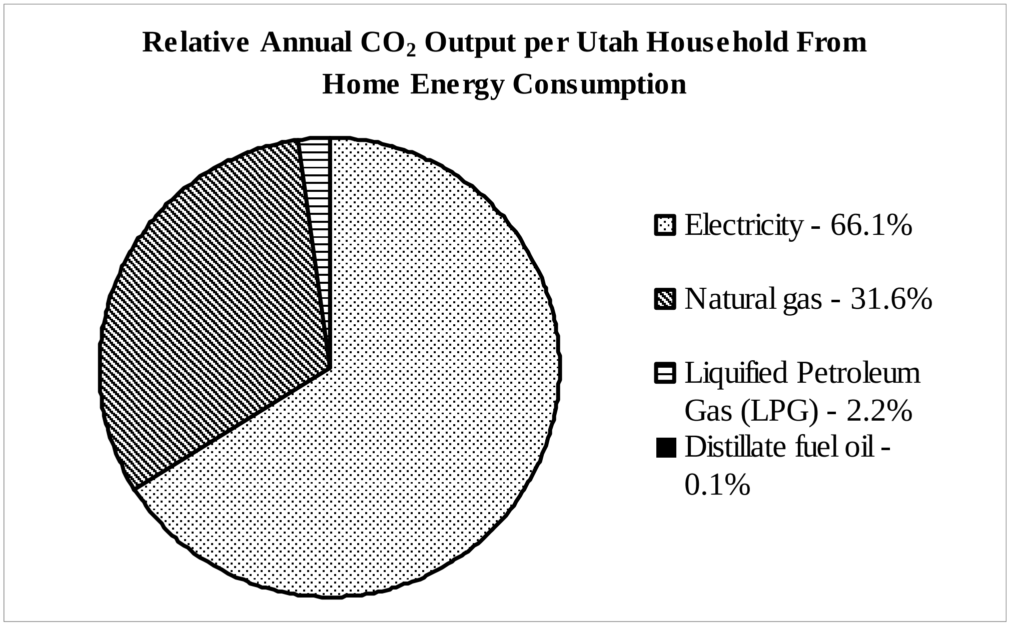

Figure 1. Relative annual CO_2 output per Utah household from home energy consumption.

Note. The data in Figure 1 were calculated based on information from the following sources: EIA (2007); EIA (2008a); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2007a).

impact. Later on, in the emissions reduction section, other forms of transportation such as bicycling, walking, light rail and local bus services will be offered as alternatives to higher carbon intensity modes of transport. The carbon footprint associated with these alternatives will be briefly reviewed, but the central emissions focus will remain on personal vehicle and commercial air transport.

According to figures from the Bureau of Transportation Statistics (BTS), 867,000 automobiles and 687,000 light trucks were registered in the state of Utah in the year 2000 (BTS, n.d.a). These estimates roughly reflect a 56%-to-44% automobile-to-light truck ratio in the state and this ratio will be used to calculate the average miles per gallon

(MPG) of a Utah vehicle. The EIA reports that vehicles in the U.S. in 2004 had an average fuel efficiency of 29.3 MPG for cars and 21.5 MPG for light trucks (2005). Combining the ratio of automobiles-to-light trucks and average MPG for each type of vehicle leads to an estimate of 25.9 MPG for the average personal vehicle used in the state of Utah:

$$(55.79\% \text{ automobiles X } 29.3 \text{ MPG}) + (44.21\% \text{ light trucks X } 21.5 \text{ MPG}) = \text{25.9 average MPG for personal vehicles in Utah households} \tag{12}$$

Motorcycles have been excluded from these calculations due to their relatively rare existence in Utah households, 1.7% of residential vehicles (BTS, n.d.a), and limited use dictated by the climate in many portions of the state.

Nationally, the ratio of automobiles-to-light trucks in 2000 was roughly 63%-to-37% (U.S. EPA, 2005). Using the aforementioned MPG averages for these vehicle types we can calculate that the national average MPG is 26.5 for personal vehicles:

$$(63.4\% \text{ automobiles X } 29.3 \text{ MPG}) + (36.6\% \text{ light trucks X } 21.5 \text{ MPG}) = \text{26.5 average MPG for personal vehicles in U.S. households} \tag{13}$$

The next step towards calculating the CO_2 output of personal vehicle transportation is to determine the total number of vehicle miles traveled per household each year. The Bureau of Transportation’s vehicle miles traveled (VMT) statistics estimate that 25.158 billion vehicle miles were traveled in Utah in 2005, or roughly 10,187 VMT per capita. The Bureau of Transportation’s national estimates for 2005 reflected a total of 2,989.807 billion VMT, equating to 10,087 VMT per capita (2006).

Next, we relate these figures back to VMT per household using the number of household figures presented earlier (U.S. Census Bureau, 2006) to conclude that 31,768 VMT are attributable to the average Utah household in 2005 and 26,913 VMT per household nationally this same year:

$$\text{25.158 billion VMT in 2005 / 791,929 households = 31,768 VMT per Utah household per year} \quad (14)$$

$$\text{2,989.807 billion VMT in 2005 / 111,090,617 households = 26,913 VMT per U.S. household per year} \quad (15)$$

The final component for estimating CO_2 output related to personal transportation is to translate VMT into an associated CO_2 footprint. First, the average number of gallons of gasoline used for personal transportation is calculated using the previously mentioned statistics:

$$\text{31,768 VMT per Utah household / 25.85 average MPG = 1,228.94 gallons of gasoline consumed per Utah household per year} \quad (16)$$

$$\text{26,913 VMT per U.S. household / 26.45 average MPG = 1,017.51 gallons of gasoline consumed per U.S. household per year} \quad (17)$$

These gallons of petroleum can be converted into CO_2 emissions by utilizing the carbon intensity of gasoline provided by the EPA of 19.4 lbs of CO_2 per gallon (2005). Utilizing this conversion metric leads to a household CO_2 footprint of 23,841 lbs in Utah and 19,739 lbs nationally related to personal vehicle transportation in 2005. These emissions

1,228.94 gallons of petroleum consumed X 19.4 lbs of CO_2 per gallon of gasoline = (18)

23,841 lbs of CO_2 emissions from personal vehicles per Utah Household per year

1,017.51 gallons of petroleum consumed per U.S. household annually X 19.4 lbs (19)

of CO_2 per gallon of gasoline = 19,739 lbs of CO_2 emissions from personal vehicles

per U.S. Household per year

totals, along with other information related to automobile travel, are summarized in Table 2.

In addition to personal vehicle transportation, there is a second major component of transportation which will be included in the household profile. Commercial air transportation is another significant activity for many households and it has a noteworthy impact on the climate. Utah-specific air transportation figures were not discernable from the data available, so national estimates will be used in their place. While Utah households may differ from the figures presented, these national estimates set a

Table 2

Automobile Transportation Statistics for Utah and U.S. Households

2005 Household Averages	VMT - Personal Vehicles	Gallons of Petroleum Used	Related CO_2 Output (lbs)	Cost of Gasoline[a]
Utah	31,768	1,229	23,841	$3,477.90
U.S.	26,913	1,018	19,739	$2,879.55

Note. The data in Table 2 were calculated based on information from the following sources: BTS (2006); BTS (n.d.a); EIA (2005); EIA (2009b); U.S. Census Bureau (2006); U.S. EPA (2005).

[a]Cost of gasoline based on EIA retail average from 2005-2008 of $2.83/gallon of mid-grade (2009b).

reasonable baseline for carbon emissions from air travel which can be adjusted to fit a specific household's actual travel profile.

The Bureau of Transportation Statistics estimates that U.S. air carriers supported 795,117,318,000 passenger miles for domestic and international noncargo flights in 2005 and that these passenger miles were the result of 747,171,000 enplanements during this same time period (BTS, n.d.b). This averages out to approximately 1,064 miles per enplanement. When combined with the total number of households in the U.S. (U.S. Census Bureau, 2006), we get 6.73 enplanements and 7,157.38 passenger miles per household in 2005:

$$747{,}171{,}000 \text{ enplanements} / 111{,}090{,}617 \text{ households} = 6.73 \text{ enplanements per U.S. household} \quad (20)$$

$$795{,}117{,}318{,}000 \text{ passenger miles} / 111{,}090{,}617 \text{ households} = 7{,}157.38 \text{ passenger miles per U.S. household} \quad (21)$$

While many of these enplanements were likely for business purposes, and not strictly personal travel, they will be included in the CO_2 transportation footprint for a few reasons. First, the BTS data available do not segregate personal from professional travel totals and the research here will not attempt to do so either. Second, whether for personal or professional reasons, the air travel figures estimated still result in significant climactic impacts in terms of their GHG contributions to the atmosphere. Finally, the inclusion of all air travel statistics provides a more holistic view of a household's CO_2 emissions footprint. This inclusion simultaneously provides a greater opportunity to offset some of that impact through choosing alternatives to air travel in both personal and professional life.

The Colorado Carbon Fund estimates that air travel contributes, on average, 0.484 lbs of CO_2 per passenger mile (n.d.). The contribution to climate change is much more dramatic when accounting for other GHGs emitted such as nitrous oxide and the net warming effect of contrails from aircraft emissions. Accounting for all aspects of the net warming effect of commercial aircraft, the Colorado Carbon Fund estimates a CO_2-eqvuivalent (CO_2e) of 1.3068 lbs per passenger mile, a 170% increase in GHG impact relative to only CO_2 emissions (Colorado Carbon Fund, n.d.). The CO_2e impact, relative to simply CO_2 emissions, for air travel is much more significant than that of vehicle travel. For example, the U.S. EPA estimates that merely 5-6% of GHG emissions from automobile travel are of non- CO_2 chemical composition (U.S. EPA, 2005). Given the significant warming impact beyond just CO_2 from air travel, this thesis will include CO_2e estimates for the air travel footprint (see Table 3) and its related emission reduction strategies.

Applying the Colorado Carbon Fund (n.d.) estimate of 1.3068 lbs of CO_2e per passenger mile to the air travel data previously provided reveals that there are approximately 9,353 lbs of CO_2e from air travel attributable to each household in a given year. Details on air travel statistics for the average household are provided in Table 3.

$$7{,}157.38 \text{ passenger miles X } 1.3068 \text{ lbs of } CO_2e \text{ per passenger mile} = 9{,}353.26 \text{ lbs of } CO_2e \text{ emissions from air travel per household each year} \quad (22)$$

Combining the details from the personal vehicle data and air travel data, we arrive

Table 3

Annual CO_2e Output From Air Travel

2005 Household Averages	# of Enplanements	Passenger Miles Traveled	Related CO_2e Output (lbs)
U.S. (also utilized for Utah totals)	6.73	7,157	9,353

Note. The data in Table 3 were calculated based on information from the following sources: BTS (n.d.b); Colorado Carbon Fund (n.d.); U.S. Census Bureau (2006).

at a total CO_2 footprint of 33,194 lbs annually from transportation for the average Utah household. The Utah figure is slightly higher than the national average transportation estimate of 29,092 lbs of CO_2 per year for reasons such as lower average fuel economy and a greater number of vehicle miles traveled.

Dietary-related Emissions

The final pillar for constructing the carbon footprint of an average Utah household is the emissions impact of dietary choices. Food consumption is something not typically associated with CO_2 emissions in the general consciousness of society today due to the often unadvertised emissions from the production and transportation of food products. However, the choice to include dietary impacts in this CO_2 model was made due to their omnipresent nature in every household, the significant carbon footprint implications, and the availability of research which estimates a typical American's dietary choices and their related GHG impact.

The emissions impact of varying dietary choices were examined in a paper by Gidon Eshel and Pamela Martin titled "Diet, Energy and Global Warming" (2006). The authors presented the fact that "in 2002, the food production system accounted for 17%

of all fossil fuel use in the U.S." (2006, p. 2). Eshel and Martin also assessed the impact from non-CO_2 GHGs in food production, predominately methane (CH_4) and nitrous oxide (NO_2). They stated that in the U.S. in 2003 there were 182.8 x 10^6 tons of CO_2-equivalent (CO_2e) of methane emitted for food production, approximately 94% of which were directly related to livestock. Similarly, agriculture-related nitrous oxide emissions totaled 233.3 x 10^6 tons of CO_2e, with 60.7 x 10^6 tons of CO_2e of NO_2 coming from animal waste (Eshel & Martin, 2006).

The striking conclusions of Eshel and Martin illustrate two important points for this thesis. First, food consumption clearly has a noteworthy impact in terms of GHG emissions and, as such, may afford the opportunity for large CO_2 emissions reduction potential for a household. Second, it is sensible to assess food consumption impacts in terms of CO_2e figures, not just CO_2-specific, due to the major role multiple GHGs play in the impact of dietary choices on the climate. The importance of these GHGs is substantiated in the article "What is Your Dinner Doing to the Climate" (Trevedi, 2008). This article states that "methane remains in the atmosphere for 9 to 15 years and traps heat 21 times as effectively as CO_2. Fertilizers and manure release nitrous oxide, which is 296 times as good as CO_2 at trapping heat and remains in the atmosphere for 114 years on average" (2008, para. 6). Fortunately, for emissions calculation purposes, CO_2e has become the adopted standard for dietary-related carbon footprint assessments (e.g., Eshel & Martin, 2006; Matthews & Weber, 2008; U.N. FAO, 2006). As such, combining the conclusions of various authors becomes relatively seamless.

The work by Eshel and Martin focused on the GHG differences between varying dietary choices, but did not provide a total footprint for the average consumer's food-related GHG emissions. Given this, we will turn to work by H. Scott Matthews and Christopher Weber entitled "Food-Miles and the Relative Climate Impacts of Food Choices in the United States" (2008) to determine the CO_2e footprint that should be attributed to the average Utah household. Matthews and Weber engaged in a thorough effort to determine the GHG impact of dietary choices in the U.S. and concluded that:

> Few studies in the United States have systematically compared the life-cycle greenhouse gas (GHG) emissions associated with food production against long-distance distribution, a.k.a. food-miles. We find that although food is transported long distances in general (1640 km delivery and 6760 km life-cycle supply chain on average) the GHG emissions associated with food are dominated by the production phase, contributing 83% of the average U.S. household's 8.1 t CO_2e/yr footprint for food consumption. Transportation as a whole represents only 11% of life-cycle GHG emissions, and final delivery from producer to retail contributes only 4%. (2008, abstract)

Matthews and Weber considered GHG emissions associated with the production, transportation, and distribution of food. The authors utilized an input-output life cycle assessment methodology to capture upstream impacts of food production. Their 6.8 t CO_2e estimate for food production alone consisted of 3.0 t CO_2 emissions, 1.6 t methane emissions, 2.1 t nitrous oxide emissions, and 0.1 t due to HFCs and other gases (2008). A major component missing from the Matthews and Weber analysis was land use impacts, such as deforestation, resulting from food production. This exclusion translates into an underestimation of the total GHG impact. For context of this underestimation, Matthews and Weber suggest that land use impacts have been estimated at roughly 35% of the total GHG impact of raising livestock (2008).

Matthews and Weber state that "all tons [cited in their paper] are metric tons, t or tonne" (2008). Using the conversion factor that one metric ton equals 2,204.6 lbs we can derive that the 8.1 t CO_2e figure equals 17,857 lbs of CO_2e per household according to the authors. For the sake of consistency in this thesis, we will convert this CO_2e estimate using the U.S. and Utah typical household sizes previously mentioned. The first step in this conversion is to estimate the per person CO_2e outputs presented by Matthews and Weber:

(17,857 lbs of CO_2e X 101,000,000 households [cited by Matthews & Weber]) / 267,000,000 residents [cited by Matthews & Weber] = 6,755 lbs of CO_2e per person annually from dietary choices (23)

Next, we convert this per person CO_2e estimate using the Utah and U.S. household sizes utilized in this thesis, 3.07 and 2.60 respectively (U.S. Census Bureau, 2006), to determine the carbon footprints related to dietary choices for the household profiles presented:

6,755 lbs of CO_2e per person X 3.07 persons per Utah household = 20,737.9 lbs of CO_2e from dietary choices for the average Utah household per year (24)

6,755 lbs of CO_2e per person X 2.60 persons per household = 17,563.0 lbs of CO_2e from dietary choices for the average U.S. household per year (25)

Equations 24 and 25 demonstrate that 20,738 lbs of CO_2e and 17,563 lbs of CO_2e are the average annual GHG contributions from dietary choices for a Utah and national household, respectively.

Summary of the Household Carbon Footprint

In order to create a composite snapshot of the average household's annual CO_2 emissions, we will aggregate the CO_2 and CO_2e emissions totals from the previous sections of this thesis. Table 4 reflects the summation of these estimates and concludes that the average Utah household produces CO_2 emissions of 81,808 lbs per year for the activities listed. The Utah average household emissions total is roughly 14.3% larger than a U.S. household's footprint which is estimated to be 71,560.6 lbs of CO_2 per year.

The relative weight of each CO_2 output category for a Utah household is portrayed in Figure 2. The figure illustrates that transportation contributes the largest amount of CO_2 emissions for an average Utah household, followed by home energy use and then dietary impact. While this analysis found that Utah households contribute 14.3% more CO_2 each year, on average, than the national household average, it is interesting to note that the relative weight each category plays in the U.S. total (see Figure 3) is nearly identical to that represented in the Utah chart. The most significant difference exists in the dietary impact portion where Utah households contribute 0.8% more to their overall CO_2 total than the national average. The slight difference in dietary impact is attributable to the fact that Utah households are typically larger than the U.S. average, 3.07 people per household compared to 2.60 people per household, and thus the total dietary impact presented was larger by roughly this same degree.

Carbon Emitting Activities Excluded From the Household Profile

While creating estimates of the average household's CO_2 footprint, this thesis focused on three primary categories: home energy use, transportation, and dietary

Table 4

Average Annual CO_2 Emissions From Utah and U.S. Households

Activity or Source	Utah – lbs of CO_2 per Household	U.S. – lbs of CO_2 per Household
Home Energy Use		
Electricity	18,441.2	17,664.1
Natural Gas	8,797.3	5,223.2
Liquefied Petroleum Gas (LPG)	607.1	639.0
Distillate Fuel	30.5	1,240.3
Kerosene	NA	121.1
Household Coal	NA	17.9
Home Energy Use Total	27,876.1	24,905.6
Transportation		
Personal Automobile	23,841.0	19,739.0
Air Travel[a]	9,353.0	9,353.0
Transportation Total	33,194.0	29,092.0
Dietary Impact Total[a]	20,737.9	17,563.0
Total Household CO_2 Footprint	81,808.0	71,560.6

Note. The data in Table 4 were calculated based on information from the following sources: BTS (2006); BTS (n.d.a); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2007); EIA (2008a); Matthews & Weber (2008); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2005); U.S. EPA (2007a).

[a]The air travel and dietary impact estimates are expressed in CO_2e terms, all other estimates are CO_2-specific.

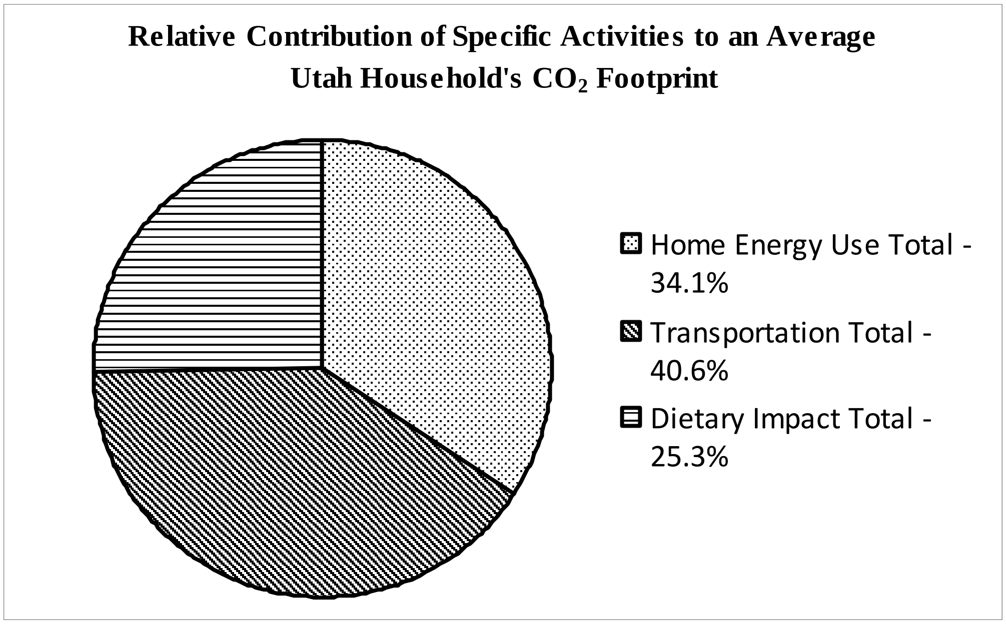

Figure 2. Relative contribution of specific activities to an average Utah household's CO_2 footprint.

Note. The data in Figure 2 were calculated based on information from the following sources: BTS (2006); BTS (n.d.a); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2008a); Matthews & Weber (2008); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2005); U.S. EPA (2007a).

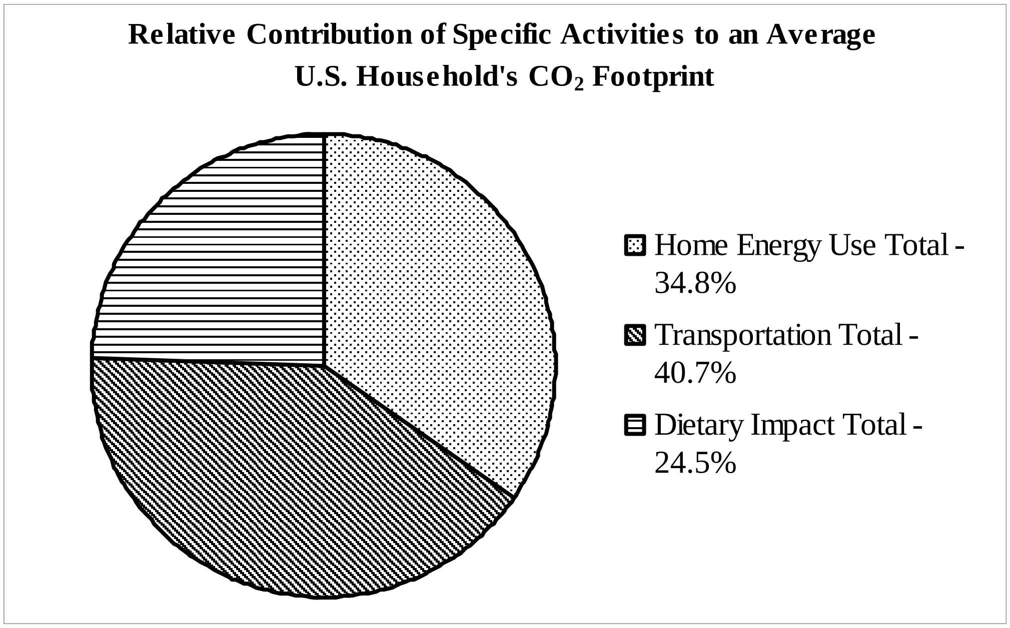

Figure 3. Relative contribution of specific activities to an average U.S. household's CO_2 footprint.

Note. The data in Figure 3 were calculated based on information from the following sources: BTS (2006); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2007); Matthews & Weber (2008); U.S. Census Bureau (2006); U.S. EPA (2005).

impacts. There are clearly other relevant categories which could have been included to create a more robust picture of a household's CO_2 emissions. However, these three main components were chosen due to their general relevancy in the average household, the ability to decipher CO_2 output estimates with reasonable accuracy, and the potential to suggest carbon mitigation strategies directly related to each. Some of the significant CO_2-emitting activities that were excluded will be briefly discussed before transitioning to the household carbon mitigation recommendations.

Many consumer consumption decisions, which are not directly related to the three major components of the CO_2 footprint presented, have been withheld from the household emissions assessment. The primary examples of these exclusions are the purchase and consumption of durable consumer goods (e.g., cars, appliances, home furnishings, electronics, etc.), nondurable consumer goods (e.g., clothing, personal products, paper products, etc.), and services (e.g., entertainment, hotels, legal, financial, healthcare, etc.). The production, transportation, and consumption of all of these goods certainly have considerable energy inputs and CO_2 outputs associated with them. However, the challenge of calculating these footprints and relating them to an average household is outside the scope of this thesis. Those households wishing to address their climate change impacts associated with the aforementioned consumer activities should follow the “Reduce, Reuse, Recycle” mantra and prioritize the ‘Reduce’ aspect to have the largest impact. Households can also consult *The Consumer’s Guide to Effective Environmental Choices* (Brower & Leon, 1999) which is an excellent source for tips on environmentally responsible consumption and provides detailed information on the ecological impact of commonly purchased and consumed goods.

Certain recreational and miscellaneous activities (e.g., boating, snowmobiling, yard care, etc.) have been excluded from the scope of this thesis due to their relatively small contribution to CO_2 totals. Furthermore, there is typically a sparse presence of these activities in an average household’s daily, or annual, routines.

Carbon emissions resulting from a household’s occupational choices, such as energy and other resource requirements at work, have also been omitted. One exception to these omissions is business related air travel which has been incorporated into the household averages via figures from the Bureau of Transportation Statistics (BTS, n.d.b).

The omission of occupational data is justified given the primary focus of this thesis on the household and its domestic activities. Also, there is a general lack of data regarding the average CO_2 impacts of an occupation. Furthermore, while there is certainly CO_2 emitted during an average individual's working hours, a wide variety of CO_2 impacts exists among the occupational possibilities and a there is a similarly large variance of non-occupational activities for any given household (e.g., homemaker, retired, student, unemployed, etc.).

CO_2 EMISSIONS REDUCTION OPTIONS FOR A HOUSEHOLD

Now that the size of a Utah household's carbon footprint has been established, we turn to assessing carbon mitigation strategies and their financial implications for the average household. Abiding by the same rationale for including three main components (home energy use, transportation, and dietary choices) in a CO_2 footprint, we will focus on addressing these same three categories with steps to diminish their impact on the Earth's climate.

The research will focus on introducing carbon reduction strategies and explaining how the CO_2 and financial impacts were calculated and transformed to relate to Utah households. Not every existing emissions reduction strategy option will be presented and there is potential for additional options to be added. Technological advancements continue to create these additional CO_2 reduction options and transform the monetary aspects of preexisting ones, often enhancing their financial appeal. Furthermore, financial incentives for conservation measures currently provided by utility companies and federal and state governments will be excluded from the analysis. These incentives would make the emissions reduction options more fiscally appealing, but have been excluded so that the analysis and conclusions remain independent of external stimulus programs.

Reducing Home Energy Emissions

Home energy use accounts for a considerable portion of a Utah household's CO_2 footprint at 34.1% of the total, or 27,876 lbs of CO_2 annually. Home energy use provides a similarly large opportunity to incorporate efficiencies and reduce its related carbon output. As the research will demonstrate, these efficiency measures provide substantial long-term cost savings to the typical household as well. This section will review the following three categories where a household's CO_2 footprint can be reduced: energy efficient appliances and lighting; maintenance and other efficiency upgrades; 'no cost' conservation steps. There are also alternative energy options for households to employ which could further reduce their carbon footprint and these will be briefly discussed. However, for reasons presented later, detailed data on alternative home energy sources will be excluded from the formal estimates for the emissions reduction model.

A large majority of the data for this section was adapted from a book by Jeffrey Langholz and Kelly Turner entitled *You Can Prevent Global Warming (and Save Money): 51 Easy Ways* (2008). This book provides suggestions for carbon mitigation strategies, and their associated financial costs and benefits for a household. Langholz and Turner incorporated data from a variety of sources and the final figures provided by them were double-checked for accuracy by staff at the U.S. Environmental Protection Agency (Langholz & Turner, 2008, p. 369). Any sources, other than the book by Langholz and Turner, used in this section will be specifically denoted.

The data provided by Langholz and Turner were calculated based on the following assumptions and its conclusions will be adapted to conform to the figures provided earlier in this thesis: the cost of electricity is 8.16 cents per kWh; the cost of natural gas is $8.00 per thousand cubic feet; the carbon coefficient for electricity is 1.64 lbs of CO_2 per kWh; the carbon coefficient for natural gas is 12 lbs of CO_2 per therm (Langholz & Turner, 2008, p. 362 – 365). The estimates from Langholz and Turner were divided by the figures presented in this thesis to create the conversion factors listed in Table 5. The conversion factors were then applied to conclusions from Langholz and Turner regarding the CO_2 emissions reductions and financial implications of varying options for households. The values found in the book by Langholz and Turner differ from those formulated in this thesis based on the following assumptions which were utilized earlier to calculate a household's CO_2 emissions footprint: the CO_2 emissions coefficient for electricity is 1.93 lbs of CO_2 per kWh in Utah and 1.34 lbs of CO_2 per kWh nationally (U. S. EPA, 2002); the CO_2 emissions coefficient for natural gas is 0.12012 lbs CO_2 per cubic foot which is equivalent to 12 lbs per therm, so the conversion factor in the table is 1.0 (U. S. EPA, 2007a); the cost of electricity is 8.68 cents per kWh for Utah and 10.83 cents per kWh nationally (EIA, 2008b); the cost of natural gas is $8.66 per thousand cubic feet in Utah and $18.33 per thousand cubic feet

Table 5

Conversion Factors Utilized to Adapt Estimates From Langholz and Turner

Category	Utah Conversion Factor	National Conversion Factor
CO_2 Output (Electricity)	1.1768	0.8171
CO_2 Output (Natural Gas)	1.0000	1.0000
Cost of Electricity	1.0637	1.3272
Cost of Natural Gas	1.0825	2.2913

Note. The data in Table 5 were calculated based on information from the following sources: EIA (2008b); EIA (2008c); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a).

nationally (EIA, 2008c).

The financial benefits for each of the CO_2 mitigation strategies were calculated using the same methodology as Langholz and Turner, with additional adjustments from the above conversion factors related to the price of energy. Langholz and Turner utilized a calculation in strictly nominal terms without adjustments for anticipated inflation in energy costs or the potential depreciating real value of a dollar (2008). While these two factors will not perfectly balance each other out, they are likely to compete against each other in the longer term in order to make the translation of nominal dollar values into real terms somewhat reasonable. The financial estimates will also adopt the associated costs of each strategy (e.g., the estimated price of an ENERGY STAR appliance) presented in the book by Langholz and Turner. An example of the methodology for monetary calculations was provided by the authors:

> For example, in tip 23, caulking and weatherstripping save the average household $56.10 a year and last for 10 years, for a *total* savings of $561. From there, we subtract the initial cost of the product to find the net savings. In this example, the caulking and weatherstripping cost $62, so $561 - $62 = $499 net savings…Since the caulking and weatherstripping will last for 10 years, we divide $499 by 10 years to get an *annual net* savings of $49.90 a year, which we round up to $50 a year. (Langholz & Turner, 2008, p. 363)

Table 6 reflects the CO_2 reduction and financial savings potential provided by energy efficient appliances and lighting upgrades. As with all of the carbon mitigation strategies mentioned in this thesis, there are additional environmental, and often financial, benefits associated with them which are not included in the table. For example, Langholz and Turner estimate that the dishwasher upgrade also results in 2,800 gallons of water saved per year equating to a $44 savings in water charges every 12 months (2008). While this should serve as further motivation for a household to apply the tips mentioned

Table 6

CO_2 Emissions Reduction Estimates and the Financial Implications for Various Efficiency Upgrades

Option	Lbs of CO_2 Reduced[a]		Net Savings[a]		Initial Cost	Lifetime of Option
	Utah (Adj)	National (Adj)	Utah (Adj)	National (Adj)		
Refrigerator Upgrade[b]	1,748.7	1,214.2	$34.04	$42.47	$750	18 years
Clothes Washer Upgrade[b]	1,241.5	862.0	$31.91	$39.82	$650	14 years
Dishwasher Upgrade[b]	900.3	625.1	$15.96	$19.91	$250	11 years
CFL Lighting[c]	844.9	586.7	$31.91	$39.82	$14/CFL	7-10 years

Note. The data in Table 6 were calculated based on information from the following sources: EIA (2008b); EIA (2008c); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a).

[a]Lbs of CO_2 Reduced and Net Savings figures are per year average estimates over the lifetime of the option.

[b]Upgrades are from a lower efficiency device to an ENERGY STAR, or other high efficiency, appliance as reported by Langholz and Turner (2008).

[c]CFL lighting estimate assumes a household replaces four 100 watt incandescent bulbs with high efficient compact fluorescents (CFLs) with equivalent luminescence.

in this thesis, the reporting focus here will remain on CO_2 emissions and energy costs and savings. Another important observation is that Utah households are able to attain greater carbon reductions than others nationally for strategies involving electricity usage. This is due to the higher CO_2 intensity of electricity produced in Utah compared to the national average. On the other hand, the average national household will realize greater net financial savings for electricity and natural gas conservation measures due to higher average prices than in Utah.

Table 7 provides information on additional efficiency upgrades, other than

Table 7

CO_2 Emissions Reduction Estimates and the Financial Implications for Various Maintenance and Efficiency Upgrades

Option	Lbs of CO_2 Reduced[a]		Net Savings[a]		Initial Cost	Lifetime of Option
	Utah (Adj)	National (Adj)	Utah (Adj)	National (Adj)		
Install an ENERGY STAR A/C	4,670.7	3,243.1	$32.97	$41.14	$2,500	15 years
Install an ENERGY STAR Furnace[b]	2,977.4	2,977.4	$78.53	$166.22	$1,100	18 years
Sealing Treatment for Duct Leaks	2,250.0	2,250.0	$88.77	$187.89	$1,000	10 years
D'MAND Shower Water System[c]	2,240.0	2,240.0	$141.30	$299.08	$442	15 years
Insulate the Attic	2,149.0	2,149.0	$269.54	$570.53	$276	15 years
Install seven ENERGY STAR Superwindows	1,864.0	1,864.0	$73.61	$155.81	$7,000	50 years
Four Faucet Aerators & Two Low-flow Showerheads)	1,671.0	1,671.0	$276.04	$584.28	$44	10 years
Tune-up for Home Heating System	1,248.0	1,248.0	$18.40	$38.95	$50	2 years
Use a House Fan Instead of A/C 33% of the time	970.9	674.1	$29.78	$37.16	$200	15 years
Programmable Thermostat	811.0	811.0	$49.80	$105.40	$60	7 years
Rainfall Sensor for Sprinkler System	704.9	489.4	$43.61	$54.42	$50	5 years
Water Heater Blanket & Turn Down 10 Degrees	697.0	697.0	$35.10	$43.80	$10	6 years
Caulking and Weather Stripping	692.0	692.0	$54.13	$114.57	$62	10 years
Window Curtains Prevent Heat Gain	566.0	393.0	$21.27	$26.54	$75	15 years

Table 7 Continued

Note. The data in Table 7 were calculated based on information from the following sources: Advanced Conservation Technology, Inc. (n.d.); EIA (2008b); EIA (2008c); ENERGY STAR (2008); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a). ENERGY STAR is a joint venture between the U.S. Environmental Protection Agency and U.S. Department of Energy whose goal is to provide information and foster the growth of energy efficient products.

[a]Lbs of CO_2 Reduced and Net Savings figures are per year average estimates over the lifetime of the option.

[b]Estimates for the ENERGY STAR furnace were calculated based on upgrading from a 78% AFUE to a 90% AFUE gas powered furnace with programmable thermostat, data provided are from the ENERGY STAR website (2008).

[c]D'MAND shower system initial cost estimate based on S-70T model from the D'MAND Systems website (Advanced Conservation Technology, Inc., n.d.). The per-year financial estimates and lbs of CO_2 reduced were determined from figures provided by Langholz and Turner (2008).

appliances and lighting, and simultaneously suggests maintenance steps which can improve overall energy efficiency. Note that undertaking multiple energy efficiency steps may reduce the listed impacts since all were assessed individually against baseline energy use estimates. For example, installing an energy efficient air conditioner would reduce the overall cooling costs and energy consumed so this would reduce the impact of a subsequent change affecting these variables (e.g., energy efficient windows would now have a lower savings than previously estimated). For this reason, it is challenging to assess the impact of multiple strategies employed in one household since every subsequent change may be affected by the prior changes. Nevertheless, combining multiple efficiency options is sure to decrease a household's overall carbon footprint to the largest degree and all should be assessed by those interested in saving money and minimizing their environmental impact.

Note the fact that the CO_2 reduction impact total of all the techniques presented appears to be outpacing the total average home energy CO_2 footprint itself. This conclusion exists because, as previously discussed, commingling carbon reduction techniques tends to reduce each option's impact relative to when it was taken in isolation. Also, the carbon mitigation techniques discussed assume that a household has not implemented related efficiency measures. For example, the appliance estimates are based on a household using a low efficiency appliance and not an ENERGY STAR version. Clearly, there are many households using higher efficiency technologies, and more conservation measures, than assumed and this results in the average carbon footprint being less than the aggregate of all the carbon mitigation options provided. While the mitigation estimates do not apply to all households, they represent reasonable averages of what is attainable for the large number of households who have yet to implement many of the possible options.

Next we transition to introducing conservation measures which impose zero initial cost on a household. Given the cost-free nature and the financial benefits of these steps, described in Table 8, they should appeal to every household, regardless of its budget situation. The 'Lifetime of Option' column has been excluded from this table since all recommendations should be continuously available at no cost.

There is also potential for CO_2 emissions reductions via alternative energy production for a residence. The decision to exclude formal estimates was made due a number of reasons. First, there exists a wide variance in the feasibility and effectiveness for certain sources, e.g., residential solar and wind, depending on a household's location and the natural resources most prominent there. A household wishing to implement alternative energy options would be best informed by seeking local expertise and estimates. Furthermore, there is a current lack of prior Utah-specific research assessing the related CO_2 and financial variables targeted by this thesis. Calculating new emissions and financial estimates for all the alternative energy sources was outside the scope of this research. Finally, the technologies for many of the options are currently experiencing high-paced market growth and are in developmental stages which will likely lead to drastic improvements in their efficiency and financial attractiveness to households over time. As these improvements are realized, adoption of alternative energy options will be more feasible for households operating under a tight budget constraint.

Before transitioning to options for reducing transportation emissions, the financial and CO_2-related benefits of several home energy use mitigation strategies will be

Table 8

CO_2 Emissions Reduction Estimates and the Financial Implications for No-cost Measures

Option	Lbs of CO_2 Reduced[a] Utah (Adj)	Lbs of CO_2 Reduced[a] National (Adj)	Net Savings[a] Utah (Adj)	Net Savings[a] National (Adj)
Always Use Cold Water & Moisture Setting for Clothes Washer	1,827.6	1,269.0	$80.84	$100.87
Refrigerator Maintenance[b]	937.6	651.0	$34.04	$42.47
Air Drying Dishes in Dishwasher	780.2	541.7	$35.10	$43.80
Toilet (water displacement)	683.2	474.4	$37.23	$46.45
Utilize 'Sleep Mode' on Computer, Printer & Monitor	511.9	355.4	$23.40	$29.20
Closing Off and Not Cooling One Room in the Summer	409.5	284.4	$19.15	$23.89
Eliminate 'phantom' electricity waste from the VCR & Stereo	274.2	190.4	$12.76	$15.93

Note. The data in Table 8 were calculated based on information from the following sources: EIA (2008b); EIA (2008c); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a).

[a]Lbs of CO_2 Reduced and Net Savings figures are per year average estimates over the lifetime of the option.

[b]Refrigerator maintenance refers to cleaning the condenser coils twice per year.

reviewed. First, the results for a household pursuing only no-cost home energy reduction options will be provided. The seven cost-free activities provided earlier have the potential for an average Utah household to reduce their CO_2 footprint by 5,424 lbs and save $242.52 each year, the national totals for these same options were 3,766 lbs and $302.61 per year. These equate to a reduction of roughly 19% of a Utah household's home energy CO_2 footprint, and 15% for a national household, all at essentially no upfront financial cost.

Utah households wishing to prioritize the financial benefits from conservation may pursue the top 10 money saving activities across all three of the home energy reduction categories. These 10 strategies are presented in Table 9 and illustrate the significant potential for households with a sufficient budget to cover initial costs and reduce carbon emissions from home energy use. As previously mentioned, the aggregated CO_2 reduction estimates likely overstate what would be realized by an average household since the incremental benefit of each can differ if multiple options are pursued simultaneously. However, these estimates reflect a clear abundance of significant carbon reduction options which additionally offer significant annual financial savings over their lifetimes.

Finally, the average CO_2 emissions reductions and financial implications for the population of all 25 of the home energy use reduction options were assessed. These figures are presented in Table 10 and can serve to construct estimates for households implementing an arbitrary mix of the strategies provided. For example, if Utah households engaged in an equal mix of only 20% of the home energy reduction options, they would reduce their CO_2 output by an average of 6,734 lbs, or 24% of the home energy CO_2 emissions total, per household and save about \$313.84 each per year. Details on these estimates are provided in equations 26 and 27.

1,346.9 lbs of CO_2 reduced on average per option X five options = 6,734 lbs of CO_2 reduced per year (26)

\$62.77 saved on average per option X five options = \$313.84 saved per year (27)

Table 9

CO_2 Emissions Reduction Estimates for the Top 10 Financial Saving Home Energy Options

Home Energy Reduction Strategies - Top 10 Financial Savers for Utah Households							
	Lbs of CO_2 Reduced[a]		Net Savings[a]				
Option	Utah (Adj)	National (Adj)	Utah (Adj)	National (Adj)	Initial Cost	Lifetime of Option
Four Faucet Aerators & Two Low-flow Showerheads)	1,671.0	1,671.0	$276.04	$584.28	$44	10 years
Insulate the Attic	2,149.0	2,149.0	$269.54	$570.53	$276	15 years
D'MAND Shower Water System	2,240.0	2,240.0	$141.30	$299.08	$442	15 years
Sealing Treatment for Duct Leaks	2,250.0	2,250.0	$88.77	$187.89	$1,000	10 years
Use Cold Water & Moisture Setting for Clothes Washer	1,827.6	1,269.0	$80.84	$100.87	NA	NA
Install an ENERGY STAR Furnace	2,977.4	2,977.4	$78.53	$166.22	$1,100	18 years
Install seven ENERGY STAR Superwindows	1,864.0	1,864.0	$73.61	$155.81	$7,000	50 years
Caulking and Weather Stripping	692.0	692.0	$54.13	$114.57	$62	10 years
Programmable Thermostat - Heat Only	811.0	811.0	$49.80	$105.40	$60	7 years
Rainfall Sensor for Sprinkler System	704.9	489.4	$43.61	$54.42	$50	5 years
Totals	17,186.9	16,412.8	$1,156.17	$2,339.07	$10,034.00	NA

Table 9 Continued

Note. The data in Table 9 were calculated based on information from the following sources: Advanced Conservation Technology, Inc. (n.d.); EIA (2008b); EIA (2008c); ENERGY STAR (2008); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a).

[a]Lbs of CO_2 Reduced and Net Savings figures are per year average estimates over the lifetime of the option.

Table 10

CO_2 Emissions Reduction Averages for all 25 Home Energy Savings Options

Option	Lbs of CO_2 Reduced[a] Utah (Adj.)	Lbs of CO_2 Reduced[a] National (Adj.)	Net Savings[a] Utah (Adj.)	Net Savings[a] National (Adj.)
Average Across All 25 Home Energy Reduction Options Presented	1,346.9	1,138.1	$62.77	$114.82

Note. The data in Table 10 were calculated based on information from the following sources: Advanced Conservation Technology, Inc. (n.d.); EIA (2008b); EIA (2008c); ENERGY STAR (2008); Langholz & Turner (2008); U.S. EPA (2002); U.S. EPA (2007a).

[a]Lbs of CO_2 Reduced and Net Savings figures are per year average estimates over the lifetimes of all options presented.

Reducing Transportation Emissions

Transportation emissions account for the largest share of an average household's CO_2 output at 40.6% of the Utah total and 40.7% of the national estimate. The reduction strategies described here were calculated based on the Utah and national vehicle miles traveled (VMT) and miles per gallon (MPG) averages presented earlier, along with a price of petroleum at $2.83 per gallon which was the average retail cost for mid-grade gasoline in the U.S. between 2005 and 2008 (EIA, 2009b). The strategies in Table 11 are based on seemingly reasonable recommendations which a household could undertake to reduce their transportation CO_2, CO_2e in the case of air travel, emissions footprint.

There is clearly an array of options available to a Utah household wishing to lessen its environmental impact associated with transportation. Likewise, there exists considerable potential for financial benefit for a household willing to adjust its transportation decisions to be more in line with sustainable behaviors. While only fuel

Table 11

CO_2 Emissions Reduction Estimates and the Financial Implications for Various Transportation Options

Option	Lbs of CO_2 Reduced: Utah (Adj)	Lbs of CO_2 Reduced: National (Adj)	Gallons of Gasoline Saved: Utah (Adj)	Gallons of Gasoline Saved: National (Adj)	Net Fuel Cost Savings: Utah (Adj)	Net Fuel Cost Savings: National (Adj)
Upgrade One Vehicle to 35 MPG	3,025.6	2,724.3	156.0	140.4	$441.36	$397.42
Upgrade All Vehicles to 35 MPG	6,232.8	4,822.1	321.3	248.6	$909.22	$703.43
Upgrade One Vehicle to 45 MPG	4,925.0	4,597.2	253.9	237.0	$718.45	$670.62
Upgrade All Vehicles to 45 MPG	10,145.8	8,137.1	523.0	419.4	$1,480.04	$1,187.01
Become a One Vehicle Household[a]	12,267.6	8,587.2	632.4	442.6	$1,789.55	$1,252.67
One Less Round Trip Flight per Year	2,779.6	2,779.6	NA	NA	Varies[b]	Varies
Two Less Round Trip Flights per Year	5,559.1	5,559.1	NA	NA	Varies	Varies
No Personal Vehicle Use for One Day per Week[c]	3,405.9	2,820.0	175.6	145.4	$496.84	$411.37
No Personal Vehicle Use for Three Days per Week	10,217.7	8,459.9	526.7	436.1	$1,490.52	$1,234.10

Note. The data in Table 11 were calculated based on information from the following sources: BTS (2006); BTS (n.d.a); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2009b); U.S. Census Bureau (2006); U.S. EPA (2005). The net financial savings for vehicle upgrades do not consider the potential costs, or savings, associated with replacing current vehicles with higher version models, or other financial benefits outside of gasoline costs (e.g., lowered costs for vehicle insurance, maintenance, etc.).

[a]The ‘One Vehicle Household’ example assumes the vehicle retained has the average MPG capability (e.g., 25.85 MPG for Utah households) and does not travel additional miles as a result of becoming the sole vehicle. Also, the costs and CO_2 impacts of alternatives which displace the vehicle(s) being relinquished are not considered in the estimates.

Table 11 Continued

[b]Financial savings estimates for households forgoing air travel were not estimated due to considerable variability in airline ticket prices and the potential for flights foregone to be part of an employer's budget, not the household's.

[c]The 'No Personal Vehicle Use' estimates do not incorporate the CO_2 output estimates and associated financial costs of alternatives (e.g., walking, biking, carpool, bus, rail, etc.) pursued in place of personal automobile travel.

costs have been considered in estimating financial benefits, there are clearly numerous other financial costs associated with owning and driving a personal vehicle. For example, the American Automobile Association (AAA) estimates that driving costs in the U.S. are 52.2 cents per mile on average for a vehicle traveling 15,000 miles (2007). The AAA study incorporated all the costs of owning and driving a vehicle including fuel, maintenance, tires, insurance, depreciation, finance charges, licensing, registration, and taxes (AAA, 2007). The AAA estimate is considerably larger than the fuel-only financial costs considered here which amount to 11.0 cents per mile for Utah drivers. This difference suggests that much greater budgetary relief is available to those wishing to reduce their personal automobile reliance.

The CO_2 output coefficients for potential travel options utilized in place of personal automobiles and air travel are not accounted for in the emissions reduction estimates. This methodology was employed to acknowledge the flexibility households have in choosing their auto transportation alternatives and the potential for zero-emissions replacement options. However, for comparison's sake, the EPA estimates that public bus transportation emits 0.24 lbs of CO_2 per passenger mile and rail emits 0.37 – 0.41 lbs of CO_2 per passenger mile (2008). Walking and biking are even better since they are essentially zero carbon output alternatives. The CO_2 output per passenger mile totals of these alternatives are a fraction of that of air travel, which was presented as 1.31 lbs CO_2e (Colorado Carbon Fund, n.d.). Furthermore, personal auto transportation emits roughly 0.75 lbs of CO_2 per passenger mile for Utah cars averaging 25.85 MPG. While local transportation alternatives do not always possess zero CO_2 impact, the fact that walking, biking and bus emit anywhere from 68% to 100% less carbon than personal automobile transportation signals the immense CO_2 mitigation possibilities of these options.

The methodology used to determine how much transportation-related carbon mitigation is realistic for an average Utah household is similar to that used in the home energy section. Rather than predicting which transportation options are most likely to be adopted, this thesis takes the average CO_2 and financial savings for all the vehicle-related strategies and provides that figure as something which can reasonably be achieved by a Utah household. This calculation reveals that a Utah household adopting just one of the vehicle transportation options will prevent an average of 7,174.3 lbs of CO_2 from being emitted each year and save $1,046.57 in fuel costs. The national estimates for this same assumption of one strategy being adopted are 5,735.4 lbs of CO_2 mitigated and $836.67 in fuel cost savings. The reduction in air travel emissions are calculated similarly with an average of 4,169.4 lbs of CO_2e prevented by selecting one of the two flight reduction strategies suggested. Combining the auto and air travel options, there is reasonable potential for Utah households to reduce their transportation-related CO_2 emissions by 11,343.7 lbs annually, or 34.2% of the Utah transportation total. The average U.S. household can achieve similarly significant results of 9,904 lbs of CO_2 emissions prevented annually, or 34.0% of the U.S. transportation emissions total, by combining one auto option and one air travel option.

Reducing Dietary-related Emissions

In their research, Eshel and Martin "demonstrate that the greenhouse gas emissions of diets varies by as much as the difference between owning an average sedan versus a Sport Utility Vehicle under typical driving conditions" (2006, abstract). Eshel and Martin's work utilized statistics from the Food and Agricultural Association (FAO) of the United Nations which determined that the U.S. food production system produced 3,774 calories per person per day in 2002 (2006). This does not necessarily mean that 3,774 calories were consumed, they could have been discarded, wasted or exported, but it is indicative of how much food, and associated carbon output, can be attributed to each person in the U.S. Of the 3,774 calories, 27.7% are animal-based with 54% coming from various meats, 41% from dairy products and the remaining 5% from eggs (Eshel & Martin, 2006). The remaining calories come from, in descending order of average daily caloric intake, wheat, soybean oil, sugar, potatoes, corn, rice and other non-animal based products (U.N. FAO, 2005). Eshel and Martin ultimately conclude that "a person consuming a mixed diet with the mean American caloric content and composition causes the emissions of 1,485 kg [3,267 lbs] CO_2e above the emissions associated with consuming the same number of calories, but from plant sources" (2006, p. 18).

Matthews and Weber found similarly significant potential for reducing one's CO_2e emissions from dietary requirements. As with the emissions footprint estimate associated with dietary choices, this thesis will utilize Matthews and Weber's conclusions for calculating a household's emissions reduction opportunities. The authors presented three main dietary adjustments an average household could make: 1) buying 100% of food locally 2) completely replacing red meat and dairy with chicken, fish, and eggs 3) completely replacing red meat and dairy with vegetables and vegetable-based products. These three options were estimated to have CO_2e emissions reduction potential of 4.5%, 24.1%, and 40.0%, respectively (Matthews & Weber, 2008).

Combining the three mentioned strategies with the household CO_2e footprints presented earlier produces the emissions reduction estimates in Table 12. The relatively small reduction related to purchasing local food fits with the estimate discussed earlier that transportation accounts for only 11% of the life-cycle GHG emissions attributed to diet (Matthews & Weber, 2008). Clearly, much larger impacts are accessible by shifting all, or a portion, of a household's diet away from red meat and dairy products. For this reason, the purchase of local foods will be excluded from the methodology used here to estimate emissions reduction estimates reasonably attainable for the average household. Also, the associated financial implications associated with each option have been excluded from this thesis. The choice to exclude financial figures was made due to the complexity of deriving such an estimate given the wide range of foods a household

Table 12

CO_2 Emissions Reduction Estimates for Various Dietary Changes

Option	Lbs of CO_2 Reduced (Everyday Adherence)		Lbs of CO_2 Reduced (Three Days per Week)		Lbs of CO_2 Reduced (One Day per Week)	
	Utah (Adj)	National (Adj)	Utah (Adj)	National (Adj)	Utah (Adj)	National (Adj)
Purchase All Food Locally	933.2	790.3	399.9	338.7	133.3	112.9
Replace Red Meat and Dairy with Chicken/Eggs/Fish	4,997.8	4,232.7	2,141.9	1,814.0	714.0	604.7
Replace Red Meat and Dairy with Vegetables and Vegetable-based Products	8,295.2	7,025.2	3,555.1	3,010.8	1,185.0	1,003.6

Note. The data in Table 12 were calculated based on information from the following sources: Matthews & Weber (2008); U.S. Census Bureau (2006).

initially consumes and the similar diversity in their replacement options. However, there are indications of cost savings concurrent with meat-reduction choices. For example, Langholz and Turner state that foods replacing beef cost 35% less, on average, than red meat (2008).

The approach for creating an average emissions reduction estimate is similar to what was employed in the home energy and transportation sections. By taking an average of the six emissions mitigation statistics from the bottom two rows of Table 12, it is calculated that a Utah household would reduce diet-related emissions by 3,481.5 lbs per year, or 17%. A national household's emissions reductions would be 2,948.5 lbs per year, also roughly 17% of the dietary total, according to this same methodology. The ability and willingness of households to utilize any, or a variety, of the emissions reduction techniques certainly varies. However, those participating in climate change mitigation behaviors can clearly produce positive impacts through their dietary choices.

The Role of Recycling in Reducing CO_2 Emissions

This thesis will also provide information regarding the emissions-reducing benefits of recycling. Though many materials associated with recycling were either only indirectly included in the emissions footprint assessment presented earlier, or fully excluded in many cases related to consumption of material goods, there exists notable potential for a household to reduce their climate change impact through this commonly available activity. Additionally, items recycled are often byproducts of the food consumption process and so emissions reductions listed in this section can be partially tied to a reduction in a household's dietary CO_2e footprint. The accessibility of recycling options is illustrated by the fact that 8,659 curbside recycling programs existed in the U.S. in 2006 (U.S. EPA, 2006c). These curbside programs serviced 48% of the nation's population including 84% in the Northeast, 76% in the West, 61% in the Midwest, and 30% in the South (U.S. EPA, 2006c).

The U.S. Environmental Protection Agency conducted a comprehensive study in 2006 titled "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks" (U.S. EPA, 2006a) which gauged the GHG reducing benefits of recycling. The estimates from this EPA study will be utilized for this section. The figures cited in Table 13 relate to the scenario where a material is recycled and used for production of future materials instead of placed in a landfill. Disposing of products in a landfill drives the need for new materials to be produced from the current mix of recycled and virgin inputs and thus creates greater energy needs and GHG output relative to the case where a product was recycled (U.S. EPA, 2006a). The methodology utilized by the EPA in calculating these emissions reductions is briefly summarized here:

> In order to compare GHG emissions from recycling to those attributable to another solid waste management options such as landfilling, EPA compared the total GHG emissions from recycling the material to the GHG emissions from managing the disposal of the same material under another waste management option….Overall, because recycling reduces the amount of energy required to manufacture materials (as compared to manufacture with virgin inputs) and leads to avoided process non-energy GHG emissions, recycling has lower GHG emissions than all other waste management options except for source reduction (2006a, p. 35).

In order to understand the CO_2e emissions reduction potential from recycling it is important to determine just how much waste is generated in an average household. The EPA estimates that in 2006 the average per capita waste generated in the U.S. was 4.6 lbs, of which 1.5 lbs, or roughly 32%, was recycled (2007b). In relation to the materials

Table 13

CO_2 Emissions Reduction Estimates for Recycling Various Materials

Material Recycled	Lbs of CO_2e Reduced		Energy Saved
	Per lb of Material	Per Item[a]	Million BTU Saved per Ton Recycled Instead of Landfilled
Glass	0.35	0.19	2.13
Aluminum	15.00	0.56	206.42
Steel	2.02	0.28	19.97
Plastic	1.74	0.16	53.23
Residential Mixed Paper	4.18	0.04	22.94

Note. The data in Table 13 were calculated based on information from the following sources: U.S. EPA (2006a); U.S. EPA (2006b).

[a]The 'Per Item' estimates assume a 12 oz. bottle of glass, a 12 oz. can for aluminum, a 8 oz. tin can for steel, a 1 liter bottle for plastic, an d 1 8 ½ X 12 inch sheet of paper for one item (U.S. EPA, 2006b).

mentioned in Table 13, the EPA estimates that 25.3% of glass containers, 45.1% of aluminum cans, 62.9% of steel cans, 30.9% of plastic drink bottles, and 51.6% 51.6% of paper and paperboard were recycled in 2006 (2007b).

For a conservative estimate of how much CO_2e emissions a household can eliminate by improving recycling behaviors, assume that one additional lb of recycling is attainable per household each day. This additional pound can come from a variety of sources including recyclables generated at home or the creation of a recycling program at work where a household member volunteers to take products to a recycling drop-off on behalf of their co-workers. Taking an average of the CO_2e reduction potential of the five materials mentioned in Table 13, generates an estimate of 4.66 lbs of CO_2e reduced per lb of a mix of these products. This translates to roughly 1,701 lbs of CO_2e reduced per year for a household:

4.66 lbs of CO_2e reduction per lb of mixed material X 365 days per year = 1,700.9 (28)
lbs of CO_2e reduced per year by recycling one additional lb of material each day

This 1,701 lbs CO_2 reduction estimate will be applied in the next section as a reasonable contribution the average household can make via recycling towards the goal of reducing their carbon footprint.

Assessing the Overall Emissions Reduction Potential for Households

The prior sections of this thesis shed light on various methods a household can employ to reduce their carbon footprint related to home energy use, transportation, and dietary choices. In the case of home energy usage, the three strategies selected included implementing only options with no upfront cost, implementing the 10 options with the greatest financial savings, and implementing a mix of $1/5^{th}$ of the total suggested options. These strategies reflected CO_2 reduction estimates for Utah households of 5,424 lbs, 17,187 lbs, and 6,734 lbs, respectively. These are significant CO_2 emissions reductions ranging from 19.5% to 61.7% of the total 27,876 lbs of CO_2 attributed to an average household's energy use in Utah. Furthermore, all of the home energy strategies presented also have a net financial benefit for the household.

Transportation was another category where significant CO_2 emissions reductions were possible at a net savings, or no financial cost, to a typical household. Allowing Utah households the discretion to adopt just one option for personal automobile travel and one option for air travel led to an average CO_2 emissions reduction of 11,344 lbs per year (note: CO_2e was utilized for the air travel emissions calculation). This large reduction translates into a 34.2% decrease of the 33,194 lbs of CO_2 emissions from transportation per Utah household each year.

The dietary section revealed that households willing to alter their behaviors regarding red meat and dairy consumption realized substantial CO_2e savings. The methodology used earlier took an average of six suggested behavior pattern changes involving the displacement of all or a portion of red meat and dairy and concluded that a participating Utah household would reduce diet-related CO_2e emissions by 3,482 lbs per year on average. This food consumption change results in an average reduction of 16.8% of the 20,738 lbs of CO_2e emissions related to a Utah household's dietary behaviors.

Finally, the environmental benefits of recycling were estimated at 1,701 lbs of CO_2e emissions prevented each year if a household were able to recycle one more lb per day. The benefits of recycling are not wholly attributable to any of the emissions footprint sections discussed; however, they share applicability to dietary behaviors along with other consumption choices.

The cumulative effect of all of these CO_2 emissions reduction strategies is displayed in Table 14. The estimate of 26,309 lbs of annual CO_2 emissions reduction potential, along with associated net financial savings, is a striking conclusion. This emissions figure suggests that Utah households have the capability to reduce their carbon footprint related to home energy use, transportation, and dietary choices by a staggering 32.2% by following a mix of the reduction guidelines suggested. The emissions reductions for national households, demonstrated in Table 15, likewise reflect that substantial CO_2 emissions reductions are accessible along with net financial benefits.

Table 14

Cumulative Estimates of CO_2 Emissions Reductions for Utah Households Employing a Mix of Home Energy, Transportation, Dietary, and Recycling Strategies

Activity or Source - Utah Households	Lbs of CO_2 Emitted per Household	Lbs of CO_2 Emissions Reduced per Household	Percentage of CO_2 Emissions Reduced
Home Energy Use Estimates	27,876	9,782[a]	35.1%
Transportation Estimates	33,194	11,344	34.2%
Dietary Impact Estimates	20,738	3,482	16.8%
Recycling Estimate	NA	1,701	NA
Total Household CO_2 Impact	81,808	26,309	32.2%

Note. The data in Table 14 were calculated based on information from the following sources: BTS (2006); BTS (n.d.a); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2008a); EIA (2008b); EIA (2008c); ENERGY STAR (2008); Langholz & Turner (2008); Matthews & Weber (2008); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2005); U.S. EPA (2006a); U.S. EPA (2006b); U.S. EPA (2007a); U.S. EPA (2007b). All emissions reduction estimates were calculated based on a household employing a partial mix of strategies involving home energy use, transportation, dietary changes, and recycling.

[a]The home energy emissions reduction estimates were calculated based on the average of the three emissions reduction strategies presented. These three strategies ranged from 5,424 lbs to 17,187 lbs of CO_2 emissions reduction potential.

Table 15

Cumulative Estimates of CO_2 Emissions Reductions for U.S. Households Employing a Mix of Home Energy, Transportation, Dietary, and Recycling Strategies

Activity or Source – U.S. Households	Lbs of CO_2 Emitted per Household	Lbs of CO_2 Emissions Reduced per Household	Percentage of CO_2 Emissions Reduced
Home Energy Use Estimates	24,906	8,623[a]	34.6%
Transportation Estimates	29,092	9,904	34.0%
Dietary Impact Estimates	17,563	2,949	16.8%
Recycling Estimate	NA	1,701	NA
Total Household CO_2 Impact	71,561	23,177	32.4%

Note. The data in Table 15 were calculated based on information from the following sources: BTS (2006); BTS (n.d.b); Colorado Carbon Fund (n.d.); EIA (2005); EIA (2007); EIA (2008b); EIA (2008c); ENERGY STAR (2008); Langholz & Turner (2008); Matthews & Weber (2008); U.S. Census Bureau (2006); U.S. EPA (2002); U.S. EPA (2005); U.S. EPA (2006a); U.S. EPA (2006b); U.S. EPA (2007a); U.S. EPA (2007b). All emissions reduction estimates were calculated based on a household employing a partial mix of strategies involving home energy use, transportation, dietary changes, and recycling.

[a]The home energy emissions reduction estimates were calculated based on the average of the three emissions reduction strategies presented. These three strategies ranged from 5,424 lbs to 17,187 lbs of CO_2 emissions reduction potential.

CONCLUSION

The conclusions of this research have dramatic implications for climate change mitigation efforts. Specifically, the emissions reduction strategies highlighted demonstrate that households have access to numerous carbon mitigation options which simultaneously provide the incentive of financial savings. The suggestion that average Utah households have the immediate capability to reduce their emissions by roughly 32.2% by pursuing a reasonable mix of home energy use, transportation, dietary, and recycling strategies is both empowering and promising for citizens interested in more sustainable lifestyles.

In addition to the encouraging possibilities for individual households, this thesis suggests that the CO_2 emissions reduction targets of broader proposals are well within reach. The Western Climate Initiative, which includes Utah and other western states and Canadian provinces, has developed a goal to reduce GHG emissions 15% below 2005 levels by 2020 (WCI, 2008). The Kyoto Protocol stated a similar goal of a 7% reduction of 1990 levels of GHG emissions for the U.S. by 2012 (UNFCCC, n.d.). If these initiatives were able to efficiently engage citizens and promote sensible behavior regarding carbon emissions, their reduction goals could be achieved, or surpassed, while also providing significant financial savings.

In order for the CO_2 emissions reductions suggested here to be successful, there must be a combination of education and market penetration for the options involved.

Presenting the climate change mitigation strategies as environmentally, socially, and economically preferable lifestyle changes should attract a large segment of the population and guide society towards more sustainable behavior.

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