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A New Tool for Identifying Opportunities and Targeting Behavioral Programs[1]

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Introduction

A growing body of research provides clear evidence of the large-scale energy and carbon reductions that could be achieved by shifting household practices and technology choices. Estimates of achievable savings have ranged from 20 to 30 percent in the short- to medium-term in the residential and personal transportation sectors alone. Nationally, the savings from such interventions would reduce total U.S. energy consumption by roughly 9% and cut carbon emissions by 7.4% (Dietz et al 2009, Laitner et al 2009). While such findings are useful, they are unable to identify *city-specific* opportunities that take unique, local factors into account, such as local climatic conditions, the characteristics of the local building stock, technology saturation, technology use patterns, and the lifestyles, attitudes and preferences of local populations. This paper will lay out a new, low-cost approach for assessing the level of *achievable* energy savings that could be realized in particular cities through programs that focus on energy consumption practices or behaviors. The approach uses a set of estimation techniques akin to those used by the above cited studies but draws from sub-national data sets to derive city-specific estimates that account for local conditions, patterns and practices. The results identify the scale of achievable savings and highlight the ten sets of behaviors that are likely to provide the largest savings opportunities. This paper briefly summarizes the findings of national behavior-wedge studies and discusses the need for city-specific profiles. It then outlines the core components of the Behavior Wedge profile and preliminary profile results for one U.S. city. The final sections of the paper provide an overview of the underlying methodology, conclusions and information about on-going research and next steps.

A Review of National Behavior Wedge Research

Since 2008, a growing body of research has begun to explore the range of energy and carbon savings that might be accomplished through policies and interventions that focus on shifting the energy use practices and technology choices of the nation's 115 million households (Gardner and Stern 2008, Laitner et al. 2009, Dietz et al. 2009, and NRDC and Garrison Institute 2010). In general, these studies suggest that current levels of energy consumption and carbon emissions from the household and personal transportation sectors alone could be reduced by an estimated 20-30% in the short to medium-term (<10 years) through efforts that influence the everyday practices and purchasing decisions of households. Such savings could reduce national level carbon emissions by 7.5 to 14 percent and reduce energy consumption by an estimated 9 percent. The remainder of this section summarizes and compares the findings of several of the national behavior-wedge assessments.

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In 2008 Gardner and Stern presented a compelling assessment of the potential carbon emissions savings that could come from moderate shifts in the energy use practices of U.S. households and reductions in home energy use and the energy associated with personal transportation. According to the authors, the strategic engagement of U.S. households in energy conservation and energy efficiency has the potential of reducing national carbon emissions by as much as 11 percent without the need for the development of any new technologies, making any major economic sacrifices, or reducing households' sense of well-being.

The study aptly points out that U.S. households currently account for about 38 percent of national carbon emissions – just through their direct actions alone. Notably, this amount of emissions is large - "greater than that of any entire country except China and larger than the entire U.S. industrial sector" (Gardner and Stern 2008: p13). The potential savings are also large. Gardner and Stern's research suggests that by changing the selection and use of household and motor vehicle technologies, emissions from households and personal transportation sources could be reduced by nearly 30 percent.

This savings opportunity is not new but it has remained unrealized for several important reasons. Foremost among these, households lack accurate, accessible, and actionable information on how best to achieve potential savings through their own actions. Overcoming this barrier requires that households know not only what they can do but which actions will produce the most benefits. Gardner and Stern's study points to evidence that although many householders are motivated, they lack the necessary knowledge to act and often make choices based on mistaken notions about which actions are most beneficial.

According to the authors:

> *When strategies are proposed for households, they often appear in laundry list format, giving little or no priority to effectiveness. It is easy for households that want to cope with rising gasoline prices and heating and cooling bills to respond by taking small actions under the impression they are saving energy, while they are actually making a negligible dent in their personal energy consumption* (p14).

Similarly, estimates of potential savings made by householders often diverge dramatically from similar estimates made by energy experts (sometimes by a factor of four). In general, householders have been found to emphasize highly visible actions that can reduce energy use if repeated regularly, such as lowering winter thermostat settings and turning off lights, and they overestimate the potential energy savings from these actions. Meanwhile the savings from many actions with higher energy-saving potential but low visibility (such as installing storm windows) were underestimated.

Gardner and Stern conclude that "the public needs more direct and coherent advice concerning household and individual actions" (2008: p15). And the demand for such advice is becoming increasingly apparent. People are increasingly asking, 'What can I do?' Unfortunately, Gardner and Stern found that the advice found in most books and articles is unlikely to lead to effective action because such advice takes the form of long and unranked lists of recommended actions.

> *When people are faced with a laundry list of advice, they may feel confused and overwhelmed, and consequently take no action, or they may carry out one or two actions—probably the easiest to remember and perform. However, the behaviors that are easiest to remember and perform, for*

example, turning out lights when leaving rooms, tend to have minimal impact on climate change. Thus, long and unranked lists of behaviors are likely to be ineffective at best and may even be counterproductive, if they lead people to feel satisfied that they have done their part after accomplishing very little (p15).

The solution? According to decades of research, the authors suggest: "it is much more effective to focus campaigns on a very small number of specific actions that can make a real difference and disseminate the message repeatedly through multiple media outlets, using sources that are credible to target audiences" (2008: p16). Timing is also important. When possible, information should be provided when audience members are poised to make choices about the issue the message addresses (for example, in public health, in the doctor's office or at the cigarette counter). *A necessary first step is to identify which actions are the most effective.* By identifying the most promising opportunities, programs can be more targeted and have a greater impact.

Given the significant level of savings identified by Gardner and Stern, it is notable that the assessment is based on an evaluation of only 27 specific actions in the household and personal transportation sectors. Of these actions, the authors categorize 13 as curtailment types of behaviors in which people are required to cut back on certain activities. The remaining 14 actions are categorized as *efficiency* behaviors which they characterize as choices to invest "in home equipment that lowers energy costs without sacrificing desired energy services." The following table summarizes the most impactful savings opportunities as identified by Gardner and Stern's study.

Table 1: Behavior Related Savings Estimates from Gardner and Stern (2008)

	Action Type	**Estimated Savings (% of sector emissions)**
Invest.	Buy a more fuel efficient vehicle	13.5%
Low cost	Install and upgrade attic insulation and ventilation	Up to 7%
Beh.	Car pool to work with one other person	4.2%
Beh.	Replace 85% of all incandescent bulbs with cfls	4.0%
Beh.	Get frequent tune ups and air filter changes	3.9%
Beh.	Turn HH temperature down (heating) or up (cooling)	3.4%
Beh.	Alter driving practices (no jack rabbit starts, etc)	3.2%
Invest.	Install more efficient heating unit	2.9%
Invest.	Replace poor windows with high efficiency windows	2.8%
Beh.	Combine trips to ½ current mileage	2.7%
Beh.	Cut highway speed from 70 to 60 mph	2.4%
Invest.	Install more efficient AC unit	2.2%
	13 Other Actions	6.6%
	TOTAL potential savings (unadjusted)	58.8%
	TOTAL potential carbon savings (adjusted for HH eligibility and double counting of savings)	30%

*Results assume that equipment is only replaced at the end of old equipment's useful life.
Source: adapted from Gardner and Stern (2008)

Several subsequent studies (Laitner et al. 2009, Dietz et al. 2009, and NRDC and Garrison Institute 2010) have performed similar assessments of the energy and carbon emissions savings opportunities associated with household energy use and personal transportation practices and decisions. These studies have come to similar conclusions. For example, in 2009 Laitner et al. assessed the amount of *energy* (as opposed to carbon) that could be saved by households. This study explored a list of roughly 120 behaviors associated with household energy use and personal transportation practices. Similar to Gardner and Stern (2008), Laitner and his team of researchers concluded that current levels of energy use in the residential and personal transportation sectors could be reduced by an estimated 20-25 percent in the short-term (5-8 years), representing a reduction of 9 percent of total U.S. energy consumption. The estimates were formulated to reflect the "realistically achievable savings" as opposed to the entire savings opportunity assuming a best case scenario. According to the study's estimates, the largest reductions in energy consumption are associated with energy end uses such as refrigeration, air conditioning, lighting, space heating and personal transportation, while additional savings opportunities are associated with hot water heating, consumer appliances and other miscellaneous end uses. Notably, 57 percent of the estimated savings resulted from low-cost and no-cost types of behaviors while 43 percent were associated with household investments in insulation, appliances and HVAC equipment. Monte Carlo simulations were used to account for likely variation in: household eligibility, household participation rates, and the range of energy savings that might result from specified actions.

During the same year, Dietz et al. (2009) considered the potential *carbon* savings from a list of just 33 actions representing 17 household action types in 5 behaviorally distinct categories. Their estimates used a similar methodology as Laitner et al. (2009) with the goal of estimating the "reasonably achievable emissions reductions (RAER)." Their findings suggest achievable *carbon* savings of 20% in the household sector within 10 years if the most effective non-regulatory interventions are used. As shown in the following table, this study suggests that the largest savings are likely to be associated with ten household action types – half of these are associated with investment-type activities while the other half are strictly associated with conservation decisions and practices.

Table 2: Behavior Related Savings Estimates from Dietz et al. (2009)

	Action Type	Estimated Savings
Invest.	Fuel Efficient Vehicles	5.02%
Beh.	Weatherization	3.39%
Invest.	Appliances	1.87%
Invest.	HVAC Equipment	1.72%
Beh.	Driving Behavior	1.23%
Invest.	Low Resistance Tires	1.05%
Beh.	Car Pooling	1.02%
Invest.	Energy Efficient Water Heater	0.86%
Beh.	Thermostat Settings	0.71%
Beh.	Routine Auto Maintenance	0.66%
	7 Other Actions Types	2.47%
	Total	20%

Source: adapted from Dietz et al. 2009

A final study by the Natural Resources Defense Council (NRDC)and the Garrison Institute (2010) also considered the potential *carbon* savings that could be achieved by U.S. households. This study reviewed a more diverse set of conservation-related behaviors and found that roughly 1/7th (14.2%) of total U.S. greenhouse gas emissions could be saved if "Americans adopted a series of simple and inexpensive emissions-reducing measures in the areas of transportation, household energy consumption, diet, and waste over the next 10 years." This sum is roughly equivalent to the total greenhouse gas emissions of Germany, the largest polluter in Western Europe. The study looked at 32 potential actions and found that 38 percent of the estimated savings would come from household energy use, 29 percent from personal transportation, 17 percent from dietary shifts and reductions in food waste, and 16 percent from recycling and responsible consumption practices. Some notable differences associated with this study are that 1) it assumes action on the part of *all* eligible participants (not just a particular proportion of eligible participants), 2) it looks beyond household energy consumption and personal transportation and also considers the impact of dietary practices as well as recycling and consumption, and 3) it is predominantly focused on actions that involve little in the way of investments. The following table shows the estimated GHG savings (in carbon equivalents) from the 12 most impactful actions. These 12 actions represent nearly 70% of the estimated carbon savings that could be achieved through the 32 actions identified in the study.

Table 3: Behavior Related Savings Estimates from NRDC and Garrison (2010)

	Action Type	Abatement (MMtCO2e)
Beh.	Increase recycling by 50%	106
Low cost	Address building leaks and attic insulation	84
Beh.	Car pool 2 days per week or telecommute 1 day per week	73
Beh.	Switch from red meat to poultry 2 days per week	72
Beh.	Reduce food waste by 25%	65
Beh.	Take one fewer domestic flights per year	56
Beh.	Use programmable thermostat settings	47
Beh.	Reduce idling by 50%	43
Invest.	Upgrade to an Energy Star refrigerator	39
Beh.	Hang dry clothes in summer	35
Beh.	Drop dairy 2 days per week	35
Low cost	Insulate water heater, install low flow shower heads and faucet aerators	34
	20 Other actions	311
	TOTAL	1000

Source: adapted from NRDC and Garrison Institute (2010)

These studies have laid the groundwork needed to quantify the savings opportunities associated with everyday choices and practices and to recognize the impact that they could have on energy consumption and carbon emissions at the national level. They also provide an effective framework for assessing the scale of the behavioral opportunities that abound in our nation. Where they fall short, however, is in their inability to account for important sources of variation across regions, states, and cities.

The Need for City-Specific Behavioral Profiles

As progress on national climate policy continues to be deadlocked, cities have emerged on the forefront of efforts to address today's energy and climate change challenges. As part of their efforts, cities around the nation and the world have recognized the importance of engaging with urban residents using people-centered approaches that help households move away from wasteful energy use practices, reduce energy consumption, and lower carbon emissions. These approaches are appealing on many levels. When compared to more traditional technology-focused efforts, emerging research (as summarized above) suggests the people-centered initiatives – focused on the decisions and practices of people and households – can achieve faster reductions with much smaller investments – all while achieving sizeable contributions toward sustainability goals.

The current roadblock for cities lies in the mismatch between national-level research and city-level sustainability initiatives. While national-level research provides compelling evidence for aggregate, national-level savings opportunities, it is unable to translate those findings into insights that are actionable at the city level. More specifically, national-level estimates fail to account for area-to-area variation in a wide range of important variables such as climate characteristics, building infrastructure, technology saturation and technology use patterns. Without more specialized information, cities (and states) lack the ability to effectively develop and justify behaviorally-focused policies and programs at city and state levels.

What cities need are quantifiable estimates of the scale of potential savings for *their* particular city and clear information concerning the sets of behaviors that promise the largest savings opportunities given *their* city's unique characteristics. Such information is vital to city sustainability efforts because it provides cities with the means to:

- Evaluate the relative importance of behavioral initiatives as part of a larger, city-wide sustainability, climate, and/or energy initiative,
- Prioritize investments in different types of projects and programs and focus limited resources on a more precise and promising set of interventions,
- Write more effective funding proposals, and
- Develop more targeted marketing and communications efforts,

In sum, the efforts of cities to enhance local sustainability efforts would benefit greatly from city-specific information about behavioral opportunities that recognize local conditions and enhance the likelihood of effectively engaging city residents. Not surprisingly, however, this type of information is expensive to develop because it requires cities to engage in primary data collection efforts and analysis. In response, an effort was established to develop a low-cost means of producing city-level estimates of behavioral opportunities for energy and carbon savings. The goal was to develop an estimation model that would use existing data (from a variety of sources) to arrive at reliable measures of *achievable* savings. The results of the analysis would be captured in a city-level Behavior Wedge Profile.

Behavior Wedge Profile Components and Preliminary Results for the City of Baltimore

A Sample Behavior Wedge (BW) Profile was produced for the City of Baltimore. This sample profile serves as a proof of concept, demonstrating the feasibility of developing a set of low-cost Behavior Wedge profiles for cities across the United States and is included in Appendix A. The BW profile is not meant to be an exhaustive report documenting all potential savings opportunities; rather its primary purpose is to provide a focused summary and rank ordering of *achievable* savings opportunities from behavioral initiatives for a particular city. Although the majority of the data used to develop the profile come from the Residential Energy Consumption Survey (RECS), the profile does not reflect all of the information and insights that can be gleaned from RECS data. A great deal of additional information from RECS and other data sources was intentionally omitted from the report in order to make the profile as concise and user-friendly as possible. With that objective in mind, the BW Profile focuses on identifying and characterizing existing behavioral opportunities rather than describing the myriad data points involved in establishing those estimates or other related (and often interesting and relevant) information.

Achievable savings opportunities versus the universe of potential savings. Similar to prior, national-level behavior wedge studies, the sample Behavior Wedge Profile represents a conservative estimate of the true range of potential energy/carbon savings that could be achieved through shifts in behaviors, practices and choices. The estimate is considered to be conservative for at least two reasons: 1) the estimation methodology is focused on a subset of the long list of practices that could result in energy savings, and 2) estimates of gross savings opportunities are moderated by estimates of household eligibility and participation rates.

The choice to focus on a subset of behaviors was made to consciously highlight those behaviors that offer the greatest savings opportunities. As noted by Gardner and Stern above, the presentation of laundry lists of actions is rarely helpful and can often be overwhelming. Given the more than 200 behaviors associated with residential energy consumption, we chose to narrow our focus to those that were likely to prove most beneficial. The development of the Behavior Wedge profile was therefore strategically constructed with a focus on a limited range of behavior-based savings opportunities. The identification of the most relevant behavioral opportunities was informed by previous research and information pertaining to the *size of potential* savings, household eligibility, and the likelihood of adoption. As a result, while **t**he estimated energy savings presented in the BW Profile represent only a slice of the larger universe of potential behavior-related energy savings, they are likely to result in the greatest savings. Profile estimates are also moderated by critically assessing the proportion of households that are eligible to participate in any particular behavior as well as their likelihood of participation. For example, households that don't have dishwashers are not eligible to reduce energy consumption through reduced use or changes in dishwasher settings. Similarly, households that don't have central air conditioning are not eligible to reduce AC-related demand through the use of programmable thermostats. Such estimates are further moderated by estimating the likelihood of participation as assessed by a panel of experts.

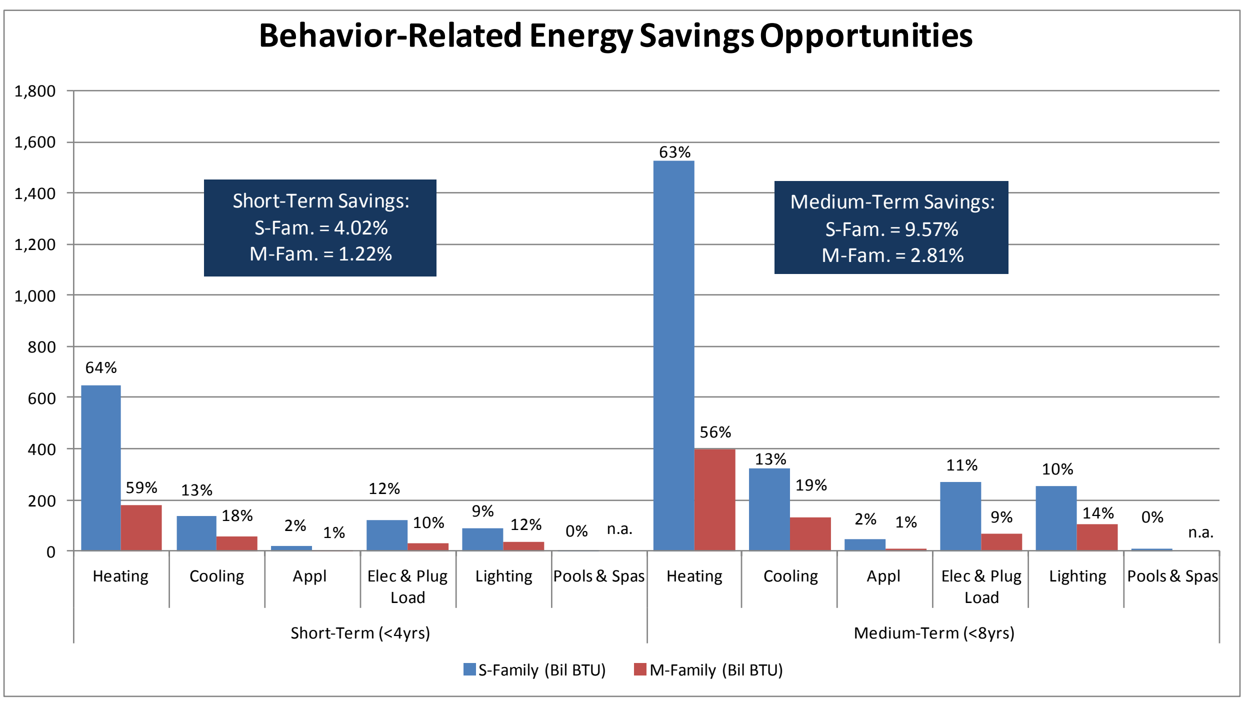
Behavior Wedge Profile – What does it include? What does it look like? As part of the effort to develop a prototype Behavior Wedge profile for cities, we developed a sample profile for The City of Baltimore. The sample BW Profile presents a tangible example of what a profile may look like – whether it is developed for a particular city, each of the 50 states, or particular geographic regions.

The sample profile is organized so as to present aggregate-level savings opportunities first, followed by the presentation of more detailed savings assessments which are organized according to discrete energy end uses. Given the large differences in housing characteristics between single-family and multi-family homes, all estimates are also broken down by housing type. Finally, savings estimates are provided for both the short-term (<4 years) and the medium-term (<8 years).

The sample profile has three discrete parts: An overview of achievable savings opportunities, two listings of the top-ten behaviors (one for single-family and one for multi-family homes), and a more detailed breakdown of savings opportunities by end use. Finally, some addition information on the local backdrop – such as housing characteristics, infrastructural information, and population demographics of the targeted region – is provided to establish the context. Each of these is discussed in more detail here.

Overview of Achievable Savings by Housing Type and Energy End Use. The BW profile begins with a bar chart that provides an overview of achievable savings by housing type and energy end use in the short-term (<4 year) term and the medium-term (<8 year). Each bar shows the aggregate amount of achievable savings across households in billion Btus. The percentage above each bar indicates the proportion of short- and/or medium-term savings that will come from a particular end-use. The dark blue text boxes show the aggregate savings opportunity for single-family and multi-family households in the short and medium-term. These figures can be added together to derive the total achievable savings. Medium-term savings are cumulative.

According to the preliminary results for The City of Baltimore, behavioral approaches offer the opportunity for reducing current levels of residential energy consumption by 5.25 percent in the short term and 12.4 percent in the medium term. The majority of the savings opportunities are in single-family homes. (This is in part a reflection of the much larger energy footprint of single-family homes as well as the higher amounts of energy waste in single-family homes, and the fact that there is a greater proportion of single family homes than multi-family homes.) Within the single-family realm, heating-related behaviors account for roughly 63 percent of savings opportunities while cooling-related behaviors represent approximately 13 percent of savings opportunities. Electronics and plug loads represent 11 percent of the savings opportunities while lighting represents 10 percent. These same energy end uses represent the largest opportunities in multi-family dwellings albeit with somewhat different proportions.



The Behavior Wedge Profile consistently presents data and savings opportunities by housing type to facilitate the design of innovative intervention strategies that take into account variations in barriers and opportunities. For example, strategies that are focused on multi-family homes need to consider the potential opportunities and barriers associated with centralized metering, high-levels of resident interaction, availability of property managers, and differences in technology saturation such as dishwashers and central AC. Alternatively, strategies that are focused on single-family homes are more likely to benefit from a focus on efforts to reduce heating and cooling in unused rooms.

Top Ten Energy Saving Strategies by Housing Type. The Behavior Wedge Profile also includes two top ten lists: the first rank orders savings opportunities for reducing energy consumption in single-family homes while the second rank orders the same opportunities for multi-family homes. Each table specifies the sets of behaviors that matter most – placing them at the top of the list – and quantifies the achievable savings for each set of behaviors.

In the case of the sample profile for Baltimore, we found that the largest achievable savings were associated with thermostat setbacks and settings for heating and cooling. Together, this set of behaviors held the opportunity for reducing current energy demand by 3.2 percent. Five other heating-related behaviors also made the top ten list, including items 2 and 3 – furnace maintenance and the reduction in wasteful heating practices. Number four on our list was plug-load management which represented the opportunity for reducing current energy demand by over 1 percent. Altogether this set of top ten behaviors represented a savings opportunity of 11.4 percent among single-family homes.

Top Ten Strategies for Reducing Energy Consumption in *Single Family* ***Homes***

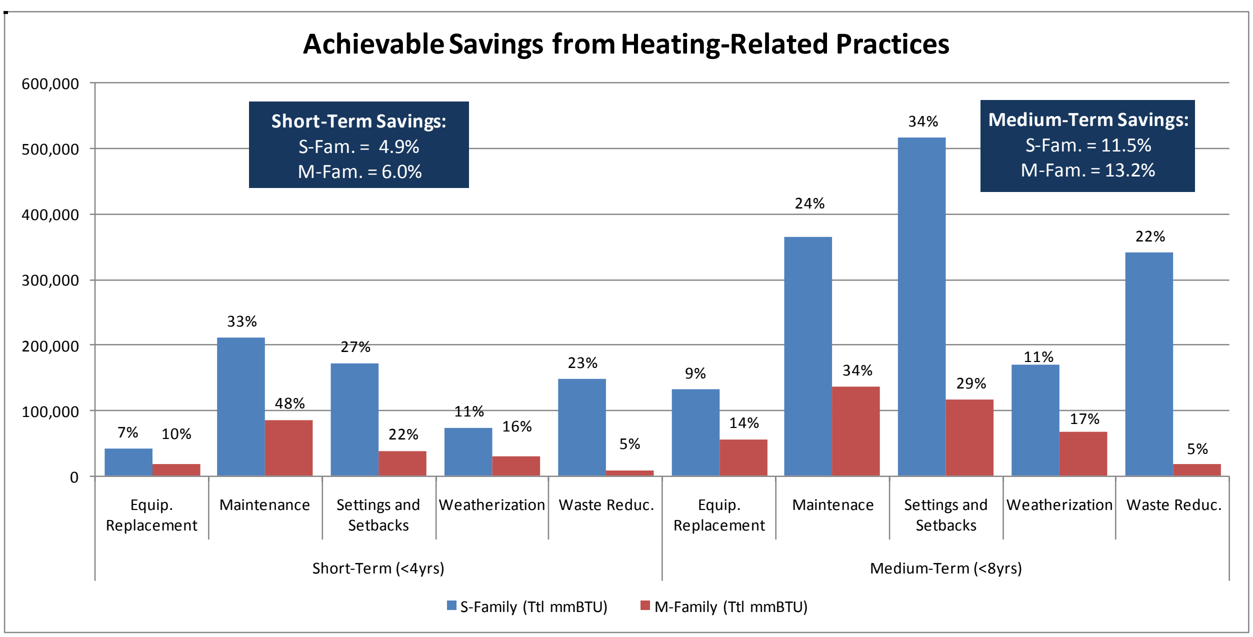
		Savings
1	Heating & Cooling: Setbacks and programmable thermostats	3.20%
2	Heating: Furnace maintenance	1.84%
3	Heating: Reduce wasteful heating practices	1.72%
4	Plug load: Plug Load management	1.09%
5	Heating & Cooling: Weatherization	1.06%
6	Lighting: CFL bulb replacement	0.89%
7	Heating: Accelerated furnace replacement	0.67%
8	Cooling: AC maintenance	0.43%
9	Electronics: Accelerated replacement of desktops with laptops	0.26%
10	Cooling: Alternative technologies and reductions in solar heat gain	0.20%
	Total Achievable Savings	**11.36%**

Achievable Savings by End Use. The third section of the BW Profile reviews behavioral opportunities associated with specific end uses. For each end use, a bar chart is used to illustrate the size of the savings opportunities (in BTUs) associated with specific behaviors with short-term estimates on the left side of the chart and medium-term estimates on the right side. As before, estimates are broken out by single-family and multi-family housing types. In these charts, the percentages represent the proportion of savings associated with the given end use category (i.e. heating). Below each chart, the profile highlights notable trends and opportunities particular to the end use category

The sample Behavior Wedge Profile provides an assessment of each of the following end use categories and associated behaviors:

- **Heating**: equipment replacement, maintenance, adjustment of settings and setbacks, weatherization, and waste reduction.
- **Cooling**: equipment replacement, maintenance, adjustment of settings and setbacks, weatherization, and supplemental cooling strategies (ceiling fans, window film, etc.)
- **Appliances**: eliminate or downsize second refrigerator or freezer, replace old washing machine with energy efficient model, change settings and use frequency, and air-dry laundry.
- **Plug Load and Electronics**: vampire load management with smart strips, plug load management with settings and conservation strategies, and replacing desktops with laptops.
- **Lighting (and Pools and Spas)**: light bulb replacement with CFL or LED, turning off unnecessary lighting, enhanced day-lighting, and using more efficient pool pumps, settings and solar covers.

The following chart illustrates the achievable savings estimates for five heating-related behaviors. According to the estimates, behavioral programs could reduce heating-related energy demand by an estimated 11.5 percent among single-family homes and 13.2 percent in multi-family properties in the medium term. In multi-family homes, the largest proportion of savings is associated with furnace system maintenance and thermostat settings and setbacks. Together, such programs account for 58 percent of achievable heating-related savings in single-family homes and 63 percent of achievable savings in multi-family homes. In addition, residents of single-family homes can further reduce consumption by choosing to close doors and heating ducts in unused rooms.



Detailed assessments of the behavioral opportunities associated with other energy end uses are also provided in the profile but not discussed here. (See the sample profile for more information.)

City-Specific Demographics and Characteristics. The final section of the profile provides important background information concerning city-specific demographic patterns, building stock, and other factors that are likely to play a role in shaping engagement strategies. This information may be drawn from RECS data, the Census Bureau, and other reliable sources. For example, as illustrated in the Table 9 (on page 17 of this paper), the sample profile for Baltimore highlights the age and average square footage of the city's housing stock. Compared to other urban areas in the state, housing in Baltimore is both older and smaller with more than 80 percent of Baltimore's housing stock built before 1970. Prior to 1970, average home sizes averaged 1350 square feet. Such characteristics are critical for understanding the unique sets of challenges and opportunities a particular city may face when attempting to design energy programs and should be kept in mind as city officials consider the adoption of practices and strategies employed by other cities. Key demographics variables include rates of home ownership, household size, predominance of households in poverty, level of household income, and employment information. These types of measures can provide a picture of local conditions and provide insights concerning potential strategies.

The Behavior Wedge Assessment Methodology

The measures of achievable savings presented in the prototype Behavior Wedge Profile were estimated through the use of algorithmic modeling techniques and data from the 2009 Residential Energy Consumption Survey and the U.S. Census. More specifically, a set of algorithms was developed for each of the 23 behaviors included in the profile assessment to model the complex relationships between housing characteristics, technology saturation, technology use patterns, demographics, attitudes, and energy demand. Once the algorithms were specified, existing data for the locale in question were plugged into the model to estimate measures of achievable savings.

The development of profile estimates involved 5 components. First, a set of algorithms was created to estimate the amount of energy that could be saved from each of the 24 behaviors included in the prototype assessment. Second, RECS data were mined for relevant information about housing characteristics, technology saturation and technology use patterns particular to the four-state region that includes the state of Maryland. Third, many of the RECS measures were normalized and several measures of relevant variables were respecified. Fourth, Census data were used to weight the RECS data so as to make it better reflect the specific housing characteristics of Baltimore – primarily in terms of the size and age of the existing housing stock. Finally, the relevant RECS data were plugged into the algorithmic model to create preliminary savings estimates. The estimates were subsequently summarized through the use of charts, tables, and text as presented in the Residential Sector *Behavior Wedge Profile for the City of Baltimore.* These steps are discussed in more detail below.

Model Specification and Algorithm Development. Prior to the development of the estimation algorithms, a short list of 23 energy-related residential behaviors was selected for inclusion in the model. The selection process was made using insights from national-level assessments, a review of the larger energy behavior literature, and the expertise of a small set of advisors. While the abbreviated list of 23 behaviors may be expanded in the future, the goal for the prototype model was to create a list that was both manageable in size and also likely to represent the largest savings opportunities. The following list documents the full set of behaviors (practices and choices) that were included as the basis of model estimates.

Table 4: Behaviors Included in the Prototype Model

	Behavior	Change in Practice	Purchasing/ Investment Decision
1	Accelerated heating equipment replacement		x
2	Regular heating equipment maintenance	x	
3	Setback of heating thermostat	x	
4	Use of programmable thermostat for heating,	x	
5	Heat-related weatherization	x	
6	Heat conservation actions (closing doors and vents)	x	
7	Accelerated cooling equipment replacement		x
8	Cooling equipment maintenance	x	
9	Setback of cooling thermostat	x	
10	Use of programmable thermostat for AC	x	
11	Cooling-related weatherization	x	
12	Cooling conservation actions (use of ceiling fans, blinds and shades)	x	
13	Discarding a second refrigerator	x	
14	Purchasing an energy efficient clothes washer		x
15	Using cold water and efficient settings on washers	x	
16	Air drying clothes	x	
17	Replacing desktop computers with laptops		x
18	Managing vampire loads	x	
19	Managing plug loads	x	
20	Installing CFLs	x	
21	Turning off unused lights	x	
22	Increased use of daylighting	x	
23	Using best practices for pools and spas (pump settings, covers and pump replacement)	x	

For each of the behaviors listed above, four distinct algorithms were developed to provide estimates across two time periods and two types of housing structures. As such, two algorithms estimated achievable *short-term* savings (achievable in 4 years or less) while the other two estimated achievable *medium-term* savings (achievable in 5- 8 years). During each time period, distinct algorithms were also created to separately calculate the achievable savings for *single-family* homes and for *multi-family* homes. Medium-term savings were calculating by reassessing household eligibility given changes in product saturation and/or shifts in behaviors needed to achieve short-term savings. The process starts with an assessment of short-term savings opportunities (1-4 years), followed by an assessment of medium-term savings opportunities (years 5-8). These savings estimates are then added together to determine the cumulative savings opportunities in the medium term (within the first 8 years). In other words, for each of the 23 actions noted above, a set of four estimates was developed taking into account both the savings period and the housing type – as illustrated in the following table.

Table 5: Algorithm Components

		Savings Period	
Housing Type		Short-Term	Medium-Term
	Single Family	(Number of Balt. Homes) x (% single family) x (% eligibility) x (likely short-term participation) x (current energy use) x (estimated savings per HH)	(Number of Balt. Homes) x (% single family) x (% eligibility) x (likely medium-term participation) x (current energy use) x (estimated savings per HH)
	Multi-Family	Number of Balt. Homes) x (% multi family) x (% eligibility) x (likely short-term participation) x (current energy use) x (estimated savings per HH)	Number of Balt. Homes) x (% multi family) x (% eligibility) x (likely medium-term participation) x (current energy use) x (estimated savings per HH)

Each of the sample equations show in the table (above) specifies the number of homes that fit the category in question (single-family or multi-family), the percentage of homes that are eligible to "participate" in the behavior in question, an estimate of likely participation rates, and an estimated level of savings per household for the behavior in question.

In the development of the sample profile for Baltimore, measures of the number and types of homes relied on Census data for the city of Baltimore. Eligibility measures were determined based on information gleaned from the RECS data set. For example in order to determine the proportion of households that were eligible to unplug or dispose of a second refrigerator, the model draws from RECS data that measure the proportion of households with two or more refrigerators. Likely short-term and long-term participation was drawn from an assessment of historical program participation rates (see

Laitner et al. 2009) and expert assessments. Estimates of savings per household were calculated using expert advice from a small group of energy experts and published DOE data sources.

Measures of current energy use comprised a core variable for each of the algorithms. Such measures had to be estimated for each of the behaviors using RECS data as well as other data sources. The estimates were triangulated using RECS measures of household energy consumption for the geographic area in question and other estimates of energy use for specific climate zones. Household-level measures were also aggregated (using local housing information) to develop an estimate of city-wide, residential energy consumption as illustrated in the following table.

Table 6: Aggregate Estimates of Household Energy Consumption in Baltimore

	Households	Avg. Energy Use for *Heating* per HH (mmBTU)	Total Energy Use per HH (mmBTU)	Residential Energy Use for *Heating* – Baltimore (mmBTU)	Residential Energy Use Baltimore (mmBTU)
Total	296,000			16,469,200	25,582,715
Single-family	67%	68.8	103.1	13,636,480	20,440,840
Multi-family	33%	29.0	52.6	2,832,720	5,141,875

In order to assess the achievable savings for each of the behaviors at the aggregate level, the algorithms were applied to the reference case for Baltimore using data from RECS for Maryland. The following table provides estimates for aggregate-level savings associated with the accelerated replacement of heating equipment in Baltimore and illustrates the set of savings estimates created for each of the 23 behaviors.

Table 7: Achievable Savings from the Accelerated Replacement of Heating Equipment

	Aggregate Energy Savings across HHs (mmBTU)			**Savings as a % of Total Energy Use**		
	Single-family	Multi-family	Total	Single-family	Multi-family	Total
Short-term	42,328	18,234	60,562	0.32%	0.61%	0.37%
Medium-term	89,947	38,746	128,693	0.68%	1.29%	0.79%
Short + Medium	132,275	56,980	189,255	1.00%	1.90%	1.20%

Data Selection and Variable Development. As noted above, relevant variables relating to infrastructure, housing characteristics, technology saturation and technology use were identified and pulled from the RECS micro data for the region in question to create a region-specific data set. These data were used to assess the proportion of households living in certain types of housing, determine which types of households had access to different types of technologies, and to assess variations in household use of these technologies. Such assessments also considered how these patterns varied for urban versus non-urban households and for single-family versus multi-family households.

For example, in order to understand the achievable savings opportunities of a heating related behavior like replacement of central heating equipment it's important to know the current proportion of households that have a furnace, a boiler, or a space heater, and knowing the age of that equipment can help determine the likelihood of adoption as well as a broad understanding of the likely efficiency levels of existing technology (and therefore the potential efficiency gains).

The following table provides some examples of several heating-related variables that were assessed in the development of the savings estimation model. The table reveals that roughly 45 percent of urban single-family households with furnaces reported regular furnace maintenance while only 28 percent of urban multi-family households with furnaces reported the same. Roughly 35 percent of both single and multi-family units with furnaces reported having furnaces that were at least 15 years old. While 25 percent reported furnaces that were at least 20 years old.

Table 8: Heating Equipment for Urban Households within Selected State-Subset

Heating	Urban Single-Family Households		Urban Multi-Family Households	
Space Heater (Electric or Kerosene)	33,022	1.6%	0	0.0%
Routine Maintenance Level (High)	912,175	44.5%	195,028	28.2%
Age of heating equipment (15-19)	229,393	11.2%	77,324	11.2%
Age of heating equipment (20+)	568,012	27.7%	175,478	25.4%

Integrating Census Data to Reflect the Baltimore's Housing Characteristics. Since RECS data are not collected at the city level, Census data were used to weight the RECS data with the goal of making it more representative of the type of housing found in the City of Baltimore.

We were particularly interested in the comparative age and size of the housing stock for Baltimore compared with urban Maryland more generally. A comparison revealed important distinctions. As can be seen in Table 9, the housing stock in Baltimore tends to be both older and smaller than that for urban areas in Maryland as a whole. Census data indicate that while roughly 29 percent of urban Maryland homes were built before 1950, the comparable proportion of homes in Baltimore is 55.4 percent. And, whereas roughly 33 percent of homes in urban Maryland were built between 1980 and 2000, the comparable number for Baltimore was a much smaller 8 percent. Given these differences in the average age of the housing stock, it isn't surprising that the average home size in Baltimore is also smaller than the average urban home within the state. As shown in the following table, the average home in Baltimore is roughly 1280 square feet compared to the average home size in urban Maryland of roughly 1650 square feet.

Table 9: Housing Characteristics: Urban Maryland and Baltimore

Age of Residence	Avg. Home Size (SqFt)	Urban MD Single-Family	Urban MD Multi-Family	SF + MF Total	Baltimore
2000-2009	2465	4.7%	17.1%	7.8%	3.4%
1990-1999	2200	16.8%	11.1%	15.4%	3.3%
1980-1989	1770	20.5%	10.5%	17.9%	4.6%
1970-1979	1685	7.6%	13.2%	9.0%	6.5%
1950-1969	1350	22.1%	17.9%	21.0%	26.9%
Older than 1950	1020	28.3%	30.2%	28.8%	55.4%
Average/Total	1650	100.0%	100.0%	100.0%	100.0%
Estimated Avg. Home Size Baltimore (SqFt)		1697	842		1276
% of HH Reporting Adequate insulation		77.3%	80.7%	78.4%	

Source: U.S. Census
Notes: Average home size in the US has been increasing over the past 60 years. Most of Baltimore's housing stock is from 1970 or earlier and is smaller than overall national averages or even state averages.

RECS data were also adjusted to account for differences in demographic measures. The following table provides critical information concerning the number of housing units in Baltimore as well as differences in the distribution of housing units across single-family and multi-family housing sectors. As documented in the following table, Baltimore represents roughly 11 percent of Maryland's population and roughly 12 percent of Maryland's housing stock. Nevertheless home ownership rates in Baltimore are much lower than for Maryland as a whole (roughly 50% in Baltimore compared with 72% in Maryland. Moreover, a larger proportion of Baltimore's homes (33%) are multi-family units compared with just 26 percent for Maryland as a whole. In addition, it is valuable to note that the median value of owner occupied housing in Baltimore is roughly half that of the larger state and that while the number of people per household is roughly the same in Baltimore (compared with the larger state), the median household income in Baltimore is only 56 percent of the median income for the state. One final point of interest is that the poverty rate in Baltimore is much higher than for the state overall, such that more than 1 in 5 residents of Baltimore live in poverty while less than 1 in 10 Maryland residents do. These measures provide important insights into the housing conditions of Baltimore residents as well as their likely propensity to engage in particular energy saving behaviors such as investments in energy efficient technologies.

Given the Census data reviewed here, we would expect that there the proportion of Baltimore residents who are renters is much higher than in the rest of the state, and that much of the housing stock in Baltimore was built without energy efficiency in mind. In addition, the relatively low income levels and high rates of poverty in Baltimore diminish the likelihood that residents can afford to finance investments in more energy efficient technologies. These same insights may also suggest that many cash-strapped residents of Baltimore may be disproportionately more interested in reducing their energy consumption and more likely to do so using a variety of non-investment approaches. Such insights are incorporated into the model estimates.

Table 10: Population Demographics: Maryland and Baltimore

	Baltimore	Balt/MD	Maryland
Population	619,493	11%	5,828,289
Housing Units	296,450	12%	2,391,350
Home Ownership Rate	49.80%	72%	69%
Housing Units in MF Structures	33.10%	129%	25.70%
Median value of owner-occupied Housing	160	49%	329
Persons per Household	2.52	96%	2.62
Median Household Income	$ 39,386	56%	$ 70,647
Persons below Poverty	21.3%	248%	8.6%

Source: Census Bureau 2011

Model Results. The results of the assessment were compiled in a summary table which shows the short-term and medium-term savings opportunities for each of the behaviors that were assessed. Separate estimates of achievable savings are provided for single-family and multi-family homes. The sample Behavior Wedge Profile illustrates the results using a variety of charts and tables as well as descriptive text. (The Sample Profile for the City of Baltimore is included in Appendix A.)

Table 11: Estimated SHORT-TERM* Achievable Residential Sector Energy Savings Opportunities for Baltimore

		Single-Family Homes		Multi-Family Homes		Total Resident. Savings	
	Actions	BTU	% of total energy consump.	BTU	% of total energy consump.	BTU	% of total energy consump.
1	Heating Equip. Replacement	42,328	0.17%	18,234	0.07%	60,562	0.24%
2	Heating Equip. Maintenance	211,640	0.84%	86,333	0.34%	297,973	1.18%
3	Heating Settings Setback	66,186	0.26%	15,022	0.06%	81,208	0.32%
4	Heating (Program. Therm.)	105,897	0.42%	24,035	0.10%	129,932	0.51%
5	Weatherization	74,128	0.29%	29,443	0.12%	103,571	0.41%
6	Close Rooms-Doors-Vents	148,256	0.59%	8,412	0.03%	156,668	0.62%
7	Cooling Equip. Replacement	13,187	0.05%	3,550	0.01%	16,737	0.07%
8	Cooling Equip. Maintenance	48,840	0.19%	23,908	0.09%	72,748	0.29%
9	Cooling Settings Setback	15,103	0.06%	4,558	0.02%	19,662	0.08%
10	Cooling (Program. Therm.)	24,165	0.10%	7,293	0.03%	31,459	0.12%

11	Cooling Weatherization	16,916	0.07%	8,934	0.04%	25,850	0.10%
12	Cooling Supplemental	16,916	0.07%	8,934	0.04%	25,850	0.10%
13	2nd Fridge-Freezer Removal	7,677	0.03%	435	0.00%	8,112	0.03%
14	Energy Efficient Washer	6,317	0.02%	3,282	0.01%	9,599	0.04%
15	Appliance Settings	3,000	0.01%	488	0.00%	3,488	0.01%
16	Air Drying Laundry	2,455	0.01%	399	0.00%	2,854	0.01%
17	Computer Replacement	26,201	0.10%	13,493	0.05%	39,694	0.16%
18	Vampire Load Mgmt.	65,616	0.26%	11,930	0.05%	77,546	0.31%
19	Plug Load Mgmt & Conserv.	28,121	0.11%	5,113	0.02%	33,234	0.13%
20	CFL Bulb Replacement	61,998	0.25%	31,094	0.12%	93,091	0.37%
21	Turn off Lighting	13,419	0.05%	3,109	0.01%	16,529	0.07%
22	Increased Daylighting	13,419	0.05%	1,555	0.01%	14,974	0.06%
23	Pools-Spas	3,636	0.01%	0	0.00%	3,636	0.01%
	TOTAL	**1,015,421**	**4.02%**	**309,556**	**1.22%**	**1,324,977**	**5.24%**

*Short-term is defined as <4 years.

Conclusions and On-going Research

Overall, the ideas presented in this paper confirm that the energy and carbon savings opportunities associated with behavior-based approaches could result in significant reductions in energy use and carbon emissions and that a low-cost means of providing valuable, city-specific assessments of such opportunities is viable. According to the set of recent, national-level assessments reviewed earlier in this paper, potential savings from the residential sector and personal transportation alone have been estimated at between 20 and 30 percent of current levels of energy consumption and carbon emissions. Similarly, the city-level model presented in this paper estimated the achievable savings for residential households in the city of Baltimore (excluding personal transportation) to be roughly 14 percent in the medium term. While the scale of national-level savings opportunities has become increasingly well documented, city-level assessments like the Behavior Wedge Profile provide a new and compelling means of accounting for significant differences in regional and sub-regional characteristics including those associated with climate, building stock, technology saturation, technology use, and conservation attitudes and practices.

Notably, the Behavior Wedge assessment work discussed in this paper has not only identified a potential, low-cost means of helping cities to identify and target behavioral opportunities for addressing energy and climate challenges but has also laid the groundwork for the full development of such a model. The first phase of model development (as described in this paper) involved the creation of a prototype model and the development of a sample Behavior Wedge Profile for the City of Baltimore. Work on the second stage of this effort began this year and will include 1) the refinement of the residential sector model, 2) the development of a similar model for the commercial buildings sector, and 3) the application of both models in the creation of Behavior Wedge Profiles for five U.S. cities.

Through the completion of this work, our goal is to offer cities rigorous and reliable, low-cost estimates of behavior savings opportunities. Such estimates will help cities around the United States to develop more targeted and effective programs and achieve greater success in reducing energy and carbon savings.

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