Synapse
Energy Economics, Inc.

Feasibility Study of Alternative Energy and Advanced Energy Efficiency Technologies for Low-Income Housing in Massachusetts

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1. Introduction and Summary

1.1 Background and Objective of the Study

The Low-Income Energy Affordability Network (LEAN) recently received a grant from the Massachusetts Technology Collaborative (MTC) regarding the energy needs and interests of low-income citizens. A specific purpose of the grant is to develop and implement projects that will integrate "alternative energy" and "advanced energy efficiency" technologies into residential buildings and other facilities utilized by low-income residents.

Alternative energy measures are defined as those technologies utilizing renewable resources or highly efficient processes to generate electricity or heat. Advanced energy efficiency measures are defined as new or emerging efficiency technologies that are not currently provided through low-income energy efficiency programs in Massachusetts.

The grant includes funding of $750,000 annually for four years for LEAN to investigate and implement alternative energy and advanced energy efficiency measures. These measures will be assessed and implemented through the low-income energy efficiency programs that are currently being offered by the Massachusetts low-income weatherization program network.

LEAN anticipates a multi-phase approach to identifying measures to implement through the MTC grant. The first phase includes a preliminary feasibility study of the broad universe of potential alternative energy and energy efficiency measures. This purpose of this phase is to narrow the list of potential measures to those that appear to offer the greatest amount of benefits to low-income customers in Massachusetts. This phase is also designed to identify the ranges of costs and benefits that might be expected from the selected alternative energy and energy efficiency measures. The purpose of this report is to assist LEAN with this first phase of measure assessment. It should therefore be regarded as preliminary, not definitive, and subject to confirmation in the field.

A subsequent phase of the LEAN investigation will include implementation of one or more of the most promising measures identified in the first phase. The measures' installation, costs, savings and performance in general will be monitored to provide actual field experience, and indicate the potential for integrating the measure into the low-income programs.

One of the key goals of the grant is to generate the maximum public benefits from the alternative energy and energy efficiency measures. Thus, one of the key objectives of this report is a preliminary assessment of the various costs and benefits of the measures studied.

As noted below, we make several simplifying assumptions in order to be able to compare costs and benefits across many different types of measures. Consequently, our results should be viewed as general indications of cost-effectiveness. Additional, more site-specific analyses should be conducted before measures are fully rejected or adopted.

1.2 Summary of Results

The methodology used to identify and assess the advanced energy efficiency and alternative technology measures is described in Chapter 2. The descriptions of each measure, along with some of our key assumptions, are provided in Chapters 4 and 5. The more detailed assumptions and calculations for each measure are presented in Appendices B and C.

Table 1.1 below presents a summary of the cost-effectiveness indicators for the alternative energy measures. In most cases the net benefits of the alternative energy measures are less than the net costs. In other words, most of these measures are uneconomic relative to conventional electricity and heat generation sources. However, the analysis here does not account for some important benefits – such as environmental benefits, power quality, and fuel diversity – that make some of these measures more attractive. Thus the relative standing of the technologies in Table 1.1 may be more useful than the precise economic indicators themselves.

The micro wind and small wind stand out as the most cost-effective technologies considered here, assuming that sufficient wind is available at the customer's site. The micro Stirling engine and the microturbine are also relatively economic. The wood hybrid furnace/boiler is very economic if the wood fuel is available for free or at low cost, but becomes much less economic when fuel is priced at the cost of firewood.

Among the PV measures, the efficient inclined roof stands out as the most economic option. The building integrated PV systems are very expensive, and would only make sense in niche applications.

Table 1.1 Cost-Effectiveness Indicators for Alternative Energy Measures

Technology	End-Use	Cost of Electricity Generated ($/MWh)	Cost of Heat Generated ($/mmBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)
[A]	[B]	[P]	[Q]	[R]	[S]	[T]
Microturbine (gas)	electricity & heat	61	18	24	-55,321	0.86
Microturbine (biodiesel)	electricity & heat	71	29	-5	-306,381	0.52
Internal Combustion (biodiesel)	electricity & heat	56	25	-40	-436,555	0.66
Micro Stirling Engine (gas)	electricity & heat	77	0.7	15	-4,549	0.77
Fuel Cell PEM (gas)	electricity & heat	91	5.3	55	-53,246	0.63
Fuel Cell SO (gas)	electricity & heat	202	14	113	-389,273	0.32
PV: inclined roof (efficient)	electricity	257	---	65	-18,041	0.41
PV: inclined roof (less efficient)	electricity	284	---	78	-16,436	0.41
PV: flat roof	electricity	361	---	111	-19,489	0.34
PV: ground mounted	electricity	279	---	74	-17,427	0.40
PV: building integrated	electricity	615	---	224	-33,046	0.22
Wind Micro (0-3 kW)	electricity	59	---	12	567	1.16
Wind Small (3-60 kW)	electricity	59	---	14	6,506	1.13
Micro Hydro	electricity	95	---	35	-7,684	0.59
Wood hybrid furnace/boiler	space heating	---	14	-9	-6,335	0.81
Wood hybrid (free wood)	space heating	---	3.3	6	18,249	3.24

Table 1.2 presents a summary of the benefit cost ratios of the advanced energy efficiency measures. The ratios are presented for both the incremental costs and total costs cases. [1]

Table 1.2 Benefit-Cost Ratios of the Advanced Energy Efficiency Measures

Measure	End-Use Type	Incremental Cost	Total Cost
Laminar flow aerators	Water heating	14.2	12.2
Cellulose insulation (vs. no insul.)	Building envelope	5.8	5.8
Water heater: indirect	Water heating	19.5	5.7
Duct sealing: aerosol	Heating distribution	4.8	4.8
Wireless thermostats	Heating supply	5.0	3.8
High perf. windows (vs. new)	Building envelope	3.6	3.6
Drainwater heat recovery	Water heating	3.0	3.0
High-Eff. Refrig. (vs. existing)	Appliance	2.4	2.3
Water heater: instantaneous	Water heating	3.2	2.3
Cellulose insulation (vs. fiberglass)	Building envelope	5.7	1.9
ENERGY STAR Clothes Washers	Appliance	4.6	1.8
Advanced HVAC fan motors	Heating distribution	2.2	1.7
Hot water recirculation systems	Water heating	1.6	1.6
White Light Emitting Diodes	Lighting	1.7	1.5
Solar Hot Water (flat plate)	Water heating	1.1	1.1
High efficiency bathroom fans	Heating distribution	4.4	1.1
Occupancy sensors	Lighting	1.1	1.1
High perf. Windows (vs. existing)	Building envelope	0.9	0.9
HVAC smart zoning controls	Heating supply	0.9	0.9
Solar Hot Water (evacuated tube)	Water heating	0.7	0.7
High-efficiency gas boilers	Heating supply	18.7	0.7
Water heater: condensing	Water heating	0.9	0.6
Heat Pump: ground-coupled	Heating supply	1.1	0.4
High-Eff. Refrig.(vs. new)	Appliance	3.0	0.4
Heat Pump: advanced cold-climate	Heating supply	2.7	0.3
Trombe Wall	Heating supply	0.3	0.3
Ceramic insulating paint	Building envelope	3.4	0.1

Many of these measures are cost-effective and have relatively short payback periods. However, the cost-effectiveness of many advanced efficiency measures is very much dependent upon whether the measure is a retrofit (in which case the results of our total cost case is relevant), or the efficiency measure is being installed at a time when the baseline measure would be replaced anyway (in which case the results of our incremental case are relevant). Figure 3.3, presented in Chapter 3, presents a graphical depiction of how the cost-effectiveness results can vary between the total cost case and the incremental cost case.

While there are many cost-effective advanced efficiency measures available, the most promising measures include laminar flow aerators, indirect water heaters, duct sealing, wireless thermostats, and high efficiency refrigerators (versus existing). Many of the efficiency measures studied here will have only limited applications among low-income households in Massachusetts, for a variety of reasons outlined in Chapter 4 below.

[1] See Chapter 2 for a discussion of how we define our incremental cost and our total cost cases.

2. Methodology and Assumptions

Developing the Lists of Measures

We developed a list of alternative energy measures by identifying all renewable or highly efficient technologies that might be applicable to residential buildings in Massachusetts. In some cases where a certain technology typically uses a fossil fuel (such as microturbines) we looked into the impacts of using biodiesel as an alternative fuel in order to see the costs and benefits of using a renewable fuel. The list of alternative energy measures was developed and finalized with input from a committee designated by LEAN to oversee this study.

We developed the list of advanced energy efficiency measures in two steps. First, we conducted a review of recent literature, organizations and web sites that provide information on emerging or advanced energy efficiency technologies. This list included technologies for any type of residential building fuel or end-use. Based on this review, we compiled a list of many energy efficiency technologies that could be considered advanced energy efficiency measures. By design, we excluded from this list those efficiency measures that are currently being offered to low-income customers through the Massachusetts energy efficiency programs. The resulting list of advanced energy efficiency technologies is presented in Appendix A.

Second, we narrowed this list down to those that appear to offer the most promise for customers in the Massachusetts low-income energy efficiency programs. We placed the highest priority on space heating measures, and the next highest priority on water heating measures, as these represent the largest portion of energy bills for Massachusetts low-income customers. We placed very little emphasis on air conditioning measures, because there is relatively little electricity consumption devoted to air conditioning use among Massachusetts low-income customers. We also placed a low priority on efficiency measures applicable to new construction or major rehabilitation projects, because LEAN's initial focus is on integrating advanced efficiency measures into its retrofit program that addresses existing low-income housing units. The resulting shorter list of energy efficiency measures was developed and finalized with input from the LEAN committee.

Assumptions for a Typical Housing Unit

We developed several assumptions regarding the "typical housing unit" where an alternative energy or advanced energy efficiency measure would be installed. We attempted to standardize these assumptions as much as possible, in order to allow for comparison of the costs and benefits across the different technologies. The typical housing unit assumptions are meant to represent the energy consumption patterns of the typical low-income housing unit in Massachusetts. In particular, we assumed that:[2]

[2] Based on Weatherization Assistance Program data provided by Art Willcox.

- The typical housing unit uses oil for *space heating*, and consumes 85 MMBtu of oil per year for this purpose. This is roughly equal to the average space heating oil consumption across single-family and 2-4 unit multi-family housing units in Massachusetts.
- The typical housing unit also uses oil for *water heating*, and consumes 27 MMBtu of oil per year for this purpose. This is roughly equal to the water heating oil consumption used in single-family and 2-4 unit multi-family homes in Massachusetts.

The vast majority of low-income housing units in Massachusetts use oil or natural gas for space heating and water heating purposes. In general, housing units heated with oil tend to have higher heating bills than those heated with natural gas, all else being equal.[3] By choosing oil as the avoided fuel, we may have made the technologies look slightly more cost effective than they would if we had chosen natural gas. We purposefully made this choice in order to avoid screening out measures prematurely. We used this same rationale in choosing oil as the fuel for water heating.

We recognize that many low-income housing units in Massachusetts will have different characteristics than those assumed here. The size of any one particular unit will make a big difference in the amount of fuel consumed, as will the size and the activities of the unit's occupants. Again, the assumptions above were used in order to allow us to keep our analysis simple and to compare results across technologies.

Cost Effectiveness Methodology and Assumptions

We used several different cost-effectiveness indicators to assess the costs and benefits of the alternative measures. These indicators present the costs and benefits in different forms and from different perspectives. Each indicator is defined and summarized below.

Cost of Electricity Generated or Saved

The cost of electricity generated represents the per-unit cost (in $/MWh) to generate electricity from an alternative energy measure. It can be compared to either avoided costs (in $/MWh), or the per-unit costs of other types of generation (in $/MWh), in order to provide a general indication of how an alternative energy measure compares with conventional generation sources.

The cost of electricity saved represents the per-unit cost (in $/MWh) to save electricity from an advanced energy efficiency measure. It can be compared to avoided costs (in $/MWh), in order to provide a general indication of how an efficiency measure compares with conventional generation sources.

[3] This is simply an observed fact, perhaps the result of several factors: oil heated homes may be older housing and thus have more infiltration, less insulation, and larger windows; oil heated homes may have less efficient heating and DHW equipment; and, oil heated homes may have older occupants who need higher temps. On the flip side, gas homes may be more recently constructed and thus would have improved energy performance.

The cost of electricity generated or saved equals the annualized cost of the measure divided by the annual electricity generated or saved.

- For the alternative energy measures, the annualized cost equals the sum of the capital costs, the installation and interconnection costs divided by the measure lifetime, plus the annual fuel costs and the annual maintenance costs, all divided by MWh produced. For those alternative energy measures that would generate renewable energy credits (RECs) the annual cost is reduced by the estimated revenues from those RECs.[4]

- For the advanced energy efficiency measures, the annualized cost equals the up-front cost divided by the measure lifetime, plus any other costs associated with the operation of the measure, all divided by MWh saved.

Cost of Heat Generated or Saved

The cost of heat generated or saved represents the per-unit cost (in $/MMBtu) of either generating heat from an alternative energy measure or saving heat from an advanced energy efficiency measure. It can be compared to the per-unit cost (in $/MMBtu) of other forms of generating heat, in order to provide a general indication of how a measure compares with conventional sources of heat.

The cost of heat generated or saved equals the annualized cost of the measure divided by the annual heat generated or saved. The annualized costs of the measure are the same as those described above for the cost of electricity generated or saved.

For those alternative energy measures that generate both electricity and heat (cogeneration), the total costs were divided into electricity portions and heating portions, based on the Btu content of the output. Thus, for the cogeneration measures, the cost of electricity generated and the cost of heat generated should be considered together in order to provide an indication of the total cost of the measure.

Payback Period

The payback period represents the number of years required for the annual cost savings of a measure to equal the total up-front cost of the measure. The payback period is calculated from the perspective of the customer, and thus provides a rough indication of the value of the measure to a typical low-income customer in Massachusetts. The savings are based on the retail price of electricity or oil, as opposed to the avoided cost of electricity or oil.[5]

For all measures, the payback period is equal to the up-front cost divided by the annual savings.

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[4] A REC is the unit of credit represented by the production of one MegaWatt-hour (MWh) of electrical generation by a renewable energy system and consumed by an end-use customer in the state of Massachusetts.

[5] As indicated in Table 2.1, the retail cost of electricity (10.8 ¢/kWh) is higher than the avoided cost of electricity (roughly 5.0 ¢/kWh for energy plus roughly $54/kW for avoided capacity, transmission and distribution).

- For alternative energy measures, the up-front costs are equal to the capital cost plus the installation and interconnection cost. The annual savings are equal to the amount of electricity avoided times the average Massachusetts low-income customer electricity price, plus the amount of oil avoided times the average Massachusetts residential oil price, minus the cost of fuel required for generation, and minus any annual maintenance costs. For those alternative energy measures that would generate renewable energy credits (RECs), the annual savings are increased by the estimated revenues from those RECs.
- For the advanced energy efficiency measures, the up-front costs are equal to the measure cost plus the installation cost, where appropriate. (See the discussion below about analyses using incremental and total costs for the efficiency measures.) The annual savings are equal to the amount of electricity saved times the average Massachusetts low-income customer electricity price, plus the amount of oil saved times the average Massachusetts residential oil price, plus any water savings times the average Massachusetts water price, minus any other costs associated with the operation of the efficiency measure.

The payback period can be applied consistently across all alternative energy and energy efficiency measures. Thus, it provides a cost-effectiveness benchmark not only within these two categories, but also across them. However, there are two important caveats to note with regard to payback periods.

First, for some alternative energy measures, the payback periods are negative. This occurs when the annual costs of operating a measure (e.g., the fuel cost) are greater than the annual savings associated with the measure. In such cases, the measure will never pay for itself, and the negative payback period cannot be compared with the positive ones.

Second, most of the alternative energy measures have payback periods that are longer than their measure lifetime. This means that the measure will cost more than it will save during its useful lifetime, i.e., the measure is uneconomic from this perspective. In such cases, the payback periods may still be useful indicators for comparing the cost-effectiveness across different measures. However, in so doing it is important to take account of the measure life. In other words, if two measures have a payback period of 25 years, and the first measure has an estimated lifetime of 20 years, while the second measure has an estimated lifetime of 15 years, the first measure should be considered more cost-effective.

<u>Total Resource Costs</u>

The Massachusetts Department of Telecommunications and Energy (DTE) requires energy efficiency program administrators to use a total resource cost (TRC) test in evaluating the cost-effectiveness of energy efficiency programs. We have applied the DTE's TRC test for both the alternative energy and the advanced energy efficiency measures.

The TRC test is meant to represent the total direct cost to society of implementing a particular measure.[6] Thus, the benefits are estimated by using electricity and oil *avoided costs*, as opposed to electricity and oil *prices*. Both the costs and benefits are presented in terms of present value dollars, where the discount rate represents a relatively low-risk investment.

According to the TRC test, the cost of each measure includes the full cost of purchasing, installing and operating a measure – regardless of which party incurs the cost (e.g., a customer versus an efficiency program administrator). The benefit of each measure includes the total benefits, again regardless of the party that may enjoy the benefits. Thus, for electricity efficiency measures, the benefits include avoided electric energy costs, avoided capacity costs, and avoided transmission and distribution costs.

The Massachusetts DTE also requires the TRC test to account for non-energy benefits, including non-energy resource savings (e.g., oil, gas, water), customer benefits (e.g., reduced operation and maintenance costs, customer health and safety benefits), and non-energy utility benefits associated with low-income customers (e.g., reduced arrearages, utility savings on the low-income discount rate).

In our analyses of the energy efficiency measures, we have accounted for the benefits of water savings, wherever data were available. We have also accounted O&M benefits for the LED lighting measure.

Because the measures analyzed here are expected to be applied to low-income customers, we have applied a single, simple estimate of low-income benefits to all of the efficiency measures. We have scaled-up the total benefits from the efficiency measures by 50 percent to reflect the total low-income non-energy benefits associated with each measure. This value approximates the various methods in use by Massachusetts efficiency program administrators. While this is a very approximate underestimate of actual low-income non-energy benefits, it provides a useful indication of the amount of benefits that would be expected from these measures. Because we have accounted for these low-income non-energy benefits in the TRC results, these results cannot be applied directly to measures that would be provided to non-low-income customers.

We present the TRC results in two forms:

- Net Benefits. The TRC net benefits are equal to the cumulative present value of the benefits minus the cumulative present value of the costs. It provides an estimate of the total amount of money that would be saved by a measure over its operational life, in present value terms. If the net benefits are positive, then the measure is considered to be cost-effective.

- Benefit-Cost Ratio. The TRC benefit-cost ratio (BCR) is equal to the cumulative present value of the benefits divided by the cumulative present value of the costs. If the BCR is equal to or greater than one, the measure is considered to be cost-effective. This provides a very useful indicator for assessing cost-effectiveness

[6] We use the term total "direct" costs to society, because the DTE's TRC test does not include some important, and potentially significant, "indirect" costs, such as environmental costs or economic development costs.

across all efficiency measures. The BCR provides a better means of comparing cost-effectiveness across measures than the net benefits, because it normalizes the costs and the benefits for size – i.e., a large measure such as a refrigerator can be compared directly with a small measure such as a light bulb.

Incremental Costs versus Total Costs

It is important to distinguish between the incremental cost and the total cost of a new measure when assessing cost-effectiveness.[7] If a measure is being installed to replace a similar measure that has reached the end of its useful life, and will therefore be replaced irrespective of a program, then only the incremental cost is relevant. Here the incremental cost is the difference between the cost of the alternative energy or advanced energy efficiency measure and the cost of installing a new standard measure (i.e., conventional, less efficient) instead.

If a measure is instead being installed as a retrofit – i.e., to replace a functioning piece of equipment with remaining useful life – then the total cost is relevant. This is because the total cost represents the full cost that must be incurred in order to implement the measure and obtain the benefits. Here the total cost is equal to the total measure cost plus any additional cost for installation or interconnection.

We assumed that alternative energy measures would all be installed as "retrofit" measures. This is appropriate because most of the measures (e.g., photovoltaics, wind) would be installed in addition to existing energy measures. Thus, for all the alternative energy measures, the cost-effectiveness analyses are based on total costs.

For energy efficiency measures, we prepared two cost-effectiveness scenarios:

- Incremental costs. Here we included only the incremental cost of the efficiency measure relative to a new standard measure. In most cases, we did not include installation costs, under the assumption that the standard measure would require similar installation costs.
- Total costs. Here we included the total cost of the efficiency measure, plus the cost of installing the measure.

In practice, the costs and benefits of a particular retrofit measure will fall somewhere in between the two extremes of the incremental cost and the total cost scenarios. If an efficiency measure replaces an existing measure with very few years left in its operating life, then the costs and benefits will be closer to those of the incremental cost scenario. If an efficiency measure replaces an existing measure with many years left in its operating life, then the costs and benefits will be closer to those of the total cost scenario.

Low-income customers will frequently purchase a second-hand appliance to replace an existing one that has reached the end of its useful life. In this case, the cost-effectiveness will fall somewhere between the two extremes of our incremental cost case and the total cost case. The cost of the second-hand appliance will be less than the cost of purchasing

[7] In our analysis we treat the total versus incremental energy *savings* the same way that we treat the total versus incremental *costs*. In this discussion, we refer only to costs for simplicity.

a new measure, and thus the incremental cost of the efficiency measure will be higher than the cost in our incremental cost case but lower than the cost in our total cost case. The savings from replacing (or avoiding the purchase of) the second-hand appliance will probably be close to the savings we assume in our total cost case, i.e., the savings from an efficient measure relative to an older measure. Combined, the costs and benefits will most likely fall somewhere between our total cost and incremental cost cases.

Savings to Investment Ratio

The US Department of Energy uses a Savings to Investment Ratio (SIR) to assess the benefits and costs of efficiency measures and programs. The numerator in this ratio is the cumulative present value of the annual electricity benefits, plus the cumulative present value of the annual fossil fuel benefits, where the benefits are calculated by multiplying the relevant annual savings by the relevant avoided costs. The denominator in this ratio is the cost of the efficiency measure, including installation costs. If the SIR is equal to one or greater, then the savings are expected to exceed the investment, and the measure or program is considered to be cost-effective. SIRs are always based on the total cost of an efficiency measure (as opposed to the incremental cost).

Cost of CO_2 Reductions

One of the reasons for installing the alternative energy and energy efficiency measures is to achieve environmental benefits. We have estimated the amount of CO_2 emissions avoided by operating these measures, as one indicator of the potential environmental benefits.

We have also normalized these benefits and put them in economic terms by estimating, for each measure, the cost of reducing CO_2 emissions. This cost is equal to the annual net cost of the measure divided by the annual net CO_2 reductions expected from each measure.

For the alternative energy measures:

- The annual net cost of each measure is equal to the difference between the annualized costs minus the annual savings. The annualized costs equal the sum of the capital costs, the installation and interconnection costs divided by the measure lifetime, plus the annual fuel costs and the annual maintenance costs. The annual savings equal the amount of electricity and/or heat generated times the system avoided cost for the relevant fuel.
- The annual net CO_2 reduction is equal to the amount of CO_2 displaced minus any CO_2 emissions that might be generated. The amount of CO_2 displaced from electricity generation is based on the average CO_2 emissions from the New England Power Pool in recent years and the average CO_2 displaced from heat generation is based on the CO_2 content of oil. (It should be noted that CO_2 reduction is somewhat less where heat is provided by gas.) The amount of CO_2 emissions that might be generated are based on the emission rates presented in Table 4.1 below in the Microturbine section.

For the advanced energy efficiency measures:

- The annual net cost of each measure is equal to difference between the annualized costs minus the annual savings. The annualized cost equals the up-front cost divided by the measure lifetime, plus any other annual costs associated with the operation of the measure. The annual savings is equal to the electricity savings times the electric system avoided cost, plus the heat savings times the oil avoided costs.
- The annual net CO_2 reduction is equal the amount of CO_2 displaced by the efficiency measure. The amount of CO_2 displaced from electricity savings is based on the average CO_2 emissions from the New England Power Pool in recent years, and the average CO_2 displaced from heat savings is based on the CO_2 content of oil. CO_2 reduction is somewhat less where heat is provided by gas.

Cross-Cutting Assumptions

We also made several assumptions that were applied across several, or all, of the measures studied. These assumptions are described below.

Table 2.1 Cross-Cutting Assumptions

Assumption	Value	Notes and Source
Low-income electricity price	10.8 ¢/kWh	Weighted average across MA.
Residential oil price	\$7.4/MMBtu, on average over ten years	AESC Study Group 2003
Residential gas space heating price	\$8.0/MMBtu, on average over ten years	AESC Study Group 2003
Residential gas water heating price	\$7.4/MMBtu, on average over ten years	AESC Study Group 2003
Biodiesel price	\$15.4/MMBtu	Zapotec Energy. Assumes B100 at \$2.00 per gallon and 130 kBtu per gallon HHV
Residential water price	\$7.1/1000 gal	AESC Study Group 2003
Electric energy avoided costs	roughly \$50/MWh	AESC Study Group 2003
Electric capacity, plus transmission and distribution	roughly \$54/kW	AESC Study Group 2003
Oil avoided costs	\$7.4/MMBtu, on average over ten years	AESC Study Group 2003
System losses	9.4%	Average across MA, from DOER, based on Energy Efficiency Annual Reports.
Value of renewable energy credit	\$30/MWh	Rough estimate by authors of average price over the next 15 years.

All costs presented here and elsewhere in this study are in constant 2004 dollars.

As indicated, we relied upon the most recent New England avoided cost study (AESC Study Group 2003) for several key assumptions regarding prices and avoided costs. Oil and gas prices have already increased significantly relative to those forecast in this study, and electricity avoided costs are expected to be higher than those in this study due to rising costs of oil and natural gas.

Nonetheless, we have used the costs from this study because it is the most recent and comprehensive study of avoided costs in Massachusetts. It also allows us to use electricity and oil price forecasts that are based on consistent assumptions. To the extent that oil and gas prices continue to increase, and to the extent that the assumptions presented above turn out to be too low, our analyses will understate some of the benefits of the alternative energy and energy efficiency measures.

Caveats about the Assumptions and Results

In order to consistently compare many different types of alternative energy and advanced energy efficiency measures, we have made many simplifying assumptions. In so doing, we have not indicated the full range of potential costs and benefits of these measures, and our results might not apply to many different, site-specific applications.

Therefore, our results should be used for preliminary assessment purposes, but should not be used for definitive inclusion or exclusion of measures without further research. In particular, more site-specific assessments should be conducted to better estimate the costs and benefits that these measures would have in specific applications.

There are several particular caveats worth noting here. First, for many measures, especially the alternative energy measures, there is a range of sizes and costs that might be applicable to housing units in Massachusetts. We have chosen those sizes and costs that we expect to be representative for low-income housing units in Massachusetts. Actual sizes and costs might vary considerably, and result in different costs and benefits.

Second, we used assumptions that represent a "typical housing unit" for low-income customer in Massachusetts. While our assumptions appear to be a good representation of typical low-income housing units, there will be many housing units that will differ significantly from these assumptions. The costs and benefits will differ significantly as well.

Third, as described above, we assumed that the typical housing unit would be using oil for space heating and for water heating. Housing units that use different fuels for space and water heating may experience significantly different costs and benefits than those presented here.

Fourth, in many cases, we relied upon cost and savings data from the manufacturers of the measures, especially for the efficiency measures. With emerging technologies it is often necessary to rely upon manufacturers because there are few other sources available. These costs and savings data may be optimistic, due to biases of the manufacturers. They also might not represent the costs and savings of the same product offered by other manufacturers.

In sum, the results here should be seen as a preliminary assessment, and additional, more site-specific analysis should be performed before adopting or rejecting measures.

3. Overview and Comparison of Technologies

3.1 Alternative Energy Technologies

Table 3.1 presents a summary of the cost-effectiveness indicators for the alternative energy measures. [8] In most cases the net benefits of the alternative energy measures are less than the net costs. In other words, most of these measures are uneconomic relative to conventional electricity and heat generation sources. However, the analysis here does not account for some important benefits – such as environmental benefits, power quality, and fuel diversity – that make some of these measures more attractive. .[9]

The micro wind and small wind stand out as the most cost-effective technologies considered here, assuming that sufficient wind is available at the customer's site. The micro Stirling engine and the microturbine are also relatively economic. The wood hybrid furnace/boiler is very economic if the wood fuel is available for free or at low cost, but becomes much less economic when fuel is priced at the cost of firewood.

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Technology	End-Use	Cost of Electricity Generated ($/MWh)	Cost of Heat Generated ($/mmBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)
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Internal Combustion (biodiesel)	electricity & heat	56	25	-40	-436,555	0.66
Micro Stirling Engine (gas)	electricity & heat	77	0.7	15	-4,549	0.77
Fuel Cell PEM (gas)	electricity & heat	91	5.3	55	-53,246	0.63
Fuel Cell SO (gas)	electricity & heat	202	14	113	-389,273	0.32
PV: inclined roof (efficient)	electricity	257	---	65	-18,041	0.41
PV: inclined roof (less efficient)	electricity	284	---	78	-16,436	0.41
PV: flat roof	electricity	361	---	111	-19,489	0.34
PV: ground mounted	electricity	279	---	74	-17,427	0.40
PV: building integrated	electricity	615	---	224	-33,046	0.22
Wind Micro (0-3 kW)	electricity	59	---	12	567	1.16
Wind Small (3-60 kW)	electricity	59	---	14	6,506	1.13
Micro Hydro	electricity	95	---	35	-7,684	0.59
Wood hybrid furnace/boiler	space heating	---	14	-9	-6,335	0.81
Wood hybrid (free wood)	space heating	---	3.3	6	18,249	3.24

Except for TRC net benefits and the TRC benefit-cost ratio, all costs are in constant 2004 dollars.

8 Note that payback period uses price to calculate economic benefits, and the TRC test uses avoided costs. In addition, the payback period uses constant dollars, while the TRC tests use present value dollars. Also the TRC tests include low-income non-energy benefits. Thus, two measures can have the same BCR but different payback periods.

9 Also note that we chose a single "typical size" for each technology to study here. The cost-effectiveness results will vary for different sizes of technologies.

Among the PV measures, the efficient inclined roof stands out as the most economic option. As expected, the building integrated PV systems are very expensive, and would only make sense in niche applications.

Figure 3.1 presents the payback periods for the alternative energy measures. The figure does not include information for the measures with negative payback periods (the biodiesel microturbine, and the wood hybrid furnace/boiler), because these measures will never pay for themselves. The figure also presents the measure life to indicate whether, and the extent to which, the payback period exceeds the measure life.

Figure 3.1 Payback Periods for the Alternative Energy Measures

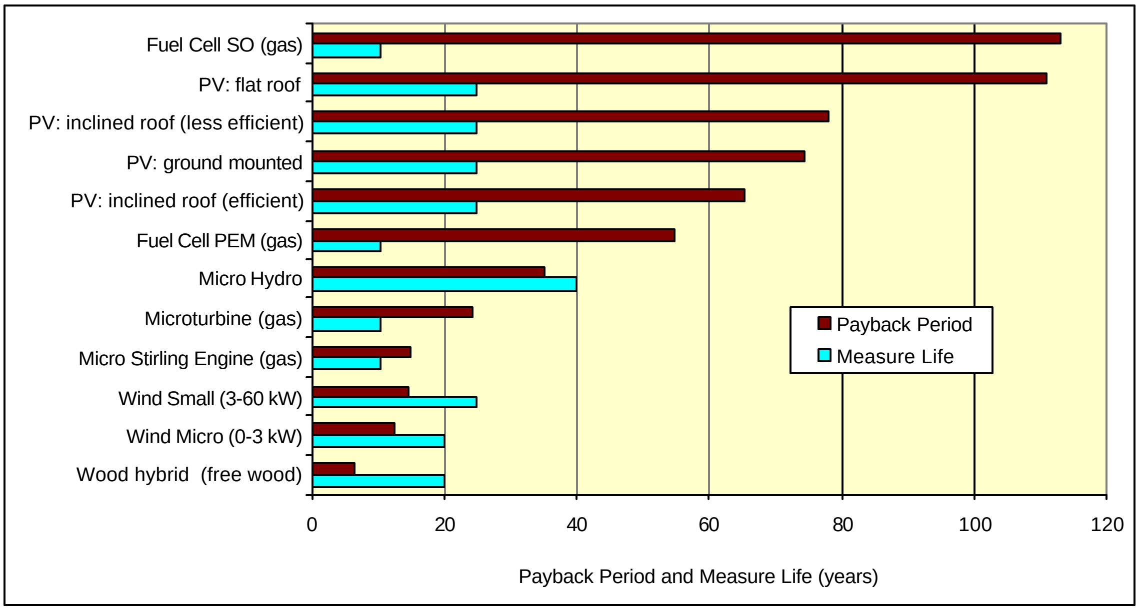
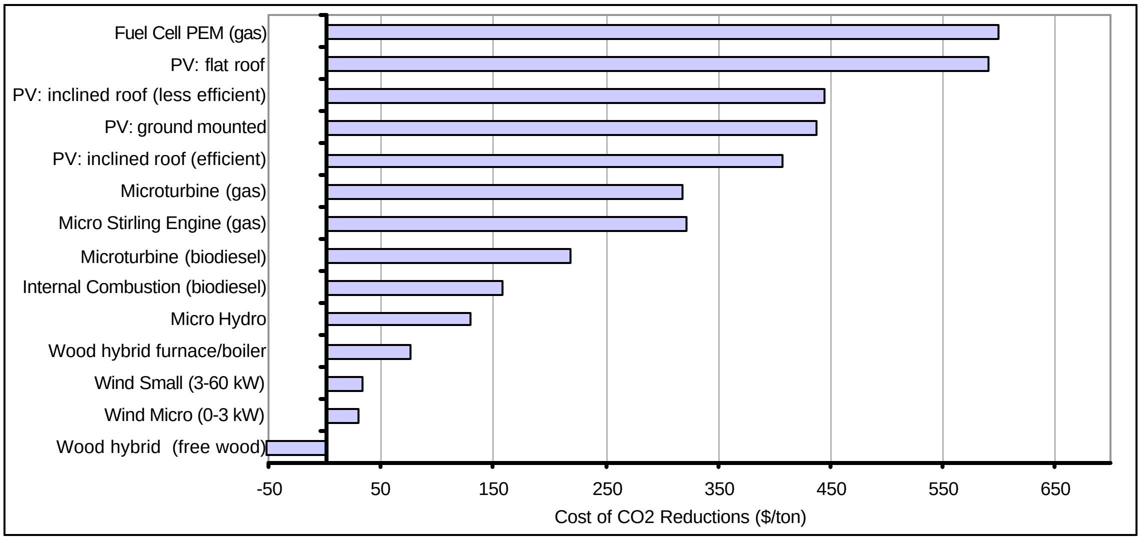


Figure 3.2 presents the cost of CO_2 reductions from the alternative energy measures. It does not include the information for the two measures with the highest costs – building integrated PV and SO fuel cells – because these costs were too high for the scale of this figure.[10]

Note that, with the exception of the wind and wood technologies, these alternative energy measures represent a relatively expensive option for reducing CO_2 emissions. The efficiency measures studied here (presented below) – not to mention the more conventional efficiency measures – generally offer a much lower-cost means of reducing CO_2 emissions.

[10] The wood hybrid furnace (with free wood) has a negative cost of CO_2 reductions, because this measure is so cost-effective that it results in a net reduction in costs from this perspective. A similar effect occurs with the most cost-effective energy efficiency measures.

Figure 3.2 Cost of CO_2 Reductions from the Alternative Energy Measures



3.2 Advanced Energy Efficiency Technologies

The tables below present a summary of the cost-effectiveness indicators for the advanced energy efficiency measures.[11] Table 3.2 presents the cost-effectiveness results using incremental costs, and Table 3.3 presents the cost-effectiveness results using total costs. Table 3.3 also includes the results for the Savings to Investment Ratios based on the U.S. Department of Energy's (US DOE's) definition of cost effectiveness.

Figure 3.3 presents the benefit-cost ratios for most of the advanced energy efficiency measures, including both the results using the incremental costs and the results using the total costs. The results using the incremental costs are indicated by the top mark, and the results for the total costs are indicated by the bottom mark.

Note that Figure 3.3 does not include the results for laminar flow fixtures, as these would have required too large a scale. Also note that for the four measures to the right we set the incremental cost BCR result to 6.0, so that we could maintain a useful scale. These measures actually have much higher incremental cost BCRs than indicated here.

As noted above in Section 2, the actual results for a retrofit measure is likely to fall somewhere in between these two extremes. If an efficiency measure replaces an existing measure with very few years left in its operating life, then the costs and benefits will be closer to those of the incremental cost scenario. If an efficiency measure replaces an existing measure with many years left in its operating life, then the costs and benefits will be closer to those of the total cost scenario.

[11] Solar Hot Water and Trombe Wall are included in the efficiency section (as opposed to in the generation section), because they are considered here as primarily measures to reduce the use of existing hot water and heating systems.

Table 3.2 Cost Effectiveness of the Efficiency Measures – Incremental Costs

Measure	End-Use Type	Cost of Electricity Saved ($/MWh)	Cost of Heat Saved ($/MMBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)
[A]	[B]	[O]	[P]	[Q]	[R]	[S]
Occupancy sensors	Lighting	128	---	12	4	1.1
White Light Emitting Diodes	Lighting	86	---	9.8	38	1.7
ENERGY STAR Clothes Washers	Appliance	595	22	4.2	1,064	4.6
High-Eff. Refrig. (vs. existing)	Appliance	30	---	5.3	730	2.4
High-Eff. Refrig.(vs. new)	Appliance	25	---	4.3	136	3.0
Drainwater heat recovery	Water heating	---	3.4	9.2	1,100	3.0
Hot water recirculation systems	Water heating	---	12.5	17.6	299	1.6
Laminar flow aerators	Water heating	---	5.6	1.0	393	14
Solar Hot Water (flat plate)	Water heating	---	9.1	25	629	1.1
Solar Hot Water (evacuated tube)	Water heating	---	14.5	39	-2,227	0.7
Water heater: condensing	Water heating	---	31	25	-126	0.9
Water heater: instantaneous	Water heating	---	23	6.4	2,438	3.2
Water heater: indirect	Water heating	---	9.9	2.4	4,043	19.5
Advanced HVAC fan motors	Heating distribution	45	---	2.1	388	2.2
Duct sealing: aerosol	Heating distribution	---	2.1	7.1	3,180	4.8
High efficiency bathroom fans	Heating distribution	20	---	6	134	4.4
Heat Pump: ground-coupled	Heating supply	---	9.5	23	355	1.1
Heat Pump: advanced cold-climate	Heating supply	---	3.9	10	1,505	2.7
High-efficiency gas boilers	Heating supply	---	33	1.5	3,269	18.7
Trombe Wall	Heating supply	---	37	125	-23,504	0.3
Wireless thermostats	Heating supply	---	2.1	4.2	1,661	5.0
Ceramic insulating paint	Building envelope	---	3.1	4.2	318	3.4
Cellulose insulation (vs. no insul.)	Building envelope	---	1.8	4.8	6,223	5.8
Cellulose insulation (vs. fiberglass)	Building envelope	---	1.8	4.9	2,007	5.7
High perf. Windows (vs. existing)	Building envelope	---	10.4	49	-35	0.9
High perf. windows (vs. new)	Building envelope	---	2.7	13	194	3.6

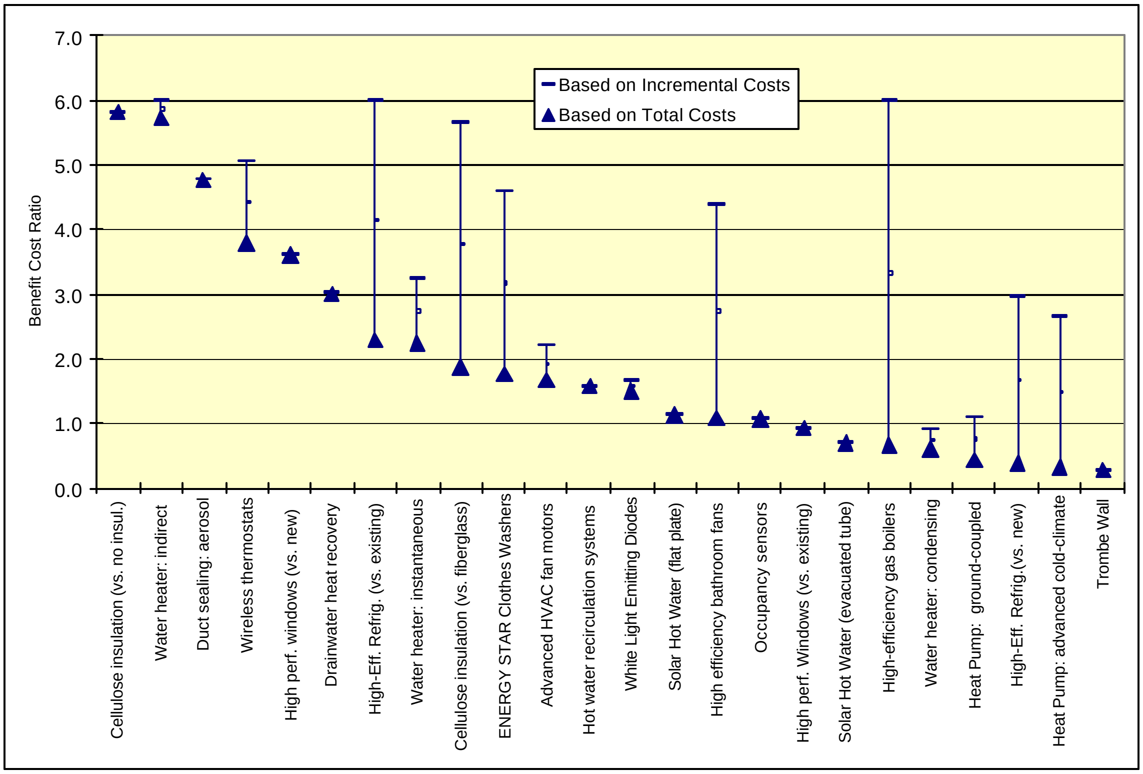
Except for TRC net benefits and the TRC benefit-cost ratio, all costs are in constant 2004 dollars.

Table 3.3 Cost Effectiveness of the Efficiency Measures –Total Costs

Measure	End-Use Type	Cost of Electricity Saved ($/MWh)	Cost of Heat Saved ($/MMBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)	Savings to Investment Ratio (DOE)
[A]	[B]	[O]	[P]	[Q]	[R]	[S]	[T]
Occupancy sensors	Lighting	128	---	12	4	1.1	0.8
White Light Emitting Diodes	Lighting	95	---	11	32	1.5	1.1
ENERGY STAR Clothes Washers	Appliance	1,538	44	11	594	1.8	0.3
High-Eff. Refrig. (vs. existing)	Appliance	32	---	5.6	705	2.3	3.1
High-Eff. Refrig.(vs. new)	Appliance	184	---	32	-310	0.4	0.5
Drainwater heat recovery	Water heating	---	3.4	9.2	1,100	3.0	2.0
Hot water recirculation systems	Water heating	---	12.5	17.6	299	1.6	0.6
Laminar flow aerators	Water heating	---	6.5	1.2	388	12.2	1.1
Solar Hot Water (flat plate)	Water heating	---	9.1	25	629	1.1	0.7
Solar Hot Water (evacuated tube)	Water heating	---	15	39	-2,227	0.7	0.5
Water heater: condensing	Water heating	---	37	40	-820	0.6	0.4
Water heater: instantaneous	Water heating	---	26	11	1,962	2.3	1.0
Water heater: indirect	Water heating	---	11	8	3,517	5.7	3.8
Advanced HVAC fan motors	Heating distribution	58	---	4.8	289	1.7	4.3
Duct sealing: aerosol	Heating distribution	---	2.1	7	3,180	4.8	3.2
High efficiency bathroom fans	Heating distribution	79	---	24	15	1.1	1.2
Heat Pump: ground-coupled	Heating supply	---	24	58	-5,971	0.4	0.3
Heat Pump: advanced cold-climate	Heating supply	---	31	83	-4,820	0.3	0.2
High-efficiency gas boilers	Heating supply	---	47	41	-1,688	0.7	0.4
Trombe Wall	Heating supply	---	37	125	-23,504	0.3	0.2
Wireless thermostats	Heating supply	---	2.7	6	1,528	3.8	3.3
Ceramic insulating paint	Building envelope	---	151	205	-5,928	0.1	0.0
Cellulose insulation (vs. no insul.)	Building envelope	---	1.8	5	6,223	5.8	3.8
Cellulose insulation (vs. fiberglass)	Building envelope	---	5.4	15	1,144	1.9	1.2
High perf. Windows (vs. existing)	Building envelope	---	10	49	-35	0.9	0.6
High perf. windows (vs. new)	Building envelope	---	2.7	13	194	3.6	2.4

Except for TRC net benefits and the TRC benefit-cost ratio, all costs are in constant 2004 dollars.

Figure 3.3 Bene fit-Cost Ratios for the Efficiency Measures – Incremental and Total Costs



Note that many of the efficiency measures are cost effective (i.e., with a BCR equal to or greater than one) under both scenarios. Several measures have a large range that includes both cost effective and non-cost effective results. This is particularly true for the measures with large up-front and installation costs, such as the heat pumps and water heaters. Thus, it is important that the appropriate costs (incremental versus total) are considered when these measures are evaluated for site-specific applications.

Figure 3.4 presents the payback periods for the advanced energy efficiency measures. It does not include the payback period for the Trombe Wall, because it is too long for the scale of this figure. Again, note that some measures have longer operating lives than others, and thus payback periods may not be directly comparable.

The results presented in Figure 3.4 are based on the total cost scenario. The payback periods are significantly shorter under the incremental cost scenario, as indicated in Tables 3.2 and 3.3.

Figure 3.5 presents the cost of CO_2 reductions from the advanced energy efficiency measures. It does not include the information for the Trombe Wall because this cost was too high for the scale of this figure.

The results presented in Figure 3.5 are based on the total cost scenario. The CO_2 reduction costs are significantly lower under the incremental cost scenario.

Figure 3.4 Payback Periods for the Advanced Energy Efficiency Measures

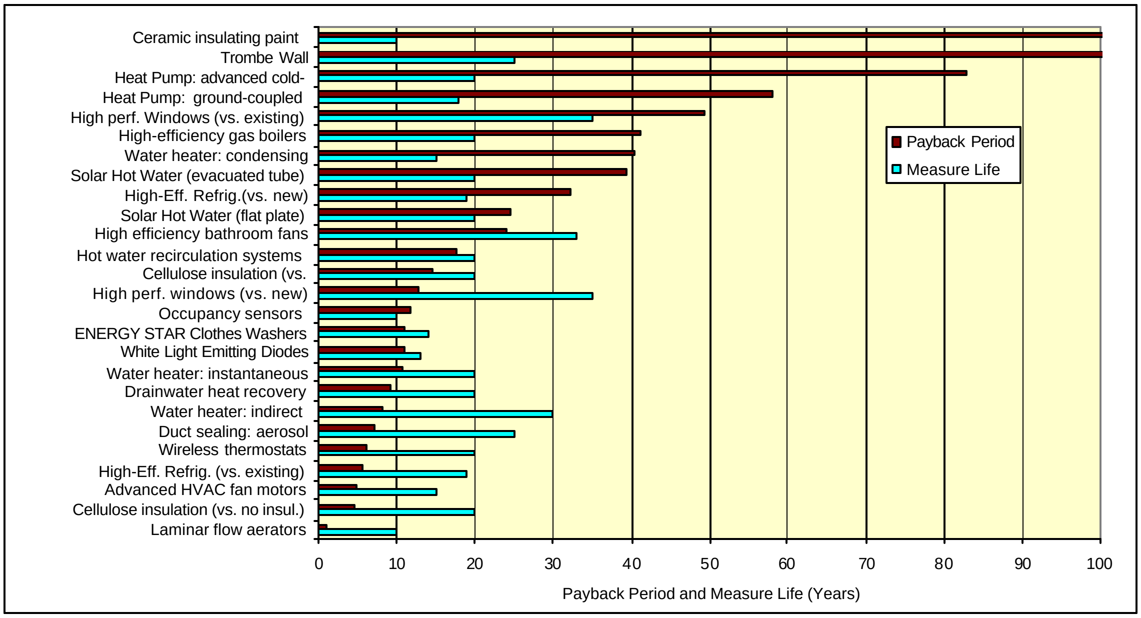
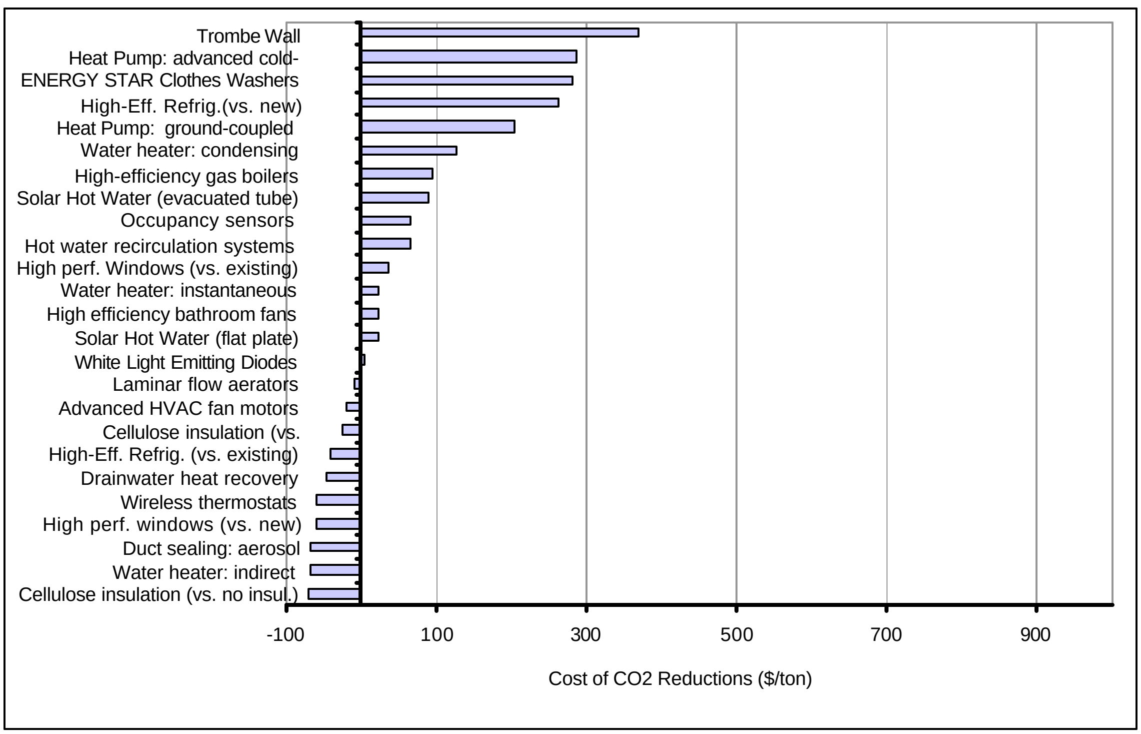


Figure 3.5 Cost of CO_2 Reductions from the Advanced Energy Efficiency Measures



Note that several of the efficiency measures can reduce CO_2 emissions for a negative net cost. This is because these measures result in a net savings in total resource costs, i.e., the economic cost of the measures are more than offset by the economic savings. Such measures are often described as "no regrets" options for addressing environmental problems because they make sense regardless of the environmental benefits. Under the incremental cost scenario, many more of the efficiency measures have a negative net cost of reducing CO_2 emissions.

4. Alternative Energy Measures

4.1 Microturbine: Natural Gas and Biodiesel

Microturbines are efficient, reliable, clean, small gas turbines that can operate on a variety of gaseous and liquid fuels, including but not limited to distillate oil, liquefied petroleum gas, sour gas, and biogas. The size of microturbines ranges from 30 to 400 kW, while the size of conventional gas turbines ranges from 500 kW to 300 MW. For this report, we focused on the lower end of the size range, from 30 to 100 kW, given the applicability to low-income residents and the availability of data. Like fuel cells, microturbines can operate as combined heat and power (CHP) generators. Recovered heat can produce domestic hot water, heat building space, and drive absorption cooling or desiccant dehumidification equipment. Currently equipment life is at or slightly over 10 years.

For our analysis, we examined two types of microturbines: one using natural gas and the other using biodiesel. Installed costs do not differ between the two selected applications. Total installed costs of microturbines are significantly lower than fuel cells and can be competitive with reciprocating engines (See Table below). Microturbine units tend to include heat recovery equipment. In this case, the capital costs are the same between power-only and CHP applications. Otherwise, heat recovery equipment would cost $100 per kW (GRI and NREL 2004). Installation cost for CHP application requires roughly an additional $220 per kW (GRI and NREL 2004).

The major differences among biodiesel and natural gas-based applications are fuel costs and emission rates. We assume residential natural gas price at $9.50 per MMBtu and biodiesel at $15.38 per MMBtu. The price of biodiesel is derived from its heating value of 130,000 Btu per gallon and its price of $2.00 per gallon.

Emissions from microturbines are significantly lower when compared to other combustion-type distributed generators and central power generation (See Emissions Table below). NOx and SO2 emission rates from biodiesel-based microturbines are almost the same as the rates from natural gas-based microturbines (MEIDEN 2003). CO_2 emission from biodiesel is 330 pounds per MWh, which represents the lifecycle emission rates of biodiesel use including carbon recycling by growing plants (EPA 2002 and Barrett Consulting Associates 2004). This emission rate is a significant decrease from the CO_2 emission of 1500 to 1750 pounds per MWh for the natural gas application.

Operating Characteristics	**Natural Gas & Biodiesel**
Typical Size (kW)	30
Lifetime (years)	10
Electric Capacity Factor (%)	90%
Electricity Generation (KWh)	236,520
Heating Efficiency (%)	44%
Heat Generation (MMBtu)	1466

Installation and Operating Costs	Natural Gas	Biodiesel
Capital Costs ($/kW)	1,560	1,560
Installation and Interconnection Costs ($)	30,100	30,100
Maintenance Costs ($/year)	4,730	4,730
Fuel Price ($/MWh)	8.0	15.4
Fuel Use (MWh/year)	3,565	3,565

Cost-Effectiveness:	Natural Gas	Biodiesel
Cost of Generated Electricity ($/MWh)	61	71
Cost of Generated Heat ($/MMBtu)	18	29
Payback Period (years)	24	never pays back
TRC Benefit-Cost Ratio	0.86	0.52

Table 4.1 Emission Rates from Relevant Generation Technologies

Emissions	NOx (lb/MWh)	SO_2 (lb/MWh)	CO_2 (lb/MWh)
PEM	0.06-0.1	negligible	1170-1360
SOFC	0.05	negligible	910
MT natural gas	0.45-1.25	negligible	1500-1750
MT biodiesel	1.2	negligible	330
Gas-Fired Lean Burn IC Engine	2.2	negligible	1108
Biodiesel	29	negligible	330
Diesel Engine	26	3	1500
Wood Steam Plant	1.5	0.3	0
Diesel Engine	4.7-21.8	0.45	1432
Coal Power	5.6	13.4	2115
Average Fossil Power	5.1	11.6	2031

Microturbine systems are a mature technology that became commercially available in 1999-2000. There are several microturbine manufactures including Bowman Power Limited, Capstone Turbines, Inc., Elliott Energy Systems, Ingersoll Rand Energy Systems, and Turbec Inc.

Given the available smallest size of 30 kW, microturbines are suitable for multi-family buildings, clusters of homes, or apartment complexes. Also, in order to take advantage of the efficiencies of combined heat and power, the residential facility must have sufficient opportunities for using the generated heat.

4.2 Internal Combustion: Biodiesel

The biodiesel cogeneration technology consists of a stationery internal-combustion diesel engine with heat recovery equipment driving a 45-kW electrical generator. Since the 100% biodiesel fuel (B100) is produced from vegetable oil, the electricity produced (374,490 kWh/yr at 95% capacity factor) is classified as a renewable source. The best application for this technology in a residential setting is multifamily housing with 30 or more units where all the electricity and recovered heat is utilized on-site. The reason for this is that with 30 units or more, both the electrical and thermal output of the engine would be fully utilized, giving the greatest overall economical advantage. (Zapotec).

The engine-generator set is commercially available from numerous vendors in New England at approximately $2,200/kW installed. The diesel engine requires no modification to run biodiesel. Stationary diesel engines typically need to be replaced after approximately 40,000 hours of operation or approximately 5 years of continuous running. The units are built to do just this. The maintenance cost is 2 to 3 cents per kWh produced.[12] The single most important factor for the viability of biodiesel cogeneration is the cost of biodiesel. An increasing number of suppliers in Massachusetts should lead to competitive pricing. (Zapotec).

The engine replacement cost is figured into the maintenance cost of 3 cents per kWh produced, or $11, 200 per year, which is an average cost over 20 years for equipment maintenance and periodic engine replacement.

Operating Characteristics	
Typical Size (kW)	45
Lifetime (years)	20
Electric Capacity Factor (%)	95%
Electricity Generation (KWh)	374,490
Heating Efficiency (%)	40%
Heat Generation (MMBtu)	1503

Installation and Operating Costs	
Capital Costs ($/kW)	1,300
Installation and Interconnection Costs ($)	39,600
Maintenance Costs ($/year)	7,490
Fuel Price ($/MWh)	15.4
Fuel Use (MWh/year)	3,760

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	56
Cost of Generated Heat ($/MMBtu)	25
Payback Period (years)	never pays back
TRC Benefit-Cost Ratio	0.66

Because of the large size, biodiesel is suitable for multi-family buildings, clusters of homes, or apartment complexes. Also, in order to take advantage of the efficiencies of

12 The engine replacement cost is included in this maintenance cost of 3 cents per kWh produced, or $11,200 per year, which is an average cost over 20 years for equipment maintenance and periodic engine replacement.

combined heat and power, the residential facility must have sufficient opportunities for using the generated heat.

There are no special considerations for low-income applications. Fuel must be stored indoors (i.e., above 45 degrees F year-round), and cogeneration equipment must also be indoors.

4.3 Micro Stirling Engine: Gas

A Stirling engine, invented in 1816 by a Scottish minister, Robert Stirling, is a heat engine that alternately compresses and expands a working gas to operate a piston. Stirling engines run on an external heat source, which simplifies design, minimizes noise and vibration. This feature also allows the engines to run on any type of fuel including solar energy and heat from hot spring water.

There are two types of Stirling engines: kinematic engines and free-piston engines. Kinematic Stirling engines use a rotating power shaft to move pistons. Their size is typically larger than free-piston engines (5-500 kW). Free-piston engines have few moving parts because they use oscillating pistons that are supported by mechanical springs and gas bearings, resulting in low maintenance costs, and a longer life. In addition, the engines can operate for a long time (more than 50,000 hours) without maintenance. Their size ranges from 0.01 to 25 kW. (Dunn 2000; ACEEE 2004a)

There are three companies that makes Stirling engine in the U.S.

- STM Power sells 55kW CHP unit with its Stirling engine that can run on methane, natural gas and propane. In New England area, Northern Power is selling the CHP units. STM Power is also selling or will soon sell units that can run on liquid fuel, such as vegetable oil and palm oil. (STM Power)
- Sunpower currently sells the prototype 1kW free-piston engine for testing purposes. The engine costs from $50,000 to $60,000. However, the engine at the manufacturing stage (~100,000 units/year) is estimated to cost around $1000 within the next five years. (Sunpower) This engine does not include CHP capabilities.
- Infini Corporation located in Washington already has plans to sell 1kW Stirling at $1,000 next year in European and Asian countries. The company is now searching for partners in the U.S. (Infini Corporation) This engine does not include CHP capabilities.

The cost of heating equipment for the CHP application is very uncertain. Manufacturers provide estimates in the range of $4000 to $6000. These costs do not tend to scale with the size of the engine.

For our analysis, we assume a 2 kW Stirling engine with CHP application will cost $6,000. This includes $2000 (i.e., $1000/kW) for the Stirling engine, plus $4000 for the CHP component.

The electrical efficiency of Stirling engines ranges from 15% to 30%, with many reporting a range of 25% to 30% (ACEEE 2004a). Among the range we chose 25% for our analysis. As mentioned above, Stirling engines can use various types of fuels. For our analysis, we assume Stirling engines use natural gas.

Operating Characteristics	
Typical Size (kW)	2
Lifetime (years)	10
Electric Capacity Factor (%)	76%
Electricity Generation (KWh)	13,288
Heating Efficiency (%)	40%
Heat Generation (MMBtu)	46

Installation and Operating Costs	
Capital Costs ($/kW)	2,500
Installation and Interconnection Costs ($)	2,700
Maintenance Costs ($/year)	266
Fuel Price ($/MWh)	8.0
Fuel Use (MWh/year)	116

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	73
Cost of Generated Heat ($/MMBtu)	0.7
Payback Period (years)	13
TRC Benefit-Cost Ratio	0.81

Given the relatively small capacities of this measure, it could apply to both single family and multi family housing units.

4.4 Fuel Cell: PEM (Gas)

Fuel cells are more efficient, reliable, cleaner and quieter technologies than other distributed generation systems, and use various types of technologies. Among them, proton exchange membrane (PEM) fuel cell is predicted to become the dominant fuel cell technology for residential and small commercial use for its small size and low temperature heat recovery (ACEEE 2004b). The size ranges from 1 kW to 250 kW. The operating temperature is low, around 150^{o}F/93^{o}C, which limits the range of potential CHP applications, but can provide domestic hot water (heating output is 0.04 MMBtu/hour). However, PEM fuel cells have relatively fast-start up times, while solid oxide fuel cells (SOFC) have long start-up times. Two disadvantages over SOFC are that PEM requires a reformer to produce power and heat from any fuels other than hydrogen and that PEM have lower electric efficiencies (30 to 40%). We assume the technology uses natural gas, but it can use various fuels including, but not limited to liquefied petroleum gas (LPG), sour gas, and biogas (GRI and NREL 2003). Currently equipment life is approximately 10 years. Emissions from fuel cells are significantly lower when compared to other combustion type distributed generators and central power generation (see Emissions Table in Microturbine Section).

Operating Characteristics	
Typical Size (kW)	10
Lifetime (years)	10
Electric Capacity Factor (%)	85%
Electricity Generation (MWh)	74,460
Heating Efficiency (%)	39%
Heat Generation (MMBtu)	298

Installation and Operating Costs	
Capital Costs ($/kW)	4,950
Installation and Interconnection Costs ($)	5,600
Maintenance Costs ($/year)	2,475
Fuel Price ($/MWh)	8.0
Fuel Use (MWh/year)	847

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	91
Cost of Generated Heat ($/MMBtu)	5.3
Payback Period (years)	55
TRC Benefit-Cost Ratio	0.63

This technology is at the demonstration stage. GE Fuel Cell Systems is the leading manufacturer of this technology in the U.S. Other manufacturers include Plug Power, Ballard Power Systems, and Nuvera Fuel Cell. Nuvera Fuel Cell is an international fuel cell developer with offices located in Cambridge, Massachusetts and Milan, Italy. The company recently announced the first sales of its 5 kW fuel cell at the 2005 Hanover Fair in Germany.(Nuvera Fuel Cell website).

Total installed costs are quite high, but are predicted to decline dramatically for the next 25 years down to $1300 per kW in 2030 for a micro size PEM application. (GRI and NREL 2003) As the prices decline over time, PEM technology will be more available in Massachusetts.

PEM with a wide range of capacity is applicable to single family, multi-family, clusters of homes, and apartment complexes.

Fuel cells in general require periodic replacement of parts and materials such as air and fuel filters, reformer igniter or spark plug, water treatment beds, and sulfur adsorbent bed catalysts. Fuel cells also need major overhauls such as shift catalyst replacement (3 to 5 years), reformer catalyst replacement (5 years), and stack replacement (4 to 8 years). Basic maintenance can be performed by in-house personnel, or can be contracted out to manufacturers. (Energy Nexus Group 2002)

4.5 Fuel Cell: SOFC (Gas)

The solid oxide fuel cell (SOFC) is not as far along as other fuel cell development, such as the proton exchange membrane (PEM) or phosphorous acid fuel cell (PAFC). However SOFC attracts various stakeholders' attention because it is one of the most promising technologies for stationary (including residential) and mobile applications. One notable example is a U.S. D.O.E. program called the Solid State Energy Conversion Alliance (SECA). This program is a collaborative effort where national laboratories, manufacturers, universities and other research organizations participate, and which aims to develop a wide range of SOFC applications at a significantly lower cost (at no more than $400 per kW) (GRI and NREL 2003; SECA web).

SOFC uses a solid, ceramic electrolyte, which makes it a reliable and stable technology. The size ranges from 1 kW to 250 kW while a smaller scale SOFC faces some technical challenges at this early development stage (Kyocera website). The operating temperature is highest among all types of fuel cells (1400^{o}F to 1750^{o}F) (GRI and NREL 2003; Kyocera website). This allows SOFC to produce high quality heat, which is suitable for facilities with high heating loads such as industrial manufacturers (ACEEE 2004b).

High operating temperature requires the technology much longer start-up time than other types of fuel cells. However, there are also advantages: first, high temperature allows SOFC to utilize hydrogen and carbon monoxide (which damages PEM); second, the high temperature eliminates the use of an external fuel reformer, resulting in cost savings (Fuel Cell Energy). Manufacturers are examining methods to reduce operating temperatures while allowing SOFC to reform gaseous fuels inside of the system. According to a manufacture, lower temperature allows the technology to use inexpensive metals for wiring and pipes (Acumentrics).

Electrical efficiency of SOFC is very high and can reach from 45% to 60%. We assume the technology uses natural gas, but as with PEM, SOFC can use various kinds of fuels including, but not limited to liquefied petroleum gas (LPG), sour gas, and biogas. SOFC also can operate with or without heat recovery. As noted in the PEM section, emissions from SOFC are very low as compared to other fossil fuel based distributed generators and central power generation (see Emissions Table in Microturbine Section).

Operating Characteristics	
Typical Size (kW)	25
Lifetime (years)	10
Electric Capacity Factor (%)	85%
Electricity Generation (KWh)	186,150
Heating Efficiency (%)	25%
Heat Generation (MMBtu)	354

Installation and Operating Costs	
Capital Costs ($/kW)	15,000
Installation and Interconnection Costs ($)	16,350
Maintenance Costs ($/year)	8,000
Fuel Price ($/MWh)	8.0
Fuel Use (MWh/year)	1,411

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	202
Cost of Generated Heat ($/MMBtu)	14
Payback Period (years)	113
TRC Benefit-Cost Ratio	0.32

Given the wide range of capacity (1 kW to 250 kW) that is predicted to be available in the near future, SOFC may be appropriate for single family and multi-family housing. This technology is currently in demonstration and R&D stages. There are two manufacturers based in Massachusetts that are actively developing SOFC technology. ZTEK, based in Woburn, MA, has demonstrated a 25 kW SOFC at the Tennessee Valley Authority's facility in Huntsville, AL, and also plans to demonstrate a 25 kW SOFC at Dinosaur State Park in Rocky Hill, CT, starting in mid-2005. Acumentrics, based in Westwood, Massachusetts, has developed small scale SOFC, 2 kW, 5 kW, and 10 kW. Last year the company sent a 5 kW SOFC system to NREL to test it with various biogas fuels (Fuel Cell Works web).

Fuel cells in general require periodic replacement of parts and materials such as air and fuel filters, reformer igniters or spark plugs, water treatment beds, and sulfur adsorbent bed catalysts. Fuel cells also need major overhauls such as shift catalyst replacement (3 to 5 years), reformer catalyst replacement (5 years) (not applicable for SOFC), and stack replacement (4 to 8 years). Basic maintenance can be performed by in-house personnel, or can be contracted out to manufacturers. (Energy Nexus Group 2002)

4.6 Photovoltaics

We examined five different solar photovoltaic (PV) technologies and installation modes: typical inclined roof mounted panels, advanced inclined roof mounted, panels mounted on a flat roof, ground-mounted panels, and building integrated PV. The assumptions below were developed by Zapotec Energy.[13]

Advanced panels/inclined roof: The data in this category reflect the use of the most efficient PV panels commercially available today, which convert sunlight to electricity in

[13] All costs are expressed in terms of the rated DC wattage of the PV system, which is the sum of the individual module power ratings at standard test conditions (STC) when the product is shipped by the manufacturer. The AC output of PV is inconsistent across different systems of equal DC capacity, so AC capacity is rarely quoted. The AC output of a PV system is usually 80 to 90 percent of the DC output.

the 14 to 15 percent efficiency range. The capacity factor of these installations is governed by the panel efficiency and the roof angle and aspect. We assume that these factors combine to produce an average capacity factor of 18% across a number of installations. Capital costs of advanced panels are in the range of $6.50 per Watt, and installation costs for roof-mounted systems are roughly $3.00 per Watt.

Typical panels/inclined roof: Here we assume typical silicon PV panels mounted flush on an inclined roof, with a module conversion efficiency of 10 to 11 percent. We assume a capacity factor for these systems of 15%. Capital costs for typical panels are in the range of $5.50 per Watt, and installation costs are $3.00 per Watt.

Typical panels/flat roof: Panels mounted on a flat roof are less efficient than panels on an inclined roof, because they can only be mounted at a 5% angle from horizontal due to the risk of excessive wind loading on the panels. We assume an average capacity factor of 14% from this less-than-optimal inclination. In addition, these installations require specialized hardware, adding capital costs relative to an inclined roof installation. The unit capital cost is $7.00 per Watt. The installation costs are slightly less, since the work can be done quickly while standing on a level surface. The same unit installation cost of $3.00 per Watt was used, though, to account for the installation of a second layer of roofing material recommended by the manufacturers.

Typical panels/ground mounted: When roof space is not available or if the building is not ideally oriented, PV panels can be mounted on the ground. System capacity factors are typically higher than roof mounted systems (we assume 16%), because the angle and aspect can be optimized, assuming no constraints on the placement of the PV array on the property. The unit capital cost is $6.00 per Watt, and includes the required footings in the ground. There can be additional costs for wiring; however installation labor costs are typically lower because roof work is not needed. The net result is a similar installation cost of $3.00 per Watt.

Building integrated panels: With building integrated applications, the PV technology is embedded in building materials such as roof shingles and siding. Building integrated capacity is considerably more expensive than PV panels. We assume capital costs of $10.00 per watt, roughly 80 percent more than typical panels mounted on an inclined roof. In a retrofit scenario, installation costs would be significantly higher than for a PV panel installation. Thus, building integrated systems are typically only considered for new construction.

Operating Characteristics	Inclined Roof		Flat Roof	Ground	Integrated
Typical Size (kW)	2.76	2.76	2.52	2.76	2.55
Lifetime (years)	25	25	25	25	25
Electric Capacity Factor (%)	15%	18%	14%	16%	12%
Electricity Generation (KWh)	3,627	4,352	3,091	3,868	2,684
Heating Efficiency (%)	---	---	---	---	---
Heat Generation (MWh)	---	---	---	---	---

Installation and Operating Costs	Inclined Roof		Flat Roof	Ground	Integrated
Capital Costs ($/KW)	5,500	6,500	7,000	6,000	10,000
Installation Costs ($)	8,280	8,280	7,560	8,280	12,768
Maintenance Costs ($/year)	200	200	200	200	200
Fuel Price ($/MWh)	0.0	0.0	0.0	0.0	0.0
Fuel Use (MWh/year)	0	0	0	0	0

Cost-Effectiveness:	Inclined Roof		Flat Roof	Ground	Integrated
Cost of Generated Elec. ($/MWh)	284	257	361	279	615
Cost of Generated Heat ($/MMBtu)	---	---	---	---	---
Payback Period (years)	78	65	111	74	224
TRC Benefit-Cost Ratio	0.41	0.41	0.34	0.40	0.22

All of the PV technologies and balance-of-system hardware are commercially available and appropriate for homes in Massachusetts. The capacity factors assumed here are based on average Massachusetts insulation levels. There are no interconnection costs in Massachusetts for PV systems less than 10 kW (except in a few urban areas served by area network distribution systems), and all utilities offer net metering.

PV systems require no special attention from the residents, and there are no special considerations for low-income applications.

4.7 Micro Wind (0-3 kW)

Smaller wind generators, with a one to three kilowatt capacity, cannot meet all the electricity needs of a typical home. They are commonly used to power specific applications such as water pumps, boats, recreational vehicles and appliances. However, these turbines can reduce energy bills for residents in areas with a robust wind resource. The smaller micro turbines are typically used for battery charging and other small-scale activities. The larger turbines can take on a portion of household electricity use, such as several appliances.

As defined here, micro wind turbines range in size from several hundred Watts to three kW. The Air 403XM, made by Southwest Windpower, is a typical 400-Watt turbine. The turbine has a rotor diameter of just over three feet, and it weighs about 13 pounds. It starts producing electricity in wind speeds of roughly seven mph and produces about 450 kWh per year in a Class 3 wind regime (annual average wind speed of 12.1 mph). Many areas of Massachusetts have average windspeeds of at least 12 mph, and large portions of the Berkshires and coast have average speeds in the range of 14 to 15 mph. The turbine can be mounted on a rooftop or on a tilt-up pole with guy wires. The turbine sells for about $900, and kits for 30-foot tilt-up towers cost about $150. Designed for marine applications, the turbine is very durable (only two moving parts, watertight housing and marine-grade coated aluminum finish). It is designed to operate for 15 to 20 years with no maintenance, and we found no reports of significant maintenance costs.

The Bergey BWC XL.1 is representative of a larger micro wind turbine. The turbine is rated at one kW at 25 mph, and produces roughly 1,550 kWh per year in a Class 2 wind regime (annual average wind speed of 10.7 mph). This number rises to about 2,100 kWh per year in Class 3 regimes. The turbine has a rotor diameter of nearly eight feet, and it weighs 75 pounds. It is typically mounted on a tilt-up pole secured by guy-wires at a height between 30 and 100 feet. The turbine sells for roughly $2,000. Bergey suggests that this turbine be taken apart every few years and the bearings repacked. Most owners perform this maintenance themselves. A visit from a qualified technician typically costs $100 to $200 (Bergey, 2005B). See other micro turbines at the ABS Alaskan website (ABS Alaskan, 2005).

Marlec Engineering Company in the UK is another leading manufacturer of micro wind turbines. Product information is available at its website (Marlec, 2005). AWEA lists other manufacturers at: www.awea.org/faq/smsyslst.html. AWEA provides excellent "advice from an expert" on small wind issues at: www.awea.org/faq/sagrillo/index.html.

Micro wind turbines can be grid connected or operate in parallel to grid supply. The smaller micro turbines are rarely grid connected, because they do not produce sufficient energy to warrant interconnection. However, even stand alone turbines reduce grid generation, as they reduce the home's demand for grid energy.

Operating Characteristics	
Typical Size (kW)	0.9
Lifetime (years)	20
Electric Capacity Factor (%)	25%
Electricity Generation (KWh)	1,971
Heating Efficiency (%)	---
Heat Generation (MMBtu)	---

Installation and Operating Costs	
Capital Costs ($/kW)	2,889
Installation and Interconnection Costs ($)	500
Maintenance Costs ($/year)	20
Fuel Price ($/MWh)	0
Fuel Use (MWh/year)	0

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	59
Cost of Generated Heat ($/MMBtu)	---
Payback Period (years)	12
TRC Benefit-Cost Ratio	1.2

Micro wind technology is fully commercial and has a proven track record. Pole-mounted turbines need sufficient land for tilt-down maintenance, but no open land is required for a roof-mounted system. In both cases, surrounding buildings and trees can cause turbulence and compromise the wind resource considerably. Many residential areas limit tower heights to 35 feet, and a variance is needed to exceed this.

The major consideration for micro wind is the wind resource. With a greater wind resource, more energy is produced, resulting in a more cost-effective project. At average wind speeds below about 10 mph, capacity factors of some models fall to very low levels. A wind map of Massachusetts can be found at: http://truewind.teamcamelot.com/ne/.

The durability of micro wind turbines and their low maintenance requirements make them ideal for residential applications. There are no special considerations for low-income applications.

4.8 Small Wind (3-60 kW)

We define small wind turbines as those between three and 60 kW. These turbines can serve a single residence or a cluster of homes. Small wind turbines are usually mounted on towers between 60 and 120 feet high. Taller towers (100 feet and higher) may be needed in Class 2 winds (AWEA/SEED 2003).

Total installed costs range from $3,000-$5,000 per kW (Edwards, 2004; AWEA, 2005). A three-kW turbine mounted on a 60 to 80-foot tower costs about $15,000, including accessory components and batteries (units that are not grid connected are often installed with battery storage capability). One of the most common small turbines in use today is the Bergey 10-kW unit. Total installed costs of this unit are roughly $40,000, as indicated in the table below (US DOE, 2001; AWEA, 2005). In the table below, installed costs are shown at $4,000 per kW, based on this Bergey system.

Very little unbiased information is available on the maintenance costs of small wind turbines. Bergey maintains that maintenance costs for the 10-kW unit are very low because the unit has a sealed bearing housing, and we found no reports to contradict this claim. However, more work should be done to canvass small wind owners and installers regarding maintenance costs. AWEA lists other manufacturers at: www.awea.org/faq/smsyslst.html. Also see AWEA's "advice from an expert" on issues related to small wind: www.awea.org/faq/sagrillo/index.html.

Capacity factors for small wind turbines range from 15% to about 27% depending on the wind resource.

Operating Characteristics	
Typical Size (kW)	10
Lifetime (years)	25
Electric Capacity Factor (%)	27%
Electricity Generation (KWh)	23,652
Heating Efficiency (%)	---
Heat Generation (MMBtu)	---

Installation and Operating Costs	
Capital Costs ($/kW)	2,290
Installation and Interconnection Costs ($)	17,100
Maintenance Costs ($/year)	500
Fuel Price ($/MWh)	0.0
Fuel Use (MWh/year)	0

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	59
Cost of Generated Heat ($/MMBtu)	---
Payback Period (years)	14
TRC Benefit-Cost Ratio	1.1

Small wind technology is fully commercial. Because small turbines are usually mounted on relatively high towers, they are best suited to rural areas. At least an acre of land is recommended (US DOE, 2001). Depending on the county, permitting a small wind turbine can be time and resource intensive (AWEA/SEED, 2005). Northwest Sustainable Energy for Economic Development (SEED) is a good source of information on what to expect in permitting small wind turbines (206-328-2441), as well as on considering small wind for low-income customers. SEED initiated a project designed to develop small wind turbines at low-income locations, but eventually altered the program to focus on larger turbines, with a portion of the revenue going to low-income assistance. The resource intensiveness of the permitting process was an important factor in this decision.

Interconnection for systems 10 kW and smaller is streamlined in Massachusetts, and net metering is offered by all utilities. There are no special considerations for low-income applications.

4.9 Micro Hydro

Small hydro power systems can be constructed near residences, where a river with significant head is available.[14] Systems can be as small as one hundred Watts or as large as several kW. The electricity generated by a micro hydro system depends primarily on head (vertical drop in water level), flow (gallons per minute) and turbine size. The need for significant flow or head makes micro hydro most applicable to rural sites, however urban locations that once used hydropower, such as old mills, are quite attractive for hydro redevelopment.

A common misconception is that micro hydro turbines are placed directly within a river. In fact, in most systems river water is directed into a tube (or penstock), which carries the water to the turbine. The vertical distance from the top of the penstock to the turbine is the system's head. The water leaving the turbine is directed back to the river, but the

[14] All of the micro hydro projects we reviewed had heads of over 150 feet. It is not clear whether projects with heads smaller than this would be feasible.

turbine itself is located on dry land for easy maintenance. Thus, the systems head need not be a single vertical drop, as in large dams; it can be measured as the vertical drop along a certain portion of the river.

"Crossflow" turbines are available for applications where head is not available but strong annual flow is available. Crossflow turbines generate power from mass flow rather than pressure. They are much less common than turbines that rely on head, and feasibility is more site-specific. Windstream Power Systems seems to be a good place to get an initial evaluation of a site.

With a favorable water resource, micro-hydro can provide relatively low-cost alternative energy. One small river in Northern California feeds five residential micro hydro systems. Data on these systems is presented in an article in *Home Energy* (Perez, 1990). The projects range in size from approximately 100 W to 2.2 kW. In terms of dollars per kW, the lowest cost project was roughly $3,500 per kW (a 2.2 kW project), and the highest cost project cost about $23,900 per kW (a 120 Watt project). While the article was published in 1990, costs for micro turbines have not fallen much in real terms, nor has the cost of piping (a substantial fraction of project costs). In the table below, we use the average cost per kW of these five projects ($14,800) to represent total installed costs.[15] Windstream Power Systems (Windstream, 2005) is a good source of data on current turbine costs, as is Suntrek Energy Systems (Suntrek, 2005). For other case study data, see: O Schultze, 1998.

Maintenance of micro hydro systems is limited to replacing brushes and bearings in the alternator every few years and clearing debris from the intake filter (the latter may need to be done frequently in the fall and spring). We include turbine replacement in maintenance costs after 20 years. We assume a project lifetime of 40 years. This may be conservative; depending on the type of piping used, much of the system could last longer than this.

Operating Characteristics	
Typical Size (kW)	0.92
Lifetime (years)	40
Electric Capacity Factor (%)	50%
Electricity Generation (KWh)	4,030
Heating Efficiency (%)	---
Heat Generation (MMBtu)	---

15 We have adjusted the cost data presented in this article in two ways. First, we have converted costs from 1990 to 2004 dollars using the CPI. Second, the article presents *average* power output for each project. This is not consistent with the standard practice of describing electric generators by their peak output. Costs shown in dollars per *average* kW would not be comparable to the other costs in this report, shown in dollars per *peak* kW. Thus, we have estimated the peak capacities of these five hydro projects as 15% greater than their average capacities, based on information in the article. We believe that the adjusted dollar per kW figures are comparable to the cost figures presented for other technologies.

Installation and Operating Costs	
Capital Costs ($/kW)	10,870
Installation and Interconnection Costs ($)	4,800
Maintenance Costs ($/year)	135
Fuel Price ($/MWh)	0.0
Fuel Use (MWh/year)	0

Cost-Effectiveness:	
Cost of Generated Electricity ($/MWh)	95
Cost of Generated Heat ($/MMBtu)	---
Payback Period (years)	35
TRC Benefit-Cost Ratio	0.59

Small hydro turbines are commercially available. The major factor in the applicability of micro hydro is having a suitable waterway (i.e., sufficient head or flow) near the residence. A small portion of the residences in Massachusetts are likely to be near such a waterway. However, any residence located near a river should be evaluated for a micro hydro system, because the right configuration can result in low-cost alternative energy.

In addition to the type of micro hydro system described above, larger systems can also be constructed to serve multiple homes. These systems usually entail significant earthwork and construction, making them less suitable to LEAN's purposes. However, considerable information is available on larger micro hydro systems, with much of it focused on rural electrification in developing countries. See: ITDG, 2005 and Khennas et. al., 2005)

Most micro hydro systems are located in rural areas and are not connected to the local grid. However, larger systems (over about a kW) could be interconnected and net metered. (Smaller systems would not produce enough energy to warrant interconnection.) Interconnection of systems under 10 kW is streamlined in Massachusetts.

There are no special considerations for low-income applications.

4.10 Wood Hybrid Furnace/Boiler

A number of wood-burning furnaces and boilers are now available at the residential scale. Many of these units can accommodate multiple fuels, allowing wood to supplement a fossil-fueled system. Furnaces and boilers designed for both interior and exterior installation are available. These systems are likely to be quite cost effective where a low- or no-cost supply of wood is available. Where wood must be purchased at typical "firewood" rates, savings will be much smaller. (Prices for split wood fluctuate considerably, generally following oil and gas prices.) In the table below, we include data on systems with access to free wood and systems that pay market prices for split wood.

Wood burning boilers and furnaces are very similar in cost and performance (Zapotec). Information representing standard features and pricing can be found at: Yukon Eagle, 2005 and Thermo-Control, 2005. The key consideration in selecting between these two technologies is the type of heating system currently in the building (e.g., forced hot air or hot water/steam).

Operating Characteristics	
Typical Size (Btu/hour)	125,000
Lifetime (years)	20
Electric Capacity Factor (%)	---
Electricity Generation (MWh)	---
Heating Efficiency (%)	80%
Heat Generation (MMBtu)	130

Installation and Operating Costs	Free Wood	$170/cord
Capital Costs ($/KW)	0.02	0.02
Installation Costs ($)	2,000	2,000
Maintenance Costs ($/year)	175	175
Fuel Price ($/MWh)	0.0	8.3
Fuel Use (MWh/year)	162	162

Cost-Effectiveness:	Free Wood	$170/cord
Cost of Generated Electricity ($/MWh)	---	---
Cost of Generated Heat ($/MMBtu)	3.3	14
Payback Period (years)	6.4	never pays back
TRC Benefit-Cost Ratio	3.2	0.81

Wood/hybrid boilers and furnaces are commercially available and applicable to homes in Massachusetts. As noted, however, supplementing a fossil-fueled heating system with wood is likely to be most cost effective in rural areas where a low-cost source of wood is available.

Note that wood-burning heating systems must be stoked frequently – typically every day or every other day. In a single-family home, this will need to be done by the resident. For multi-family buildings, a superintendent could do this. In rental properties there may be a concern with operation of the furnace across different tenants (i.e., the current tenant is willing and able, but what about future tenants?).

There are no special considerations for low-income applications.

5. Advanced Energy Efficiency Measures

5.1 Wall-Mounted Occupancy Sensors for Lighting

Occupancy sensors detect movements of people and automatically turn lights on and off. Manufacturing companies claim that they may reduce electricity consumption for lighting by 50 percent or more in some circumstances. Great savings would be achieved when occupancy censors are applied to areas that are not often occupied including stairwells, hallways, and rooms.

There are commonly two types of sensors: passive infrared (PIR), which require a direct line of sight to the movement of infrared (heat) source, and ultrasonic (US), which sense any movement of objects. Because PIR sensors turn lights on when it detects a change in infrared level, they are relatively resistant to false triggering. PIR sensors can be effective within a 15-foot range. (Wisconsin PSC)

Cost and Operating Characteristics	
Lifetime (years)	10
Measure Cost – Total ($)	63
Measure Cost – Incremental ($)	63
Electricity Savings (kWh)	49
Energy Savings (MMBtu)	0

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	128	128
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	12	12
TRC Benefit-Cost Ratio	1.1	1.1

These devices are readily available in Massachusetts. They are easy to install and they are low maintenance. Yet, the location of the sensors must be carefully chosen so that the sensors can correctly detect the movement of occupants since false triggering of sensors often occur due to incorrect positioning of the device.

5.2 White LED Lighting

Light Emitting Diode (LED) technology for producing white lamps has been around for some time. Red and green LED lamps are now often applied to traffic signals. White LED lamps are being adopted for retail displays, building exterior illumination, task lighting, elevators, kitchens (under-cabinet), and backlighting for liquid crystal displays (ACEEE 2004a). But many diodes are required to produce a large amount of light and, for everyday room lighting use, the technology has been too expensive to manufacture relative to traditional fluorescent and incandescent light bulbs. However, recently, there has been a major technology breakthrough that has enabled manufacturers to produce LEDs for a lower cost.

LEDs consume 25% less energy than fluorescent light bulbs (which are already efficient) and they last ten times as long as fluorescents. In addition, they do not buzz like some fluorescent bulbs do, nor do they flicker. LED lamps are also dimmable, unlike some fluorescent lamps. (NAHB Research Center)

The information in the table below presents the costs and savings of LED lighting relative to the costs and savings of an incandescent light bulb. Our analysis is based on LED lighting that consumes 29 watts relative to a 75-watt incandescent bulb. If the LED lighting were to be compared with compact florescent light bulbs – the standard measure for efficiency programs – then it would be significantly less cost-effective than indicated here.

Cost and Operating Characteristics	
Lifetime (years)	13
Measure Cost – Total ($)	63
Measure Cost – Incremental ($)	57
Electricity Savings (kWh)	51
Energy Savings (MMBtu)	0

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	86	95
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	10	11
TRC Benefit-Cost Ratio	1.7	1.5

One important problem with LED light technology thus far is that it may not provide the amount of light that traditional bulbs emit. Therefore, this technology may be best suited for purposes where a small amount of lumens is required.

LED lamps are available with standard screw-in bases that traditionally hold incandescent fixtures. However, in order to be run on standard 120V, AC power, LEDs sometimes require an inexpensive transformer ($6-20.) In older homes, it is sometimes difficult to get behind the walls to install this transformer. In this case, an electrician is definitely needed, which adds to the cost of the LED light products.

One benefit of LED lamps is that there is no glass involved and there are no filaments that may break. In addition, mercury poisoning is not an issue for this technology.

5.3 ENERGY STAR Clothes Washers

ENERGY STAR clothes washers minimize both energy and water use; ENERGY STAR clothes washers use 50% less energy than standard washers; most full-sized ENERGY

STAR qualified washers use 18-25 gallons of water per load, compared to the 40 gallons used by a standard machine. (ENERGY STAR)

ENERGY STAR qualified clothes washers are available in both top-loading and front-loading designs. Front-loading designs are the most efficient in terms of water use; because clothes spin horizontally, the machine only needs to be half-filled with water. As the clothes rotate down towards the bottom of the barrel, they rotate through the pool of water at the bottom of the barrel, whereas for top-loaders, the clothes must be completely covered by water throughout the wash and rinse cycles.

Cost and Operating Characteristics	
Lifetime (years)	14
Measure Cost – Total ($)	775
Measure Cost – Incremental ($)	300
Electricity Savings (kWh)	36
Energy Savings (MMBtu)	1.6

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	595	1538
Cost of Saved Energy ($/MMBtu)	22	44
Payback Period (years)	4.2	11
TRC Benefit-Cost Ratio	4.6	1.8

ENERGY STAR qualified clothes washers are available as both residential and residential-style commercial clothes washers in Massachusetts. Residential-style commercial clothes washers may or may not be coin-operated. However, program installations can minimize delivery of coin operated models based on contractual arrangements with property owners.

The cost effectiveness of clotheswashers is very much dependent upon the amount of use, i.e., the number of clothes washes per week. The cost-effectiveness calculations developed for this study should be compared to recent analysis conducted through the Massachusetts LEAN Best Practices initiative for low-income energy efficiency programs to help identify consumption levels required for cost-effective measure delivery.

5.4 High-Efficiency Refrigerators

ENERGY STAR's new standards established in 2004 require 15% better performance than older standards, resulting in 1.16 kWh/day or 422 kWh/yr at 20 cubit feet size. Emerging high-efficiency refrigerators will achieve higher efficiency than these 2004 standards, and consume less than 1 kWh/day or 365 kWh/yr at 20 cubit feet size. This will be accomplished by several modifications to refrigerators, such as the use of vacuum panel insulation instead of foam insulation around the freezer compartment and free-piston linear compressors. The latter technology was developed by Sunpower and LG Electronics. (ACEEE 2004a)

We have performed two scenarios for the high-efficiency refrigerators. The first compares the high-efficiency refrigerators with retrofitting an existing, old refrigerator (i.e., prior to 1993). This comparative standard is based on an analysis of existing change out characteristics of the Massachusetts low-income energy efficiency programs operated statewide, (excluding the WMECO service territory). The second compares the high-efficiency refrigerators with installing a new standard refrigerator available in Massachusetts today. The latter are much more efficient than old, existing refrigerators in place today, and thus the costs and benefits of the high-efficiency refrigerators will vary considerably between the two scenarios.

Cost and Operating Characteristics	vs. existing	Vs. new
Lifetime (years)	19	19
Measure Cost – Total ($)	575	520
Measure Cost – Incremental ($)	520	70
Electricity Savings (kWh)	903	149
Energy Savings (MMBtu)	0	0

Cost-Effectiveness (vs. existing):	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	30	32
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	5.3	5.6
TRC Benefit-Cost Ratio	2.4	2.3

Cost-Effectiveness (vs. new):	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	25	184
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	4.3	32
TRC Benefit-Cost Ratio	3.0	0.4

There are no special installation or maintenance issues with high efficiency refrigerators.

5.5 Drainwater Heat Recovery / Drain Heat Recovery (DHR)

The drain heat recovery (DHR) system can be installed to existing waste drain pipes, to capture heat from warm drainwater and to preheat cold water that goes to showers and/or a water heater. DHR system can generally store recovered heat for later use. Without storage capacity, DHR systems provide heat only when hot water is being used (e.g., during showering).

One of the important features of DHR system is a spiral copper tube that needs to be attached to a main waste drain pipe to recover heat from the waste pipe. Accordingly, water in the spiral tube is heated by hot/warm water in the waste pipe. The heated water is delivered to hot water storage in the storage model, or is delivered to showers and sinks. Other non-storage units have a horizontal heat exchange device that thermally connects the drain pipe and the cold water supply tube and exchanges heat between them. (NAHB Research Center)

DHR systems reduce the energy needed for heating water and increase the capacity of water heaters. As a result, users of this system found that DHR system saves 30%-50% of energy used for heating water. (WaterFilm Energy Inc)

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	550
Measure Cost – Incremental ($)	550
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	8.1

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	3.4	3.4
Payback Period (years)	9.2	9.2
TRC Benefit-Cost Ratio	3.0	3.0

DHR systems can readily be installed in both existing and new homes. A plumber installs them into the main waste line in the home. However, this technology may not work in multi-family buildings if access to the main line is difficult.

Once this system is installed, little or no maintenance is required.

5.6 Hot Water Recirculation Systems

The hot water recirculation system brings hot water quickly (typically within 30 seconds) to the fixtures at home by a push of a button. There are two steps for this system to work out: first it sends cooled water that has been sitting in the hot water pipe (water that is normally discarded down the drain) back to the water heater through the cold water pipe; second once the cooled water is back to the heater and the water reaches a desired temperature in the tank, hot water becomes readily available at the faucets.

The system is designed so that it does not allow hot water to enter cold water lines and cold water fixtures still receive cold water. It is usually installed under the sink farthest from the water heater, while each fixture typically has a button that will activate the pump to supply hot water quickly for use. It also provides other options to activate the circulation, such as a wireless remote control, timer or motion sensor. A motion sensor can be applied to doors so that the system circulates the water right after people enter the bathroom or the house. A wireless remote control can be placed anywhere in home and is often used for existing homes when the button system (which requires some electronic wiring) is difficult to install. (ACT, Inc. Metlund® Systems website)

This system provides hot water energy savings in three ways.

- The system allows users to set the temperature of the water heater lower (as low as 120°F) because hot water is hotter than before installing the system. Water heaters are generally set at 140 to 150°F at the time of installation.
- Hot water reaches the fixtures before the heat is lost in the pipe, since the system circulates hot water rapidly. (ACT, Inc. Metlund®Systems website)
- The system reduces wasted hot water. Some people leave water running and return to the shower room when they know that the water is hot enough. In this case, they often waste some hot water before coming back to the bathroom. (ORNL and Palo Alto City, 2002)

Further, this technology cleans the storage tank and extends its lifetime because the fast water flow creates turbulence at the bottom of the tank which prevents sediments from forming. This also delays rusting and leaking. (ACT, Inc. Metlund®Systems)

An ORNL study found that water savings for a household of four occupants varied from about 900 gallons to about 3000 gallons per point of use, per year. (Point of use is a single fixture, such as a sink or shower.) (ORNL and Palo Alto City, 2002) We assume this technology will save roughly 2000 gallons per point of use per year, as a mid-point of ORNL's estimates. Our water and energy savings estimates are for each point of use.

Some recent savings realization studies show actual savings may be significantly lower than those estimated by ORNL. These studies should be identified and reviewed, and pilot installations of this measure should be monitored for actual savings.

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	500
Measure Cost – Incremental ($)	500
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	2.1

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	12.5	12.5
Payback Period (years)	18	18
TRC Benefit-Cost Ratio	1.6	1.6

The system is rather simple. It can be installed in a few hours and does not require major modifications to the plumbing system. However, installation can be expensive in some older homes, due to the difficulty of setting up return loops.

This measure can be delivered to low-income housing stock throughout Massachusetts, though plumbing should be examined in each proposed application to insure that aging or damaged plumbing systems are addressed before the installation of the measure, or selected out.

Post installation maintenance is limited to possible pump malfunctions, and initial user surveys indicate high product satisfaction with product reliability. Commonly, warranties are in the three years range while actual lifetimes have yet to be field-tested.

Client education may be required to minimize continuing water use behaviors that might reduce measure savings. As noted above, studies indicate actual savings can be much lower than expected, and client water use behaviors may in part be responsible for these study results. Study methodology may also be an issue due in part to small sample size.

5.7 Laminar Flow Aerators

Any time water fixtures are to be replaced in US homes, homeowners are required to install low-flow fixtures. Traditional low-flow fixtures, however, have some disadvantages due to their aerated technology: 1) Some people dislike the feel of aerated water, and 2) Aerated fixtures result in some splashing of water.

Laminar flow fixtures instead deliver a steady stream of water that does not splash. Despite the fact that laminar fixtures are low flow, they deliver water that *feels* stronger than traditional low-flow fixtures. The technology involves creating many streams of water very close to one another. This simulates the feel of high flow water pressure. (NAHB Research Center)

Laminar flow fixtures can be installed in a bathroom sink, kitchen sink, and/or showerhead, and delivers 1.5 gallons per minute (GPM) for a bathroom sink, 2.0 GPM for a kitchen sink, and 2.5 GPM for a shower. As a result, water savings result in 27% to 70% as compared to water consumption with an aerator (OMNI website). This will also lead to significant fuel savings by reducing the use of hot water.

The table below presents amounts of water used, in gallons per minute (GPM), by the Omni laminar flow fixtures, along with the amount of water used by pre-1992 fixtures with an aerator and new fixtures based on EPA 1992 standards.

Plumbing Fixture	Pre-1992 fixtures with aerator	EPA 1992 Standards	With OMNI Flow Control	% Water Savings (relative to pre-1992)
Half Bath/Public Restroom	2.5 GPM	2.5 GPM	0.5 GPM	83-90%
Lavatory Sink	2.5 GPM	2.5 GPM	1.5 GPM	45-70%
Kitchen Bar Sink	2-3 GPM	2.5 GPM	2.0 GPM	27-60%
Shower	3-4 GPM	2.5 GPM	2.5 GPM	27-60%

Source: OMNI website at http://www.omniflowcontrols.com/savings.htm

For our analysis, we assume applying laminar flow fixtures to two lavatory sinks and one kitchen bar sink per home, and use pre-1992 fixtures with an aerator as a baseline. Note the performance of our baseline is very similar to EPA 1992 standards for lavatory and kitchen sinks. Therefore, our analysis is also applicable to new fixtures based on EPA 1992 standards. Our analysis does not include replacing shower fixtures, as the laminar flow shower fixtures do not appear to save water relative to EPA Standards.

Cost and Operating Characteristics	
Lifetime (years)	10
Measure Cost – Total ($)	35
Measure Cost – Incremental ($)	30
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	0.5

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	5.6	6.5
Payback Period (years)	1.0	1.2
TRC Benefit-Cost Ratio	14	12

Many homes probably have not been upgraded to meet 1992 low-flow fixture standards. Laminar fixtures would exceed these standards. Laminar flow aerators, (and showerheads where applicable), should be installed as a replacement measure for routine fixture change outs already determined cost-effective as a technological upgrade to existing energy efficient faucet aerators. The application should be monitored consistent with existing Massachusetts low-income energy efficiency program procedures to insure quality of selected products.

Fixtures are readily available throughout Massachusetts.

Installation is quick and hassle-free, and there are no special maintenance issues.

5.8 Solar Hot Water – Flat Plate

Solar water heating systems often consists of two main parts: a solar collector and a storage tank. A flat-collector, which is the most common type, is mounted on the roof. It has a thin, flat, rectangular box with a transparent cover and small tubes in the box. The tubes carry water or other fluid, such as antifreeze solution to be heated. An absorber plate, which is painted in black, attaches to the tubes inside the box and absorbs the heat. Heated water is stored in the storage tank, which is well-insulated and usually larger than a regular water heater.

There are two types of flat-collector: active and passive. Active systems are the most common and move the liquid between collector and the storage tank. Passive systems do not have pumps and just rely on gravity for circulating of the liquid (NREL website).

Generally, flat plate collectors are most appropriate for low temperature applications (under 140°F; 60°C), such as domestic hot water and space heating (Home Power Magazine website). Most systems require a back-up energy source (for times when there is insufficient sunlight available), such as electricity or gas.

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	4,980
Measure Cost – Incremental ($)	4,980
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	27.4

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	9.1	9.1
Payback Period (years)	25	25
TRC Benefit-Cost Ratio	1.1	1.1

For these systems, for maximum effect, the home must have a roof surface that is south facing and unshaded.

There is the potential for freezing. The fluid used in the system is usually a water-glycol mixture, which will freeze, similar to a car radiator.

Solar water systems require regular maintenance and upkeep.

For these reasons, there may be relatively few opportunities to apply this measure to low-income housing units in Massachusetts.

5.9 Solar Hot Water – Evacuated Tube

The difference between the evacuated tube and the flat panel solar hot water heaters lies in the solar collection mechanism. The evacuated tube technology consists of a series of tubes in which all air has been evacuated. The tubes are exposed in the air and much larger than the tubes of the flat-collector type. They contain a heat pipe to absorb solar energy and transfer it to water. The evacuated nature of the tubes results in very little heat loss as the water travels throughout the tube. This results in the delivery of higher temperature water to the storage tank. (NAHB Research Center)

Evacuated tube solar collectors are more efficient than flat-plate collectors due to the following reasons:

- This technology can perform well in both direct and diffuse solar radiation.
- The heat loss is minimized due to the vacuum in the tubes. This feature makes these collectors particularly useful in areas with cold, cloudy winters.
- Sunlight is perpendicular to the tubes for most of the day because the circular evacuated tubes are exposed to the sunlight. (EERE website)

Because of these reasons, this system can perform well in areas with cold, cloudy winters and is also suitable for high temperature applications (over 140°F; 60°C) (Home Power Magazine website) However, it is important to note that this system is more expensive than a flat-plate collector. (EERE website)

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	7,620
Measure Cost – Incremental ($)	7,620
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	26.2

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	9.8	14.5
Payback Period (years)	39	39
TRC Benefit-Cost Ratio	0.7	0.7

For these systems, for maximum effect, the home must have a roof surface that is south facing and unshaded.

There is the potential for freezing. The fluid used in the system is usually a water-glycol mixture, which will freeze, similar to a car radiator.

Solar water systems require regular maintenance and upkeep.

For these reasons, there may be relatively few opportunities to apply this measure to low-income housing units in Massachusetts.

Solar hot water and PV measures could be installed together, potentially resulting in reduced installation costs. Consequently, the two measures combined could be more cost-effective than each measure applied separately.

5.10 Water Heater: Residential Condensing

Conventional domestic water heaters only capture 60% of the energy that is put into them. Condensing boilers can capture as much as 90% of the input energy. This is a result of condensing boilers' forced draft burners, which eliminate off-cycle heat transfer to the flue. In addition, condensing units capture almost all of the heat value of condensing flue gas water vapor to liquid. (ACEEE 2004a)

Condensing boilers are typically installed as combination space and water heating units. The information contained below applies to water heating only. Additional costs and savings would result from a combined unit. Such condensing boilers can be installed with a tankless coil or an indirect hot water storage tank as appropriate for the number of occupants and use. Trained vendor availability also must be considered.

Cost and Operating Characteristics	
Lifetime (years)	15
Measure Cost – Total ($)	1,900
Measure Cost – Incremental ($)	1,200
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	7.8

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	31	37
Payback Period (years)	25	40
TRC Benefit-Cost Ratio	0.9	0.6

Condensing units are readily available to Massachusetts residents.

There are no special considerations for this technology.

5.11 Water Heater: Instantaneous Whole House Units

Most water heaters in residential homes in U.S. and Canada store hot water around the clock. Yet, those living in the home do not need hot water all of the time, and thus much of the energy used to heat the water is wasted.

One of the solutions is an instantaneous hot water system that does not require storage (therefore, it is sometimes referred to as tankless). Although the flow rate is limited, it provides hot water continuously and does not run out of hot water like a storage tank water heater, thus providing a cost-effective DHW option where the occupancy and usage applications are appropriate. The determination of an appropriate installation for one such unit should be based upon the maximum simultaneous hot water demand and the unit flow rate. The flow rate is temperature independent as it is continuous at the specified temperature, (routinely 125°F). Further, it eliminates standby energy loss, thereby reducing energy consumption by 10 to 15% (ACEEE 2003a).

The instantaneous water heater can use propane gas, natural gas, or electricity to heat water. Our analysis assumes the instantaneous water heater uses natural gas. Gas instantaneous water heaters can provide a large quantity of hot water (up to 199,000 Btu at 3 gallons per minute) unlike electric heaters (ACEEE 2004a) and typically cost less to operate (NAHB Center). The instantaneous water heaters are expected to last 20 years, which is longer than the 15 year typical life of a traditional tank-type water heater (NAHB Center).

This technology has been used in many countries outside of the US.

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	1,200
Measure Cost – Incremental ($)	720
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	8.7

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	23	26
Payback Period (years)	6.4	11
TRC Benefit-Cost Ratio	3.2	2.3

This technology is readily available in Massachusetts.

The room where the instantaneous heater is installed must allow venting of the combustion products to the outdoors. Consequently, there may be relatively few opportunities to apply this measure to low-income housing units in Massachusetts.

5.12 Water Heater: Indirect with Efficient Gas Boiler

Indirect water heaters, when integrated with new high efficiency boilers or furnaces, can be one of the least expensive methods for producing domestic hot water.

An indirect water heater circulates water through a heat exchanger in the boiler system or through a heat exchanger coil in the furnace to be heated and sent to an insulated storage tank. Hot water stored in the insulated storage tank obviates frequent operation of the furnace or boiler (unlike a tankless coil water heater) and improves its fuel economy. (ACEEE 2003a) The indirect tank provides a cost-effective application where the number of occupants and amount of usage requires a hot water demand level beyond that which can be provided by instantaneous systems, or where such systems can not be installed.

"Electronic controls determine when water in the tank falls below a reset temperature and trigger the boiler or furnace to provide heat as long as needed. The more sophisticated of these systems rely on a heat purge cycle to circulate leftover heat remaining in the heat exchanger in to the water storage tank after the boiler shuts down, thereby further improving overall system efficiency." (ACEEE 2003a, page 100)

Cost and Operating Characteristics	
Lifetime (years)	30
Measure Cost – Total ($)	750
Measure Cost – Incremental ($)	220
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	12

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	9.9	11
Payback Period (years)	2.4	8.1
TRC Benefit-Cost Ratio	19	5.7

This product is available to Massachusetts's residents.

This technology is most cost-effective when replacing both space and water heating systems. It is also important to ensure that the system is properly sized for both heating and hot water needs.

5.13 Advanced HVAC Fan Motors

Standard HVAC fan motors use multi-tap permanent slip capacity (PSC) induction motors. These are reasonably efficient at 35 – 65%. Advanced HVAC Fan motors use electronically commuted DC permanent magnets (DCPM). These motors modulate continuously and can be 10% (when full loaded, i.e., when heating and cooling the home) to 100% (when light loaded, i.e., when using ventilation/circulation only) more efficient than standard motors. (ACEEE 2004a)

Cost and Operating Characteristics	
Lifetime (years)	15
Measure Cost – Total ($)	180
Measure Cost – Incremental ($)	80
Electricity Savings (kWh)	510
Energy Savings (MMBtu)	0

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	45	58.0
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	2.1	4.8
TRC Benefit-Cost Ratio	2.2	1.7

This measure is only applicable in homes that use furnaces for space heat. Although this measure could be retrofitted onto existing furnaces, the costs of engineering and implementing the measure would likely be a barrier. Application is more cost effective in new installations where the technology is integrated into the upgraded heating system package. Consequently, there may be relatively few opportunities to apply this measure to existing low-income housing units in Massachusetts.

This measure, or one similar to it, is already offered to all residential customers, through the HVAC Products and Services programs delivered by the Massachusetts energy efficiency program administrators.

5.14 Duct Sealing: Aerosol

Aerosol duct installation involves forcing insulating particles through heating and cooling systems. The particles are suspended by the airflow. Naturally, the particles try to escape the pressurized ducts through leaks. In the process, they adhere to the leak surfaces and permanently close them off. (NAHB Research Center)

Aerosol duct sealing is a practical fix for leaky ductwork, particularly in attic spaces. It works best on leaks of less than one-quarter inch in size. This technology, when used in conjunction with tape and mastic, makes heating and cooling ducts 5 to 8 times more airtight compared to use of tape and mastic alone. (NAHB Research Center)

Typical duct system leakage can be significant and can result in high heating and cooling energy loss. Duct leakage results in distribution system efficiencies of 80 percent on average, and in many instances, (particularly in manufactured homes), significantly higher losses can occur. (ACEEE 2004a). Duct leakage contributes to reduced comfort, and reduced heating supply to the structure generally, and often to particular parts of the building. This can often result in an inability to meet both heating and cooling loads. However, our analysis only considers fuel savings for space-heating purposes, because we assume that the space-cooling load is relatively low in Massachusetts low-income housing units.

Cost and Operating Characteristics	
Lifetime (years)	25
Measure Cost – Total ($)	850
Measure Cost – Incremental ($)	850
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	16

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	2.1	2.1
Payback Period (years)	7.1	7.1
TRC Benefit-Cost Ratio	4.8	4.8

Aerosol sealing services are available in Massachusetts through, for example, Aeroseal, Inc. Availability of contractors, limitations on applications due to ductwork accessibility, and condition may limit market penetration levels for this measure. Consequently, there may be relatively few opportunities to apply this measure to low-income housing units in Massachusetts.

Aerosol sealing can be used in new or existing homes. However, "fixing existing home duct leakage is often problematic and expensive as ducts are often in hard or impossible to access locations such as small attic, crawl spaces, and duct chases" (ACEEE 2004a, page 90). Nevertheless, it is a cost-effective measure since aerosol duct sealing significantly reduces energy lost through the duct distribution system.. Lack of consumer awareness is a major barrier to the implementation of this measure, but this limitation may not impact the delivery of this measure to the low-income clients.

The installation process does not have a negative effect on indoor air quality. This product is a vinyl polymer that will not off gas at any point in its lifetime, however, in the initial application and immediate drying period, those with sensitivity to vinyl should not be in the building during installation. Over time the reduction in movement of low quality air through the ductwork will significantly improve indoor air quality.

5.15 High Efficiency Bathroom Fans

Many basic bathroom fans are not only noisy and ineffective at air flow movement, but they also use large amounts of energy. To address these problems, high efficiency bathroom fans are available.

Fan exhaust capacity is rated in liters per second (l/s) or cubic feet per minute (cfm). A normal bathroom requires a good-quality fan that draws 25 l/s (50 cfm). A poor-quality fan won't exhaust enough air and will be too noisy for regular use. Older units that can move this amount of air typically have sound ratings of up to 4 sones and consume 80 watts. High efficiency bathroom fans have sound ratings of 0.5 sones or less and consume about 20 watts.

Installing an energy-efficient fan system also involves ducting. Undersized, or sagging ducting, ineffective or clogged backdraft dampers, and exhaust louvers can cut rated airflow by more than 50 percent and thus greatly reduce the efficiency of the exhaust system.

Retrofit applications would be particularly appropriate for houses with existing fans that are serving large families. More extensive use would maximize energy savings and other non-energy benefits. (CMHC)

Cost and Operating Characteristics	
Lifetime (years)	33
Measure Cost – Total ($)	160
Measure Cost – Incremental ($)	40
Electricity Savings (kWh)	62
Energy Savings (MMBtu)	0

Cost-Effectiveness:	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	20	79
Cost of Saved Energy ($/MMBtu)	---	---
Payback Period (years)	6.0	24
TRC Benefit-Cost Ratio	4.4	1.1

This measure is readily available in Massachusetts.

Because the high-efficiency fans are more effective at moving air from inside the bathroom to outside the house, there will be more heat loss relative to regular bathroom fans. Thus, there may be some fossil-fuel losses in the winter that offset the electricity savings. These losses are not accounted for in our analysis.

5.16 Heat Pump: Ground-Coupled / GeoExchange

A geothermal heat pump (GHP) uses the natural heat storage capacity of the ground or ground water to provide energy efficient heating and cooling. During the winter time, a GHP extracts thermal energy from the ambient temperature (50° and 70°F) depending on latitude) in the ground (3 – 6 feet for horizontal loop systems and 150 to 450 feet for vertical loop systems). During the summer time, it reverses this process to cool the building by moving heat in the building to the ground. The system does not convert electricity to heat but to use electricity to move thermal energy between the building and the ground. They can also be used as a source of domestic hot water. (US DOE 1997; Geothermal Heat Pump Consortium (GHPS) website)

A GHP system is composed of indoor heat pump equipment, a ground loop, and a flow center to connect the indoor and outdoor equipment. The system exchanges the heat between the ground and the heat pump through the ground loop. A GHP system with the ground loop is also called a closed-loop system as opposed to an open-loop system.

Open-loop system draws well water in an aquifer to the building, where the well water is used to exchange heat with a heat pump. Subsequently, the well water is pumped back to the same aquifer via another well, called a discharge well. This type of system is less common but can be cost-effective if ground water is plentiful (GHPS website)

Ground loops have two kinds: horizontal or vertical. A GHP with a horizontal loop is often the most cost effective if there is sufficient yard space available. The loop is typically 400 to 600 feet per ton of heating and cooling capacity and needs to be placed 3 to 6 feet below the ground. A GHP with a vertical loop is suitable for homes with limited yard space or for retrofit applications. It is generally more expensive to install, but requires less piping than horizontal loops. The vertical loop needs to be buried in the ground at 150 to 450 feet deep. (GHPS website)

Our analysis is for a heat pump that replaces an oil heat system. Cost-effectiveness would be greater for replacing an electric heat system.

Cost and Operating Characteristics	
Lifetime (years)	18
Measure Cost – Total ($)	11,600
Measure Cost – Incremental ($)	4,220
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	25

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	9.5	24
Payback Period (years)	23	58
TRC Benefit-Cost Ratio	1.1	0.4

GHPs can be placed in both new and retrofit homes for either heating or cooling purposes. Horizontal loops are more suitable for new construction. However, new types of digging equipment allow for retrofitting with minimal disturbance to lawns and also even for installing under the existing buildings or driveways.(GHPS website)

Installation costs are high relative to other energy efficiency measures, due to the difficulties of installing the ground loop. As mentioned above, installation of horizontal loops require a large land area, which makes it difficult to install in urban areas. Vertical loops are more suitable for urban applications. On the other hand, for homes with large yard in a rural area, locating GHP installation is much easier. It could include existing water bodies, ponds, wells, etc.

There may be a lack of trained installers in the area. The Geothermal Heat Pump Consortium or International Ground Source Heat Pump Association provides information on product manufacturers and installers at www.geoexhange.org or www.igshpa.okstate.edu.

Once installed, these systems seem to run without problems. “Surveys show that the number of satisfied geothermal heat pump customers stands at 95% or higher.” (US DOE 1997, page 7)

5.17 Heat Pump: Advanced Cold-Climate / Frostless Heat Pump

Standard residential air-source heat pumps are not suitable for cold-climate areas because they lose efficiency and capacity at a temperature below the mid-30s^{o}F. In cold climates, standard air-source heat pumps often need to rely on inefficient resistance heat for capacity shortfall.

There have been some R&D efforts to improve the performance of heat pumps in cold climate. The Nyle Special Products in partner with EnerKon Corporation have been developing cold climate heat pumps (CCHPs)- the first and only heat pump that maintains high efficiency down to 0°F and below. A CCHP consists of two compressors (a two-stage compressor and a second booster compressor), intelligent controls, and a plate heat exchanger to improve low temperature performance (ACEEE 2004a).

The Nyle Special Products’ new CCHP appears to have become commercialized and presented significant performance and saving records over standard air-source heat pumps. The company reports the CCHP can achieve 40% or more energy savings for heating and 25% energy costs for cooling (See Nyle Special Products’ website http://www.nyletherm.com/spaceheating.htm). Chelan County Public Utility District (PUD) in Washington purchased a CCHP and reported 60% energy savings (Chelan

Country PUD 2005). An engineer with Chelan Country PUD found this incredibly high but cautions that more testing is needed to confirm the savings.

The pump's performance is as follows: Seasonal Energy Efficiency Ratio[16] of 16, Heating Season Performance Factor[17] of 9.6, and Coefficient of Performance[18] of 2.7 at 17^{o}F. See also the table below for the comparison of energy efficiency between a typical high-efficient heat pump and CCHP.

	Typical Hi-Efficiency Heat Pump (3-Ton)		CCHP 3-Ton Unit	
Outdoor F°	Btu/hr	Efficiency	Btu/hr	Efficiency
40	32,500	320%	38,000	330%
20	24,500	240%	65,000	280%
0	16,000	170%	47,000	230%

*Both units compared without back-up resistance heat

Source: Nyle Special Products at http://www.nyletherm.com/spaceheating.htm

The Oak Ridge National Laboratory (ORNL) is also developing an advanced air-source heat pump, called a "frostless" heat pump that is more suitable to colder climate. The ORNL's frostless heat pump produces warmer air faster and for a longer time while minimizing the defrosting cycle. In a cold climate below about 40oF, frost starts to accumulate on the outdoor heat exchanger coil of standard heat pumps and the temperature of the indoor heat exchanger begins to decrease. This effect requires the heat pump to defrost the outside heat exchanger by temporarily reversing the pump's cycle and draws the indoor heat outside to melt the frost, and thus makes the pump perform inefficiently. (ORNL website) The frostless heat pump provides small amount of heat to the refrigerant accumulator to reduce the impact of defrosting. According to ACEEE, this method is only be effective at a temperature rage of 41 to 32^{o}F ORNL is planning to commercialize this technology in partnership with American Best. (ACEEE 2004a)

Cost and Operating Characteristics	Advanced cold-climate
Lifetime (years)	20
Measure Cost – Total ($)	7,300
Measure Cost – Incremental ($)	920
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	12

[16] It is the ratio of the total number of BTUs of heat removed from the air against the total amount of energy required by the unit.

[17] This factor accounts for efficiency reduction caused by defrosting, temperature fluctuations, supplemental heat, fans and on/off cycling.

[18] It is the ratio of the work or useful energy output of a system against the amount of work or energy put in to the system. This factor is used as a measure of the steady state performance or energy efficiency of heating, cooling, and refrigeration appliances.

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	3.9	31
Payback Period (years)	10	83
TRC Benefit-Cost Ratio	2.7	0.3

Despite the fact that the new CCHP appears to be a promising technology to achieve great energy savings, the production of the CCHP has recently been discontinued because the inventor and patent holder of the CCHP technology have revoked manufacturing rights from Nyle Special Products. However, this does not mean that this product will not be available in the future. It is possible that the company might develop a similar product or other manufacture companies might develop this technology in partnership with an investor.

Given its predicted performance in cold climates, it may be well suited for homes in Massachusetts. Piloting opportunities could be pursued where product reliability is assured.

5.18 High-Efficiency Gas Boilers

Boilers account for nearly half of the heating systems in the Northeast. Of these, two-thirds are powered by gas.(Consortium for Energy Efficiency (CEC) web). In order to qualify as ENERGY STAR appliances, gas boilers need to achieve an annual fuel utilization efficiency rate (AFUE) of 85% or greater, while conventional gas boilers have an AFUE of 80% or less (ENERGY STAR website). High-efficiency gas-boilers have features such as:

- electric ignition, which eliminates the need to have the pilot light burning all the time (ENERGY STAR website)
- new combustion technologies that extract more heat from the same amount of fuel (ENERGY STAR website)
- sealed combustion that uses outside air to fuel the burner, reducing draft and improving safety (ENERGY STAR website)
- new heat exchanger that use a different material (e.g., cast aluminum) to transfer heat faster (Dunkirk)

For our analysis, we assume 90% AFUE with a new measure (i.e., Dunkirk Quantum 90) and 80% AFUE with a baseline measure. The size of the boiler is assumed to be 84,000 Btu/hr to 90,000 Btu/hr. Based on these assumptions and using the energy savings calculator for gas boilers from ENERGY STAR website, we estimated that the new measure uses approximately 80% of the baseline energy consumption. Note that there are a few other new boilers that have higher efficiency, such as Dunkirk Quantum Leap with 95% AFUE and Burnham Hydronics Opus with 98%. However, we did not choose them as new measures because we found that both products were either discontinued or not available in Massachusetts.

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	5,186
Measure Cost – Incremental ($)	186
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	17

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	33	47
Payback Period (years)	1.5	41.2
TRC Benefit-Cost Ratio	19	0.7

Many conditions will affect the extent to which high efficiency gas boilers can be installed for low-income clients. These include: commercial availability, trained installation vendors, housing stock limitations, and fuel consumption levels. Consequently, there may be relatively few opportunities to apply this measure to low-income housing units in Massachusetts.

The installation of these high efficiency boilers could be combined with some residential hot water measures, such as indirect storage tanks, to maximize the total energy savings potential.

5.19 Trombe Wall

The term "Trombe wall" refers to a wall designed to collect solar energy and distribute it slowly to a living space. While the term is often used to describe any wall designed for this purpose, a true Trombe wall is faced with a single or double layer of glass, placed one to six inches away from the masonry wall to create a small airspace. During the day sunlight shines through the glazing and hits the surface of the thermal mass. The air between the glazing and the thermal mass warms and rises, taking heat with it. The warmer air moves through vents at the top of the wall and into the living area while cool air from the living area enters at vents near the bottom of the wall.

Trombe walls and other thermal masses are usually considered only for new construction, however, if additional glazing is being added as a retrofit measure, thermal mass should be considered as a way to store and distribute heat in the living space. In fact, where significant south-facing glass is installed without thermal mass to absorb and distribute heat, the result can be a very uncomfortable living space. We assume a total installed cost of $32,500 for a10 feet high x 25 ft wide Trombe wall. (Zapotec)

Cost and Operating Characteristics	
Lifetime (years)	25
Measure Cost – Total ($)	32,500
Measure Cost – Incremental ($)	32,500
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	35

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	37	37.1
Payback Period (years)	125	125.5
TRC Benefit-Cost Ratio	0.3	0.3

Trombe walls and other thermal masses are commercially available and applicable to homes in Massachusetts.

This technology requires a south-facing wall, as well as suitable indoor space. Specifically, the indoor space needs adjacent rooms that can be accessed through duct work, since warm air from the trombe wall is conveyed to other rooms through duct work. (Zapotec)

5.20 Wireless Thermostats

Wireless technologies are now available to replace hard-wired thermostats. The main advantage to the wireless system is in installation: walls do not have to be opened up, allowing for simpler installation and less expensive to repair or replace over time.

Wireless thermostats can be placed anywhere in the home. However, to be effective energy efficiency measures, they must be installed in conjunction with zoned heating spaces. This requires, either zoned supply and return piping for forced hot water systems, or zoned damper systems for forced warm air systems. Homes with steam systems would not be able to make use of this measure.

The NAHAB Research Center estimates that wireless thermostats reduce space heating demand by as much as 20%. For our analysis, we assume they can reduce space heating demand by 12%, in order to be conservative.

Cost and Operating Characteristics	
Lifetime (years)	20
Measure Cost – Total ($)	420
Measure Cost – Incremental ($)	285
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	10

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	2.1	2.7
Payback Period (years)	4.2	6.1
TRC Benefit-Cost Ratio	5.0	3.8

Wireless thermostats are readily available in Massachusetts. Honeywell is one of the major manufacturers of this product.

Wireless thermostats typically require homeowners to replace Two "AA" lithium batteries once a year. Also, as with hard wired thermostats, the programming aspects of the wireless thermostats are sometimes intimidating to many homeowners and tenants. (NAHB Research Center)

5.21 Ceramic Insulating Paint

The science behind insulating paint involves high-tech ceramic particles. These particles are very small and hollow – they can pack together tightly, forming an insulating matrix of ceramic material. Together these traits cause the ceramic particles to act as excellent insulators and infiltration impediments. (Hy-Tech)

This technology can be employed in two ways.

- Insulating additives can be mixed into traditional paint products. In this approach, the ceramic particles are purchased separately and can be added to any interior or exterior house paint.
- Pre-Mixed insulating house paint. The company that manufactures the ceramic particles also sells pre-mixed paint products.

Hy-Tech Thermal Solutions is the only company that manufactures this product.

Cost and Operating Characteristics	
Lifetime (years)	10
Measure Cost – Total ($)	6,432
Measure Cost – Incremental ($)	132
Electricity Savings (kWh)	0
Energy Savings (MMBtu)	4

Cost-Effectiveness:	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	3.1	151
Payback Period (years)	4.2	205
TRC Benefit-Cost Ratio	3.4	0.1

In addition to its insulating properties, ceramic insulating paint offers additional benefits to home owners and tenants:

- Improved fire resistance.
- Protection of paint surface from UV rays (less fading, as particles reflect UV light).
- Increased durability (ceramic particles are very hard.) This means one needs to paint less often – decreased maintenance costs.
- Resists corrosion, abrasion, mold, and mildew.
- Ceramics are non-toxic.
- Not a hassle to use – just add particles to paint and paint as usual.
- Helps deaden sound (good for multi-families).
- Environmentally friendly (ceramics are inert).

5.22 Sprayed Cellulose Insulation

Cellulose insulation is composed of organic materials, such as recycled paper. When sprayed to walls, cellulose requires water or adhesive, in order to stick together and to the walls of the cavity. The tight cellulose material prevents air circulation in the insulated wall and thus reduces condensation and moisture problems. (NAHB Research Center)

Wet Spray cellulose generally performs better than fiberglass because it reduces air flow and tightens the structure 36 to 38 percent more than fiberglass batts. Even if they have the same R-value, cellulose insulation can save more energy than fiberglass batts because of the reduced air flow. According to a study done by the University of Colorado, a building insulated with cellulose consumed 26.4 percent less energy than a fiberglass-insulated building. Further, a survey conducted in Massachusetts showed that the cellulose insulated building consumes 32% less energy for space heating than fiberglass of the same R-value. (CIMA)

We have performed two scenarios of the costs and benefits of sprayed cellulose insulation. First, we compare it to a housing unit that is not insulated. Second, we compare it to a housing unit that is insulated with fiberglass batts. In both cases, we only included the costs and savings associated with insulating the attic in a typical housing unit.

Cost and Operating Characteristics	**Versus No Insulation**	**Versus Fiberglass**
Lifetime (years)	20	20
Measure Cost – Total ($)	1,305	1,305
Measure Cost – Incremental ($)	1,305	435
Electricity Savings (kWh)	0	0
Energy Savings (MMBtu)	37	12

Cost-Effectiveness (Versus No Insulation):	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	1.8	1.8
Payback Period (years)	4.8	4.8
TRC Benefit-Cost Ratio	5.8	5.8

Cost-Effectiveness (Versus Fiberglass):	Incremental Case	Total Case
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	1.8	5.4
Payback Period (years)	4.9	15
TRC Benefit-Cost Ratio	5.7	1.9

This product is readily available in Massachusetts. However, this measure is often not a viable option for attic insulation applications given the effects it would have on existing electrical, lighting, storage, and other structural conditions found in a retrofit environment. Wall insulation applications will be constrained as well. This wet spray application will be most appropriate in open, empty bays, and gut rehab/new construction situations. Thus, there may only be very limited applications for low-income housing units in Massachusetts.

Availability of trained installation vendors may also be an issue in some locations in Massachusetts.

Sprayed cellulose significantly increases fire resistance. This is a non-energy benefit under the TRC test.

5.23 High Performance Windows

Windows are a primary source of heat loss in homes throughout Massachusetts. ACEEE states that windows can account for 25 percent of heat loss of homes. High performance windows adopt low emissivity glazing, inert gas fills, insulating spacers, and better design of window frames and, save up to 20% of energy usage for space heating, relative to standard new windows.

ACEEE describes high-performance windows as those that have a U-value of less than 0.25. (The U-value is the inverse of the R-value. The lower the U value, the less heat that is lost through the window surface.) These high-performance windows exceed the ENERGY STAR requirement for efficient windows, which is a U-value less than 0.35. (ACEEE 2004a)

We have performed two scenarios for high-performance windows. First, we compare the installation of high-performance windows with the installation of standard new windows commercially available in Massachusetts today. We rely upon the ACEEE study , which indicates that a high-performance window with a U-value of less than 0.25 will reduce gas space heating costs by roughly 0.8 MMBtu per window, relative to new windows. Second, we compare replacing old existing windows with high-performance windows. Here, we assume that standard new windows installed in Massachusetts today can save roughly 0.5 MMBtu per window, relative to existing windows. Therefore, the total savings of the high-performance window in this case is 1.3 MMBtu per window (0.8+0.5).

Cost and Operating Characteristics	**Vs. Existing**	**Vs. New**
Lifetime (years)	35	35
Measure Cost – Total ($)	475	75
Measure Cost – Incremental ($)	475	75
Electricity Savings (kWh)	0	0
Energy Savings (MMBtu)	1.3	0.8

Cost-Effectiveness (Vs. Existing):	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	10.4	10.4
Payback Period (years)	49	49
TRC Benefit-Cost Ratio	0.9	0.9

Cost-Effectiveness (Vs. New):	**Incremental Case**	**Total Case**
Cost of Saved Electricity ($/MWh)	---	---
Cost of Saved Energy ($/MMBtu)	2.7	2.7
Payback Period (years)	13	13
TRC Benefit-Cost Ratio	3.6	3.6

This measure is readily available in Massachusetts. The MassSAVE program offered by Massachusetts energy efficiency program administrators currently offers a $10 rebate for installing efficient new windows.

Installation specifications should identify visible transmittance, solar heat gain coefficient, UV blockage, and framing standards for installation in the low-income market.

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Appendix A. List of All Advanced Efficiency Measures Considered

Category	Technology
Appliances	
	1-watt standby power for home appliances
	ENERGY STAR Clothes Washers
	gas oven/range w/ electronic ignition instead of pilot light
	high efficiency dehumidifiers
	high efficiency refrigerators (1 kWh per day)
	IT wiring for home automation systems
Building Envelope - Existing Homes	
	airtight drywall approach (multi-family)
	ceramic insulating paint
	combination ventilation and drip edge system
	cool color roofing
	exterior insulation and finish systems
	exterior insulation: vinyl siding
	insulation alternatives: non-fiberglass batts
	insulation alternatives: sprayed fiber insulation
	insulation alternatives: sprayed foam insulation
	low energy elevators
	mineral-wool based exterior insulation & finishing
	phase change materials
	plastic composite siding
	vacuum insulation panel (VIP)
Building Envelope - New Construction	
	advanced framing techniques: optimum value engineering
	autoclaved aerated concrete
	concrete construction
	drywall clips and stops
	electric radiant ceiling panels
	frost-protected shallow foundations
	high quality envelope insulation
	HVAC Equipment and duct installation w/in conditioned space
	insulated concrete forms (wood fiber composite)
	insulated headers
	insulation alternatives: blown or foamed through membrane
	Leak-proof duct fittings
	pre-cast concrete passive solar home
	pumice-crete
	radiant floor heating - dry system hydronic
	rammed earth construction
	steel L-headers

	straw bale construction
	structural insulated panels
	transparent insulation (multi-family)
	underground air supply
	wood foundations
Cooling	
	2-stage evaporative cooler
	displacement ventilation (multi-family)
	enthalpy heat exchangers (multi-family)
	evaporative coolers
	external shading devices
	gas engine driven chillers (multi-family)
	Heat pump: ductless (mini-split)
	hydronic radiant cooling
	radiant barriers
	reinforced grass paving systems (multi-family)
	desiccant cooling/dehumidification (multi-family)
	shading with vegetation
	solar cooling
Heating and Cooling Distribution, etc	
	advanced HVAC fan motors
	aerosol duct sealing
	building automation systems (multi-family)
	gas-fired humidification (multi-family)
	heat/energy recovery ventilators
	high efficiency bathroom fans
	humidity-sensing control device
	mini-duct (high velocity heating/cooling) air distribution
	programmable brushless direct current motors
Heating Supply	
	heat pump: ground-coupled /geoexchange
	heat pump: advanced cold-climate / frostless heat pump
	heat pump: residential gas absorption chiller
	HVAC "smart" zoning controls
	modular air handler hot water coil
	modulating furnace
	passive solar ventilation air pre-heater (Solar Wall)
	programmable thermostats
	recuperative gas boilers
	wireless thermostats
Lighting	
	airtight CFL downlights
	compact fluorescent lighting
	fiber optic lighting
	general service halogen Infrared reflecting (HIR) lamps
	HID electronic ballasts and lamps

	high-quality CFL fixtures
	light-sensing controls
	occupancy sensors
	replacement of exit signs in buildings
	replacement of magnetic ballasts with electronic ballasts
	solar powered walkway and patio lights
	white LED lighting
Water/plumbing	
	drain water recovery
	hot water recirculation systems (multi-family)
	laminar flow fixtures
	low flow faucets
	low flow shower heads
	low flush toilets
	water heater: heat pump
	water heater: residential condensing
	water heater: tankless w/out space heating
	water heater: tankless with space heating
Windows and Doors	
	electrochromic glazing
	energy efficient interior storm windows
	gas-filled windows
	heating glass
	high performance windows (U<0.25)
	low conductivity window frames
	low-E glass and spectrally selective glazing
	composite window frames
	tinted glass windows
	tubular skylights
	warm edge windows
	window film

Appendix B. Table of Alternative Energy Measure Cost and Performance

		Energy Produced						Measure Costs				
Technology	End-Use	Size (kW or Btu/hr)	Lifetime (year)	Electric Capacity Factor (%)	Electricity Generation (kWh)	Heating Efficiency (%)	Heat Generation (mmBtu)	Capital Costs ($)	Capital Cost Per kW ($/kw)	Installation + Interconnect. Costs ($)	Fuel Price ($/mmBtu)	Fuel Use (mmBtu/yr)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]
Microturbine (gas)	electricity & heat	30	10	90%	236,520	44%	1466	46,800	1,560	30,100	8.0	3,565
Microturbine (biodiesel)	electricity & heat	30	10	90%	236,520	44%	1466	46,800	1,560	30,100	15.4	3,565
Internal Combustion (biodiesel)	electricity & heat	45	20	95%	374,490	40%	1503	58,500	1,300	39,600	15.4	3,760
Micro Stirling Engine (gas)	electricity & heat	2	10	76%	13,288	40%	46	6,000	3,000	2,700	8.0	116
Fuel Cell PEM (gas)	electricity & heat	10	10	85%	74,460	39%	298	49,500	4,950	5,600	8.0	847
Fuel Cell SO (gas)	electricity & heat	25	10	85%	186,150	25%	354	375,000	15,000	16,350	8.0	1,411
PV: inclined roof (efficient)	electricity	2.76	25	18%	4,352	---	---	17,940	6,500	8,280	0.0	0
PV: inclined roof (less efficient)	electricity	2.76	25	15%	3,627	---	---	15,180	5,500	8,280	0.0	0
PV: flat roof	electricity	2.52	25	14%	3,091	---	---	17,640	7,000	7,560	0.0	0
PV: ground mounted	electricity	2.76	25	16%	3,868	---	---	16,560	6,000	8,280	0.0	0
PV: building integrated	electricity	2.55	25	12%	2,684	---	---	25,536	10,000	12,768	0.0	0
Wind Micro (0-3 kW)	electricity	0.9	20	25%	1,971	---	---	2,600	2,889	500	0.0	0
Wind Small (3-60 kW)	electricity	10	25	27%	23,652	---	---	22,900	2,290	17,100	0.0	0
Micro Hydro	electricity	0.92	40	50%	4,030	---	---	10,000	10,870	4,800	0.0	0
Wood hybrid furnace/boiler	space heating	125,000	20	---	---	80%	130	3,000	0	2,000	8.3	162
Wood hybrid (free wood)	space heating	125,000	20	---	---	80%	130	3,000	0	2,000	0.0	162

Notes and Sources (for the columns)

[C] Keep size to 60 kW or less, in order to ensure that the measure is behind the meter.
[G] Heating Efficiency = efficiency of fuel conversion to useful heat
[H] Heat Gen. = useful heat generated by AE technology in a year
[K] In Massachusetts, for installations of 10 kW and under the interconnection costs are standardized. Above 10 kW interconnection gets more expensive.
[N] Major overhauls are levelized in maintenance costs.
[O] Annualized costs equal (the sum of the capital, installation and interconnection costs, divided by the lifetime), plus the annual maintenance costs, plus any annual fuel costs.
[P] The cost of generated electricity is (the annualized cost minus the revenue from RECS) divided by the electricity generation per year.
[P] For cogeneration measures: the "electric portion" of the annualized cost is divided by the annual MWh production.
[Q] For cogeneration measures: the "heat portion" of the annualized cost is divided by the annual heat generation.
[R] Payback period is equal to the (capital + installation + interconnection) costs divided by the annual savings.
[R] Annual savings is equal to the fuel cost savings, plus any revenues from RECs, less any fuel costs, less maintenance costs.
[R] A negative payback period occurs when the annual costs exceed the annual savings; indicating that the measure will never pay for itself.
[S] & [T] The Net Benefits and the BCR include a scaler for LI non-energy benefits. The benefits are scaled up by 50%.
[S] & [T] The Net Benefits and the BCR do not include the revenues from RECs, as these are a transfer payment.
[V] The cost of CO2 saved is equal to the annualized cost, minus the annual avoided costs, divided by the tons of CO2 saved. The avoided costs are system avoided costs (not price), thus this is from a TR
[W] The revenue from RECs is equal to the electricity generation times the assumed REC price. This revenue is included in the cost of generated electricity and the payback period.

Alternative Energy Measures Cost and Performance (continued)

	Cost-Effectiveness					Other Impacts			Applicability	
Technology	Cost of Electricity Generated ($/MWh)	Cost of Heat Generated ($/mmBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)	CO2 Saved (lbs/yr)	Cost of CO2 Saved ($/ton)	Revenue From RECs ($/yr)	Housing Type (S, M or M+)	Commercialization Status
[A]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]
Microturbine (gas)	61	18	24	-55,321	0.86	94,182	317	0	M+	Com
Microturbine (biodiesel)	71	29	-5	-306,381	0.52	394,563	218	7,096	M+	Com
Internal Combustion (biodiesel)	56	25	-40	-436,555	0.66	492,884	158	11,235	M+	Com
Micro Stirling Engine (gas)	77	0.7	15	-4,549	0.77	6,135	322	0	M, M+	Com in 2006
Fuel Cell PEM (gas)	91	5.3	55	-53,246	0.63	28,593	600	0	M+	Com
Fuel Cell SO (gas)	202	14	113	-389,273	0.32	73,697	1,245	0	M+	Com in 3 years
PV: inclined roof (efficient)	257	---	65	-18,041	0.41	4,352	406	131	S, M, M+	Com
PV: inclined roof (less efficient)	284	---	78	-16,436	0.41	3,627	444	109	S, M, M+	Com
PV: flat roof	361	---	111	-19,489	0.34	3,091	591	93	S, M, M+	Com
PV: ground mounted	279	---	74	-17,427	0.40	3,868	438	116	S, M, M+	Com
PV: building integrated	615	---	224	-33,046	0.22	2,684	1,081	81	S, M, M+	Com
Wind Micro (0-3 kW)	59	---	12	567	1.16	1,971	29	59	S, M, M+	Com
Wind Small (3-60 kW)	59	---	14	6,506	1.13	23,652	33	710	S, M, M+	Com
Micro Hydro	95	---	35	-7,684	0.59	4,030	130	121	S, M, M+	Com
Wood hybrid furnace/boiler	---	14	-9	-6,335	0.81	20,930	76	0	S, M, M+	Com
Wood hybrid (free wood)	---	3.3	6	18,249	3.24	20,930	-52	0	S, M, M+	Com

Appendix C. Table of Efficiency Measure Cost and Performance

Advanced Energy Efficiency Measures: Incremental Cost Case

Measure	End-Use Type	Lifetime (years)	Annual Electric Use (kWh)	Annual Electric Savings (kWh)	Annual Electric Savings (%)	Annual Oil/Gas Use (MMBtu)	Annual Oil/Gas Savings (MMBtu)	Annual Oil/Gas Savings (%)	Other Savings ($/yr)	Measure Cost ($)	Incremental Measure Cost ($)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]
Occupancy sensors	Lighting	10	0	49	30%	0	0	0%	0	38	63
White Light Emitting Diodes	Lighting	13	31	51	62%	0	0	0%	0.3	58	57
ENERGY STAR Clothes Washers	Appliance	14	25	36	59%	1.8	1.6	47%	55	750	300
High-Eff. Refrig. (vs. existing)	Appliance	19	347	903	72%	0	0	0%	0	520	520
High-Eff. Refrig.(vs. new)	Appliance	19	347	149	30%	0	0	0%	0	520	70
Drainwater heat recovery	Water heating	20	0	0	0%	0	8.1	30%	0	400	550
Hot water recirculation systems	Water heating	20	15	0	0%	0	2.1	8%	14	350	500
Laminar flow aerators	Water heating	10	0	0	0%	0	0.5	2%	26	30	30
Solar Hot Water (flat plate)	Water heating	20	0	0	0%	0	27.4	101%	0	1,980	4,980
Solar Hot Water (evacuated tube)	Water heating	20	0	0	0%	0	26.2	97%	0	5,120	7,620
Water heater: condensing	Water heating	15	100	0	0%	19	7.8	29%	0	1,800	1,200
Water heater: instantaneous	Water heating	20	190	0	0%	18	9	32%	64	1,100	720
Water heater: indirect	Water heating	30	0	0	0%	15	12	46%	0	600	220
Advanced HVAC fan motors	Heating distribution	15	299	510	63%	2.2	0	0%	0	105	80
Duct sealing: aerosol	Heating distribution	25	0	0	0%	0	16	19%	0	700	850
High efficiency bathroom fans	Heating distribution	33	18	62	77%	0	0	0%	0	110	40
Heat Pump: ground-coupled	Heating supply	18	7,890	0	0%	0	25	22%	0	7,600	4,220
Heat Pump: advanced cold-climate	Heating supply	20	10,805	0	0%	0	12	14%	0	4,300	920
High-efficiency gas boilers	Heating supply	20	0	0	0%	68	17	20%	0	3,186	186
Trombe Wall	Heating supply	25	0	0	0%	0	35	41%	0	32,500	32,500
Wireless thermostats	Heating supply	20	14	0	0%	0	10	12%	0	320	285
Ceramic insulating paint	Building envelope	10	0	0	0%	0	4	5%	0	432	132
Cellulose insulation (vs. no insul.)	Building envelope	20	0	0	0%	0	37	44%	0	1,305	1,305
Cellulose insulation (vs. fiberglass)	Building envelope	20	0	0	0%	0	12	14%	0	1,305	435
High perf. Windows (vs. existing)	Building envelope	35	0	0	0%	0	1.3	1.5%	0	400	475
High perf. windows (vs. new)	Building envelope	35	0	0	0%	0	0.8	0.9%	0	400	75

Notes and Sources (for the columns):

[C] Unless better information was available, we assumed lifetimes as follows: water heating 20, heating and cooling distribution 15, heating and cooling supply 20, and building envelope 20.

[D[If a measure consumes electricity in order to save fossil fuels, then the cost of the electricity is included in the Other Costs column.

[E] Can be calculated as the difference between baseline and efficiency measure, or input directly.

[G] If a measure consumes fossil fuels in order to save electricity, then the cost of fossil fuels is included in the Other Costs column.

[H] Can be calculated as the difference between baseline and efficiency measure, or input directly.

[L] Can be calculated as the difference between baseline and efficiency measure, or input directly.

[N] Annualized costs equals INCREMENTAL cost divided by lifetime, plus other costs for the measure less other costs for the baseline measure. N = (L / C) + M - W.

[O] Cost of saved electricity ($/kWh) equals the annualized costs divided by the annual electricity savings. O = N / E *1000.

[P] Cost of saved energy ($/MMBtu) for the oil/gas savings equals annualized cost divided by mbtu savings. P = N / H

[Q] Payback period includes the electricity savings plus the oil/gas savings. Q = L / ((E * electric price) + (H * gas price) + J - M + W).

[R] & [S] The Net Benefits and the BCR include a scaler for LI non-energy benefits. The benefits are scaled up by 50%.

[Y] The cost of CO2 saved is equal to the annualized cost, minus the annual avoided costs, divided by the tons of CO2 saved. The avoided costs are system avoided costs (not price), thus this is from a

Advanced Energy Efficiency Measures: Incremental Cost Case (continued)

Measure	Other Costs ($/yr)	Annualized Costs ($/yr)	Cost of Electricity Saved ($/MWh)	Cost of Heat Saved ($/MMBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)	Annual Electric Use (kWh)	Annual Oil/Gas Use (MMBtu)	Total Up-Front Cost ($)	Other Costs (Savings) ($/yr)
[A]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]
Occupancy sensors	0	6.3	128	---	12	4	1.1	---	---	---	0
White Light Emitting Diodes	0	4.4	86	---	9.8	38	1.7	82	---	1	0
ENERGY STAR Clothes Washers	0	21.4	595	22	4.2	1,064	4.6	61	3.4	450	0
High-Eff. Refrig. (vs. existing)	0	27.4	30	---	5.3	730	2.4	1,250	---	450	0
High-Eff. Refrig.(vs. new)	0	3.7	25	---	4.3	136	3.0	496	---	450	0
Drainwater heat recovery	0	27.5	---	3.4	9.2	1,100	3.0	---	27	---	0
Hot water recirculation systems	1.6	26.6	---	12.5	17.6	299	1.6	---	27	---	0
Laminar flow aerators	0	3.0	---	5.6	1.0	393	14	---	27	---	0
Solar Hot Water (flat plate)	0	249	---	9.1	25	629	1.1	0	27	---	0
Solar Hot Water (evacuated tube)	0	381	---	14.5	39	-2,227	0.7	0	27	---	0
Water heater: condensing	11	90.8	---	31	25	-126	0.9	0	27	600	0
Water heater: instantaneous	21	56.5	---	23	6.4	2,438	3.2	0	27	380	0
Water heater: indirect	0	7.3	---	9.9	2.4	4,043	19.5	0	27	380	0
Advanced HVAC fan motors	18	22.9	45	---	2.1	388	2.2	809	0	25	0
Duct sealing: aerosol	0	34.0	---	2.1	7.1	3,180	4.8	0	85	---	0
High efficiency bathroom fans	0	1.2	20	---	6	134	4.4	80	0	70	0
Heat Pump: ground-coupled	0	234	---	9.5	23	355	1.1	0	112	3,380	0
Heat Pump: advanced cold-climate	0	46.0	---	3.9	10	1,505	2.7	0	85	3,380	0
High-efficiency gas boilers	0	9	---	33	1.5	3,269	18.7	0	85	3,000	0
Trombe Wall	0	1,300	---	37	125	-23,504	0.3	0	85	0	0
Wireless thermostats	7	21.3	---	2.1	4.2	1,661	5.0	0	85	35	0
Ceramic insulating paint	0	13.2	---	3.1	4.2	318	3.4	0	85	300	0
Cellulose insulation (vs. no insul.)	0	65.3	---	1.8	4.8	6,223	5.8	0	85	0	0
Cellulose insulation (vs. fiberglass)	0	21.8	---	1.8	4.9	2,007	5.7	0	85	870	0
High perf. Windows (vs. existing)	0	13.6	---	10.4	49	-35	0.9	0	85	0	0
High perf. windows (vs. new)	0	2.1	---	2.7	13	194	3.6	0	85	325	0

Advanced Energy Efficiency Measures: Incremental Cost Case (continued)

Measure	Other Costs ($/yr)	Annualized Costs ($/yr)	Cost of Electricity Saved ($/MWh)	Cost of Heat Saved ($/MMBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)	CO2 Saved (lbs/year)	Cost of CO2 Saved ($/ton)	Housing Type (S, M or M+)	Commercialization Status
[A]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[X]	[Y]	[Z]	[AA]
Occupancy sensors	0	6.3	128	---	12	4	1.1	49	66	S, M, M+	Com
White Light Emitting Diodes	0	4.4	86	---	9.8	38	1.7	51	-14	S, M, M+	Com, Proto
ENERGY STAR Clothes Washers	0	21.4	595	22	4.2	1,064	4.6	294	52	S, M, M+	Com
High-Eff. Refrig. (vs. existing)	0	27.4	30	---	5.3	730	2.4	903	-45	S, M, M+	Com
High-Eff. Refrig.(vs. new)	0	3.7	25	---	4.3	136	3.0	149	-56	S, M, M+	Com, 2004
Drainwater heat recovery	0	27.5	---	3.4	9.2	1,100	3.0	1,304	-47	S, M	Com
Hot water recirculation systems	1.6	26.6	---	12.5	17.6	299	1.6	344	66	S, M, M+	Com
Laminar flow aerators	0	3.0	---	5.6	1.0	393	14	87	-20	S, M, M+	Com
Solar Hot Water (flat plate)	0	249	---	9.1	25	629	1.1	4,411	23	S, M, M+	Com
Solar Hot Water (evacuated tube)	0	381	---	14.5	39	-2,227	0.7	4,223	90	S, M, M+	Com
Water heater: condensing	11	90.8	---	31	25	-126	0.9	1,261	53	S, M, M+	Com
Water heater: instantaneous	21	56.5	---	23	6.4	2,438	3.2	1,406	-11	S, M, M+	Com
Water heater: indirect	0	7.3	---	9.9	2.4	4,043	19.5	2,007	-84	S, M, M+	Com
Advanced HVAC fan motors	18	22.9	45	---	2.1	388	2.2	510	-45	S, M, M+	Com
Duct sealing: aerosol	0	34.0	---	2.1	7.1	3,180	4.8	2,600	-66	S, M, M+	Com
High efficiency bathroom fans	0	1.2	20	---	6	134	4.4	62	-95	S, M, M+	Com
Heat Pump: ground-coupled	0	234	---	9.5	23	355	1.1	3,967	26	S, M, M+	Com
Heat Pump: advanced cold-climate	0	46.0	---	3.9	10	1,505	2.7	1,916	-45	S, M, M+	Com
High-efficiency gas boilers	0	9	---	33	1.5	3,269	18.7	2,737	-86	S, M, M+	Com
Trombe Wall	0	1,300	---	37	125	-23,504	0.3	5,635	369	S	Com
Wireless thermostats	7	21.3	---	2.1	4.2	1,661	5.0	1,642	-67	S, M, M+	Com
Ceramic insulating paint	0	13.2	---	3.1	4.2	318	3.4	684	-54	S, M, M+	Com
Cellulose insulation (vs. no insul.)	0	65.3	---	1.8	4.8	6,223	5.8	5,957	-71	S, M, M+	Com
Cellulose insulation (vs. fiberglass)	0	21.8	---	1.8	4.9	2,007	5.7	1,932	-70	S, M, M+	Com
High perf. Windows (vs. existing)	0	13.6	---	10.4	49	-35	0.9	209	37	S, M, M+	Com
High perf. windows (vs. new)	0	2.1	---	2.7	13	194	3.6	129	-59	S, M, M+	Com

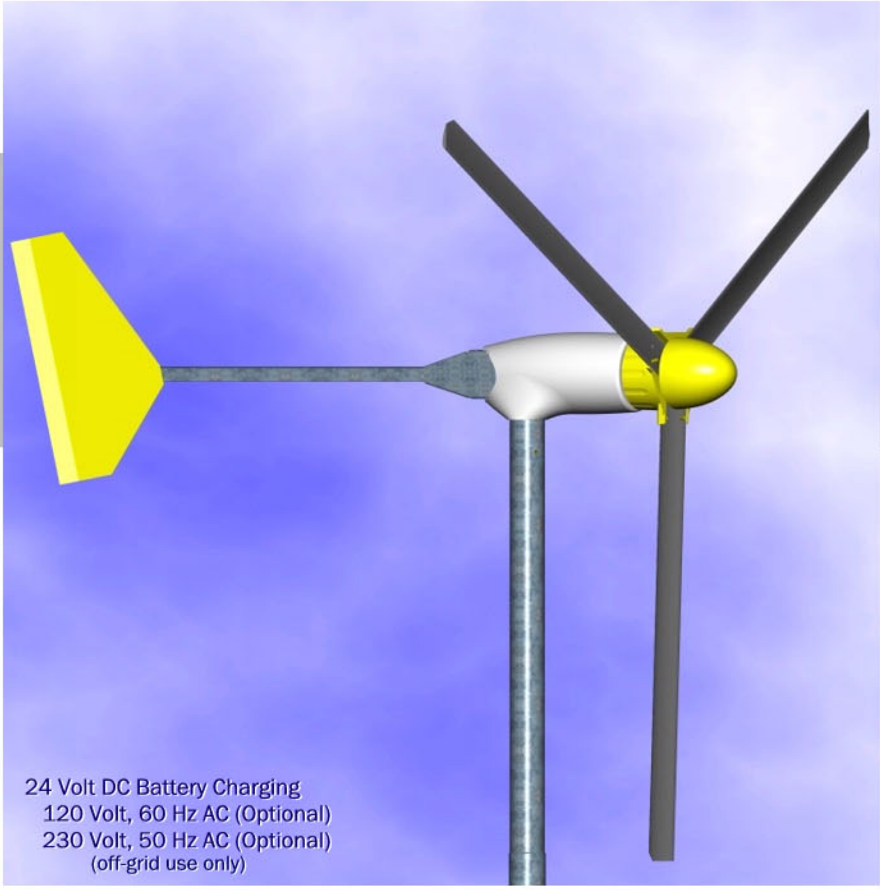
Advanced Energy Efficiency Measures: Total Cost Case

		Measure Costs				Cost-Effectiveness					
Measure	End-Use Type	Measure Cost ($)	Measure Installation Cost ($)	Other Costs ($/yr)	Annualized Costs ($/yr)	Cost of Electricity Saved ($/MWh)	Cost of Heat Saved ($/MMBtu)	Payback Period (years)	TRC Net Benefits (pv$)	TRC Ben-Cost Ratio (bcr)	Savings to Investment Ratio (DOE)
[A]	[B]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]
Occupancy sensors	Lighting	38	25	0	6.3	128	---	12	4	1.1	0.8
White Light Emitting Diodes	Lighting	58	5	0	4.8	95	---	11	32	1.5	1.1
ENERGY STAR Clothes Washers	Appliance	750	25	0	55.4	1,538	44	11	594	1.8	0.3
High-Eff. Refrig. (vs. existing)	Appliance	520	25	0	28.7	32	---	5.6	705	2.3	3.1
High-Eff. Refrig.(vs. new)	Appliance	520	0	0	27.4	184	---	32	-310	0.4	0.5
Drainwater heat recovery	Water heating	400	150	0	27.5	---	3.4	9.2	1,100	3.0	2.0
Hot water recirculation systems	Water heating	350	150	2	26.6	---	12.5	17.6	299	1.6	0.6
Laminar flow aerators	Water heating	30	5	0	3.5	---	6.5	1.2	388	12.2	1.1
Solar Hot Water (flat plate)	Water heating	1,980	3,000	0	249.0	---	9.1	25	629	1.1	0.7
Solar Hot Water (evacuated tube)	Water heating	5,120	2,500	0	381.0	---	15	39	-2,227	0.7	0.5
Water heater: condensing	Water heating	1,800	100	11	137.5	---	37	40	-820	0.6	0.4
Water heater: instantaneous	Water heating	1,100	100	21	80.5	---	26	11	1,962	2.3	1.0
Water heater: indirect	Water heating	600	150	0	25.0	---	11	8	3,517	5.7	3.8
Advanced HVAC fan motors	Heating distribution	105	75	18	29.6	58	---	4.8	289	1.7	4.3
Duct sealing: aerosol	Heating distribution	700	150	0	34.0	---	2.1	7	3,180	4.8	3.2
High efficiency bathroom fans	Heating distribution	110	50	0	4.9	79	---	24	15	1.1	1.2
Heat Pump: ground-coupled	Heating supply	7,600	3,000	0	588.9	---	24	58	-5,971	0.4	0.3
Heat Pump: advanced cold-climate	Heating supply	4,300	3,000	0	365.0	---	31	83	-4,820	0.3	0.2
High-efficiency gas boilers	Heating supply	3,186	2,000	0	259.3	---	47	41	-1,688	0.7	0.4
Trombe Wall	Heating supply	32,500	0	0	1,300	---	37	125	-23,504	0.3	0.2
Wireless thermostats	Heating supply	320	100	7	28.0	---	2.7	6	1,528	3.8	3.3
Ceramic insulating paint	Building envelope	432	6,000	0	643.2	---	151	205	-5,928	0.1	0.0
Cellulose insulation (vs. no insul.)	Building envelope	1,305	0	0	65.3	---	1.8	5	6,223	5.8	3.8
Cellulose insulation (vs. fiberglass)	Building envelope	1,305	0	0	65.3	---	5.4	15	1,144	1.9	1.2
High perf. Windows (vs. existing)	Building envelope	400	75	0	13.6	---	10	49	-35	0.9	0.6
High perf. windows (vs. new)	Building envelope	75	0	0	2.1	---	2.7	13	194	3.6	2.4

Notes and Sources (for the columns):

[L] Measure installation costs: Unless otherwise noted, these are rough estimates by Synapse, with reality check from Art Wilcox.
[N] Annualized costs equals TOTAL cost divided by lifetime, plus other costs for the measure less other costs for the baseline measure. N = (K / C) + M - X.
[O] Cost of saved electricity ($/kWh) equals the annualized costs divided by the annual electricity savings. O = N / E *1000.
[P] Cost of saved energy ($/MMBtu) for the oil/gas savings equals annualized cost divided by mbtu savings. P = N / H
[Q] Payback period includes the electricity savings plus the oil/gas savings. Q = K / ((E * electric price) + (H * gas price) + J - M + X).
[R] & [S] The Net Benefits and the BCR include a scaler for LI non-energy benefits. The benefits are scaled up by 50%.
[T] Savings to Investment Ratio (SIR) is based on the DOE definition, and typically (but not always) equals (kWh savings * electricity price * measure life) / total cost.
[T] The SIRs do not include the scaler for LI non-energy benefits.

Appendix D. Spec Sheet for Bergey Windpower BWC XL1 Turbine



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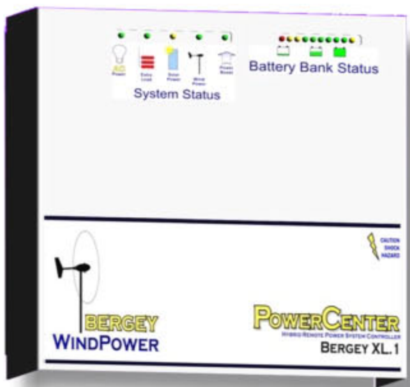
- Optional Integrated 500 W Sine Inverter
- Complete Tubular Tilt-up Towers Available
- Complete "Plug and Play" Systems Available

The Bergey XL.1 is the most technically advanced small wind turbine ever. It comes from the world's leading manufacturer of small wind turbines and is backed by a full 5-year warranty. The XL.1 wind turbine is designed for high reliability, low maintenance, and automatic operation in adverse weather conditions. And the XL.1's "all-in-one" PowerCenter provides complete hybrid system integration, including an optional on-board sine wave inverter. Owner installations are a snap with Tilt-up Tower options from 30 - 104 ft.

Easy to install, extremely reliable, and a solid value, the Bergey XL.1 is the clear choice for your home energy system.

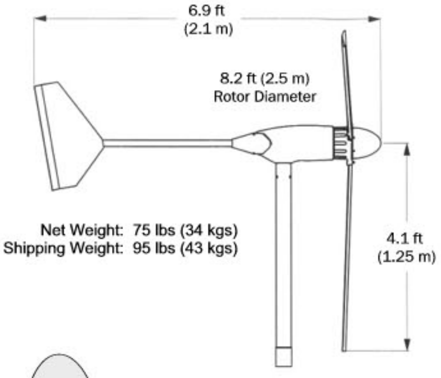


BWC XL.1 PowerCenter Controller

All-Inclusive Tilt-up Tower Kits Available:
30 ft (9 m)
43 ft (13 m)
64 ft (20 m)
84 ft (26 m)
104 ft (32 m)

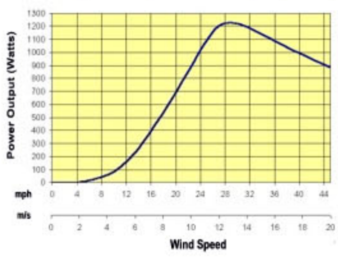
30 ft Tilt-up Tower, with Optional 200 W Solar Array

The Only Moving Parts Are The Parts You See Moving



Performance

Start-up Wind Speed ... 6.7 mph (3 m/s)
Cut-In Wind Speed ... 5.6 mph (2.5 m/s)
Rated Power ... 1,000 Watts
Rated Wind Speed ... 24.6 mph (11 m/s)
Rated Rotor Speed ... 490 RPM
Furling Wind Speed ... 29 mph (13 m/s)
Max. Design Wind Speed ... 120 mph (54 m/s)



Predicted Energy Production

Wind Speeds Taken at Top of Tower

Annual Average Wind Speed (m/s)		3.5	4	4.5	5	5.5	6	6.5
Annual Average Wind Speed (mph)		7.8	8.9	10.1	11.2	12.3	13.4	14.5
Production in kWh (24 VDC)	Daily	1.9	2.8	3.9	5.1	6.4	7.7	8.9
	Monthly	55	85	115	155	195	235	270
	Annually	680	1,010	1,410	1,850	2,320	2,790	3,260

Wind Speeds Taken at 10 meters (per standard wind resource maps)

US-DOE Wind Power Class			1	2	3	4	5	6	7
Annual Average Wind Speed (mph)			~ 8.9	~ 10.7	~ 12.1	~ 13.0	~ 13.9	~ 15.0	~ 18.8
Annual Average Wind Speed (m/s)			~ 4.0	~ 4.8	~ 5.4	~ 5.8	~ 6.2	~ 6.7	~ 8.4
Production in kWh (24 VDC)	30 ft (9m) Tower	Daily	2.6	4.3	5.8	6.8	7.8	9.1	12.7
		Monthly	80	130	175	205	240	275	385
	64 ft (20m) Tower	Daily	4.1	6.4	8.2	9.3	10.4	11.7	14.7
		Monthly	125	195	250	285	320	355	445
	104 ft (32m) Tower	Daily	5.2	7.8	9.7	10.9	12.0	13.1	15.4
		Monthly	160	235	295	330	365	400	465

Assumptions: Inland site, Rayliegh Wind Distrubution, Shear Exponent = 0.20, Altitude = 1000ft (300m).
Note: Battery charge regulation (batteries full) and wire run losses will reduce actual XL.1 performance.
Your Performance May Vary.

Dealer:

BERGEY WINDPOWER

Simplicity • Reliability • Performance

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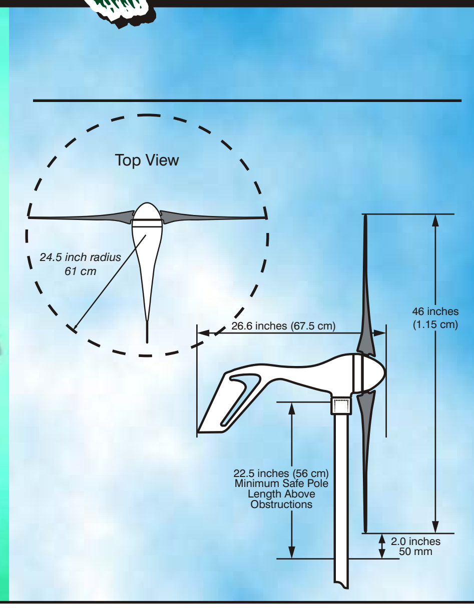
Appendix E. Spec Sheet for Southwest Windpower Air X Turbine

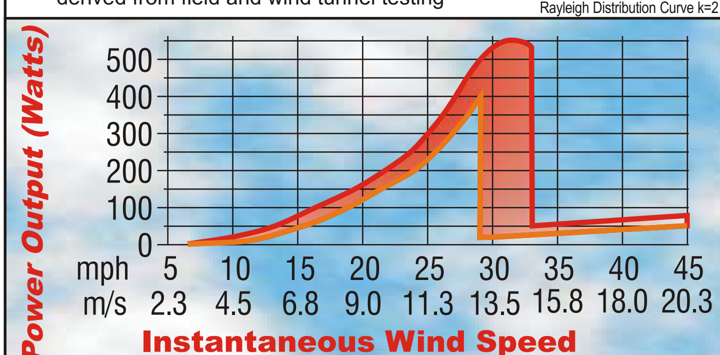
AIR X SPECIFICATIONS

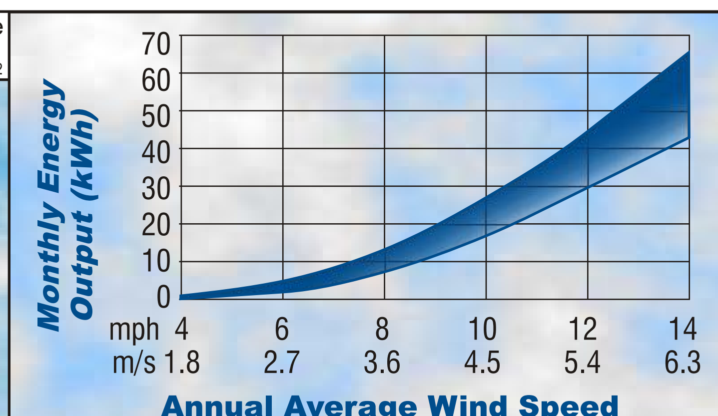


Rotor Diameter:	**46 inches (1.15m)**
Weight:	**13 lbs (5.85 kg) (Shipping: 27" x 15" x 9" (686x38x228mm)/17 lbs (7.7kg))**
Mount:	**1.5" schedule 40 pipe (1.9" OD, 48 mm)**
Start-up wind speed:	**7 mph (3.13 m/s)**
Voltage:	**12 and 24 VDC (48 VDC in development)**
Rated Power:	**400 watts @ 28 mph (12.5 m/s)**
Turbine Controller:	**Microprocessor-based internal regulator with Peak Power Tracking**
Blades (three):	**Carbon fiber composite**
Body:	**Cast aluminum** (AIR-X Marine is powder coated for corrosion protection)
Kilowatt hrs. per month:	**38 kWh/mo @ 12 mph (5.4 m/s)**
Warranty:	**3 Year Limited Warranty**
Survival Wind speed:	**110 mph (49.2 m/s)**
Over-speed protection:	**Electronic torque control**

Performance Curves*
*derived from field and wind tunnel testing

Non-Turbulent Site
Turbulent Site
Rayleigh Distribution Curve k=2





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