Cool Citizens

Everyday Solutions to Climate Change

Household Solutions:

Residential carbon dioxide emissions profile and calculations of CO_2 reduction measures

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Introduction

The following tables—and their extensive footnotes—detail the characteristics of the "typical" U.S. single-family household that we have profiled in the *Cool Citizens: Household Solutions* brief. This background report also describes our calculations, assumptions, and methods of estimating energy- and greenhouse-saving measures.

We have developed this profile for energy consumption, energy costs, and the emissions of greenhouse gases (carbon dioxide only, in this case) resulting from the direct and indirect use of energy in the household. (We exclude related emissions of greenhouse gases such as methane from coal mines and landfills, nitrous oxide from fertilizers, and leaking refrigerants in this analysis. A number of these emissions and how homeowners and consumers can help curb the rising atmospheric concentrations of these sources will be discussed in future briefs in this series.) We have carefully broken out energy use and emissions by end uses (such as heating, cooling, and appliances) after consideration of the various fuels used for each end use and the carbon dioxide content of fuels. Bear in mind that this household profile is an amalgamated average for a great variety of climate zones, heating and cooling requirements, types of installed equipment, size and age and condition, and numerous other factors that will very likely differ from your consumption and CO_2 emissions patterns. Furthermore, the carbon content of electricity generated at your utility's power plants may be higher or lower than the U.S. average emissions per kilowatt-hour we use in this study (1.43 lbs CO_2 per kWh consumed).

Our goal is to discuss numerous ways for ordinary homeowners to cost-effectively reduce their CO_2 emissions in their own homes. The creation of the detailed emissions by end uses is critical for developing realistic estimates of how much our emissions are reduced by individual measures (adding insulation in the attic or replacing an old refrigerator, for example). We have also been able to estimate the cost of the energy and emission-saving measures, which enables us to develop a strategy for the best combination of measures and their implementation sequence. This takes two paths: the first is to estimate the savings by each measure in isolation (identified in the following tables as the non-integrated approach, and under space heating and cooling as analysis "A"). The second approach estimates savings of each measure *after* the savings from the previous measures have reduced the energy consumption and emissions that remain (the integrated approach, or analysis "B"). This is particularly relevant in space heating, cooling, and water heating. Again, these are best-guess estimates only, and applied to a hypothetical "average" house.

The *Cool Citizens: Household Solutions* brief discusses how these measures, costs, and savings can be combined to maximum benefit for the homeowner, the communities in which we live, and the world's climate. That brief details how all homeowners can dramatically reduce emissions of carbon dioxide at a profit, no matter where or in which type of home we live. The brief presents, for the intrepid, information on how climate neutrality, or *net zero emissions*, can be achieved by 2012. This strategy first maximizes emissions-reducing measures (prioritized and sequenced from zero to high cost) before carbon offset options are considered. The analysis suggests that emissions can be reduced from 26,028 lbs CO_2 to 8,316 lbs CO_2 per household per year.

Let us also be clear that these are estimates based on our educated guesses. No measure will match precisely your situation or your savings. If we have committed any errors of research or judgment, please feel free to let us know.

Respectfully,

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The typical American single-family home, 1997[1]

Percent of U.S. homes (73.7 of 101.5 million, 1997) [2]	**73%**
Size	**2,280 ft^2**
Heated area [3]	**1,950 ft^2**
Cooled floorspace [4]	**1,725 ft^2**
Consumption per square foot per year [5]	**52,000 Btu**
Expenditures per square foot per year	**$0.63**
Average yearly energy bill	**$1,441**
Site energy consumed per year	**118.5 million Btu**
Electricity consumption per year	**11,330 kWh**
Main space heating: 58% gas + 24% electric + 10% oil + 5% propane + 2.5% wood;	
Percentage using air conditioning (50% central AC + 23% room AC) [6]	**73%**
Percentage using active solar systems [7]	**1%**
Percentage with single-pane windows [8]	**62%**
Percentage with insulated exterior walls [9]	**69%**
Percentage with insulated heating/cooling ducts [10]	**32%**
Percentage with extra insulation on water heaters [11]	**24%**

Water heating fuels:[12] natural gas: 55.5%, electric: 36.1%, fuel oil: 4.3%, LPG: 3.5%

Appliance saturation:[13] freezers: 41.7%, washers: 92.3%, dishwasher: 56.5%, hot tubs: 5.3%, aquarium: 4.1%, waterbed heaters: 9.6%, well pumps: 17.5%

Electricity consumption, cost, and CO_2 emissions of appliances & widgets

Appliance or gizmo	Electricity kWh/yr	Cost $/yr	CO_2 emissions lbs/yr
Air conditioner (room)	1,187	95	1,697
Air conditioner (central)	2,923	234	4,180
Aquarium, terrarium	600	48	858
Car engine block-heater	500	40	715
Coffee maker	100	8	143
Clock	25	2	36
Clothes dryer	1,060	85	1,516
Clothes washer (incl. hot water)	1,080	86	1,544
Clothes washer (excl. hot water)	99	8	142
Dehumidifier	400	32	572
Demand water heater (electric)	350	28	501
Dishwasher (incl. hot water)	935	75	1,337
Dishwasher (excl. hot water)	330	26	472
Electric blanket	120	10	172
Exhaust fan	15	1	21
Fan (whole-house)	80	6	114
Fan (ceiling)	50	4	72
Fan (room)	20	2	29
Furnace fan	600	48	858
Hair dryer	50	4	72
Home computer	130	10	186
Humidifier	100	8	164
Iron	50	4	72
Lighting (average consumption)	1,500	120	2,145
Lighting (two all-night lights)	730	58	1,044
Microwave oven	220	18	315

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Pipe and gutter heater	**100**	**8**	**143**
Pool pump	**1,500**	**120**	**2,145**
Range	**840**	**67**	**1,201**
Refrigerator (average in use)	**1,281**	**102**	**1,832**
Refrigerator (best new 21-ft^3)	**555**	**44**	**794**
Safety outlets (5 GFIs)	**48**	**4**	**69**
Security system	**160**	**13**	**229**
Spas, hot tub	**2,300**	**184**	**3,289**
Stereo and radio	**75**	**6**	**107**
Space heater	**500**	**40**	**715**
Sump pump	**40**	**3**	**57**
Telephone (cordless)	**36**	**3**	**51**
Telephone answering machine	**36**	**3**	**51**
Television, black & white	**50**	**4**	**72**
Television, color (average use)	**197**	**16**	**282**
Television, color (when off)	**33**	**3**	**47**
Toaster oven	**50**	**4**	**72**
Vacuum	**25**	**2**	**36**
Vacuum (cordless)	**36**	**3**	**51**
VCR	**40**	**3**	**57**
Waterbed	**960**	**77**	**1,373**
Water heater, electric	**2,892**	**231**	**4,136**
Water heater (standby losses)	**428**	**34**	**612**
Water heater (distribution losses)	**431**	**34**	**616**
Well pump	**360**	**29**	**515**

Richard Heede (1995), *Homemade Money: How to Save Energy and Dollars in Your Home*, Rocky Mountain Institute, Snowmass, CO, pp. 194-95. Revised 2002.

Security system data from LBNL's Leaking Electricity website «http://eetd.lbl.gov/leaking».

Average costs are based on an electric rate of 8 cents per kWh.

1 kWh consumed (or saved) = 1.43 lbs of CO_2 emitted (or saved) at the power plant. Updated to 1998 U.S. generation mix (Heede, March 2002).

Energy and Carbon Dioxide Factors
(including U.S. electricity mix, 1999)

	Energy (Btu per unit) [14]	CO_2 (lbs per unit) [15]	CO_2 (lbs/million Btu)
Natural Gas	1,027 Btu/ft^3	0.1164 lbs CO_2/ft^3	117 lbs
Heating Oil	138,700 Btu/gallon	22.38 lbs CO_2/gallon	161 lbs
Propane	91,333 Btu/gallon	12.67 lbs CO_2/gallon	139 lbs
Electricity	10,346 Btu/kWh	1.43 lbs CO_2/kWh [16]	419 lbs

Space Heating Energy Consumption, Cost, and CO_2 Emissions in a Typical Single-Family Home, 1997

	Homes (million)	Energy (units)	Energy (10^6 Btu/yr)	Cost ($/yr)	CO_2 (lbs/yr)
Gas [17]	42.5	70,000 ft^3	72.4	$481	8,148
Electric [18]	17.7	4,730 kWh	48.8	$337	6,764
Oil [19]	7.1	733 gallons	101.7	$745	16,407
Propane [20]	3.5	627 gallons	57.3	$602	7,944
Wood [21]	1.9	4.1 cords	82.1	$328	19,547
Kerosene [22]	0.5	298 gallons	40.2	$341	6,418
No heating	0.7	0	0	$0	0
Average [23]	73.7	na	68.1	$476	8,829

Water Heating Energy Consumption, Cost, and CO_2 Emissions in a Typical Single-Family Home, 1997

	Homes (million)	Energy (units)	Energy (10^6 Btu/yr)	Cost ($/yr)	CO_2 (lbs/yr)
Gas [24]	40.9	25,000 ft^3	25.5	$158	2,910
Electric [25]	27.1	3,047 kWh	31.5	$217	4,357
Oil [26]	3.3	220 gals	30.5	$181	4,925
Propane [27]	2.6	267 gals	24.4	$198	3,383
Solar, other [28]	0.6	na	na	na	na
Average [29]	73.7	na	27.8	$202	3,558

CO_2 per Single-Family Home, 1997

	Cost $/yr	Energy 10^6 Btu/yr	CO_2 lbs/yr	Percent of CO_2
Space heating [30]	$476	68.1	8,829	33.9%
Air conditioning [31]	$105	13.6	1,882	7.2%
Water heating [32]	$202	27.8	3,558	13.7%
Refrigerator, freezer [33]	$146	18.9	2,607	10.0%
Cooking [34]	$46	6.5	825	3.2%
Other Appliances [35]	$346	44.7	6,182	23.8%
Lighting [36]	$120	15.5	2,145	8.2%
Total	**$1,441**	**195.1**	**26,028**	**100.0%**

Household CO_2 Savings

Free Stuff

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Lower water heater temp to 120ßF [37]	**1.67**	**214**	**$12.12**	**$0.00**
Increase AC thermostat by 3Fß [38]	**2.45**	**339**	**$18.90**	**$0.00**
Lower thermostat in winter by 2Fß [39]	**2.72**	**353**	**$19.04**	**$0.00**
Wash clothes in cold water [40]	**2.56**	**327**	**$18.58**	**$0.00**
Air dry clothes during summer [41]	**5.64**	**779**	**$43.60**	**$0.00**
Unplug extra fridge in garage [42]	**3.24**	**448**	**$25.04**	**$0.00**
Use energy-saving appliance features [43]	**5.61**	**769**	**$43.04**	**$0.00**
Turn off unneeded lights [44]	**2.72**	**376**	**$21.04**	**$0.00**
Total free stuff [45]	**26.61**	**3,605**	**$201.36**	**$0.00**
Free stuff, not counted in integrated retrofit package (offequip in appliances)				
Turn off home office equipment [46]	***0.99***	***137***	***$7.68***	***$0.00***
Save cold water [47]	***0.96***	***133***	***$32.20***	***$0.00***
Install water-saving toilets [48]	***0.54***	***75***	***$18.07***	***$400.00***

Household CO_2 Savings

Heating & Cooling: Building Shell

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Seal large air leaks [49]	**11.36**	**1,489**	**$80.76**	**$10.07**
Add attic insulation [50]	**16.34**	**2,142**	**$116.20**	**$15.56**
Weatherize windows, doors [51]	**4.74**	**621**	**$33.70**	**$25.72**
Add basement insulation [52]	**8.85**	**1,148**	**$61.88**	**$29.04**
Add air gap window films [53]	**5.65**	**733**	**$39.51**	**$70.91**
Add an attic radiant barrier [54]	**1.36**	**188**	**$10.50**	**$90.43**
Add wall insulation [55]	**6.54**	**857**	**$46.48**	**$91.02**
Total building shell [56]	**54.84**	**7,178**	**$389.03**	**$34.73**
Other measures:				
Upgrade to superwindows [57]	***7.29***	***971***	***$51.36***	***$133.88***
Roof whitening [58]	***3.40***	***471***	***$26.25***	***$229.30***
Add low-e films [59]	***2.72***	***377***	***$21.00***	***$241.38***

Household CO_2 Savings

Heating & Cooling: Building Shell B[60]

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Seal large air leaks [61]	**11.36**	**1,489**	**$80.76**	**$10.07**
Add attic insulation [62]	**12.90**	**1,682**	**$91.01**	**$19.82**
Weatherize windows, doors [63]	**3.33**	**438**	**$23.74**	**$36.53**
Add basement insulation [64]	**5.74**	**745**	**$40.15**	**$44.72**
Add air gap window films [65]	**3.19**	**414**	**$22.30**	**$125.81**
Add wall insulation [66]	**3.62**	**476**	**$25.84**	**$163.87**
Add an attic radiant barrier [67]	**0.91**	**126**	**$7.05**	**$134.92**
Total building shell [68]	**41.05**	**5,370**	**$290.85**	**$46.82**
Other measures:				
Upgrade to superwindows [69]	***7.29***	***971***	***$51.36***	***$133.88***
Roof whitening [70]	***3.40***	***471***	***$26.25***	***$229.30***
Add low-e films [71]	***2.72***	***377***	***$21.00***	***$241.38***

Household CO_2 Savings

Heating & Cooling: Equipment

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Programmable thermostat [72]	**8.17**	**1,071**	**$58.10**	**$9.34**
Seal and insulate ducts [73]	**11.58**	**1,512**	**$81.90**	**$17.64**
Heating system modification [74]	**4.09**	**530**	**$28.56**	**$50.25**
Heating system tune-up [75]	**4.09**	**530**	**$28.56**	**$150.94**
Air conditioner tune-up [76]	**2.04**	**282**	**$15.75**	**$285.71**
Total heating/cooling equip. [77]	**29.97**	**3,925**	**$212.87**	**$22.52**
Additional measures:				
Replace AC (9.0 to 12.0 SEER) [78]	***3.40***	***471***	***$26.25***	***$65.36***
Replace 0.50 AFUE with 0.75 AFUE [79]	***22.68***	***2,940***	***$158.51***	***$37.79***
Upgrade from 0.75 to 0.96 AFUE [80]	***14.98***	***1,942***	***$104.72***	***$17.16***
Replace 0.50 AFUE w 0.96 AFUE [81]	***32.69***	***4,238***	***$228.48***	***$34.08***
More [82]			***$***	***$***

Household CO_2 Savings

Heating & Cooling: Equipment B[83]

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Programmable thermostat [84]	**4.06**	**534**	**$29.02**	**$18.73**
Seal and insulate ducts [85]	**5.12**	**670**	**$36.34**	**$39.80**
Heating system modification [86]	**1.89**	**248**	**$13.48**	**$107.53**
Heating system tune-up [87]	**1.40**	**181**	**$9.78**	**$444.44**
Air conditioner tune-up [88]	**1.00**	**130**	**$7.25**	**$615.38**
Total heating/cooling equip. [89]	**13.47**	**1,763**	**$95.87**	**$48.97**
Additional measures:				
Replace AC (9.0 to 12.0 SEER) [90]	***1.42***	***184***	***$10.27***	***$166.66***
Replace 0.50 AFUE with 0.75 AFUE [91]	***7.63***	***946***	***$51.02***	***$117.51***
Upgrade from 0.75 to 0.96 AFUE [92]	***5.04***	***625***	***$33.71***	***$53.29***
Replace 0.50 AFUE w 0.96 AFUE [93]	***11.00***	***1,364***	***$73.54***	***$105.86***
More [94]			***$***	***$***

Household CO_2 Savings

Heating & Cooling: Total Savings[95]

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Simple additive approach:				
Total prior to measures	**81.70**	**10,711**	**$581.00**	
Building shell improvements	**54.84**	**7,178**	**$389.03**	**$34.73**
Heating/cooling equip. measures	**29.97**	**3,925**	**$212.87**	**$22.52**
Total heating & cooling [96]	**-3.11**	**-392**	**-$20.90**	**$31.02**
Remaining heating & cooling	***less***	***than***	***zero***	
Iterative savings approach:				
Total prior to measures	**81.70**	**10,711**	**$581.00**	
Building shell improvements	**41.05**	**5,370**	**$290.35**	**$46.82**
Equipment & systems measures	**13.47**	**1,763**	**$95.87**	**$48.97**
Total heating & cooling [97]	**54.52**	**7,133**	**$386.22**	**$47.28**
Remaining heating & cooling	**27.18**	**3,578**	**$194.78**	
Percent savings	**66.73%**	**66.60%**	**66.50%**	

Household CO_2 Savings

Water Heating Measures

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Simple additive approach:				
Total prior to measures	**27.80**	**3,558**	**$202.00**	**na**
Insulate water heater [98]	**2.06**	**263**	**$14.95**	**$12.66**
Efficient showerheads [99]	**2.89**	**370**	**$21.01**	**$18.02**
Faucet aerators [100]	**0.86**	**110**	**$6.22**	**$27.27**
Fix hot water leaks [101]	**0.22**	**28**	**$1.62**	**$28.57**
Insulate hot & cold water pipes [102]	**0.41**	**53**	**$3.01**	**$37.74**
Total water heating savings [103]	**6.44**	**824**	**$46.81**	**$18.59**
Remaining after measures taken	**21.36**	**2,734**	**$155.19**	**na**
Savings fraction (excl free stuff)	**23.2%**	**23.2%**	**23.2%**	
Free stuff: [104]				
Lower water heater temp to 120ßF [105]	***1.67***	***214***	***$12.12***	***$0***
Wash clothes in cold water [106]	***2.56***	***327***	***$18.58***	***$0***
Total water heating savings	***10.67***	***1,365***	***$77.51***	***na***
Remaining after measures taken	***17.13***	***2,193***	***$124.49***	***na***
Savings fraction (incl free stuff)	***38.4%***	***38.4%***	***38.4%***	
Calculated but not included in the core analysis:				
Add solar water heating system [107]	***11.67***	***1,494***	***$84.80***	***$117.14***
Switch from electric/oil to gas [108]	***6.00***	***1,447***	***$59.00***	***$55.30***

Household CO_2 Savings

Appliances

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Total prior to measures	**70.10**	**9,614**	**$538.00**	
Cooking savings [109]	**1.30**	**165**	**$9.20**	**$30.30**
Home office equipment savings [110]	**0.99**	**137**	**$7.68**	**$36.00**
New H-axis clothes washer [111]	**2.54**	**326**	**$18.48**	**$67.75**
Dryer savings from new H-axis [112]	**1.20**	**166**	**$9.29**	**$0.00**
Cut phantom loads by half [113]	**2.27**	**313**	**$17.52**	**$128.21**
New efficient refrigerator [114]	**6.00**	**829**	**$46.40**	**$46.40**
Total appliance savings [115]	**14.30**	**1,936**	**$108.57**	**$49.08**
Remaining after measures taken	**55.8**	**7,678**	**$429.43**	
Savings fraction	**20.4%**	**20.1%**	**$20.2%**	
Free Stuff:				
Air dry clothes during summer [116]	***5.64***	***779***	***$43.60***	***$0.00***
Use energy-saving appliance features [117]	***5.61***	***769***	***$43.04***	***$0.00***
Unplug extra fridge in garage [118]	***3.24***	***448***	***$25.04***	***$0.00***

Household CO_2 Savings

Lighting

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Simple additive approach:				
Total prior to measures	**15.52**	**2,145**	**$120.00**	**na**
Replace 6 interior incandescents [119]	**4.10**	**566**	**$31.68**	**$30.77**
Replace remaining bulbs w CFLs [120]	**4.36**	**602**	**$33.68**	**$30.72**
Replace 1 exterior incandescent [121]	**1.52**	**210**	**$11.76**	**$47.37**
Occupancy sensor [122]	**0.48**	**66**	**$3.68**	**$60.00**
Total lighting savings [123]	**10.46**	**1,444**	**$80.80**	**$33.21**
Remaining after measures taken	**5.06**	**701**	**$39.20**	**na**
Savings fraction	**67.40%**	**67.32%**	**67.33%**	**na**
Free Stuff:				
Turn off unneeded lights [124]	***2.72***	***376***	***$21.04***	***$0.00***
Additional measures:				
More [125]	***ne***	***ne***	***ne***	***ne***

Household CO_2 Savings

All Measures

	Energy (10^6 Btu/yr)	CO_2 Saved (lbs/yr)	$ Saved ($/yr)	CSC life ($/ton/$CO_2$)
Integrated approach:				
Total prior to measures	**195.10**	**26,028**	**$1,441.00**	
Total free stuff [126]	**26.61**	**3,605**	**$201.36**	**$0.00**
Total building shell	**41.05**	**5,370**	**$290.85**	**$46.82**
Total heating/cooling equipment	**13.47**	**1,763**	**$95.87**	**$48.97**
Total water heating [127]	**6.44**	**824**	**$46.81**	**$18.59**
Total appliances	**14.30**	**1,936**	**$108.57**	**$49.08**
Total lighting	**10.46**	**1,444**	**$84.80**	**$33.21**
Total household savings [128]	**112.33**	**14,942**	**$828.26**	**$34.82**
Remaining after measures	**82.77**	**11,086**	**$612.74**	
Savings fraction	**57.58%**	**57.41%**	**57.48%**	
Add solar water heating, save:	**11.67**	**1,494**	**$80.80**	**$117.14**
Total savings after solar DHW	**124.00**	**16,436**	**$909.06**	**$45.61**
Remaining after all measures [129]	**71.10**	**9,592**	**$531.94**	**na**
Savings fraction:	**63.56%**	**63.15%**	**63.09%**	**na**

Green power: [130]

Total CO_2 Emissions from U.S. *Single-Family* Homes, 1997

	CO_2 10^6 tons	Carbon 10^6 metric tonnes	Percent* of Res l CO_2	Percent♦ of total U.S. CO_2
Space heating [131]	325.35	80.49	27.49%	5.33%
Air conditioning [132]	69.35	17.16	5.86%	1.14%
Water heating [133]	131.11	32.44	11.08%	2.15%
Refrigerator, freezer [134]	96.07	23.77	8.12%	1.58%
Cooking [135]	30.40	7.52	2.57%	0.50%
Other Appliances [136]	227.81	56.36	19.25%	3.73%
Lighting [137]	79.04	19.56	6.68%	1.30%
Total	**959.13**	**237.30**	**81.04%**	**15.73%**

*** Total residential emissions 1997: 292.8 million metric tonnes carbon = 1,183.5 million short tons CO_2 and 19.7% of total U.S. CO_2 emissions.[138]**

♦ Total U.S. CO_2 emissions, 1997: 1,509.0 million metric tonnes carbon = 6,099.6 million tons CO_2.

Total GHG emissions, 1998: 8,245 million tons $CO_{2\text{-e}}$.[139]

Total residential emissions in 2012 is forecast to reach 333 million tonnes carbon (1,345 million tons CO_2). For the residential sector to achieve its Kyoto target by 2012 (0.93 of 1990) means total residential emissions of 966 million tons CO_2, or saving 379 million tons CO_2. Based on the 73.7 million single-family homes in 1997, this means saving 5.144 tons CO_2 per existing single-family household, or 10,288 lbs CO_2 per household in 2012. This is considerably less than the sum of CO_2 savings identified in our analysis.[140]

Conclusion #1: if the U.S. greenhouse gas reduction commitment agreed to in Kyoto in 1997 is equally shared by all emissions sectors, then residential sector savings can be achieved by implementing 63 percent of the identified measures in the 73.7 million single-family households alone.[141]

Conclusion #2: Full adoption of climate neutrality in the U.S.'s *existing* 73.7 million single-family homes would achieve 87 percent of *total* U.S. CO_2 reduction needed by 2012.[142]

Scenarios of U.S. Carbon Reduction[143]*

Carbon Emissions and Total Energy Costs in Residential and Commercial Buildings

(million metric tonnes of carbon and billion 1995 $)

	1990	1997	2010			
			Business-As-Usual Case	Efficiency Case (35%)	High-Effic, Low-C (65%)	All Hands on Deck (100%)♦
Residential	**253**	**285**	**319**	**306**	**287**	**265**
Commercial	**209**	**225**	**252**	**240**	**225**	**208**
Res l + Com l	**462**	**511**	**571**	**546**	**511**	**473**
Res l + Com l energy bills (billion $)	**$226B**	**$228B**	**$251B**	**$233B**	**$218B**	**?**
Res l + Com l cost of effic (billion $)	**na**	**na**	**0**	**$7B**	**$13B**	**?**
Res l + Com l total energy cost (billion $)	**$226B**	**$228B**	**$251B**	**$240B**	**$231B**	**?**

* **Interlaboratory Working Group (1997), *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond.***

˙www.ornl.gov/ORNL/Energy_Eff/CON444¨

♦ **All hands on Deck is Heede s surmise regarding achieving 100 percent of the technical potential by 2010**

End Notes

[1] Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, Residential Energy Consumption Survey, DOE/EIA-0632 (97), www.eia.doe.gov. This latter statistic includes EIA's own assessment of per household energy consumption with primary conversion losses included.

[2] EIA (1999), *A Look at Residential Energy Consumption in 1997*, p. 42.

[3] Energy Information Administration (1995), *Housing Characteristics 1993*, DOE/EIA-0314, p. xvi.

[4] Energy Information Administration (1995), *Housing Characteristics 1993*, p. 83. Detached units only.

[5] EIA (1999), *A Look at Residential Energy Consumption in 1997*, p. 68.

[6] Of 73.7 million single-family households, 36.8 million use central AC and 17.1 million use room AC. 55% of respondents say that large tree(s) shade the home. EIA (1999), *Residential Energy Consumption in 1997*, p. 68.

[7] Energy Information Administration (1995), *Housing Characteristics 1993*, p. xi. Average of all housing stock.

[8] Energy Information Administration (1995), *Housing Characteristics 1993*, p. 171.

[9] Energy Information Administration (1995), *Housing Characteristics 1993*, p. 173.

[10] Energy Information Administration (1995), *Housing Characteristics 1993*, p. 13.

[11] Energy Information Administration (1995), *Housing Characteristics 1993*, p. 13.

[12] EIA (1999), *A Look at Residential Energy Consumption in 1997*, p. 83.

[13] EIA (1999), *A Look at Residential Energy Consumption in 1997*, p. 81-82.

[14] Energy used on site for natural gas, oil, and propane; no adjustment for system losses before fuel delivery. DOE typically uses site energy for electricity (3,412 Btu/kWh). However, to accurately reflect energy lost in conversion, transmission, distribution, plant use, and other system losses, we divide electric end-use retail sales by primary fuel input (for 1997): 10.05 quad ÷ 32.62 quad = 0.308. (Detail: (retail sales of 10.65Q less net purchases from NPPs of 0.48Q less net imports of 0.12Q) divided 32.62Q = 0.308) Therefore, a kWh consumed equals 11,080 Btu primary input (3,412 Btu/kWh ÷ 0.308 = 11,080 Btu/kWh). This factor is used in this report. Energy Information Administration (1998), *Annual Energy Review 1997*, p. 207, diagram on electricity.

[15] Energy Information Administration (1997), *Form EIA-1605: Voluntary Reporting of Greenhouse Gases, Instructions*, Appendix C.

[16] Primary energy input per kWh consumed. Calculated for 1999: total emissions at U.S. electric utilities of 2,189.77 million tons CO_2 plus emissions from Non-utility Power Producers (NPPs) of 312.96 million tons CO_2 equals 2,502.73 million tons CO_2 = 4.7831 trillion lbs CO_2. Dividing by 1999 total end-use consumption (utility retail sales plus NPP sales to end-users) of 3.501 trillion kWh = 1.4297 lbs CO_2 per kWh *consumed*. (10^6 Btu ÷ 3,412 Btu/kwh) x 1.4297 lbs CO_2 per kWh = 419.02 lbs CO_2 per million Btu. Note: this includes transmission and distribution losses; the implied grid loss factor equals total net generation + net trade (3.706 trillion kWh + 0.029 trillion kWh) ÷ total end-use consumption = 3.735 / 3.501 = 0.9373. Source: Energy Information Administration (2001), *Annual Energy Review 2000*, Tables 8.1 and 12.6; www.eia.doe.gov/ Heat rate figure is for 2000, electric utility powerplants, EIA, (2001), *Annual Energy Review 2000*, Appendix.

[17] 42.5 million gas-heated homes @ 70.0k ft^3/hh/yr x 1,027 Btu/ft^3 = 71.9 million Btu/hh/yr. Carbon: 70,000 ft^3/hh/yr x 0.1164 lbs CO_2/ft^3 = 8,148 lbs CO_2/hh/yr. Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, Residential Energy Consumption Survey, p. 140, www.eia.doe.gov.

[18] 17.7 million electric-heated single-family homes: 4,730 kWh/hh/yr x 10,346 Btu/kWh = 48.8 million Btu/hh/yr (16.1 million Btu site energy, we use primary). Carbon: 4,730 kWh/yr x 1.43 lbs CO_2/kWh = 6,764 lbs CO_2/hh/yr.

[19] 7.1 million oil-heated homes @ 733 gallons/hh/yr x 138,700 Btu/gallon = 101.7 million Btu/hh/yr. Carbon: 733 gallons/hh/yr x 22.384 lbs CO_2/gallon = 16,407 lbs CO_2/hh/yr.

[20] 3.5 million propane-heated homes @ 627 gallons/hh/yr x 91,333 Btu/gallon = 57.3 million Btu/hh/yr. Carbon: 627 gallons/hh/yr x 12.67 lbs CO_2/gallon = 7,944 lbs CO_2/hh/yr.

[21] 2.8 million wood-heated homes @ 4.1 cords/hh/yr x 20 million Btu/cord = 82.1 million Btu/hh/yr (this only counts single-family households using wood as primary space-heating fuel, and excludes 18.8 million additional single-family households using some wood (1.4 cords or 27.2 million Btu/hh/yr average)). Carbon: 4.1 cords/hh/yr x 4,768 lbs CO_2/cord = 19,547 lbs CO_2/hh/yr. Note: burning wood is a net-zero carbon emitter, since the tree fixed the carbon from the atmosphere in the first place, but the timing of the carbon release is altered, and we include these emissions in the calculation of the U.S. average. We assume that the average cord costs $80.

[22] 0.5 million kerosene-heated homes @ 298 gallons/hh/yr x 135,000 Btu/gallon = 40.2 million Btu/hh/yr. Carbon: 298 gallons x 21.537 lbs CO_2 per gallon = 6,418 lbs CO_2/hh/yr.

[23] Weighted average heating energy = 76.0 million Btu/hh/yr ((natural gas 3.11Q + fuel oil 0.74Q + kerosene 0.04Q + LPG 0.21Q + electricity of 0.31Q site energy + electricity conversion losses 0.63Q =) 5.02Q ÷ 73.7 million single-family homes = 68.1 million Btu per household per year. Weighted heating energy costs = $476 /hh/yr ($35.07 billion ÷ 73.7 million homes. Weighted CO_2 average = 8,829 lbs CO_2/hh/yr (650.66 billion lbs CO_2/yr ÷ 73.7 million homes). Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, p. 139 (total space heating energy), p. 154 (annual heating costs).

[24] 40.9 million gas water heaters @ 25,000 ft^3hh/yr x 1,027 Btu/ft^3 = 25.7 million Btu/hh/yr. Carbon: 25,000 ft^3/hh/yr x 0.1164 lbs CO_2/ft^3 = 2,910 lbs CO_2/hh/yr. Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, p. 187.

[25] 27.1 million electric water heaters @ 3,047 kWh/hh/yr x 10,346 Btu/kWh = 31.5 million Btu/hh/yr (10.4 million Btu site energy; we use primary, and the heat rate at powerplants is 10,346 Btu per kWh). Carbon: 3,047 kWh/hh/yr x 1.43 lbs CO_2/kWh = 4,357 lbs CO_2/hh/yr.

[26] 3.3 million oil water heaters @ 220 gallons/hh/yr x 138,700 Btu/gallon = 30.5 million Btu/hh/yr. Carbon: 220 gallons/hh/yr x 22.384 lbs CO_2/gallon = 4,925 lbs CO_2/hh/yr.

[27] 2.6 million propane water heaters @ 267 gallons/hh/yr x 91,333 Btu/gallon = 24.4 million Btu/hh/yr. Carbon: 267 gallons/hh/yr x 12.67 lbs CO_2/gallon = 3,383 lbs CO_2/hh/yr.

[28] Get data on solar water-heating systems in the nation's 66.8 million single-family homes.

[29] Weighted average water heating energy = 27.8 million Btu/hh/yr (((natural gas 1.04Q + fuel oil 0.10Q + kerosene 0.00Q + LPG 0.06Q + electricity of 0.28Q site energy + electricity conversion losses 0.57Q =) 2.05Q ÷ 73.7 million single-family homes). Weighted energy costs = $202 /hh/yr ($14.9 billion ÷ 73.7 million homes). Weighted average water heating CO_2 emissions = 3,558 lbs CO_2/hh/yr (262.2 billion lbs CO_2/yr ÷ 73.7 million homes). Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, p. 186.

[30] Annual single-family household expenditure for space heating in 1997 = $476; total energy = 68.1 million Btu on average (including primary energy for electricity); and 8,829 lbs CO_2 per year. See previous table for details, based on Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*.

[31] Of 73.7 million single-family households in 1997, 36.8 million use central AC (2,221 kWh/hh/yr, rising to 2,522 kWh/hh/yr for households with income above $50,000 per year) plus 17.1 million use room AC (886 kWh/hh/yr). Energy Information Administration (1999), p. 163. (72.6 million of 101.5 million U.S. households use AC for a total consumption of 122 billion kWh (101 billion kWh central AC + 21 billion kWh room AC.)

Single-family households use 97 billion kWh for cooling (82 for central + 15 for room AC) or 0.33 Quads; adding primary energy conversion losses (10,346 Btu heat rate ÷ 3,412 Btu per kWh = 3.032; 3.032 x 0.33 Q) of 1.001 Q. 1.001 Q ÷ 73.7 million single-family households = 13.58 million Btu/hh/yr on average. Of course, homes that use AC use more, on average (central air users average 2,221 kWh per year, or 2,221 kWh x 3,412 Btu/kWh x 3.032 = 22.98 million Btu/hh/yr; naturally, larger homes in hot climates use far more. Average consumption over 73.7 million single-family households is thus: 97 billion kWh ÷ 73.7 million hh = 1,316 kWh/hh/yr. Costs average 1,316 kWh x $0.08 = $105 per year. Carbon: 1,316 kWh x 1.43 lbs CO_2 per kWh = 1,882 lbs CO_2/hh/yr.

[32] Annual single-family household expenditure for water heating in 1997 = $202; total energy = 27.8 million Btu on average (including primary energy for electricity); and 3,558 lbs CO_2 per year. See previous table for details, based on Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*.

[33] Based on all 101.5 million households (single-family, multi-family, and mobile homes), households average 1.16 refrigerators totaling 1,323 kWh/yr (1,454 kWh/yr in single-family hh) (i.e., each unit averages 1,141 kWh/yr); 117.5 million refrigerators in 101.3 households with fridges using 134.1 billion kWh. 33.7 million households have 36.9 million freezers that average 1,013 kWh per year, or an average per household of 369 kWh/hh/yr, using a total of 37.4 billion kWh (both refrigerators and freezers are more populous in single-family homes, but this data does not exist in the newer RECS databases).

1,454 kWh for fridges in single-family homes x 1.43 lbs CO_2 per kWh = 2,079 lbs CO_2.

369 kWh for freezers in average household x 1.43 lbs CO_2 per kWh = 528 lbs CO_2. Sum = 2,607 lbs CO_2/hh/yr.

Cost: 1,454 + 369 = 1,823 kWh/hh/yr x $0.08 = $146. Energy: 1,823 kWh x 3,412 Btu/kWh x 3.032 = 18.86 million Btu/hh/yr. Carbon: 1,823 kWh/hh/yr x 1.43 lbs CO_2 per kWh = 2,607 lbs CO_2/hh/yr.

[34] For energy used in cooking we use the data from the 1991 American Electric Power survey summarized in EIA (1995), *op cit*, p. 10. 58.3 million of 96.6 million total households (60.4 percent) use electric stovetops and ovens averaging 521 kWh/yr for electric homes but 0.604 x 521 kWh/yr if averaged over all single-family homes = 315 kWh/yr. Plus 217 kWh/yr for microwaves (assume 95% saturation = 206 kWh/yr): 315 + 206 = 521 kWh average. Average electric consumption for cooking = 5.8 million Btu/yr. Carbon: 521 kWh/yr x 1.43 lbs CO_2/kWh = 745 lbs CO_2/hh/yr. Plus gas and propane stovetops and ovens (used by 0.396 of households): assume gas households use as much *end-use* energy as electric households (i.e., 521 kWh x 3,412 Btu/kWh = 1.78 million Btu = 1,730 ft^3 of gas. Multiply by 0.396 = 685 ft^3/yr x 1,027 Btu/ft^3 = 0.7 million Btu and 80 lbs CO_2/yr. Adding average electric and gas:

5.8 million Btu (electric) + 0.7 million Btu (gas) = 6.5 million Btu for the average single-family household. Carbon: 745 lbs CO_2/hh/yr (electric) + 80 lbs CO_2/yr (gas) = 825 lbs CO_2/yr.

[35] We estimate "other appliances" as follows: average total electricity consumption is 11,278 kWh/hh/yr for single-family households. From this we subtract the other uses discussed above and in previous tables: space heating average (4,730 kWh/yr in 17.7 of 73.7 million households) is 1,120 kWh/yr; air conditioning = 1,316 kWh/yr; water heating (3,027 kWh/yr x 27.1 of 73.7 million households) averages 1,120 kWh/yr; lighting averages 1,500 kWh/yr; refrigerators + freezers averages 1,883 kWh/yr; Electric cooking (stoves, ovens, and microwaves) averages 521 kWh/yr; Sum = 6,955 kWh/yr; Total of 11,278 kWh/yr minus 6,955 kWh/yr = 4,323 kWh for other appliances such as TVs, phones, VCRs, stereos, clothes washer and dishwashers and dryers (electric portions only), waterbed heaters, well pumps, home office equipment, and so forth.

Cost: 4,323 kWh/yr x $0.08 = $346. Total energy: 4,323 kWh x 3,412 Btu/kWh x 3.032 = 44.73 million Btu/yr. Carbon: 4,323 kWh/yr x 1.43 lbs CO_2/kWh = 6,182 lbs CO_2/yr.

(**Note:** this may be an underestimate for single-family homes, certainly for the better-educated and higher-income toy-enriched crowd, —perhaps balanced by folk who'd seek this information for its spiritual or planetary solutions.)

[36] EIA (1995), RECS'93, p. 10 and RECS'97, p. 16 cite the average household as using 940 kWh/yr, including outdoor lighting. Yet 53 homes whose owners agreed to use lighting data loggers for the RECS survey used 2,930 kWh/yr. Hence, we use the more accepted figure of 1,500 kWh/yr for single-family homes. Energy: 1,500 kWh/yr x 10,346 Btu/kWh (primary) = 15.52 million Btu. Cost = $120/yr. Carbon 1,500 kWh/yr x 1.43 lbs CO_2/kWh = 2,145 lbs CO_2/hh/yr. Note: of 73.7 million single-family households, 21.3 million use exterior lighting all night: one 100 watt lamp on 12 hrs/day x 365 days = 438 kWh per year; the remaining 52.4 million households either do not use exterior lighting or do not keep them "on all night." Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, p. 101.

[37] Each 10˚F reduction saves 3-5 percent on water heating (Heede, 1995, *Homemade Money*, p. 153). Assuming your water heater thermostat can be reduced from 140 to 120˚F without compromising quantity, and 3% savings per 10F˚, 0.03 x 2.0 = 6.0 percent savings: 0.06 x 27.8 million Btu and $202 and 3,558 lbs CO_2 = 1.67 million Btu and $12.12 and 213.5 lbs of CO_2 saved per year.

[38] Each degree warmer will save 3-5 percent on cooling costs (Wilson and Morrill, 1998, *Consumer Guide to Home Energy Savings*, 6th edition, American Council for an Energy-Efficient Economy, Washington, DC, p. 133). Danny Parker of FSEC reports "each degree F that the house is cooled below 80˚F increases annual cooling by 12%." We conservatively use 6 percent per degree F x 3F˚ = 18 percent savings: 0.18 x $105 = $18.90, 0.18 x 13.6 million Btu = 2.45 million Btu, 0.18 x 1,882 lbs CO_2 = 338.8 lbs CO_2 per year.

[39] "You can save about 2% on your heating bill for each degree that you lower the thermostat" (Wilson & Morrill, 1998, *op. cit.* p. 110). Lowering the thermostat by two degrees saves 0.04 x 68.1 million Btu and $476 and 8,829 lbs CO_2 = 2.72 million Btu and $19.04 and 353 lbs CO_2 per year.

[40] 18.3 percent of hot water is used in clothes washers (Bancroft, Shepard, Lovins, and Bishop, 1991, *The State of the Art: Water Heating*, COMPETITEK, Rocky Mountain Institute, Snowmass, CO, pp. 14-15). Assuming that washing most—not all—loads in cold water saves 50% of this energy (conservative: switching from hot/warm to cold/cold saves 80-95 percent, Heede, 1995, *Homemade Money*, p. 185), you'll save (0.50 x 0.183) = 0.092 x 27.8 million Btu + $202 + 3,558 lbs CO_2 = 2.56 million Btu + $18.58 + 327 lbs CO_2 every year.

[41] Based on EIA (2000), *A Look at Residential Energy Consumption in 1997*, p. 16, electric clothes dryers use 1,090 kWh/yr and 55.9 million of 101.5 million (55 percent) households have them. While many families can (and do) air dry clothes all year, we assume air drying clothes six months per year, saving 1/2 of 1,090 kWh/yr = 545 kWh/yr and thus saves 5.64 million Btu and $43.60 and 779.4 lbs of CO_2 per year. We have not reduced savings by the fraction of households with dryers (surely nearer 100 percent in single-family households than 55 percent cited for all households). See also "The clothesline" chapter in John C. Ryan (1999), *Seven Wonders: Everyday Things for a Healthier Planet*, Northwest Environment Watch, Sierra Club Books.

[42] One in four single-family households have a second refrigerator in the garage or basement (often an older inefficient beast using 1,600+ kWh per year, but we use the EIA average fridge consumption here). Simply unplugging it will save, on average, 1,141 kWh/yr (and 11.80 million Btu, $91.28 and 1,632 lbs CO_2 per year), but averaged over *all* single-family households will save 0.274 x 1,141 kWh/yr = 313 kWh/yr, which saves 3.24 million Btu and $25.04 and 448 lbs CO_2 per year. Let's assume that the extra six-pack stored in the garage-fridge can be chilled in another way, and a replacement fridge is not needed. If it is, consider replacing it with a smaller high-efficiency fridge (the smallest refrigerator listed in the best resource on the energy-efficient appliances is the 15 cubic foot Magic Chef that uses 437 kWh per year; Wilson, Alex et al, 1999, *Consumer Guide to Home Energy Savings*, www.aceee.org, p.38. A Danish VestFrost 7.5 cf freezer uses less than 200 kWh per year. See www.realgoods.com). Note also that alternate refrigerants—such as hydrocarbons now used in many European models—help improve efficiency and reduce leakage of stronger "global warming potential" (GWP) refrigerants still commonly used in U.S.-made refrigerators.

[43] We estimate that using energy-saving features on dish washers, clothes washers (other than washing in cold discussed above), water dryers, refrigerators, and freezers will save, on average, 8 percent of appliances' electricity use: 0.08 x 70.1 million Btu = 5.61 million Btu, 0.08 x $538.00 = $43.04, and 0.08 x 9,614 lbs CO_2 = 769 lbs CO_2 per

year at zero cost. If your appliances are old and without such features, your energy bills are already high and your savings opportunities many when they fail (soon). For example: using the moisture sensing setting available on most dryers reduces dryer energy consumption by an estimated 15 percent on average (we use 8 percent savings here to reflect users that already use this feature, do not have it available, and the 15 percent of single-family households that do not have a dryer (see above)). Based on average dryer consumption of 1,090 kWh per year = 11.28 million Btu and $87.20 and 1,559 lbs CO_2 per year: 0.08 x 11.28 million Btu = 0.90 million Btu, and 0.08 x $87.20 = $7.02, and 1,559 lbs CO_2 per year = 125 lbs CO_2 per year. Again, since this is at no cost, we do not calculate Cost of Saved Carbon or the simple payback period. Heede, Richard (1995), *Homemade Money*, p. 187.

[44] *If* each homeowners turns off one 60 watt incandescent light for 12 unneeded hours daily (inside during the day and outside at night, for example), then over the year they'd save 263 kWh worth 2.72 million Btu at the power-plant at which they'd prevent 376 lbs of CO_2 from entering the atmosphere — all while keeping $21.04 at home.

[45] Other free savings are of course available to the ardent conservationist. Heating and cooling of un-used rooms, for example, saving cold water (see below), air dry clothes all year, turn off additional lights, maximize dishwasher and clotheswasher loading, use the refrigerator more efficiently, reduce cooking energy by use of double (stacked) pots, lids on pots, smaller flames, turning off oven a few minutes early, reduce the need for washing dishes, save hot water by turning off taps or washing and rinsing more efficiently, shorter showers, and so forth *ad infinitum*. **Note:** Look for information on the behavioral aspects of energy use and savings.

[46] According to the Energy Information Administration, the 61.3 million single-family households use home office equipment (83 percent of all single-family households and 60.4 percent of all U.S households); 29.2 million single-family households use personal computers (5.2 million homes have two or more computers, 82 percent of all home PCs, to which 10.7 million printers are connected); use of other home office equipment (e.g., printers, copiers, fax machines, modems) fall along similar percentages. Many communities have very high computer usage and connectivity (e.g., 79% in San Francisco; Austin, San Diego, & Boston also high; www.yahoo.com survey Apr02.

We summed EIA's somewhat dated energy consumption estimate for all residential use of home office equipment: 16.0 billion kWh/yr and 808 kWh/hh/yr. Spreading the estimated electricity consumption for home office equipment (computers 317 kWh/yr, printers 250 kWh, fax 216 kWh, and copiers 25 kWh only = 808 kWh/hh) among all single-family households: 29.2 million of 73.7 million single-family households have PCs: 29.2/73.7 = 0.396, thus, average household annual consumption for this equipment is 0.396 x 808 kWh/hh/yr = 320 kWh/hh/yr = 3.31 million Btu/yr costing $25.60 and emitting 458 lbs CO_2 per year.

Clearly, households that use such equipment use more electricity (in fact, 2.6 million single-families surveyed keep computers on all the time: a typical desktop computer uses 140 watts (55 watts CPU and 80-90 watts monitor): 140 watts x 8,760 hrs/yr = 1,226 kWh per computer per year, not counting sleep mode; Kawamoto et al, 2001, *Electricity Used by Office Equipment and Network Equipment in the U.S.*, Lawrence Berkeley National Laboratory, www.enduse.lbl.gov/Projects/InfoTech.html). In any case, using the average diluted by equipment penetration and consumption, we have 320 kWh/hh/yr: using a conservative estimate that the average user can (a) turn equipment off more frequently (especially the monitor during even brief periods of non-use), (b) install and use software and hardware equipment controls, (c) keep equipment off when not needed (especially printers), and (d) upgrade to more efficient and sleep-mode enabled equipment (including laptops that use 15 watts on average vs 140 w for desktops), we estimate the average household can save 30 percent of computers and related office equipment electricity consumption: 0.30 x 3.31 million Btu = 0.99 million Btu, and 0.30 x $25.60 = $7.68, and 0.30 x 458 lbs CO_2 = 137 lbs CO_2 per year. As we pointed out above, households that use home office equipment can save proportionately more than suggested here (as a baseline, at least 1/0.396 or 2.5 times as much). Finally, since this is primarily behavioral in nature, and secondarily technological, we do not recommend investing money to replace equipment but instead to shop carefully when buying new equipment. We do not, therefore, calculate Cost of Saved Carbon, or simple payback period.

[47] Saving cold water also represent opportunities to reduce emissions, albeit beyond the home's fence. Estimates of the energy embodied in water supply, delivery, and treatment range from 0.005 to 0.011 kWh per gallon consumed (McCabe and Wilkinson, respectfully). If we use the midpoint of this range (0.008 kWh/gallon) and adjust for the flow reduction that is tied to energy reduction (estimated by Dyballa at 0.7) then 0.7 x 0.008 kWh/gallon = 0.0056 kWh saved per gallon of water saved. Since each kWh of electricity consumption means an average of 1.43 lbs CO_2, we can estimate the greenhouse gas savings per saved gallon of water in the water supply and treatment system: 0.0056 kWh/gallons x 1.43 lbs CO_2/kWh = 0.008 lbs CO_2 per saved gallon. *If* a homeowner reduces water waste by ten percent of total annual use—estimates for which range from 70,000 to 300,000 gallons per household per year (we use 166,000 gallons/hh/yr, based on AWWA 1998: 175.1 gallons per capita per day x 2.594 persons/hh in 1999 x 365 d/yr)—by such easy measures as not over-watering lawns, turning off taps, etc: 0.10 x 166,000 gallons/yr x 0.008 lbs CO_2 per saved gallon = 133 lbs CO_2 saved per year. Saving 16,600 gallons also saves the water utilities 93 kWh per year, worth (3,412 Btu/kWh x 3.0322 conversion losses) 0.96 million Btu/yr. If we use the average water rate ($1.94 per 1,000 gallons), then we save on utilities: $1.94 per k gallons x 16.6 k gallons = $32.20 per year.

Outdoor water consumption averages 103.5 gcpd and equals 97,990 gallons per household per year (indoor totals 66,090 gallons/hh/yr, of which clothes washers = 22.7 percent, showers = 17.8 percent, faucets = 15.4 percent, leaks = 12.7 percent, toilets = 26.1 percent, dish washers = 1.4 percent, baths = 1.2 percent, and other domestic = 2.1 percent). McCabe, Michael (1991), *Relation Between Water and Energy Conservation*, National Institute of Standards and Technology, Gaithersburg, MD; Dyballa, Cindy, and Chris Connelly (1991), "Electric and Water Utilities: Building Cooperation and Savings," (Dyballa was with EPA, and Connelly with the Bruce Company, but I do not have a citation); Wilkinson, Robert (1999), *Methodology for Analysis of the Energy Intensity of California's Water Systems*, Rocky Mountain Institute, Snowmass, CO; American Water Works Association (1998), "Residential End Use Study," www.waterwise,org/wtruse98

[48] Another cold water saving measure is to replace high-flow toilets with water-efficient models that lower per flush water consumption from the existing average of 3.48 gallons per flush (gpf) to 1.6 gpf. The American Water Works Association estimates that 26.1 percent of typical residential water consumption is through toilets. Therefore, saving 1.88 gpf, or 54 percent: 0.54 x 0.261 x 66,090 gallons = 0.54 x 17,250 gallons = 9,315 gallons saved x 0.008 lbs CO_2 per saved gallon = 75 lbs CO_2 saved per year. Saving 9,315 gallons also saves the water utilities 52 kWh per year, worth (3,412 Btu/kWh x 3.0322 conversion losses) 0.54 million Btu/yr. Water supply savings: $1.94 per k gallons x 9.32 k gallons = $18.07 per year. At a replacement cost of $150 per toilet, and we replace two toilets per household, then the simple payback = $300 ÷ $18.07/yr = 16.60 years. Assuming the toilets last for 20 years, then the Cost of Saved Carbon = $300 ÷ (20 x 75 lbs CO_2) = $300 ÷ 0.75 tons CO_2 = $400.00 per ton of CO_2 saved. This is clearly not cost-effective as a carbon dioxide reduction measure, and these cold water savings are excluded from our total household savings. On the other hand, water-saving 2.5 gpf toilets are standard, and neither the full cost nor the marginal cost should be applied to the CSC calculation (which is then $0.00).

Note: New estimate of space heating energy lost by typical flushing pattern (which drains 2.5 to 5.0 gallons of water heated in the tank between most flushes): approximation: 66,090 gallons indoor x 0.261 toilet fraction = 17,250 gallons per year. If we assume that 40 percent is used during heating season, and three-quarters of which sits around long enough to be heated, then: 17,050 x 0.40 x 0.75 = 5,115 gallons per year that is heated. 5,115 gallons x 8.35 lbs/gallon = 42,710 lbs x deltaT (75°Fout - 55°Fin) 20F° = 854,205 Btu lost to toilet flushing. The average million Btu for space heating (8,829 lbs CO_2 for 68.1 million Btu average) = 129.6 lbs CO_2 per million Btu. Hence CO_2 emissions due to lost heat from flushing = 129.6 lbs $CO_2/10^6$ Btu x 0.854 million Btu = 110.7 lbs CO_2. Space heating CO_2 saved by low-flow toilet is thus 111 lbs CO_2 x 0.54 (see above) = 60 lbs CO_2 per year.

[49] Air leakage typically accounts for 25-40 percent of heat loss in winter and unwanted heat gain in summer (Heede, 1995, *Homemade Money*, RMI. p. 23). We estimate that sealing large leakage areas—especially in the basement or crawlspace plus roof or ceiling and fireplace and other obvious and high-priority air areas—will reduce heating and cooling losses by 13.9 percent (0.33 total air leakage x 0.60 large leak fraction x 0.70 leak plugging effective-ness). This is equivalent to reducing air changes per hour (ACH) from 0.8 to 0.5 in 2,250 ft^2 (18,000 ft^3) house in a 4,000 HDD climate, which saves 9.0 million Btu/yr. David Houghton et al, 1996, *Space Heating Technology Atlas*, E SOURCE, Boulder, CO, p. 107. The average household will save 0.139 x (heating's 68.1 + cooling's 13.6 million Btu/yr) and 0.139 x ($476 + $105) and 0.139 x (8,829 + 1,882 lbs CO_2/yr) = 11.36 million Btu and $80.76 and 1,489 lbs CO_2/yr per year. Assume further that such draft proofing costs $150 and lasts 20 years, yielding a Cost of saved Carbon of $150 ÷ (20 yrs x 1,489 lbs CO_2) = $150 ÷ 14.89 tons = $10.07 per ton of saved CO_2.

Simple payback = $150 ÷ $80.76/yr = 1.86 years.

[50] Heat loss through attics typically account for ~40 percent of a home's heating bill and for ~20 percent of unwanted heat gain in cooling climates. Let's assume that adding insulation to the attic cuts combined heating and cooling bills by 20 percent, saving 0.20 x 81.7 million Btu/yr and $581 and 10,711 lbs CO_2 = 16.34 million Btu and $116.20 and 2,142 lbs CO_2 per year. Assuming that such an insulation job costs $500 (1.1 cent/$ft^2$/R; add R-30 of loose-fill cellulose or fiberglass = 33 cents/ft^2 x 1,500 average attic area = $500. Houghton et al, 1996, *Space Heating Technology Atlas*, E SOURCE, Boulder, CO, p. 85) and lasts 30 years gives a Cost of Saved Carbon of $500 ÷ (30 yrs x 2,142 lbs CO_2) = $500 ÷ 32.13 tons = $15.56 per ton of saved CO_2.

Simple payback = $500 ÷ $116.20/yr = 4.30 years.

[51] Based on the footnote above, assume that weatherizing around windows and doors cuts air leakage in such areas from 25 percent of total air leakage to 7.5 percent (0.33 total air leakage x 0.25 window and door leak fraction x 0.70 leak plugging effectiveness), saving 5.8 percent on combined heating and cooling bills: save 0.058 x 81.7 million Btu/yr = 4.74 million Btu/yr and 0.058 x $581 = $33.70 and 0.058 x 10,711 lbs CO_2/yr = 621 lbs CO_2/yr. Assume further that such draft proofing costs $80 and lasts 10 years, yielding a Cost of saved Carbon of $80 ÷ (10 yrs x 621 lbs CO_2) = $80 ÷ 3.11 ton = $25.72 per ton of saved CO_2.

Simple payback: $80 ÷ $33.70/yr = 2.37 yrs.

[52] A 1985 study found that 95% of foundations were un-insulated (ORNL, *Building Foundation Design Handbook*). Un-insulated basements can account for 25-30 percent of a home's total heat loss (Heede, 1995, *Homemade Money*, p. 66). We'll use 26 percent here, and assume that a basement/crawlspace insulation job cuts this heat loss in half, saving thirteen percent on heating bills (don't forget to seal rim joists and other leakage areas first). Hence, savings total 0.13 x 68.1 million Btu and $476 and 8,829 lbs CO_2 = 8.85 million Btu and $61.88 and 1,148 lbs CO_2 per year. Assuming that such an insulation job costs $500 and lasts 30 years gives and Cost of Saved Carbon of $500 ÷ (30 yrs x 1,148 lbs CO_2) = $500 ÷ 17.22 tons = $29.04 per ton of saved CO_2. Insulating the floor above an un-heated basement or crawlspace typically costs less than insulating a foundation wall.

Simple payback = $500 ÷ $61.88/yr = 8.08 years.

[53] Windows commonly account for a third of older homes' heat loss, and 15-40 percent even in new houses, plus as

much as 75 percent of unwanted heat gain in summer (Wilson and Morrill, 1998, *Consumer Guide to Home Energy Savings*, 6th edition, American Council for an Energy-Efficient Economy, Washington, DC, p. 37). We assume that adding inexpensive heat shrink air gap films to existing windows improves U-value by a third, cutting heat loss through windows from 25 percent to 16.7 percent, saving 8.3 percent on heating bills. Hence, saving 0.083 x 68.1 million Btu and $476 and 8,829 lbs CO_2 = 5.65 million Btu and $39.51 and 733 lbs CO_2 per year. Assuming that such a window insulation retrofit costs $78 (30 cents/ft^2 x 260 ft of window area, Houghton et al, *op. cit*. p. 125) and lasts three years gives a Cost of Saved Carbon of $78 ÷ (3 yrs x 733 lbs CO_2) = $78 ÷ 1.10 ton = $70.91 per ton of saved CO_2. **Simple payback: $78 ÷ $39.51 = 1.97 years.**

[54] Florida Solar Energy Center research suggests that a properly installed radiant barrier is cost-effective in most sunbelt states and can save 7–21 percent on cooling bills. Other estimates range from 2 to 10 percent of cooling costs (John Krigger, 1992, *Your Home Cooling Energy Guide*, Saturn Resource Mngt, Helena, MT, p. 12). We'll use 10 percent savings as typical. Hence, 0.10 x 13.6 million Btu/yr = 1.36 million Btu/yr and 0.10 x $105 = $10.50/yr and 0.10 x 1,882 lbs CO_2/yr = 188 lbs CO_2 per year. We estimate that adding a radiant barrier to the attic's roof rafters costs $0.10 per square foot x average attic area of 1,700 square feet = $170 and lasts 20 years, giving a Cost of Saved Carbon of $170 ÷ (20 yrs x 188 lbs CO_2) = $170 ÷ 1.88 ton = $90.43 per ton of saved CO_2. As with many of these measures, this will be far more cost-effective in hot climates than in our "average" climate and cooling bills.

Simple payback in our average example: $170 ÷ $10.50 = 16.19 years.

[55] Adding wall insulation is important (a typical single-family house will have 1,600-3,000 ft^2 of exterior wall area; considering the often wasteful complexity of housing designs, we use 2,400 ft^2 here, revealing large savings-potential in better designs and better actual rather than nominal insulation levels). It is also expensive (an estimated $0.65/ft^2) to add cellulose to a 2x4 wall. We estimate that such a retrofit will reduce combined heating and cooling bills by 8 percent over a 30-year period. Savings total 0.08 x 81.7 million Btu and $581 and 10,711 lbs CO_2 = 6.54 million Btu and $46.48 and 857 lbs CO_2 per year. Adding wall insulation costs $1,560 (2,400 ft^2 exterior x $0.65/ft^2) yielding a Cost of Saved Carbon of $1,560 ÷ (40 yrs x 857 lbs CO_2) = $1,560 ÷ 17.14 tons = $91.02 per ton of saved CO_2.

Simple payback = $1,560 ÷ $46.48/yr = 33.56 years.

[56] Average cost of saved carbon dioxide: simple addition of total investment, ignoring life of each measure, equals $3,038, versus total CO_2 saved over the life of each measure of 87.47 tons CO_2 (64.89 tons in the integrated analysis) yields an average of $34.73 per ton of CO_2 saved.

[57] Even in heating dominated climates it seldom makes economic sense to replace existing windows with super-insulating windows. But let's assume that such an upgrade takes place at a time when windows need replacing anyway, improves unit U-value from 0.50 to 0.25, and cuts the home's window heating load from 22 percent to 11 percent, cutting energy bills by 11 percent. Hence, savings of 0.11 x 68.1 million Btu and $476 and 8,829 lbs CO_2 = 7.49 million Btu and $52.36 and 971 lbs CO_2 per year. Assuming that the *marginal* cost of replacing 260 ft^2 of windows is $5/ft^2 = $1,300 (extrapolated from Houghton et al, *op. cit*. p. 123) and lasts twenty years gives a Cost of Saved Carbon of $1,300 ÷ (20 yrs x 971 lbs CO_2) = $1,300 ÷ 9.71 tons = $133.88 per ton of saved CO_2.

Simple payback: $1,300 ÷ $52.36 = 24.83 years.

[58] Florida Solar Energy Center reports savings of 25-43% by whitening the roof on poorly insulated Florida homes and 10% savings on a home with existing R-25 roof insulation. We'll use 25 percent savings as representative of a mix of homes in cooling climates, most of which are poorly insulated. Hence, 0.25 x 13.6 million Bty/yr = 3.40 million Btu/yr and 0.25 x $105 = $26.25/yr and 0.25 x 1,882 lbs CO_2 per year = 471 lbs CO_2/yr. Roof whitening is expensive ($0.30–0.70+/ft^2) and will likely only be done when the roof needs replacement anyway. For the purposes of this exercise we assume that whitening costs $1,020 (a typical single-family home is 2,280 ft^2 and we assume a mix of one-story and two-story homes having an average roof area of 1,700 ft^2 x $0.60/ft^2) and lasts 20 years, giving a Cost of Saved Carbon of $1,020 ÷ (20 yrs x 471 lbs CO_2) = $1,080 ÷ 4.71 ton = $229.30 per ton of saved CO_2. Note that in this example we are assigning the full retrofit cost to energy savings, whereas such a retrofit would most likely be done when a roof need s replacement.

Simple payback: $1,020 ÷ $26.25 = 38.86 years.

[59] We assume here that adding low-e retrofit films cuts unwanted heat gain through 260 ft^2 of windows in a typical home by 50 percent (Southwall's Solis™, for example, reduces solar heat transmission from 83 to 45 percent), reducing solar heat gain's fraction of cooling load from 40 percent to 20 percent, thereby saving 20 percent on cooling bills. Hence, 0.20 x 13.6 million Bty/yr = 2.72 million Btu/yr and 0.20 x $105 = $21.00/yr and 0.20 x 1,882 lbs CO_2 per year = 377 lbs CO_2/yr. Low-e films cost ~$2.00 ft^2, wholesale, uninstalled (Michael Shepard et al, 1995, *Commercial Space Cooling and Air Handling Technology Atlas*, E SOURCE, Boulder, CO, p. 54) let's assume an installed cost of $5/ft^2 over 75 percent of the typical home's window area of 260 ft^2 (= 182 ft^2) and a measure life of 20 years, giving a Cost of Saved Carbon of $910 ÷ (20 yrs x 377 lbs CO_2) = $910 ÷ 3.77 tons = $241.38 per ton of saved CO_2. Naturally, savings and cost-effectiveness will be far higher in high CDD climates and most cost-effective when replacing (and downsizing) a central AC system or designing a new home in a hot climate.

Simple payback: $910 ÷ $21.00 = 43.33 years.

[60] In this version we prioritize the measures from lowest to highest "Cost of Saved Carbon" and reduce the Btu and

cost and CO_2 to be saved after each measure is implemented. This is a fairer way of calculating savings, and gives a better estimate of total energy, dollars, and carbon dioxide saved from a set of measures. In turn, we use the energy, costs, and emissions remaining after this set of building shell measures as inputs to "Heating and Cooling: Equipment" section that follows.

[61] Air leakage typically accounts for 25-40 percent of heat loss in winter and unwanted heat gain in summer (Heede, 1995, *Homemade Money*, RMI. p. 23). We estimate that sealing large leakage areas — especially in the basement or crawlspace plus roof or ceiling and fireplace and other obvious and high-priority air areas — will reduce heating and cooling losses by 13.9 percent (0.33 total air leakage x 0.60 large leak fraction x 0.70 leak plugging effective-ness). This is equivalent to reducing air changes per hour (ACH) from 0.8 to 0.5 in 2,250 ft^2 (18,000 ft^3) house in a 4,000 HDD climate, which saves 9.0 million Btu/yr. David Houghton et al, 1996, *Space Heating Technology Atlas*, E SOURCE, Boulder, CO, p. 107. On the space heating side, the average household will save 0.139 x 68.1 million Btu/yr = 9.47 million Btu and 0.139 x $476 = $66.16 and 0.139 x 8,829 lbs CO_2/yr = 1,227 lbs CO_2 per year. Cooling savings are: 0.139 x 13.6 million Btu/yr = 1.89 million Btu and 0.139 x $105 = $14.60 and 0.139 x 1,882 lbs CO_2/yr = 262 lbs CO_2 per year. Sum of savings: 11.36 million Btu, $80.76, and 1,489 lbs CO_2/yr. *Remaining after measure implemented: Heating: (68.1–9.47=) 58.63 million Btu, ($476.00–$66.16=) $409.84, (8,829–1,227=) 7,602 lbs CO_2/yr; Cooling: (13.6–1.89=) 11.71 million Btu, ($105.00–$14.60=) $90.40, (1,882–262=) 1,620 lbs CO_2/yr.* Assume further that such draft proofing costs $150 and lasts 20 years, yielding a Cost of saved Carbon of $150 ÷ (20 yrs x 1,489 lbs CO_2) = $150 ÷ 14.89 tons = $10.07 per ton of saved CO_2.

Simple payback = $150 ÷ $80.76/yr = 1.86 years.

[62] Heat loss through attics typically account for ~40 percent of a home's heating bill and for ~20 percent of unwanted heat gain in cooling climates. Let's assume that adding adequate insulation to the attic cuts heat loss and heating bills by 25 percent and reduces cooling bills by 10 percent per year. On the space heating side, the average household will save 0.20 x 58.63 million Btu/yr = 11.73 million Btu and 0.20 x $409.84 = $81.97 and 0.20 x 7,602 lbs CO_2/yr = 1,520 lbs CO_2 per year. Cooling savings are: 0.10 x 11.71 million Btu/yr = 1.17 million Btu and 0.10 x $90.40 = $9.04 and 0.10 x 1,620 lbs CO_2/yr = 162 lbs CO_2 per year. Sum of savings: (11.73+1.17=) 12.90 million Btu, ($81.97+$9.04=) $91.01, and (1,520+162=) 1,682 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (58.63–11.73=) 46.90 million Btu, ($409.84–$81.97=) $327.87, (7,602–1,520=) 6,082 lbs CO_2/yr; Cooling: (11.71–1.17=) 10.54 million Btu, ($90.40–$9.04=) $81.36, and (1,620–162=) 1,458 lbs CO_2/yr.* Estimated cost of such an insulation job is $500 (1.1 cent/$ft^2$/R; add R-30 of loose-fill cellulose or fiberglass = 33 cents/ft^2 x 1,500 average attic area = $500. Houghton et al, 1996, *Space Heating Technology Atlas*, E SOURCE, Boulder, CO, p. 85) and lasts 30 years gives a Cost of Saved Carbon of $500 ÷ (30 yrs x 1,682 lbs CO_2) = $500 ÷ 25.23 tons = $19.82 per ton of saved CO_2. **Simple payback = $500 ÷ $91.01/yr = 5.49 years.**

[63] Based on the footnote above, assume that weatherizing around windows and doors cuts air leakage in such areas from 25 percent of total air leakage to 7.5 percent (0.33 total air leakage x 0.25 window and door leak fraction x 0.70 leak plugging effectiveness), saving 5.8 percent on both heating and cooling bills. On the space heating side, the average household will save 0.058 x 46.90 million Btu/yr = 2.72 million Btu and 0.058 x $327.87 = $19.02 and 0.058 x 6,082 lbs CO_2/yr = 353 lbs CO_2 per year. Cooling savings are: 0.058 x 10.54 million Btu/yr = 0.61 million Btu and 0.058 x $81.36 = $4.72 and 0.058 x 1,458 lbs CO_2/yr = 85 lbs CO_2 per year. Sum of savings: (2.72+0.61=) 3.33 million Btu, ($19.02+$4.72=) $23.74, and (353+85=) 438 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (46.90–2.72=) 44.18 million Btu, ($327.87–$19.02=) $308.85, (6,082–353=) 5,729 lbs CO_2/yr; Cooling: (10.54–0.61=) 9.93 million Btu, ($81.36–$4.72=) $76.64, and (1,458–85=) 1,373 lbs CO_2/yr.* We estimate that such draft proofing costs $80 and lasts 10 years, yielding a Cost of saved Carbon of $80 ÷ (10 yrs x 438 lbs CO_2) = $80 ÷ 2.19 ton = $36.53 per ton of saved CO_2.

Simple payback: $80÷$23.74/yr= 3.37yrs.

[64] A 1985 study found that 95% of foundations were un-insulated (ORNL, *Building Foundation Design Handbook*). Un-insulated basements can account for 25-30 percent of a home's total heat loss (Heede, 1995, *Homemade Money*, p. 66). We'll use 26 percent here, and assume that a basement/crawlspace insulation job cuts this heat loss in half (to account for the basement walls or ceilings that are insulated), saving thirteen percent on heating bills (seal rim joists and other leakage areas first). On the space heating side, the average household will save 0.130 x 44.18 million Btu/yr = 5.74 million Btu and 0.13 x $308.85 = $40.15 and 0.13 x 5,729 lbs CO_2/yr = 745 lbs CO_2 per year. Sum of savings: 5.74 million Btu, $40.15, and 745 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (44.18–5.74=) 38.44 million Btu, ($308.85–$40.15=) $268.70, (5,729–745=) 4,984 lbs CO_2/yr; Cooling is unchanged at: 9.93 million Btu, $76.64, and 1,373 lbs CO_2/yr.* Assuming that such an insulation job costs $500 and lasts 30 years gives and Cost of Saved Carbon of $500 ÷ (30 yrs x 745 lbs CO_2) = $500 ÷ 11.18 tons = $44.72 per ton of saved CO_2. Insulating the floor above an unheated basement or crawlspace typically costs less than insulating a foundation wall. **Simple payback = $500 ÷ $40.15/yr = 12.45 years.**

[65] Windows commonly account for a third of older homes' heat loss, and 15-40 percent even in new houses, plus as much as 75 percent of unwanted heat gain in summer (Wilson and Morrill, 1998, *Consumer Guide to Home Energy Savings*, 6th edition, American Council for an Energy-Efficient Economy, Washington, DC, p. 37). We estimate that adding inexpensive heat shrink air gap films to existing windows improves U-value by a third, cutting heat loss through windows from 25 percent to 16.7 percent, saving 8.3 percent on heating bills. On the space heating side, the average household will save 0.083 x 38.44 million Btu/yr = 3.19 million Btu and 0.083 x $268.70 = $22.30 and

0.083 x 4,984 lbs CO_2/yr = 414 lbs CO_2 per year. Cooling savings are: 0.058 x 10.54 million Btu/yr = 0.61 million Btu and 0.058 x $81.36 = $4.72 and 0.058 x 1,458 lbs CO_2/yr = 85 lbs CO_2 per year. Sum of savings: (2.72+0.61=) 3.33 million Btu, ($19.02+$4.72=) $23.74, and (353+85=) 438 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (38.44–3.19=) 35.25 million Btu, ($268.70–$22.30=) $246.40, (4,984–414=) 4,570 lbs CO_2/yr; Cooling remains unchanged at: 9.93 million Btu, $76.64, and 1,373 lbs CO_2/yr.* Assuming that such a window insulation retrofit costs $78 (30 cents/ft^2 x 260 ft of window area, Houghton et al, *op. cit*. p. 125) and lasts three years gives a Cost of Saved Carbon of $78 ÷ (3 yrs x 414 lbs CO_2) = $78 ÷ 0.62 ton = $125.81 per ton of saved CO_2. **Simple payback: $78 ÷ $22.30 = 3.50 years.**

[66] Adding wall insulation is important (a typical single-family house will have 1,600-3,000 ft^2 of exterior wall area; considering the often wasteful complexity of housing designs, we use 2,400 ft^2 here, revealing large savings-potential in better designs and better actual rather than nominal insulation levels). It is also expensive (an estimated $0.65/ft^2) to add cellulose to a 2x4 wall. We estimate that such a retrofit will reduce combined heating and cooling bills by 8 percent over a 30-year period. On the space heating side, the average household will save 0.08 x 35.25 million Btu/yr = 2.82 million Btu and 0.08 x $246.40 = $19.71 and 0.080 x 4,570 lbs CO_2/yr = 366 lbs CO_2 per year. Cooling savings are: 0.08 x 9.93 million Btu/yr = 0.80 million Btu and 0.08 x $76.64 = $6.13 and 0.08 x 1,373 lbs CO_2/yr = 110 lbs CO_2 per year. Sum of savings: (2.82+0.80=) 3.62 million Btu, ($19.71+$6.13=) $25.84, and (366+110=) 476 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (35.25–2.82=) 32.43 million Btu, ($246.40–$19.71=) $226.69, (4,570–366=) 4,204 lbs CO_2/yr; Cooling: (9.93–0.80=) 9.13 million Btu, ($76.64–$6.13=) $70.51, and (1,373–110=) 1,263 lbs CO_2/yr*. Adding wall insulation costs $1,560 (2,400 ft^2 exterior x $0.65/ft^2) yielding a Cost of Saved Carbon of $1,560 ÷ (40 yrs x 476 lbs CO_2) = $1,560 ÷ 9.52 tons = $163.87 per ton of saved CO_2. **Simple payback = $1,560 ÷ $25.84/yr = 60.37 years.**

[67] Florida Solar Energy Center research suggests that a properly installed radiant barrier is cost-effective in most sunbelt states and can save 7–21 percent on cooling bills. Other estimates range from 2 to 10 percent of cooling costs (John Krigger, 1992, *Your Home Cooling Energy Guide*, Saturn Resource Mngt, Helena, MT, p. 12). We'll use 10 percent savings as typical. Hence, 0.10 x 9.13 million Btu/yr = 0.91 million Btu/yr and 0.10 x $70.51 = $7.05/yr and 0.10 x 1,263 lbs CO_2/yr = 126 lbs CO_2 per year. *Remaining after measure is implemented: Heating remains unchanged at 32.43 million Btu, $226.69, and 4,204 lbs CO_2/yr; Cooling: (9.13–0.91=) 8.22 million Btu, ($70.51–$7.05=) $63.46, and (1,263–126=) 1,137 lbs CO_2/yr*. We estimate that adding a radiant barrier to the attic's roof rafters costs $0.10 per square foot x average attic area of 1,700 square feet = $170 and lasts 20 years, giving a Cost of Saved Carbon of $170 ÷ (20 yrs x 126 lbs CO_2) = $170 ÷ 1.26 ton = $134.92 per ton of saved CO_2. As with many of these measures, this will be far more cost-effective in hot climates than in our "average" climate and cooling bills. **Simple payback in our average example: $170 ÷ $7.05 = 24.11 years.**

[68] Average cost of saved carbon dioxide: simple addition of total investment, ignoring life of each measure, equals $3,038, versus total CO_2 saved over the life of each measure of 64.89 tons CO_2 yields an average of $46.82 per ton of CO_2 saved.

[69] Note: we do not re-calculate these three measures (superwindows, roof whitening, and low-e films) after the previous measures have been implemented because their low cost-effectiveness if all assigned to energy-savings do not justify their inclusion in package retrofit. Of course, as noted below, if the roof or windows need replacing anyway, these measures will make economic sense. Even in heating dominated climates it seldom makes economic sense to replace existing windows with super-insulating windows. But let's assume that such an upgrade takes place at a time when windows need replacing anyway, improves unit U-value from 0.50 to 0.25, and cuts the home's window heating load from 22 percent to 11 percent, cutting energy bills by 11 percent. Hence, savings of 0.11 x 68.1 million Btu and $476 and 8,829 lbs CO_2 = 7.49 million Btu and $52.36 and 971 lbs CO_2 per year. Assuming that the *marginal* cost of replacing 260 ft^2 of windows is $5/ft^2 = $1,300 (extrapolated from Houghton et al, *op. cit*. p. 123) and lasts twenty years gives a Cost of Saved Carbon of $1,300 ÷ (20 yrs x 971 lbs CO_2) = $1,300 ÷ 9.71 tons = $133.88 per ton of saved CO_2. **Simple payback: $1,300 ÷ $52.36 = 24.83 years.**

[70] Florida Solar Energy Center reports savings of 25-43% by whitening the roof on poorly insulated Florida homes and 10% savings on a home with existing R-25 roof insulation. We'll use 25 percent savings as representative of a mix of homes in cooling climates, most of which are poorly insulated. Hence, 0.25 x 13.6 million Bty/yr = 3.40 million Btu/yr and 0.25 x $105 = $26.25/yr and 0.25 x 1,882 lbs CO_2 per year = 471 lbs CO_2/yr. Roof whitening is expensive ($0.30–0.70+/ft^2) and will likely only be done when the roof needs replacement anyway. For the purposes of this exercise we assume that whitening costs $1,020 (a typical single-family home is 2,280 ft^2 and we assume a mix of one-story and two-story homes having an average roof area of 1,700 ft^2 x $0.60/ft^2) and lasts 20 years, giving a Cost of Saved Carbon of $1,020 ÷ (20 yrs x 471 lbs CO_2) = $1,080 ÷ 4.71 ton = $229.30 per ton of saved CO_2. Note that in this example we are assigning the full retrofit cost to energy savings, whereas such a retrofit would most likely be done when a roof need s replacement. **Simple payback: $1,020 ÷ $26.25 = 38.86 years.**

[71] We assume here that adding low-e retrofit films cuts unwanted heat gain through 260 ft^2 of windows in a typical home by 50 percent (Southwall's Solis™, for example, reduces solar heat transmission from 83 to 45 percent), reducing solar heat gain's fraction of cooling load from 40 percent to 20 percent, thereby saving 20 percent on cooling bills. Hence, 0.20 x 13.6 million Bty/yr = 2.72 million Btu/yr and 0.20 x $105 = $21.00/yr and 0.20 x 1,882 lbs CO_2 per year = 377 lbs CO_2/yr. Low-e films cost ~$2.00 ft^2, wholesale, uninstalled (Michael Shepard et al, 1995, *Commercial Space Cooling and Air Handling Technology Atlas*, E SOURCE, Boulder, CO, p. 54) let's assume an

installed cost of \$5/ft^2 over 75 percent of the typical home's window area of 260 ft^2 (= 182 ft^2) and a measure life of 20 years, giving a Cost of Saved Carbon of \$910 ÷ (20 yrs x 377 lbs CO_2) = \$910 ÷ 3.77 tons = \$241.38 per ton of saved CO_2. Naturally, savings and cost-effectiveness will be far higher in high CDD climates and most cost-effective when replacing (and downsizing) a central AC system or designing a new home in a hot climate.

Simple payback: \$910 ÷ \$21.00 = 43.33 years.

[72] Homeowners can save 6-16 percent on their heating bills by installing a programmable thermostat (Heede, 1995, *Homemade Money,* p. 80); *Home Energy* magazine (see also Home Energy, 1997, *No-Regrets Remodeling*, p. 79) reports 20 percent savings for two 8-hr setbacks). We take 10 percent savings on both heating and cooling as representative. For heating: 0.10 x 68.1 million Btu/yr = 6.81 million Btu/yr, 0.10 x \$476 = \$47.60, and 0.10 x 8,829 lbs CO_2/yr = 883 lbs CO_2/yr; for cooling: 0.10 x 13.6 million Btu/yr = 1.36 million Btu/yr, 0.10 x \$105 = \$10.50, and 0.10 x 1,882 lbs CO_2/yr = 188 lbs CO_2/yr. Sum of savings: (6.81+1.36=) 8.17 million Btu, and (\$47.60+\$10.50=) \$58.10, and (883+188=) 1,071 lbs CO_2/yr. A programmable thermostat costs \$20-\$150; we assume a \$100 cost and a 20-year life, which yields a Cost of Saved Carbon of \$100 ÷ (20 yrs x 1,071 lbs CO_2) = \$100 ÷ 10.71 ton = \$9.34 per ton of saved CO_2. **Simple payback = \$100.00 ÷ \$58.10 = 1.72 years.**

[73] Leaky, un-insulated ducts can waste as much as 30 percent of heating energy. We assume that a 15 percent efficiency gain is readily achievable for heating and 10 percent gain for cooling. Hence, for heating: 0.15 x 68.1 million Btu/yr = 10.22 million Btu/yr, 0.15 x \$476 = \$71.40, and 0.15 x 8,829 lbs CO_2/yr = 1,324 lbs CO_2/yr; for cooling: 0.10 x 13.6 million Btu/yr = 1.36 million Btu/yr, 0.10 x \$105 = \$10.50, and 0.10 x 1,882 lbs CO_2/yr = 188 lbs CO_2/yr. Sum of savings: (10.22+1.36=) 11.58 million Btu, and (\$71.40+\$10.50=) \$81.90, and (1,324+188=) 1,512 lbs CO_2/yr. We assume that sealing and insulating ducts costs \$400 and lasts 25 years, yielding a Cost of Saved Carbon of \$400 ÷ (30 yrs x 1,512 lbs CO_2) = \$400 ÷ 22.68 ton = \$17.64 per ton of saved CO_2

Simple payback = \$400.00 ÷ \$81.90 = 4.88 years.

[74] Numerous options are feasible and cost-effective. Burner replacements, nozzle or orifice reduction, automatic flue dampers, electronic ignition, furnace fan motor upgrade (conventional fans use ~600 kWh/yr), and so on. We simply assume a representative efficiency improvement of 6 percent: 0.06 x 68.1 million Btu = 4.09 million Btu, 0.06 x \$476 = \$28.56, and 0.06 x 8,829 lbs CO_2 per year = 530 lbs CO_2 per year. We assume that a heating system modification costs \$200 and lasts 15 years, which yields a Cost of Saved Carbon of \$200 ÷ (15 yrs x 530 lbs CO_2) = \$200 ÷ 3.98 tons = \$50.25 per ton of saved CO_2. **Simple payback = \$200.00 ÷ \$28.56 = 7.00 years.**

[75] A thorough heating system tune-up can save 3-10% of heating energy and costs \$50-\$100 (Wilson and Morrill, 1998, *Consumer Guide to Home Energy Savings*, 6th edition, American Council for an Energy-Efficient Economy, Washington, DC, p. 99). We take a 6 percent savings as representative: 0.06 x 68.1 million Btu = 4.09 million Btu, 0.06 x \$476 = \$28.56, and 0.06 x 8,829 lbs CO_2 per year = 530 lbs CO_2 per year. We estimate an \$80 cost and a 2-year life, which yields a Cost of Saved Carbon of \$80 ÷ (2 yrs x 530 lbs CO_2) = \$80 ÷ 0.53 ton = \$150.94 per ton of saved CO_2. Of course, tuning up a carbon-intensive oil-fired boiler in a cold climate will save more CO_2 than the average (gas-fired moderate climate) system used here. **Simple payback = \$80.00 ÷ \$28.56 = 2.80 years.**

[76] Both room and central air conditioning systems must be inspected and maintained regularly. Over- or under-charged systems compromise efficiency (a 10% undercharge can reduce efficiency by as much as 20%; Heede, 1995, *Homemade Money,* p. 108). Krigger cites average savings of 27 percent for heat pumps (John Krigger, 1992, *Your Home Cooling Energy Guide*, Saturn Resource Mngt, Helena, MT, p. 50). Outdoor units should be shaded and be cleared for unrestricted airflow to the condenser coils. Filters should be replaced and evaporator coils cleaned. Compressors and other mechanicals should be checked. Ductwork must be sealed and insulated where possible (see above). Of course, proper sizing of the AC system and routing and installation of the ductwork is essential, after load minimization strategies have been duly considered. We assume, for representational purposes, that a "tune-up" improves efficiency and reduces electric consumption by 15%, costs \$100, and is done every two years. Cooling savings are thus: 0.15 x 13.6 million Btu/yr = 2.04 million Btu/yr, 0.15 x \$105 = \$15.75, and 0.15 x 1,882 lbs CO_2/yr = 282 lbs CO_2/yr. Cost of Saved Carbon of \$80 ÷ (2 yrs x 282 lbs CO_2) = \$80 ÷ 0.28 ton = \$285.71 per ton of saved CO_2.

Simple payback = \$80.00 ÷ \$15.75 = 5.08 years.

[77] Average cost of saved carbon dioxide: simple addition of total investment, ignoring life of each measure, equals \$860, versus total CO_2 saved over the life of each measure of 38.18 tons CO_2 yields an average of \$22.52 per ton of CO_2 saved.

[78] Half of all air conditioners are older than eight years of age and use far more electricity to provide comfort, on average, than modern technology makes possible. We estimate that the "typical" air conditioner in service has a seasonal energy efficiency rating of SEER 9.0. Upgrading — most economical when a unit has failed — to an SEER of 12.0 boosts performance by 25 percent and reduces electric consumption by the same amount. Keep in mind that all of the previous shell improvements (and the subsequent measures that also reduce internal loads) will necessitate a much smaller unit, and thus saves on equipment cost compared to sizing based on rules of thumb. If, however, we assume that we need to provide the same amount of cooling as the old unit, we'd reduce the cooling demand by 25 percent from 13.6 million Btu (based on our estimate of average cooling electric consumption of 1,316 kWh per household per year) as follows: 0.25 x 13.6 million Btu = 3.40 million Btu, and 0.25 x \$105 = \$26.25, and 0.25 x 1,882 = 471 lbs CO_2 per year. Assuming that the marginal cost of an SEER 12.0 unit over a 9.0 unit is \$200, and that the replacement unit lasts 13 years, then the Cost of Saved Carbon is \$200 ÷ (13 x 471 CO_2/yr) = \$200 ÷ 3.06

tons CO_2/yr = $65.36 per ton of CO_2 saved. **Simple payback = $200.00 ÷ $26.25 = 7.62 years.**

[79] Heating systems are also in need of upgrading to more efficient units now available on the market, but there is little rationale for doing so (except with very old, nearly failing, or very inefficient equipment) until the old beast dies. Old systems, however, are often less than 50 percent efficient whereas new furnaces and boilers are frequently near or even above 90 percent efficient at converting fuel to heat. (Don't forget that heat *delivery* efficiency is equally important and often represent several overlooked opportunities to reduce energy waste and heating bills.) For this example, let's assume that a typical home has a heating unit with 50 percent efficiency (average fuel utilization efficiency, or AFUE) and we replace it with a 75 percent AFUE unit. This means we need one third less fuel and we save 0.333 x 68.1 million Btu = 22.68 million Btu, and 0.333 x $476 = $158.51, and 0.333 x 8,829 lbs CO_2 = 2,940 lbs CO_2 per year. Assuming that the replacement cost of an AFUE 0.75 unit over the old AFUE 0.50 unit is $1,000, and that the replacement unit lasts 18 years, then the Cost of Saved Carbon is $1,000 ÷ (18 x 2,940 CO_2/yr) = $1,000 ÷ 26.46 tons CO_2/yr = $37.79 per ton of CO_2 saved.

Simple payback = $1,000.00 ÷ $158.51 = 6.31 yrs.

[80] If we assume that a replacement is necessary, and we raise the AFUE from the least-efficient now available (AFUE of 0.75) to the most efficient (AFUE of 0.96), then we save 22 percent: 0.22 x 68.1 million Btu = 14.98 million Btu, and 0.22 x $476 = $104.72, and 0.22 x 8,829 lbs CO_2 = 1,942 lbs CO_2 per year. Assuming that the marginal cost of an AFUE 0.96 unit over the AFUE 0.75 unit is $300, and that the unit lasts 18 years, then the Cost of Saved Carbon is $300 ÷ (18 x 1,942 lbs CO_2/yr) = $300 ÷ 17.48 tons CO_2/yr = $17.16 per ton of CO_2 saved.

Simple payback = $300.00 ÷ $104.72 = 2.86 years.

[81] If we go straight to the AFUE 0.96 from the existing AFUE 0.50 unit, then we save 48 percent: 0.48 x 68.1 million Btu = 32.69 million Btu, and 0.48 x $476 = $228.48, and 0.48 x 8,829 lbs CO_2 = 4,238 lbs CO_2 per year. Assuming, as above, that the cost of an AFUE 0.96 unit is $1,300, and that the unit lasts 18 years, then the Cost of Saved Carbon is $1,300 ÷ (18 x 4,238 lbs CO_2/yr) = $1,300 ÷ 38.14 tons CO_2/yr = $34.08 per ton of CO_2 saved.

Simple payback = $1,300.00 ÷ $228.48 = 5.69 years.

[82] Many more retrofit and upgrade measures are possible. Options include: variable volume fans and motors, SEER 13.0 replacement units, dehumidification units, setting units to not re-circulate with outside air, seal around window units, replacement compressors, recovering AC exhaust air to pre-heat domestic water, etc.

[83] In this version we prioritize the measures from lowest to highest "Cost of Saved Carbon" and reduce the Btu and cost and CO_2 to be saved after each measure is implemented. This is a fairer way of calculating savings, and gives a better estimate of total energy, dollars, and carbon dioxide saved from a set of measures. In turn, we use the energy, costs, and emissions remaining after this set of building shell measures as inputs to "Heating and Cooling: Equipment" section that follows.

The space heating and air conditioning energy consumption, cost, and emissions remaining after the shell improvements were "implemented" are as follows: *Heating:* 32.43 million Btu, $226.69, and 4,204 lbs CO_2 per year; *Cooling:* 8.22 million Btu, $63.46, and 1,137 lbs CO_2 per year.

[84] Homeowners can save 6-16 percent on their heating bills by installing a programmable thermostat (Heede, 1995, *Homemade Money*, p. 80); *Home Energy* magazine (see also Home Energy, 1997, *No-Regrets Remodeling*, p. 79) reports 20 percent savings for two 8-hr setbacks). We take 10 percent savings on both heating and cooling as representative. For heating: 0.10 x 32.43 million Btu/yr = 3.24 million Btu/yr, and 0.10 x $226.69 = $22.67, and 0.10 x 4,204 lbs CO_2/yr = 420 lbs CO_2 per year; For cooling: 0.10 x 8.22 million Btu/yr = 0.82 million Btu/yr, 0.10 x $63.46 = $6.35, and 0.10 x 1,137 lbs CO_2/yr = 114 lbs CO_2/yr. Sum of savings: (3.24+0.82=) 4.06 million Btu, and ($22.67+$6.35=) $29.02, and (420+114=) 534 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (32.43–3.24=) 29.19 million Btu, ($226.69–$22.67=) $204.02, and (4,204–420=) 3,784 lbs CO_2/yr; Cooling: (8.22–0.82=) 7.40 million Btu, ($63.46–$6.35=) $57.11, and (1,137–114=) 1,023 lbs CO_2/yr*. A programmable thermostat costs $20-$150; we assume a $100 cost and a 15-year life, which yields a Cost of Saved Carbon of $100 ÷ (20 yrs x 534 lbs CO_2) = $100 ÷ 5.34 ton = $18.73 per ton of saved CO_2.

Simple payback = $100.00 ÷ $29.02 = 3.45 years.

[85] Leaky, un-insulated ducts can waste as much as 30 percent of heating energy. We assume that a 15 percent efficiency gain is readily achievable for heating and 10 percent gain for cooling. Hence, for heating: 0.15 x 29.19 million Btu/yr = 4.38 million Btu/yr, 0.15 x $204.22 = $30.63, and 0.15 x 3,784 lbs CO_2/yr = 568 lbs CO_2/yr; for cooling: 0.10 x 7.40 million Btu/yr = 0.74 million Btu/yr, 0.10 x $57.11 = $5.71, and 0.10 x 1,023 lbs CO_2/yr = 102 lbs CO_2/yr. Sum of savings: (4.38+0.74=) 5.12 million Btu, and ($30.63+$5.71=) $36.34, and (568+102=) 670 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (29.19–4.38=) 24.81 million Btu, ($204.02–$30.63=) $173.39, and (3,784–568=) 3,216 lbs CO_2/yr; Cooling: (7.40–0.74=) 6.66 million Btu, ($57.11–$5.71=) $51.40, and (1,023–102=) 921 lbs CO_2/yr*. We assume that sealing and insulating ducts costs $400 and lasts 25 years, yielding a Cost of Saved Carbon of $400 ÷ (30 yrs x 670 lbs CO_2) = $400 ÷ 10.05 ton = $39.80 per ton of saved CO_2. **Simple payback = $400.00 ÷ $81.90 = 4.88 years.**

[86] Numerous options are feasible and cost-effective. Burner replacements, nozzle or orifice reduction, automatic flue dampers, electronic ignition, furnace fan motor upgrade (conventional fans use ~600 kWh/yr), and so on. We simply assume a representative efficiency improvement of 6 percent: for heating: 0.06 x 24.81 million Btu/yr = 1.49 mil-

lion Btu/yr, 0.06 x $173.39 = $10.40, and 0.06 x 3,216 lbs CO_2/yr = 193 lbs CO_2/yr; for cooling: 0.06 x 6.66 million Btu/yr = 0.40 million Btu/yr, 0.06 x $51.40 = $3.08, and 0.06 x 921 lbs CO_2/yr = 55 lbs CO_2/yr. Sum of savings: (1.49+0.40=) 1.89 million Btu, and ($10.40+$3.08=) $13.48, and (193+55=) 248 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (24.81–1.49=) 23.32 million Btu, ($173.39–$10.40=) $162.99, and (3,216–193=) 3,023 lbs CO_2/yr; Cooling: (6.66–0.40=) 6.26 million Btu, ($51.40–$3.08=) $48.32, and (921–55=) 866 lbs CO_2/yr*. We assume that a heating system modification costs $200 and lasts 15 years, which yields a Cost of Saved Carbon of $200 ÷ (15 yrs x 248 lbs CO_2) = $200 ÷ 1.86 tons = $107.53 per ton of saved CO_2.

Simple payback = $200.00 ÷ $13.48 = 14.84 years.

[87] A thorough heating system tune-up can save 3-10% of heating energy and costs $50-$100 (Wilson and Morrill, 1998, *Consumer Guide to Home Energy Savings*, 6th edition, American Council for an Energy-Efficient Economy, Washington, DC, p. 99). We take a 6 percent savings as representative. For heating: 0.06 x 23.32 million Btu/yr = 1.40 million Btu/yr, 0.06 x $162.99 = $9.78, and 0.06 x 3,023 lbs CO_2/yr = 181 lbs CO_2/yr. Sum of savings: 1.40 million Btu, and $9.78, and 181 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (23.32 – 1.40=) 22.92 million Btu, ($162.99 – $9.78=) $153.21, and (3,023 – 181=) 2,842 lbs CO_2/yr; Cooling remains unchanged: 6.66 million Btu, $48.32, and 866 lbs CO_2/yr*. We estimate an $80 cost and a 2-year life, which yields a Cost of Saved Carbon of $80 ÷ (2 yrs x 181 lbs CO_2) = $80 ÷ 0.18 ton = $444.44 per ton of saved CO_2. Of course, tuning up a carbon-intensive oil-fired boiler in a cold climate will save more CO_2 than the average (gas-fired moderate climate) system used here. **Simple payback = $80.00 ÷ $9.78 = 8.18 years.**

[88] Both room and central air conditioner systems must be inspected and maintained regularly. Over- or under-charged systems compromise efficiency (a 10% undercharge can reduce efficiency by as much as 20%; Heede, 1995, *Homemade Money*, p. 108). Krigger cites average savings of 27 percent for heat pumps (John Krigger, 1992, *Your Home Cooling Energy Guide*, Saturn Resource Mngt, Helena, MT, p. 50). Outdoor units should be shaded and be cleared for unrestricted airflow to the condenser coils. Filters should be replaced and evaporator coils cleaned. Compressors and other mechanicals should be checked. Ductwork must be sealed and insulated where possible (see above). Of course, proper sizing of the AC system and routing and installation of the ductwork is essential, after load minimization strategies have been duly considered. We assume, for representational purposes, that a "tune-up" improves efficiency and reduces electric consumption by 15%, costs $100, and is done every two years. Cooling savings are thus: 0.15 x 6.66 million Btu/yr = 1.00 million Btu/yr, 0.15 x $48.32 = $7.25, and 0.15 x 866 lbs CO_2/yr = 130 lbs CO_2/yr. Sum of savings: 1.00 million Btu, and $7.25, and 130 lbs CO_2/yr. *Remaining after measure is implemented: Heating is unchanged: 22.92 million Btu, $153.21, and 2,842 lbs CO_2/yr; Cooling: (6.66 – 1.00=) 5.66 million Btu, ($48.32 – $7.25=) $41.07, and (866 – 130=) 736 lbs CO_2/yr*. Cost of Saved Carbon of $80 ÷ (2 yrs x 130 lbs CO_2) = $80 ÷ 0.13 ton = $615.38 per ton of saved CO_2.

Simple payback = $80.00 ÷ $7.25 = 11.03 years.

[89] Average cost of saved carbon dioxide: simple addition of total investment, ignoring life of each measure, equals $860, versus total CO_2 saved over the life of each measure of 17.56 tons CO_2 yields an average of $48.97 per ton of CO_2 saved.

[90] Half of all air conditioners are older than eight years of age and use far more electricity to provide comfort, on average, than modern technology makes possible. We estimate that the "typical" air conditioner in service has a seasonal energy efficiency rating of SEER 9.0. Upgrading — most economical when a unit has failed — to an SEER of 12.0 boosts performance by 25 percent and reduces electric consumption by the same amount. Keep in mind that all of the previous shell improvements (and the subsequent measures that also reduce internal loads) will necessitate a much smaller unit, and thus saves on equipment cost compared to sizing based on rules of thumb. If, however, we assume that we need to provide the same amount of cooling as the old unit, we'd reduce the cooling demand by 25 percent from 13.6 million Btu (based on our estimate of average cooling electric consumption of 1,316 kWh per household per year) as follows: Cooling savings are thus: 0.25 x 5.66 million Btu/yr = 1.42 million Btu/yr, 0.25 x $41.07 = $10.27, and 0.25 x 736 lbs CO_2/yr = 184 lbs CO_2/yr. Sum of savings: 1.42 million Btu, and $10.27, and 184 lbs CO_2/yr. *Remaining after measure is implemented: Heating is unchanged: 22.92 million Btu, $153.21, and 2,842 lbs CO_2/yr; Cooling: (5.66 – 1.42=) 4.24 million Btu, ($41.07 – $10.27=) $30.80, and (736 – 184=) 552 lbs CO_2/yr*. Assuming that the marginal cost of an SEER 12.0 unit over a 9.0 unit is $200, and that the replacement unit lasts 13 years, then the Cost of Saved Carbon is $200 ÷ (13 x 184 CO_2) = $200 ÷ 1.20 tons CO_2/yr = $166.66 per ton of CO_2 saved.

Note: In this calculation we do not take credit for having accomplished, with the measures discussed above, reduced cooling requirements from 13.6 million Btu/yr (1,316 kWh/hh/yr) to 5.66 million Btu. This 58.4 percent reduction in cooling needs means a similarly smaller new air conditioning system. It's likely that a smaller SEER 12.0 unit would cost significantly less than a larger SEER 9.0 unit, and these savings would help reduce the cost of the previous measures. Put another way: the overall *negative marginal cost* means a negative Cost of Saved Carbon.

Simple payback = $200.00 ÷ $10.27 = 19.47 years.

[91] Heating systems are also in need of upgrading to more efficient units now available on the market, but there is little rationale for doing so (except with very old, nearly failing, or very inefficient equipment) until the old beast dies. Old systems, however, are often less than 50 percent efficient whereas new furnaces and boilers are frequently near or even above 90 percent efficient at converting fuel to heat. (Don't forget that heat *delivery* efficiency is equally

important and often represent several overlooked opportunities to reduce energy waste and heating bills.) For this example, let's assume that a typical home has a heating unit with 50 percent efficiency (average fuel utilization efficiency, or AFUE) and we replace it with a 75 percent AFUE unit, which is the *least* efficient under current legislation. This means we need one third less fuel and we save: 0.333 x 22.92 million Btu/yr = 7.63 million Btu/yr, 0.333 x $153.21 = $51.02, and 0.333 x 2,842 lbs CO_2/yr = 946 lbs CO_2/yr. Sum of savings: 7.63 million Btu, and $51.02, and 946 lbs CO_2/yr. *Remaining after measure is implemented: Heating: (22.92–7.63=) 15.29 million Btu, ($153.21–$51.02=) $102.19, and (2,842–946=) 1,896 lbs CO_2/yr; Cooling is unchanged (we list the sum* prior *to the AC replacement, which is outside the retrofit package): 6.66 million Btu, $48.32, and 866 lbs CO_2/yr*. Assuming that the installed cost of an AFUE 0.75 unit that replaces the old AFUE 0.50 unit is $1,000, and that it lasts 18 years, then the Cost of Saved Carbon is $1,000 ÷ (18 x 946 CO_2/yr) = $1,000 ÷ 8.51 tons CO_2/yr = $117.51 per ton of CO_2 saved. **Simple payback = $1,000.00 ÷ $51.02 = 19.60 yrs.**

92 If we assume that a replacement is necessary, and we raise the AFUE from the least-efficient now available (AFUE of 0.75) to the most efficient (AFUE of 0.96), then we save an additional 22 percent of the same basis: 0.22 x 22.92 million Btu/yr = 5.04 million Btu/yr, 0.22 x $153.21 = $33.71, and 0.22 x 2,842 lbs CO_2 = 625 lbs CO_2 per year. Assuming that the marginal cost of an AFUE 0.96 unit over the AFUE 0.75 unit is $300, and that the unit lasts 18 years, then the Cost of Saved Carbon is $300 ÷ (18 x 625 lbs CO_2/yr) = $300 ÷ 5.63 tons CO_2/yr = $53.29 per ton of CO_2 saved. **Simple payback = $300.00 ÷ $33.71 = 8.90 years.**

93 If we go straight to the AFUE 0.96 from the existing AFUE 0.50 unit, then we save 48 percent of the energy, cost, and emissions: 0.48 x 22.92 million Btu/yr = 11.00 million Btu/yr, 0.48 x $153.21 = $73.54, and 0.48 x 2,842 lbs CO_2 = 1,364 lbs CO_2 per year. Assuming, as above, that the cost of an AFUE 0.96 unit is $1,300, and that the unit lasts 18 years, then the Cost of Saved Carbon is $1,300 ÷ (18 x 1,364 lbs CO_2/yr) = $1,300 ÷ 12.28 tons CO_2/yr = $105.86 per ton of CO_2 saved. **Simple payback = $1,300.00 ÷ $73.54 = 17.68 years.**

94 Many more retrofit and upgrade measures are possible. Options include: variable volume fans and motors, SEER 13.0 replacement units, dehumidification units, setting units to not re-circulate with outside air, seal around window units, replacement compressors, recovering AC exhaust air to pre-heat domestic water, etc.

95 In this version we prioritize the measures from lowest to highest "Cost of Saved Carbon" and reduce the Btu and cost and CO_2 to be saved after each measure is implemented. This is a fairer way of calculating savings, and gives a better estimate of total energy, dollars, and carbon dioxide saved from a set of measures. In turn, we use the energy, costs, and emissions remaining after this set of building shell measures as inputs to "Heating and Cooling: Equipment" section that follows.

The space heating and air conditioning energy consumption, cost, and emissions remaining *after the shell improvements* were "implemented" are as follows:

Heating: 32.43 million Btu, $226.69, and 4,204 lbs CO_2 per year;

Cooling: 8.22 million Btu, $63.46, and 1,137 lbs CO_2 per year.

The space heating and air conditioning energy consumption, cost, and emissions remaining *after the equipment improvements* were "implemented" are as follows:

Heating: 22.92 million Btu, $153.21, and 2,842 lbs CO_2 per year;

Cooling: 5.66 million Btu, $41.07, and 736 lbs CO_2 per year.

These latter numbers estimate energy, cost, and emissions to keep the occupants of a single-family home comfortable after a comprehensive set of efficiency measures have been theoretically "implemented." Thorough retrofits of actual homes of every type and in every climate testify to the achievability of the reductions discussed above. As our analysis makes clear, not all of these measures are cost-effective on their own or in combination. Real world retrofits that stop at artificial thresholds of rates of return typically achieve 30 to 50 percent savings. E.g. ..

96 Average cost of saved carbon dioxide: simple addition of total investment in shell and equipment (not integrated), ignoring life of each measure, equals $3,898, versus total CO_2 saved of 125.65 tons CO_2 yields an average of $31.02 per ton of CO_2 saved.

97 Average cost of saved carbon dioxide: addition of total investment in shell and equipment (integrated), ignoring life of each measure, equals $3,898, versus total savings of 82.45 tons CO_2 for all integrated shell and equipment measures yields an average of $47.28 per ton of CO_2 saved.

98 Bancroft et al, *op. cit*, report savings from retrofit of existing water heaters range from 250-568 kWh/yr; dividing by that report's average electric water heater consumption of 4,480 kWh/yr yields savings of 5.6-12.7 percent, or about 40 to 80 percent of reported standby losses. We assume that adding a water heater wrap in the average home will cut standby losses by half. Thus: 0.50 x 0.148 x 27.80 million Btu = 2.06 million Btu, 0.50 x 0.148 x $202.00 = $14.95, and 0.50 x 0.148 x 3,558 lbs CO_2 = 263 lbs CO_2 per year. Water heater wraps cost ~$20; assuming the wrap lasts 12 years before replacement yields a Cost of Saved Carbon: $20 ÷ (12 yrs x 263 lbs CO_2) = $20 ÷ 1.58 ton = $12.66 per ton of saved CO_2. **Simple payback = $20.00 ÷ $14.95 = 1.34 years.**

99 We use Energy Information Administration's RECS data for single-family household water heater energy use (see table above). Electric water heaters consume 3,047 kWh/yr (other sources range as high as 6,000 kWh/yr; Bancroft, Shepard, Lovins & Bishop (1991), *The State of the Art: Water Heating*, Competitek, Rocky Mountain Institute, Snowmass, CO, pp. 14-15. Typical use of energy input to U.S. water heaters: distribution losses 14.9 percent (454

kWh/yr), standby losses 14.8 percent (451 kWh/yr), dishwasher 10.0 percent (305 kWh/yr), clothes washer 18.3 percent (558 kWh/yr), sinks 7.7 percent (235 kWh/yr), tub 8.4 percent (256 kWh/yr), and showers 26.0 percent (792 kWh/yr), for a total of 3,047 kWh/yr. A simple replacement of average with high-efficiency showerheads can cut hot water demand in showers by an estimated 40 percent (Competitek reports 65-68% savings). Thus, water heating savings are: 0.40 x 0.26 x 27.80 million Btu = 2.89 million Btu, 0.40 x 0.26 x \$202.00 = \$21.01, and 0.40 x 0.26 x 3,558 lbs CO_2 = 370 lbs CO_2 per year. Efficient showerheads cost ~\$20 apiece; assuming the average household installs two showerheads that last 12 years before replacement yields a Cost of Saved Carbon of \$40 ÷ (12 yrs x 370 lbs CO_2) = \$40 ÷ 2.22 ton = \$18.02 per ton of CO_2 saved. Of course, savings will be greater with an electric water heater than the average mix we use. **Simple payback = \$40.00 ÷ \$21.02 = 1.90 years.**

[100] Using the data in the previous footnote: Water saving faucet aerators cut water consumption for most uses by 50 percent or more (from 2.0 gallons per minute to less than 1.0 gpm). We use 40 percent savings in the average single-family home: 0.40 x 0.077 x 27.80 million Btu = 0.86 million Btu, 0.40 x 0.077 x \$202.00 = \$6.22, and 0.40 x 0.077 x 3,558 lbs CO_2 = 110 lbs CO_2 per year. Efficient faucet aerators cost ~\$5 apiece; assuming the average household installs three aerators that last ten years before replacement yields a Cost of Saved Carbon: \$15 ÷ (10 yrs x 110 lbs CO_2) = \$15 ÷ 0.55 ton = \$27.27 per ton of saved CO_2.

Simple payback = \$15.00 ÷ \$6.22 = 2.41 years.

[101] Leakage rates vary greatly. Mayer, DeOreo, Nelson, and Opitz (1998), *Residential End Uses of Water*; Project Update, Year Two, used sophisticated water meters to determine end uses. They report that two-thirds of homes leaked an average of 10 gallons per day; 5.5 percent leaked 100 gpd or more. We assume the typical home leaks an average of 1 gpd of *hot* water: 1 gpd x 7.48 lbs/gal x Δ80F˚ x 365 d/yr = 218,400 Btu/yr; 0.22 million Btu/yr (0.8 percent of total water heater energy); 0.008 x \$202 = \$1.62; 0.008 x 3,558 lbs CO_2 = 28 lbs CO_2 per year in the average single-family home. Assuming fixing a leaking faucet costs \$2 for a new gasket or O ring and lasts five years before replacement yields a Cost of Saved Carbon: \$2 ÷ (5 yrs x 28 lbs CO_2) = \$2 ÷ 0.07 tons = \$28.57 per ton of CO_2 saved. **Simple payback = \$2.00 ÷ \$1.62 = 0.62 years.**

[102] Bancroft et al, op. cit, reports that insulating the first 5-10 ft of hot and cold water pipes saves 33-69 kWh/yr, or 0.7 to 1.5 percent of their 4,480 kWh/yr. We estimate reducing pipe losses by ten percent: 0.10 x 0.149 x 27.80 million Btu = 0.41 million Btu, 0.10 x 0.149 x \$202.00 = \$3.01, and 0.10 x 0.149 x 3,558 lbs CO_2 = 53 lbs CO_2 per year.. Ten feet of pipe wrap plus tape costs ~\$15; assuming the wrap lasts 20 years before replacement yields a Cost of Saved Carbon: \$15 ÷ (20 yrs x 53 lbs CO_2) = \$20 ÷ 0.53 ton = \$37.74 per ton of saved CO_2.

Simple payback = \$15.00 ÷ \$3.01 = 4.98 years.

Note: When a water heater needs to be replaced, anti-convection valves should be installed and a bottom board placed under the tank. In new construction, *all* hot water pipes should be insulated, and careful attention to plumbing layout can help minimize the length of pipe runs. Of course, on-demand water heaters — since they eliminate standby losses — should also be considered.

[103] Average cost of saved carbon dioxide is calculated by dividing total investment cost (\$92 for simple measures) by total saved carbon over the life of every measure (4.95 tons CO_2) = \$18.59, on average. If we include the solar water heating system at \$3,500 cost and \$42.70 tons CO_2 saved (over 40 years), then we have investment of \$3,592 divided by 47.65 tons CO2 = \$75.38 per ton of CO_2 saved.

[104] We list savings from "free stuff" here but not those savings into the total for water heating savings, since they already appear in the "free stuff" table.

[105] Each 10˚F reduction saves 3-5 percent on water heating (Heede, 1995, *Homemade Money*, p. 153). Assuming your water heater thermostat can be reduced from 140 to 120˚F without compromising quantity, and 3% savings per 10F˚, 0.03 x 2.0 = 6.0 percent savings: 0.06 x 27.8 million Btu and \$202 and 3,558 lbs CO_2 = 1.67 million Btu and \$12.12 and 213.5 lbs of CO_2 saved per year.

[106] 18.3 percent of hot water is used in clothes washers (Bancroft, Shepard, Lovins, and Bishop, 1991, *The State of the Art: Water Heating*, COMPETITEK, Rocky Mountain Institute, Snowmass, CO, pp. 14-15). Assuming that washing most — not all — loads in cold water saves 50% of this energy (conservative: switching from hot/warm to cold/cold saves 80-95%, Heede, 1995, *Homemade Money*, p. 185), you'll save (0.50 x 0.183) = 0.092 x 27.8 million Btu + \$202 + 3,558 lbs CO_2 = 2.56 million Btu + \$18.58 + 327 lbs CO_2 every year.

[107] Solar hot water systems are feasible in every region of the country and cost-effective (if done simply) in most areas, yes, even in Ohio. A solar system can supply, on average, 75 percent of the household demand for hot water (higher fraction, of course, in the Sun Belt and lower in the Rust Belt: Tom Lane suggests a range of 65 to 90 percent is a reasonable bracket for U.S. solar insolation levels). Such a system can be installed for an estimated cost of \$3,500 and has a estimated useful life of 40 years. We assume here a solar system that displaces the need for 80 percent of other water heating fuels *after we have reduced water heating energy by the foregoing measures (DHW temp + cold water wash + tank insul + showerheads + aerators + leaks + pipe insul + H-axis clothes washer (now in Appliances) = 27.80 – 13.21 million Btu)*, we save 0.80 x 14.59 million Btu = 11.67 million Btu, 0.80 x (\$202.00 less same measures savings of \$96.00=) \$106 = \$84.80, and 0.80 x (3,558 lbs less same savings of 1,691 lbs =) 1,867 lbs CO_2 = 1,494 lbs CO_2 per year. The Cost of Saved Carbon = \$3,500 ÷ (40 yrs x 1,494 lbs CO_2) = \$3,500 ÷ 29.88 tons = \$117.14 per ton of CO_2 saved.

Simple payback = $3,500 ÷ $84.80 = 41.27 years.

In most existing homes, we do not recommend investing in a solar water heating system retrofit purely for cost-savings. In new homes, the economics alone justify a system installation. Some systems can be installed for less or generate (and thus offset) more hot water in sunnier climates, and the economics are better in larger (or more consumptive) households. Very few utilities still offer financial incentives or technical assistance. Some states offer tax incentives for the purchase of new solar systems (e.g., Colorado: both thermal and photovoltaic systems; see www.homepower.com for a list of states and incentives).

Lane, Tom (2002), *Solar Hot Water Systems 1997 to Today: Lessons Learned*, Gainesville, FL, and personal communication, April 2002. Lane's material cost estimate ranges from $2,800 (80-gallon tank, two 4x8 panels, 56,000 Btu rating (FSEC)(=16.41 kWh(th)), glycol system) to $3,200 (120-gallon tank, two 4x10 panels, 75,600 Btu rating (FSEC)(=22.16 kWh(th)), glycol system), p. 74. Installation (labor, overhead, insurance, pipe, profit, etc) adds ~$1,000 per system. On the other hand, he estimates total installed cost ranges from $2,400 to $4,600, and it's of this range that we use the average cost of $3,500. He claims that systems have a life of 40 to 120 years with minimal maintenance; we use the lower end of this range. Lane uses FSEC test procedures, which he says are representative of U.S. average insolation levels. Manufacturers make about 40 systems per week, hence little installation activity (solar pool water heating system manufacturers are far busier, installing 10-20,000 systems per year in FL alone. Lane does not know the number of installed solar DHW systems in U.S. (more are being dismantled than installed); ref to Prof. William Beckmann, Univ of Wisconsin. He also quoted Beckmann: "If one half of electric water heaters were to be half solarized, the U.S. would meet its Kyoto commitment." Rick: verify.

[108] See table on Water Heating Energy, CO_2 Emissions, and Cost above. The difference between gas and electric water heaters = 6.0 million Btu, $59.00, and 1,447 lbs CO_2 per year. This is a per household statistic, but diluting these savings over the entire single-family household sector means multiplying by (electric (27.1 million) + oil (3.3 million)) ÷ 73.7 million total households = 0.413. Hence, 0.413 x 6.0 million Btu = 2.48 million Btu, 0.413 x $59.00 = $24.37, and 0.413 x 1,447 lbs CO_2 per year = 598 lbs CO_2 per year. Since we are not including this measure in the per household savings packet, we list the savings as the higher amounts for the 30.4 million households that can switch from electricity and oil water heating to natural gas. Assuming a fuel switch + gas-fired water heater costs $600 and lasts 15 years before "replacement" yields a Cost of Saved Carbon: $600 ÷ (15 yrs x 1,447 lbs CO_2) = $600 ÷ 10.85 ton = $55.30 per ton of saved CO_2. **Simple payback = $600 ÷ $59.00 = 10.17 years.**

[109] There are a number of ways to save energy and emissions in cooking. Options include more use of pressure cookers instead of regular cooktop pots or steamers, crock pots, microwave heating, reduced flame sizes on cooktops, more efficient kitchen ventilation (including, in commercial kitchens, hoods with fume sensors), turning electric burners and ovens off a few minutes *before* cooking is done, cooking with lids on (except, of course, when the food being cooked should *not* be covered), using glass pans in the over permits lowering the oven temperature about 25F°, keeping burner pan "reflectors" clean (dirt absorbs much of the energy), letting pasta and steaming water cool down in the kitchen in the winter, putting extra coffee in a thermos instead of keeping the coffee maker on for hours, and so on. New technology is also more energy-efficient: induction stovetops and convection ovens save energy. For this calculation we assume a modest gain in overall cooking efficiency of 20 percent (many additional savings can be captured in kitchen *appliances*), and since most of the above recommendations are behavioral in nature, we compare the savings to the cost of a pressure cooker ($50): 0.20 x 6.5 million Btu = 1.3 million Btu, 0.20 x $46.00 = $9.20, and 0.20 x 825 lbs CO_2 = 165 lbs CO_2 per year. Assuming the pressure cooker has a twenty-year useful life yields a Cost of Saved Carbon of $50 ÷ (20 yrs x 165 lbs CO_2) = $50 ÷ 1.65 tons CO_2 = $30.30 ton of saved CO_2.

Simple payback = $50.00 ÷ $9.20 = 5.43 years.

[110] According to the Energy Information Administration, the 61.3 million single-family households use home office equipment (83 percent of all single-family households and 60.4 percent of all U.S households); 29.2 million single-family households use personal computers (5.2 million homes have two or more computers, 82 percent of all home PCs, to which 10.7 million printers are connected); use of other home office equipment (e.g., printers, copiers, fax machines, modems) fall along similar percentages. We summed EIA's somewhat dated energy consumption estimate for all residential use of home office equipment: 16.0 billion kWh/yr and 808 kWh/hh/yr. Spreading the estimated electricity consumption for home office equipment (computers 317 kWh/yr, printers 250 kWh, fax 216 kWh, and copiers 25 kWh only = 808 kWh/hh) among all single-family households: 29.2 million of 73.7 million single-family households have PCs: 29.2/73.7 = 0.396, thus, average household annual consumption for this equipment is 0.396 x 808 kWh/hh/yr = 320 kWh/hh/yr = 3.31 million Btu/yr costing $25.60 and emitting 458 lbs CO_2 per year. Clearly, households that use such equipment use more electricity (in fact, 2.6 million single-families surveyed keep computers on all the time: a typical desktop computer uses 140 watts (55 watts CPU and 80-90 watts monitor): 140 watts x 8,760 hrs/yr = 1,226 kWh per computer per year, not counting sleep mode; Kawamoto et al, 2001, *Electricity Used by Office Equipment and Network Equipment in the U.S.*, Lawrence Berkeley National Laboratory, www.enduse.lbl.gov/Projects/InfoTech.html). In any case, using the average diluted by equipment penetration and consumption, we have 320 kWh/hh/yr: using a conservative estimate that the average user can (a) turn equipment off more frequently (especially the monitor during even brief periods of non-use), (b) install and use software and hardware equipment controls, (c) keep equipment off when not needed (especially printers), and (d) upgrade to more efficient and sleep-mode enabled equipment (including laptops that use 15 watts on average vs 140 w for desktops) , we estimate the average household can save 30 percent of computers and related office equipment electricity consump-

tion: 0.30 x 3.31 million Btu = 0.99 million Btu, and 0.30 x $25.60 = $7.68, and 0.30 x 458 lbs CO_2 = 137 lbs CO_2 per year. As we pointed out above, households that use home office equipment can save proportionately more than suggested here (as a baseline, at least 1/0.396 or 2.5 times as much). Finally, since this is primarily behavioral in nature, and secondarily technological, we do not recommend investing money to replace equipment but instead to shop carefully when buying new equipment. We base our estimate of the Cost of Saved Carbon on buying a power control strip with an occupancy sensor that turns of the computer monitor and printer and a light after a pre-set time of inactivity (sophisticated control strips are available from www.wattstopper.com and other manufacturers). Based on an estimated cost of $90 (multiplied by the fraction of computerized households of 0.396 = $35.64 per household) and a durability of 10 years, the Cost of Saved Carbon of $35.64 ÷ (10 yrs x 137 lbs CO_2) = $35.64 ÷ 0.99 tons CO_2 = $36.00 per ton of saved CO_2.

Simple payback period = $35.64 ÷ $7.68 = 4.65 years.

[111] New horizontal-axis clothes-washers use 50-60 percent less hot water than existing vertical-axis machines. Half of 18.3 percent of water heating energy used by clothes washers = 0.50 x 0.183 x 27.80 million Btu = 2.54 million Btu, 0.50 x 0.183 x $202.00 = $18.48, and 0.50 x 0.183 x 3,558 lbs CO_2 = 326 lbs CO_2 per year. Assuming the marginal cost of a new Maytag Neptune costs ~$250 and lasts fifteen years before replacement yields a Cost of Saved Carbon of $250 ÷ (15 yrs x 326 lbs CO_2) = $250 ÷ 2.45 tons CO_2 = $102.04 ton of saved CO_2. Note on marginal cost: we checked a local appliance dealer (Sears), at which the Neptune sells for $999 vs entry-level Frigidaire's sell for $549, a $500 marginal cost.

Simple payback = $250.00 ÷ $18.48 = 13.53 years (before credit for reduced dryer use, detergent consumption, and water savings). Estimate of additional savings: H-axis machines spin-dry clothes and remove more moisture, thus reducing dryer energy by an estimated twenty percent of 13.43 percent of total appliance load per household: 0.1343 x 0.20 x 44.7 million Btu = 1.20 million Btu, and 0.1343 x 0.20 x $346.00 = $9.29, and 0.1343 x 0.20 x 6,182 lbs CO_2 = 166 lbs CO_2 per year. Water savings are worth an estimated $14.55 (according to the American Water Works Association, indoor water consumption totals 66,090 gallons/hh/yr, of which clothes washers use 22.7 percent, or 15,000 gallons per year); saving one-half of this water with an H-axis clothes washer at the national water rate of $1.94 per 1,000 gallons: 0.50 x 15 k gallons x $1.94 = $14.55 per year). Detergent savings are approximately $36; as a conservatism we use $18 detergent savings per year. Total other savings from replacing the old inefficient clothes washer with a new H-axis machine: reduced dryer use = $9.29; reduced water use = $14.55; reduced detergent = $18.00; Total = $41.84 per year. Total savings, with hot water savings above: $18.48 + $41.84 = $60.32 per year. For updates, see Raftelis Financial Consulting, www.raftelis.com, for water and wastewater rates.

Final cost savings = $60.32 per year (we use only the value of energy savings — $18.48 + $9.29 — so as to remain comparable to energy costs).

Final simple payback = $250.00 ÷ $60.32 = 4.14 years (in this sidebar we include the benefit of non-energy savings).

Final energy savings = 2.54 million Btu (hot water) + 1.20 (dryer savings) = 3.74 million Btu.

Final carbon dioxide savings = 326 lbs (hot water) + 166 lbs (dryers savings) = 492 lbs CO_2 per year (*not* counting the 60 lbs/yr saved at the water supply, pumping, and wastewater treatment plants).

Final Cost of Saved Carbon = $250 ÷ (15 yrs x 326+166 lbs CO_2) = $250 ÷ 3.69 tons CO_2 = $67.75 per ton of saved CO_2.

[112] H-axis machines spin-dry clothes and remove more moisture, thus reducing dryer energy by an estimated twenty percent of 13.43 percent of total appliance load per household: 0.1343 x 0.20 x 44.7 million Btu = 1.20 million Btu, and 0.1343 x 0.20 x $346.00 = $9.29, and 0.1343 x 0.20 x 6,182 lbs CO_2 = 166 lbs CO_2 per year. The energy, cost, and emissions savings are included in "New H-Axis Clothes Washer" above.

Dryer savings are based on EIA (1999), "other appliances" (other than refrigerators, space heating, water heating, and lighting, and most using electricity), use a total of 453.6 billion kWh per year. Estimating per household consumption on this basis thus reflects the presence (or lack thereof) of various equipment in households: Dryers: 60.9 billion kWh (13.43 percent of total: dryers are owned by 55 percent of homeowners, but by 85 percent of single-families); freezer: 37.4 billion kWh (8.25 percent); color TV: 30.8 billion kWh (6.69 percent), dish washers: 20.9 billion kWh (4.6 percent, 410 kWh/hh in households that use them), etc. For the purpose of estimating dryer savings, we use 20 percent savings of 13.43 percent of total appliance load per household: 0.1343 x 0.20 x 44.7 million Btu = 1.20 million Btu, and 0.1343 x 0.20 x $346.00 = $9.29, and 0.1343 x 0.20 x 6,182 lbs CO_2 = 166 lbs CO_2/yr. Energy Information Administration (1999), *A Look at Residential Energy Consumption in 1997*, p.16.

[113] The average home — containing numerous systems and gizmos that "leak" electricity even when off (e.g., TV, VCR, microwave) or that consume small but continuous amounts of power (e.g., security system, alarms, GFCI, answering machine) — uses 50 continuous watts to power such "phantom" loads. This adds up to 438 kWh/yr, or about 5 percent of a typical household electric consumption, and costs the U.S. ~$3 billion/yr. Researchers at Lawrence Berkeley National Laboratory has proposed, to widening industry support, that leakage be minimized to 1 watt per appliance. Based on observation and surveys of several homes — including LBL's Alan Meier's home — the typical home contains an average of 25 such phantom loads. Let's assume that each item averages 2W, which we propose to cut to 1W, thereby saving 25 watts, or 219 kWh/yr = 2.27 million Btu and $17.52, and 313 lbs CO_2. Even though none of us are going to replace these expensive gizmos in order to save energy or money (many 1 watt

models will be on the market soon, boosted by recent legislation), let's assume that gradually replacing (over the next five years, say) these 25 items costs, at the margin, $100 and last 5 years before replacement. This yields a Cost of Saved Carbon of $100 ÷ (5 yrs x 313 lbs CO_2) = $100 ÷ 0.78 tons CO_2 = $128.21 per ton of saved CO_2.

[114] The average single-family home uses 1,323 kWh/yr for 1.16 refrigerators (each average unit uses 1,141 kWh/yr, but each average single-family household uses 1,454 kWh/yr for refrigerators, so we estimate 1,454/1,141 or 1.274 units per single-family household). Replacing this unit with one consuming 561 kWh/yr saves 580 kWh/yr, which saves 6.00 million Btu (580 x 3412 x 3.0322), $46.40, and 829 lbs CO_2. The most efficient 21 cu ft top freezer models use 555 kWh/yr, whereas the most efficient 22 cu ft side-by-side with ice model uses 561 kWh/yr; Alex Wilson and John Morrill (1998), *Consumer Guide to Home Energy Savings*, American Council for an Energy-Efficient Economy, Washington, DC, pp. 177. Assuming a new refrigerator costs $1,200 and lasts 18 years before replacement yields a Cost of Saved Carbon of $1,200 ÷ (18 yrs x 829 lbs CO_2) = $1,200 ÷ 7.46 tons CO_2 = $160.86 per ton of saved CO_2.

Simple payback = $1,200.00 ÷ $46.40 = 25.86 years. This places the entire cost of the new refrigerator on the energy- and climate-saving measures. No one would replace a fridge on this basis, but more likely do so when the old units fails.

Simple payback based on estimated marginal cost = $300.00 ÷ $46.40 = 6.47 yrs (no: must be based on *marginal savings*, too).

[115] Average cost of saved carbon dioxide is calculated by dividing total investment cost ($735.64, using the marginal costs of H-axis machines and refrigerators) by total saved carbon over the life of every measure (14.99 tons CO_2) = $49.08, on average.

[116] Based on EIA (2000), *A Look at Residential Energy Consumption in 1997*, p. 16, electric clothes dryers use 1,090 kWh/yr and 55.9 million of 101.5 million (55 percent) households have them. While many families can (and do) air dry clothes all year, we assume air drying clothes six months per year, saving 1/2 of 1,090 kWh/yr = 545 kWh/yr and thus saves 5.64 million Btu and $43.60 and 779.4 lbs of CO_2 per year. See also "The clothesline" chapter in John C. Ryan (1999), *Seven Wonders: Everyday Things for a Healthier Planet*, Northwest Environment Watch, Sierra Club Books.

[117] We estimate that using energy-saving features on dish washers, clothes washers (other than washing in cold discussed above), water dryers, refrigerators, and freezers will save, on average, 8 percent of appliances' electricity use: 0.08 x 70.1 million Btu = 5.61 million Btu, 0.08 x $538.00 = $43.04, and 0.08 x 9,614 lbs CO_2 = 769 lbs CO_2 per year at zero cost. If your appliances are old and without such features, your energy bills are already high and your savings opportunities many when they fail (soon). For example: using the moisture sensing setting available on most dryers reduces dryer energy consumption by an estimated 15 percent on average (we use 8 percent savings here to reflect users that already use this feature, do not have it available, and the 15 percent of single-family households that do not have a dryer (see above)). Based on average dryer consumption of 1,090 kWh per year = 11.28 million Btu and $87.20 and 1,559 lbs CO_2 per year: 0.08 x 11.28 million Btu = 0.90 million Btu, and 0.08 x $87.20 = $7.02, and 1,559 lbs CO_2 per year = 125 lbs CO_2 per year. Again, since this is at no cost, we do not calculate Cost of Saved Carbon or the simple payback period. Heede, Richard (1995), *Homemade Money*, p. 187.

[118] One in four single-family households have a second refrigerator in the garage or basement (often an older inefficient beast using 1,600+ kWh per year, but we use the EIA average fridge consumption here). Simply unplugging it will save, on average, 1,141 kWh/yr (and 11.80 million Btu, $91.28 and 1,632 lbs CO_2 per year), but averaged over *all* single-family households will save 0.274 x 1,141 kWh/yr = 313 kWh/yr, which saves 3.24 million Btu and $25.04 and 448 lbs CO_2 per year. Let's assume that the extra six-pack stored in the garage-fridge can be chilled in another way, and a replacement fridge is not needed. If it is, consider replacing it with a smaller high-efficiency fridge (the smallest refrigerator listed in the best resource on the energy-efficient appliances is the 15 cubic foot Magic Chef that uses 437 kWh per year; Wilson, Alex et al, 1999, *Consumer Guide to Home Energy Savings*, www.aceee.org, p.38. A Danish VestFrost 7.5 cf freezer uses less than 200 kWh per year. See www.realgoods.com).

[119] Replacing six interior 60 watt incandescents with 15W CFLs saves 45 watts/hr. We assume an average 4 hr/d duty cycle: 45 watts x 4 hr/d x 365 d/yr = 66 kWh/yr per lamp, which means, for six lamps, saving 396 kWh/yr, or 4.10 million Btu and $31.68 and 566 lbs of CO_2 per year (6 x 66 kWh x 1.43 lbs CO_2/kWh). Six high-quality electronic-ballast CFLs cost ~$48 ($8, but more typically cost $6 or less at Walmart and other discounters) and last (at 4 hr/d and 8,000-hr life) 5.5 years and yield a Cost of Saved Carbon of $48 ÷ (5.5 yrs x 566 lbs CO_2) = $48 ÷ 1.56 ton = $30.77 per ton of saved CO_2.

Simple payback = $48 ÷ $31.68 = 1.89 years. After we credit the incandescent bulbs no longer needed: six lamps with each 4 hr/d x 365 d/yr = 1,460 hr/y x (at 1,460 ÷ 750-hr bulbs) 1.95 bulbs per year x 6 lamps = 11.7 incandescent bulbs per year @ $0.60 = $7.02. Adjusted payback = $60 ÷ $38.70 = 1.55 years (we use the electricity-savings only so we can compare to energy costs). Add the value of not screwing a lightbulb in your self (hah) and the payback drops to less than a year. As Amory has been heard saying: "It's a lunch you're paid to eat!"

[120] The average household contains about 20-35 lights; we use 30 bulbs here as a baseline. Since we've retrofitted six bulbs in the analysis above that used 6 x 60 watts x 4 hrs/d x 365 d/yr = 526 kWh; adding in ~150 kWh for exterior lighting per household plus the "free stuff: turning off one unneeded light" of 263 kWh per year. Since the average household uses ~1,500 kWh per year (EIA 1999, p. 16), we can retrofit the remaining 23 bulbs that use 1,500 kWh

– 526 kWh – 150 kWh (exterior) – 263 kWh = 561 kWh, or 24.4 kWh/yr per bulb. Of this electricity consumption per bulb, we estimate we can save 75 percent each (replacing each with a CFL); assuming each is a 60 watt bulb means it's on 1.1 hrs/d *on average*. Savings per bulb: 24.4 kWh x 0.75 = 18.3 kWh per year. Total savings from replacing all 23 bulbs with CFLs: 561 kWh x 0.75 = 421 kWh/yr, 421 kWh x 1.43 lbs CO_2/kWh = 602 lbs CO_2, bill savings = 421 kWh x $0.08/kWh = $33.68 per year. Cost of Saved Carbon: 23 bulbs @$8 = $184; at each bulb being used 1.1 hrs/d means lifecycle of 8,000 hrs / 1.1 hrs/d = 7,273 days = 19.9 years. 19.9 yrs x 602 lbs CO_2/yr = 5.99 tons CO_2. $184 / 5.99 tons CO_2 = $30.72 per ton of CO_2 saved.

Simple payback = $184 cost / $33.68 per year = 5.46 years.

Energy saved: 421 kWh/yr x 3,412 Btu/kWh x 3.0322 conversion losses = 4.36 million Btu.

Bulb population statistics are from Robert Sardinsky (personal communication, 6Apr02) and (forthcoming), *Review of Residential Lighting Energy Efficiency 1990-2002*, Rising Sun Enterprises, Basalt, CO, www.rselight.com, for Northwest Energy Efficiency Alliance.

[121] Replacing one exterior 90 watt incandescent with 23 watt CFL saves 67 watts/hr (exterior lights are often too bright and can be replaced with lower-wattage lamps. Exterior lights should be sconced to avoid light pollution). We assume a six-hour duty-cycle per day (nearly a third of homeowners say they leave a light "on all night"): 67 watt x 6 hr/d x 365 d/yr = 147 kWh/yr = 1.52 million Btu and $11.76 and 210 lbs of CO_2 saved per year. One high-performance costs ~$18 and lasts (at 6 hr/d and 8,000-hr life) 3.65 years and yields a Cost of Saved Carbon of $18 ÷ (3.65 yrs x 210 lbs CO_2) = $18 ÷ 0.38 ton = $47.37 per ton of saved CO_2. EIA (2001), p. 101.

Simple payback = $18 ÷ $11.76 = 1.53 years.

[122] Occupancy sensors are made for a wide array of purposes and conditions, using differing sensor technology, and of widely different cost-effectiveness. Most residential applications have poor savings-to-investment ratios, although they can save a lot of electricity in some situations (e.g., exterior lighting). We assume an installation in a garage or entry (where a hands-off switch comes in handy, but where a CFL replacement is unwarranted); we assume that the occupancy sensor reduces the use of a 75-watt bulb from two hours per day (average of immediate switch-off to forgotten periods lasting all night) to 20 minutes per day. This saves 1.67 hrs per day x 75 watts x 365 d/yr = 46 kWh/yr (=0.48 million Btu) worth $3.68 and 66 lbs CO_2. If the sensor has a life of 15 years and costs $30, then the Cost of Saved Carbon is $30 ÷ (15 yrs x 66 lbs CO_2) = $30 ÷ 0.50 ton = $60.00 per ton of saved CO_2.

Simple payback = $30.00 ÷ $3.68 = 8.15 years.

[123] Average cost of saved carbon dioxide is calculated by dividing total investment cost ($280 for lighting measures) by total saved carbon over the life of every measure (8.43 tons CO_2) = $33.21, on average.

[124] *If* each homeowners turns off one 60 watt incandescent light for 12 unneeded hours daily (inside during the day and outside at night, for example), then over the year they'd save 263 kWh worth 2.72 million Btu at the power-plant at which they'd prevent 376 lbs of CO_2 from entering the atmosphere—all while keeping $21.04 at home.

[125] Numerous other opportunities are available to reduce lighting energy consumption: increased use of day-lighting, light-tubes and light-pipes, energy-saving desk lamps, dimming CFLs, dimmers, photovoltaic yard lights, efficient torchieres, halogens, long-lived incandescent bulbs, improved ceiling fixtures, wall sconces, and better shades, lenses, and reflectors. Most of these technologies provide superior light and performance, but we do not calculate additional savings here, beyond the CFL replacements and occupancy sensor above, based primarily on poor investment-to-savings ratios.

[126] We have estimated total life-cycle carbon dioxide savings from no-cost measures at annual savings times 20 yrs. 20 years x 3,294 lbs CO_2 per year = 32.94 tons CO_2, *on average*. While "perpetual" and free savings do not have a "life of measure," but we pick a period of time roughly consonant with the durability of the costed measures.

[127] Average cost of saved carbon dioxide is calculated by dividing total investment cost ($92 for simple measures) by total saved carbon over the life of every measure (4.95 tons CO_2) = $18.59, on average. If we include the solar water heating system at $3,500 cost and $42.70 tons CO_2 saved (over 40 years), then we have investment of $3,592 divided by 47.65 tons CO2 = $75.38 per ton of CO_2 saved.

[128] Average cost of saved carbon dioxide is calculated by dividing total investment cost of $5,005.64 by total life-cycle carbon dioxide savings or 143.76 tons = **$34.82 per saved ton of CO_2.**

	Cost	**CO_2 saved**
Free stuff	$0.00	32.94 tons
Building shell	$3,038.00	64.89 tons
Heating and cooling equipment	$860.00	17.56 tons
Water heating	$92.00	4.95 tons
Appliances	$735.64	14.99 tons
Lighting	$280.00	8.43 tons
Total	**$5,005.64**	**143.76 tons**

[129] Adding the $3,500 cost of the solar DHW system to the other measures ($5,006) = $8,506. Divide by total savings (143.8 tons + 42.7 tons): $8,506 ÷ 186.5 tons CO_2 = $45.61 per ton of CO_2 saved.

[130] Let's assume that the typical homeowner cuts electricity consumption from 11,278 kWh to half (5,639 kWh). The electric bill will then be $592 per year, but the green power *margin* of 2.5 cent/kWh will cost $140.98 per year. Since this saves 8,064 lbs of CO_2 per year (5,639 kWh x 1.43 lbs CO_2/kWh), the Cost of Saved Carbon = $140.98 ÷ 4.03 tons CO_2/yr = $34.98 per ton CO_2 saved. This passes our "buy" test.

[131] Space heating: 8,829 lbs CO_2/hh x 73.7 million single-family households = 325.35 million short tons CO_2 = 80.49 million metric tonnes carbon.

[132] Space cooling: 1,882 lbs CO_2/hh x 73.7 million hh = 69.35 million tons CO_2 = 17.16 million tonnes carbon.

[133] Water heating: 3,558 lbs CO_2/hh x 73.7 million hh = 131.11 million tons CO_2 = 32.44 million tonnes carbon.

[134] Refrigeration: 2,607 lbs CO_2/hh x 73.7 million hh = 96.07 million tons CO_2 = 23.77 million tonnes carbon.

[135] Cooking: 825 lbs CO_2/hh x 73.7 million hh = 30.40 million tons CO_2 = 7.52 million tonnes carbon.

[136] Other appliances: 6,182 lbs CO_2/hh x 73.7 million households = 227.81 million tons CO_2 = 56.36 million tonnes carbon.

[137] Lighting: 2,145 lbs CO_2/hh x 73.7 million hh = 79.04 million tons CO_2 = 19.56 million tonnes carbon.

[138] Energy Information Administration (2001), *Emissions of Greenhouse Gases in the United States 2000*, U.S. DOE, DOE/EIA-0573(00), Washington, DC, p. 28; www.eia.doe.gov/oiaf/1605/frntend.html. Year 2000 (vs *1997* above) estimated emissions = 313.4 million tonnes carbon (residential) and 1,583.3 million tonnes carbon (total). The total includes non-energy emissions (e.g., cement manufacturing) and bunkers and U.S. territories.

[139] Includes "excluded" CFC emissions (excluded from the basket of six gases covered by the Kyoto gases, since CFCs and related compounds are covered by the Montreal Protocol), and comprised 652 million tons CO2-e. Analysis by Heede, (2002), *Emissions of Greenhouse Gases per Household and per Capita, 1998,* (from DOE, DOT, and EPA data).

[140] Based on the LBL report cited below (table 3.2) and adjusting their 1990 and 1997 (and therefore their 2010 forecast) upward, based on adjusted actuals from EIA's emissions statistics (EIA, 2000, *Emissions of Greenhouse Gases in the United States 2000*, p. 29), residential emissions are forecast to reach 325.9 million tonnes carbon in 2010 (adjusted from the LBL forecast of 319 million tonnes carbon, since LBLs data for 1990 and 1997 was an average of 0.9789 of EIA actuals). The average annual increment is therefore 3.445 millions tonnes carbon (delta 1990:2010 of 325.9–257.0 = 68.9 ÷ 20 = 3.445 million tonnes carbon per year), and 2010 forecast plus two years' increment is 325.9 + 6.9 = 332.8 million tonnes carbon, or 1,345.2 million tons CO_2.

[141] We identified 16,436 lbs of saved CO_2 potential per single-family household in the previous summary table. The average savings of 10,288 lbs CO_2 estimated above is thus 62.6 percent of the required savings, assuming all the savings are shouldered by retrofitting the existing stock of 73.7 million single-family households. This ignores savings in the approximately ten million new homes expected to be built by 2012 as well as savings in nearly 21.4 million multi-family households and 6.3 mobile homes.

[142] Year 2010 carbon emissions are forecast to reach 1,480 million tonnes carbon in LBNL's business-as-usual scenario (5,982.4 million tons CO_2; unadjusted LBNL, table 1.2), or 390 million tonnes (1,576.4 million tons CO_2) above 1990 emissions. 390 / 20 yrs = 19.5 million tonnes (78.8 million tons CO_2) per year. 2012 emissions = 6,140 million tons CO_2; 1990 = 1,340 million tonnes carbon (5,416.5 million tons CO_2; Kyoto target for 2012 is thus 5,416.5 million tons CO_2 x 0.93 = 5,037.3 million tons CO_2, which is 1,102.7 million tons CO_2 LBNL's BAU scenario emissions. Full adoption of climate neutrality in the U.S.'s *existing* 73.7 million single-family homes would achieve 87 percent of *total* U.S. CO_2 reduction needed by 2012. That is, existing single-family households can save, if climate neutral, 26,028 lbs CO_2/hh/yr x 73.7 million households = 959.1 million tons CO_2, which is 87 percent of the total U.S. emissions reduction target of 1,102.7 million tons CO_2. (As in the previous calculation, this ignores potential savings in nearly 28 million other housing units as well as the additional emissions from new housing units. This calculation also considers only carbon dioxide emissions and reduction targets, thus ignoring reductions needed in other gases, ie, methane, N_2O. Nor are expected other improvements in commercial buildings, industry, transportation, or electric utility de-carbonization included. In other words, this is not an integrated or comprehensive analysis, and should be viewed merely as indicative of the potential to save carbon in our nation's households.) Add in potential CO_2 reduction in household transportation, methane reduction measures, and upstream emissions from climate-friendly consumer purchasing, food choices, recreation and travel, etc, and we realize the power of individual actions if conscientiously applied in our daily lives. This is not to suggest that implementing all of the cost-effective CO_2-saving measures—much less achieving climate neutrality—in all single-family homes is likely: the opportunities may be more or less economical and practicable, but the aggregate opportunity is more of a technical potential than a realistic objective.

[143] Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies (1997), *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*, Oak Ridge National Lab, Lawrence Berkeley National Lab, National Renewable Energy Lab, Argonne National Lab, Pacific Northwest National Lab; 2 volumes, www.ornl.gov/ORNL/Energy_Eff/CON444, LBNL-40533 ORNL/CON-444. **Note:** this page *not* updated March 2002.