REDUCING CARBON EMISSIONS BY 2058

"STRIVING FOR SUSTAINABILITY AND CERTAINTY IN AN EVOLVING WORLD"

A Proposal For Future Action in the City of Boston

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Background

It has been decades since scientists first postulated that our planet is undergoing an unnatural warming. Greenhouse gases, which trap heat, are naturally present in the atmosphere. An increased concentration of these gases due to human activity, however, has resulted in a significant rise in global temperatures. The rate of warming has skyrocketed, with disastrous effects: ice caps are melting at unprecedented rates, weather trends are becoming particularly unpredictable, and species are becoming endangered. There are myriad examples of negative effects directly correlating to the temperature change. Although some people remain skeptical, the overwhelming evidence has caused most to agree that action to reduce emissions is of the utmost importance.

Energy generation processes contribute to increased concentrations of greenhouse gases in the atmosphere. Unfortunately, Greater Boston's increases in land use, energy, and water is disproportionately large compared to its population growth. This trend has been driven mainly by three factors: a movement in which smaller households occupy larger homes; an increase in the number of vehicles in use, not only totally but also per person, accompanied by an increase in the number of miles driven per person; and an increased spatial mismatch between population and job centers. Massachusetts is consuming more energy and emitting more greenhouse gases; a trend which this project aims not only to end but to reverse. According to the 2006 Climate Change Action Plan annual report card, Massachusetts earned a C- in 2006, down from C+ in 2005, and B- in 2004.1 Boston's carbon production, per person, has increased because the average number of people per household has declined from 2.37 in 1990 to 2.31 in 2000, and the number of automobiles registered in the City of Boston increased by 38% between 1990 and 2005 while the population grew by just 3.9%.2

The 1990 carbon inventory, prepared for the Cities for Climate Protection campaign, estimated that local energy use, transportation, and waste disposal in Boston produces an average of 15.4 tons of CO2 emissions per person annually. According to the US Department of Energy, Massachusetts emissions grew 17.9%, or 1% annually, from 1990 through 2006.2 This means that by 2006, Boston was producing 18.4 tons per person. ISO-New England, a non-profit corporation, projects that electricity demand in greater Boston will increase 1.1% annually over the next ten years.2

1) http://www.newenglandclimate.org/Scorecard2006.pdf
2) http://www.bostonindicators.org/indicatorsProject/Environment/Content.aspx?id=718
Current Measures

Transportation

In the past few years, the Massachusetts Department of Environmental Protection has made efforts to promote transit-oriented development in order to reduce greenhouse gas emissions. It has also implemented new programs specifically aimed at reducing the pollutants released by automobiles. These programs include the Low-Emission Vehicle (LEV) program, Rideshare program, and the Massachusetts Enhanced Emission & Safety Test. The LEV program requires that all new passenger vehicles sold and registered in Massachusetts meet California emission standards. The Enhanced Emissions & Safety Test has been in effect since October 1999. It requires that safety tests be given every year and emissions tests every other year; those vehicles which fail the safety test cannot be driven until repaired. Emissions tests vary based on the vehicle’s model, year, weight, and fuel type.

"The classifications are:

* **Light-duty Gasoline Vehicles Model Year 1996 and Newer**, including two- and four-wheel drive vehicles, will receive the On-Board Diagnostics (OBD) test. The inspector connects the vehicle's on-board computer to a computer in the station, and then downloads engine and emissions control data.

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* **Light-duty Gasoline Vehicles Model Year 1984-1995** will receive a tailpipe test, with most tested on the dynamometer, a treadmill-like device that simulates real-world driving conditions. Vehicles capable of both two-wheel and four-wheel drive are tested on a dynamometer in two-wheel mode. All-wheel drive vehicles will be given an alternative test that includes a visual check of emissions components and a two-speed idle test.

* **Heavy-duty Gasoline Vehicles** (gross vehicle weight of 10,001 or more pounds) are subject to the two-speed idle tailpipe test.

* **Light-duty Diesel Vehicles** are tested only for safety.

* **Heavy-duty Diesel Vehicles** are subject to the tailpipe test. The diesel emissions test uses an opacity meter to measure the smoke from a vehicle’s tailpipe. The darker
the smoke, the more it is polluting and the higher its opacity reading is.

*Alternate-fueled Vehicles*, except those powered exclusively by hydrogen or electricity, are tested using the OBD test.

*Vehicles Model Year 1983 or Older* are tested for safety, but are exempt from emissions testing.”

Another effort to reduce emissions was a 2005 project which equipped Boston’s diesel tourist trolleys with pollution control equipment, significantly lowering their emissions and resulting air pollution. A 2006 project retrofitted 500 school buses with pollution control equipment and supplied them with ultra-low sulfur diesel fuel (ULSD). Boston was the first major city in the country to entirely retrofit its school buses. The project reduced tail pipe emissions from the buses (specifically SO2, CO, and particulates) by over 90.

Power Generation

Wind:

The Cape Wind project is a proposal to build 130 wind turbines off the coast of Nantucket. This wind farm is projected to produce up to 420 megawatts of power, supplying the area with an average of three fourths of the electricity demand. This would save 113 million gallons of oil and reduce carbon emissions by 743,000 tons annually. Unfortunately, the project has received a mixed review. Concerns over noise and aesthetics hinder the progress of the project.

Boston is currently examining the potential for wind power by promoting pilot projects. The Community Wind Collaborative of the Massachusetts Technology Collaborative is studying the feasibility of installing wind turbines in Boston Harbor. Through its Renewable Energy Trust, the Massachusetts Technology Collaborative has launched a $4 million initiative, allowing the Community Wind Collaborative to design and construct small wind projects.

Solar:

In 2007, the City of Boston launched Solar Boston, a program to encourage widespread adoption of solar energy. Boston plans to install both solar electric (photovoltaic) and solar thermal (solar water and space heating), on all feasible and appropriate locations around the city. In this project, Boston intends to install technology to generate 10 MW of energy throughout Boston by 2015.

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1 http://www.mass.gov/dep/air/laws/levregs.doc
2 http://www.cityofboston.gov/environmentalandenergy
3 http://www.cityofboston.gov/climate/solar.asp
Energy Consumption

In 2006, Boston became the first major city in the US to use zoning to require construction projects over 50,000 square feet in size to meet Leadership in Energy and Environmental Design (LEED)’s green building standards. LEED’s standards cover a broad range of environmental aspects, including, but not limited to storm water design, transportation, habitat protection, open space maximization, site selection, pollution prevention, heating, and light pollution reduction. Additional efforts to reduce the city’s energy consumption include the replacement of traffic signal lights with LED bulbs that are 90% more energy efficient and the installation of 25 combined heat-and-power units in the Boston Public Schools.1

Industry:

Boston Carbon, a private company, has made efforts to initiate international GHG emission credits trading. Their scheme is based on the United Nations Framework Convention on Climate Change (UNFCCC).2

Project Introduction and Goals

Clearly Boston is in dire need of a change in its policy regarding energy production and consumption if it is to significantly reduce its contribution to climate change. Fortunately, there is much room for improvement. Massachusetts is currently 90% dependent on imported fossil fuels for its energy; the nation, in comparison, is 60% dependent. Of the total electricity generated in greater Boston, 96% is fueled by gas, oil, or coal. Current proposals for emissions reduction and existing standards can easily be strengthened. Our research has lead us to believe that current goals to reduce Boston’s dependence of fossil fuels, energy consumption, and vehicle emissions are much too low. For example, Massachusetts’ Renewable Portfolio Standard will require utilities to obtain 9% of their electricity from renewable sources by 2014. Boston is capable of reforming on a much larger scale.

Based on our research, we have concluded that a feasible goal is to reduce carbon emissions in Boston such that emissions do not exceed 8 tons per capita by the year 2058. We arrived at this conclusion through our assumption that Boston should primarily focus on reducing emissions by the two largest contributing sectors. In the period from 1990 to 2004, the largest contributors to emissions were the electricity generation and transportation sectors. These accounted for 29% and 36% of total emissions, respectively (see Figure 1).1 Our plan is to reduce the carbon emission due to electricity production by 95% and in the

1 http://www.bostonindicators.org/IndicatorsProject/Environment/Content.aspx?id=718
2 http://www.bostoncarbon.com/home/index.html
transportation sector by 80%. This would yield a per capita (see mathematical analysis below).

\[(.29 \times .05) + (.36 \times .2) + .35 = 43\% \text{ of our current emission}
\]

\[.43 \times 18.4 < 8 \text{ tons per capita}\]

There are two main aspects to our solution regarding electricity production: (1) switching to clean, renewable energy sources, and (2) reducing the electricity demand and consumption of the city. With this approach, Boston should be able to reduce its carbon emission from power generation by 95%. Our approach to the transportation sector regarding carbon emissions is similar. The number of cars, miles driven, and hours spent driving needs to decrease, while carpooling and public transportation use needs to increase. Furthermore, it is imperative that as the utilization of mass transit increases, buses and subway cars become more efficient.

![Figure 1](http://www.bostonindicators.org/indicators/project/environment/indicator.aspx?id=1570)

**Options**

**Power Consumption (electric and fuel)**

**Carbon Penalty:**

Impose a carbon cap for all Bostonians in order to decrease per capita output.

**Fuel Tax:**

Add a carbon tax on all oil, coal, and natural gas markets (international).

**Power Generation**

**Wind:**

Wind turbines come in many sizes for different uses and have a wind range of use-appropriate power output. The capacity of a turbine is determined largely by its rotor diameter. Present-day technology may be divided into three broad size ranges, briefly characterized below:

* Residential: rated capacity below 30 kW, rotor diameter of 4 to 43 ft, hub height of 60
to 120 ft.

* Medium: rated capacity between 30 and 500 kW, rotor diameter of 43 to 100 ft, hub height of 115 to 164 ft.
* Commercial: rated capacity between 500 kW and 4.5 MW, rotor diameter of 100 ft to more than 325 ft, hub height of 164 to more than 260 ft.

Commercial scale wind farms can be constructed on land or in the water. Small scale wind turbines, such as the one designed by Skystream\(^2\), could be installed on private rooftops, both business and residential to offset that buildings power use from the main grid.

Solar:

Solar farms could be installed in Boston to provide electricity for commercial, residential, and transportation purposes. Residential generation of solar power could be encouraged through incentives to those who choose to implement rooftop solar panels. A model for this type of solution is the solar project recently implemented by Google (see Figure 2). In October 2006, Google launched a 1,600 kilowatt project, "the largest solar panel installation on a corporate campus in the United States."\(^3\) To date, Google has installed over 90% of the 9,212 solar panels that cover the roofs of buildings and parking garages at the Googleplex. This project is expected to produce 30% of the peak electricity demand of Google's headquarters.\(^3\)

Figure 2 (http://www.google.com/corporate/solarpanels/home)

Other:

Our plan must account for the development of other technologies, such as hydroelectric, tidal, geothermal, and fusion. As these become more safe, reliable, efficient, and feasible, our plan must be able to incorporate the use of these breakthroughs in order to be successful.

**Analysis**

Greater Boston is home to over 3.5 million residents. On average, a single individual requires about 350 million BTU annually; an average of 11.7 kilowatts per capita is demanded.

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at any given time and 102.5 megawatt-hours per capita is demanded annually. At the current rate, Boston consumes over 350 million megawatt-hours per year. In order to replace Boston's current electric power producers with clean alternatives, it is imperative that the power demand be reduced.

**Power Generation**

**Solar:**

Solar power can provide substantial amounts of power, and has already done so in many locations throughout the world. Google recently transformed its power generation by covering the roofs of one of its offices in California. This project however, like many other solar powered projects, was implemented in a city that averages almost twice as many sunny days as Boston. In order for such a project to make financial sense, nearly twice as many solar panels would need to be installed in Boston to receive the same amount of energy per year. With a lack of space for panels and too few sunny days, Boston is not an ideal city for solar power. Thus solar generation of power is not a practical way of producing energy for the Boston area on a large scale. The costs of installing solar panels exceeds the revenue from the power generated.

**Wind:**

Wind energy is clean: it does not produce any harmful gases or particles, it will not increase greenhouse gases, and it does not cause acid rain. It is also domestic: it would be produced entirely in Boston, create jobs, and would not render us reliant on foreign imports. Additionally, wind patterns are predictable and reliable; we can assume the wind patterns in Boston in 2058 will not differ significantly from wind patterns today. Wind is a renewable resource, it cannot be deplete or degraded like soil or fossil fuels. The potential power that a turbine can produce is dependent on the turbines rotor size, wind speed at the hub of the rotor, and the consistency of that wind. The average wind speeds in Massachusetts (Figure 3) are poor over land, but excellent off the coast.

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The best place to put the wind turbines is certainly not on land. Land is already congested, in high demand, and does not have adequate wind speeds. Wind turbines should be as far out into the water as possible. This is for two reasons. First, the further out the turbines are, the stronger the wind. Second, the further out the turbines are, the less of an inconvenience to boating and air traffic they will be. However, this creates two complications. As the ocean depth increases, so does the cost of turbine installation. Therefore, the optimal distance out from the coast must be calculated and considered. Second, the risk of storm damage increases with distance from the shore. The optimal distance would maximize this figure of merit:

\[ \text{FOM} = \frac{\text{Power Potential}}{[\text{Damage Risk}(\text{Installation Cost})(\text{Possible Damage Repair Cost})]} \]

Considering Figure 4, which shows the chance of a hurricane reaching the coast of Massachusetts at peak hurricane season in October, we think that this risk is negligible.

![Empirical Probability of a Named Storm in October](http://images.usatoday.com/weather/hurricane/images/proboc.gif)

Electricity demands in the Northeast peak in the Summer months. The greatest recorded summer peak demand for New England was 28,000 megawatts, compared to the average power draw of 18,000 megawatts throughout the rest of the year.\(^1\) Can wind power accommodate this demand flux? Exposed coastal areas in the Northeast have class 5 or above wind resource in winter. In spring, the exposed coastal areas of the Northeast is generally less than in winter. In Boston, class 3 wind speeds can be found in the summer over Cape Cod and Nantucket Island.\(^2\) Since the winds off the coast of Boston are at their minimum during the peak demand, the new power production must be designed so that near full capacity it is capable of sustaining Boston during these summer months. This is a huge draw back because in the winter a large portion of potential power production will go unused. Perhaps the power generated during the winter could be sold to nearby municipalities. Another possibility is to store the excess energy using batteries.

The cost of wind power has decreased dramatically in the last ten years and is currently between 4 and 6 cents per kilowatt-hour. (3) This is already cheaper than some

\(^{1}\) [http://www.iso-ne.com/]
\(^{2}\) [http://rredc.nrel.gov/wind/pubs/atlas/chp2.html#seasonal]
electricity produced by fossil fuels, as can be seen in Figure 5. The gap between the prices of electricity produced by sustainable technology and fossil fuels will increase with time.

Figure 5 (raw data from: http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1472)

Figure 5 shows the immense potential of wind power technology. The data in this graph was collected by the International Energy Agency and breaks down the cost of producing energy. The graph shows that cost of wind power is only slightly greater than that of nonrenewable sources per kW of electricity. The only draw back when analyzing the cost of wind technology is that it requires a higher initial investment than electricity generated by fossil fuels. Over time, fuel prices for petroleum and coal will rise while the initial costs for wind power will decrease. This is due to economic trends and technological developments. As soon as wind energy breaks the financial barrier, the economy will favor wind energy. Energy generated by the wind will not only be an environmentally friendly solution, but also an economical solution.

The final aspect of using wind power that must be considered is the response of the public. The Cape Cod wind project is a perfect example of what we cannot allow to occur. The initial concerns about large wind turbines in the water off the coast of Boston will be over the noise produced by the rotor blades, aesthetic (visual) impacts, and the birds that have been killed by flying into the rotors. These inhibitions can be quickly subdued and with the right media coverage the people of Boston can come to embrace the wind turbines with pride. The turbines will be an icon of our innovation and symbolize Boston as a leader in environmental responsibility.

By funding the development and expansion of wind energy, the government will be forcing traditional energy companies out of business. In order to prevent this, after solar energy becomes economically beneficial, the government will release all control of these technologies to the private sector. The capitalistic economy will take over and a solution to the carbon footprint will be achieved.
Power Consumption

Implementing a tax on gas would increase the price of gasoline. This increase in price of gasoline would not necessarily decrease the demand for gasoline and would therefore have little effect on gasoline consumption. Instead, if as a nation, we tax everyone any usage of crude oil the price of gasoline, due to monopolistic economic effects would only raise slightly. Most of the tax revenue would come from a decrease in profits for Big Oil. The tax revenue would then be used to provide subsidies to decrease the price of wind energy along with other renewable energy sources. This decrease in prices will more quickly level the playing field for in the energy market and will provide economic incentive for using alternative energy sources. Also, this revenue could be used to provide a subsidy on electric vehicles and therefor make them as cheap or nearly as cheap as traditional vehicles.

The carbon cap would limit the amount of carbon a Bostonian can produce annually. When filling taxes each year, a family will also file a Carbon Footprint profile in which all production of carbon for that year are listed. Some items on the list will include the type of car and miles driven and electricity usage. If a family exceeds there carbon limit then they will be fined for all carbon produced above the carbon cap. This would greatly discourage the over production carbon lifestyle Bostonians have grown accustom to.

There is a limit to the extent of forced implementation the government can invoke on society. The government cannot force Bostonians to cover their roofs with solar panels or wind turbines. However, incentives can be created, including subsidies and tax breaks, to encourage the use of clean energy. Any resident who decides to invest in new solutions to energy, like a solar panel covered roof, will receive help with the initial investment. Also, by employing solar panels on residential rooftops, a resident will lower his carbon footprint and reduce the possibility of getting taxed. Although there is a limit to government involvement in the economy, in order to save the environment, intervention must occur.

Efficient Electric-Powered Ground transportation:

We believe that electric cars will become the norm within the next couple decades or so. Simply the existence of relatively practical cars such the Tesla Motors' Tesla Roadster, which is releasing 650 production units this year, and the Miles Electric Vehicles' X5500, to be released in 2009, combined with tax incentives for going greener, should promote electric cars to the point of ubiquity by 2058. Given this, ground transportation in general should become gas-independent. In terms of public transportation, this means maintaining and upgrading the Massachusetts Bay Transit Authority Subway, and investing in electric buses. By 2058, electric vehicles should supplant internal combustion vehicles, so that carbon emission caused by
transportation should be minimal. However, since electric cars still rely on electricity, which must be generated by some source, so increased efficiency can be achieved by regular maintenance, advances in technology, and improvements traffic flow.

Figure 6: The New Tesla Roadster.
(source: Http://teslamotors.com)

Figure of Merit

In simple terms, we defined our electricity generation cost as \( C = (\text{total cost of plant and production}) - (\text{market value of plant's total output}) \). We expanded our cost equation to

\[
C = \frac{\sum [(I_t + M_t + F_t)(1 + r)]}{\sum [E_t(1 + r) - t]}
\]

where
- \( C \) = Levelized electricity generation cost
- \( I_t \) = Investment expenditures in the year \( t \)
- \( M_t \) = Operations and maintenance expenditures in the year \( t \)
- \( F_t \) = Fuel expenditures in the year \( t \)
- \( E_t \) = Electricity generation in the year \( t \)
- \( r \) = Discount rate

Our expanded figure of merit is based on a cost equation formulated by the International Energy Agency (IEA) for combined heat and power plants; we modified the equation to describe any electric plant (10). The total cost decreases as the amount of electricity produced increases. When we applied our figure of merit to various alternative
energy sources, we found that wind energy was the most cost effective for Boston. Winds at speeds high enough to generate electricity occur year-round. The total potential amount of electricity that can be generated by wind turbines exceeds that of any other renewable energy technology. Additionally, the revenue generated by the electricity generated using wind energy outweighs the cost of building and maintaining the plants to the greatest degree.

Recommendations

The need for carbon emissions to be reduced has been shown; the best method to accomplish the reduction is not nearly as clear. Our solution is based on our comprehensive research and is comprised of two components. Primarily we want to replace our current sources of power with cleaner, renewable options as well as reducing energy consumption to make this transition possible.

Our main source of power will be wind energy, which will be harvested by giant windmills, with highly efficient turbines and blades. Instead of a lump installation, Boston will install the windmills, firstly to ease into the change of power supply, and more importantly, be able to take advantage of improving technologies. By installing offshore, energy production is maximized, especially generation to cost ratios (because of more available space). When the cost of wind energy descends below the cost of traditional sources of energy, the government will set up a bidding program to offer the offshore power plants to the private sector. After the government sells the wind farms, the economy will take over and carbon free energy will be the overall best solution. Installation of turbines along the Charles will make them a positive icon of the city. Although these may not generate much energy, they encourage "going green".

Wind energy could not satiate the current power demand of Boston. For this reason, the people of Boston must learn and put effort into decreasing their energy consumption. Public education for energy conservation is an integral part of our proposal. Depending on wind energy and other clean, renewable fuel sources is much more feasible if the amount of energy used per person decreases. Although things such as more efficient technologies and careful design of city expansion will somewhat help reduce energy usage, public cooperation is a must. In order to make energy conservation more appealing, a program that highlighted the many merits of saving energy, especially one that appealed to public logos and ethos, would be implemented. The public influenced this way may come to regard saving energy as the right thing to do, even the patriotic thing to do, then the program would be very effective. Following the lead of many public health education programs, energy conservation programs would be deployed in public schools. Much of the funding for these programs could come from the carbon-tax revenues.

Implementation of a tax program based on a yearly carbon footprint report will
encourage a major reduction in carbon emissions by encouraging a switch to cleaner ways of living. A carbon cap will be imposed on all Bostonians. There is no fee or penalty for releasing an amount of carbon up to this carbon cap. If a person exceeds this amount, a tax will be imposed on them for the amount of carbon released above the carbon cap.

Consequences:

Our proposed plan is designed to significantly reduce Boston’s carbon emissions in the transportation sector and electricity production industry. The projected reduction is illustrated in Figure 7. Note that emissions due to electricity production are almost completely removed.

![Projected Carbon Emissions for Proposed Plan: 1980-2058](image)

*Fig 7: projected emissions by sector*

Currently Boston is a large contributor to greenhouse gas emissions. Although the initial cost of our proposal is expensive, at the projected rates the costs will decrease significantly to economical levels. Additionally, the consequences will far exceed the cost of our plan. Implementing this plan is the responsibility of Boston, and through the educational program set up with the taxation revenue, the people should not only willing, but also proud to reduce their power consumption. This plan has the ability to improve the morale of the city.

One potential problem with our plan is future maintenance. This is due to our proposition to gradually increase the number of turbines. This proposal was first, so that current power companies to be slowly phased out, and second, so that as newer, better technologies are developed, they can be implemented in Boston. This is a double-edged sword: although it allows for us to include developments, it also means that by 2058 we could face the task of maintaining an assortment of wind turbines of varying technologies. This will create a problem similar to that of Boston’s subway system, in which a very large store of spare parts and a very knowledgeable maintenance labor force is required. Both of these are expensive to maintain.