Energy Savings through Pipe Selection
A Case Study of Huntsville Utilities in Huntsville, Alabama

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Introduction

Huntsville Utilities in Huntsville, Alabama, uses iron pipe for 96% of its pipe footage. Sixty-one percent of its pipe footage is ductile iron. Ductile iron has a larger-than-nominal inside diameter, resulting in energy and financial savings when compared to pipe made of other materials. This paper will demonstrate the significant energy and financial savings enjoyed by Huntsville Utilities because of their use of iron pipe.

Community Overview

Huntsville, Alabama, came to national attention during the space race. The nearby Redstone Arsenal and George C. Marshall Space Flight Center were the home of missile development for the United States. Wernher von Braun, the genius behind the German V-2 rocket program, had relocated to Huntsville after World War II and led the development of rockets with the payloads necessary to lift a spacecraft and lunar module to orbit and beyond. The multi-stage Saturn V rocket was their crowning achievement.

This activity created a hotbed of technology, science, and engineering which attracted thousands of progressive and intelligent men and women to Huntsville. Their legacy lives on today with the Huntsville area being home to more than a half-million residents and numerous cutting-edge industries specializing in technology, science, and engineering. The Huntsville Space and Rocket Center receives more than 550,000 visitors each year, chronicles America's space exploration, and is a permanent exhibit to showcase the hardware of the space program. A view of the center is shown in figure 1.[i]

Figure 1. View of the Huntsville Space and Rocket Center

Utility Overview

Huntsville Utilities provides electricity, water, and natural gas to the area. Its roots date to 1823 when the first public water system in Alabama was built by John Hunt, the city's founder. That primitive system drew water from a spring simply known as Big Spring and used hollowed cedar logs and a wooden storage tank. In 1858 the city of Huntsville purchased the water system, and in 1954 a board of directors was established to operate the utility. The primary water source today is the nearby Tennessee River, and 13 billion gallons of clean water are furnished each year to over 89,000 metered residential and commercial customers. Huntsville Utilities also provides 6 billion cubic feet of natural gas and 4 billion kilowatt - hours of electricity annually.[ii]

In the last 35 years, Huntsville water treatment plants have received the "Best Operated Surface Water Treatment Plant" award 14 times, and the "Best Operated Ground Water System in Alabama" on nine occasions. In 1992 and 2006, the EPA awarded Huntsville with their Safe Drinking Water Excellence award for region IV.[iii]

Huntsville's water system is extensive, totaling 1297 miles of 6-inch through 48-inch pipe. The table and chart below show footages for each nominal diameter. Because of the massive lengths of 6-inch and 8-inch pipe, the significant lengths of larger diameters are not noticeable in the bar graph, so be sure to note those footages in table 1.

Table 1. As-built nominal diameters and associated footages of pipe in the Huntsville, Alabama, water system

Diameter	Footage		Diameter	Footage		Diameter	Footage		Diameter	Footage
6	3,328,505		14	6,630		24	172,130		48	64,299
8	1,709,729		16	198,252		30	70,757		54	-
10	211,670		18	303,027		36	154,703		60	-
12	624,651		20	5,243		42	1,011		64	-

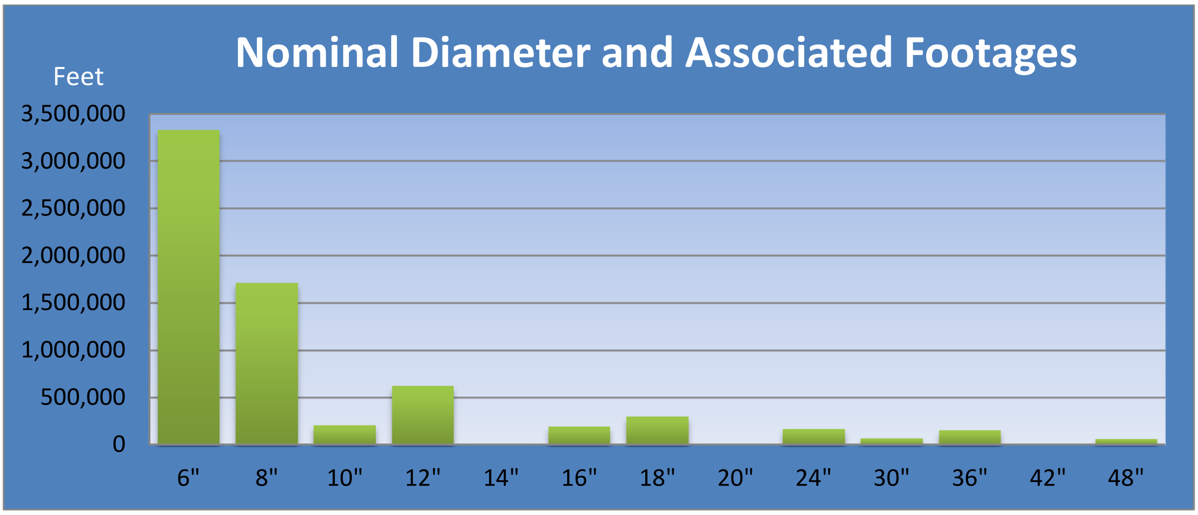

Figure 2. Nominal diameters and associated footages of pipe in the Huntsville, Alabama, water system

Iron pipe is the predominant material used by Huntsville. It has provided dependable service across a wide geography for more than 100 years. Nevertheless, alternate materials have been used from time to time for various reasons. Table 2 and figure 3 below show footages for each type of pipe material.

Table 2. As-built pipe material and associated footages in the Huntsville, Alabama water system

Pipe Material	Asbestos Cement	Gray Iron	Ductile Iron	HDPE	PVC
Footage	25,262	2,444,030	4,217,625	6,593	157,097

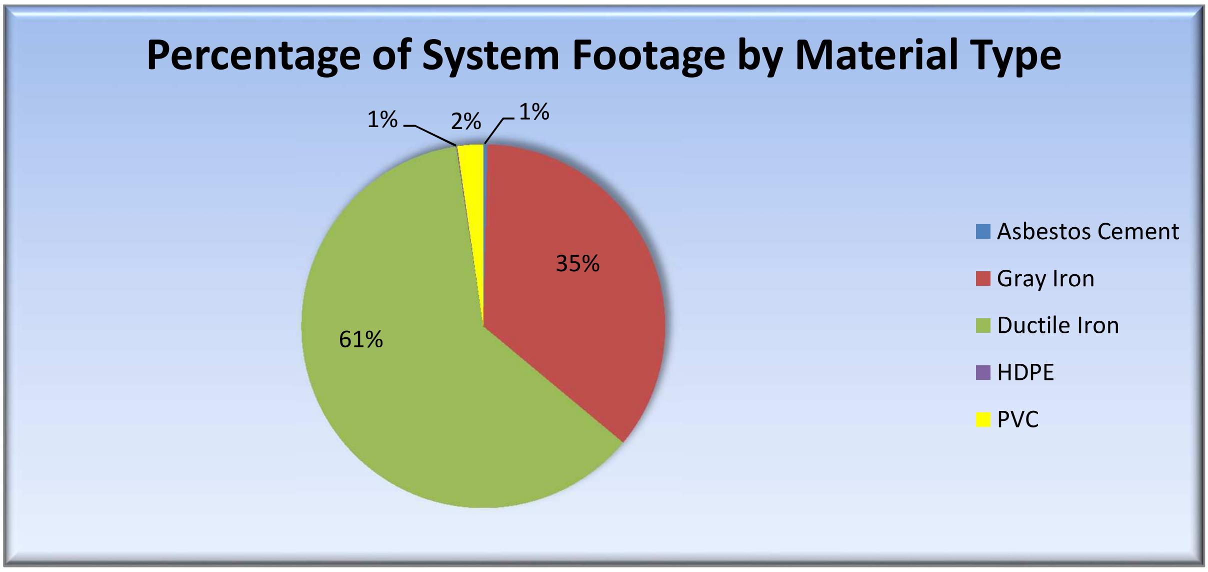

Figure 3. Pipe material as percentage of system footage in the Huntsville, Alabama water system

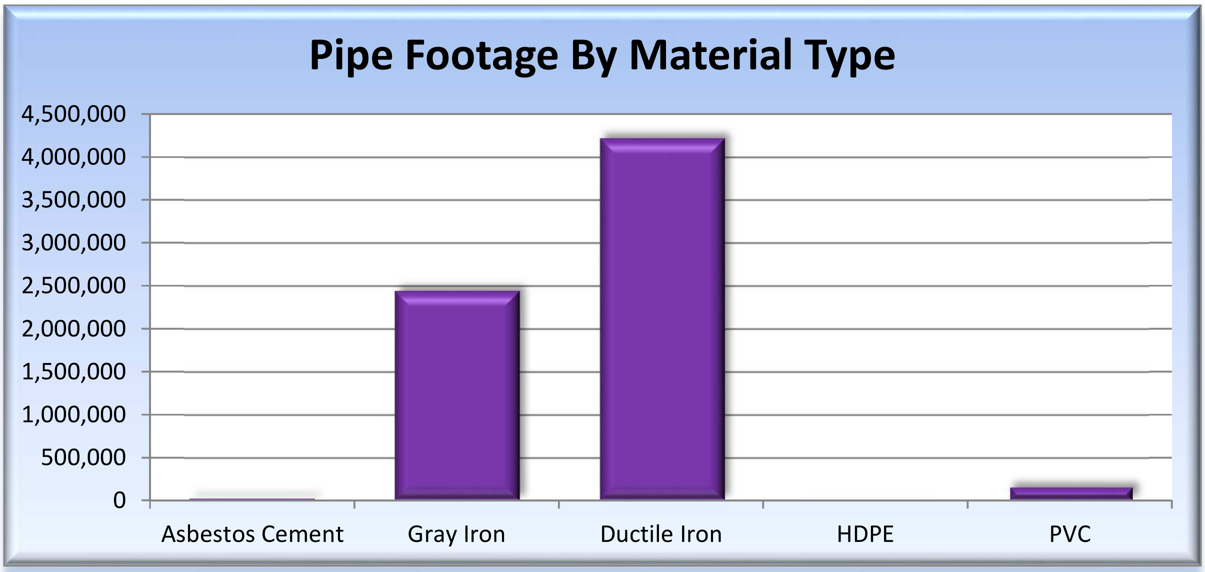

Figure 4. Pipe material and associated footages in the Huntsville, Alabama water system

Pipe Material Overview

Various pipe materials have various characteristics. Hazen-Williams coefficients of friction and internal diameter are two of particular interest here. Why do nominally same-sized pipe of different materials have different inside diameters? Aren't two 12-inch pipes both 12 inches? No, and here's why: The first national standard for water pipe was developed by the New England Water Works Association in 1926, [iv] and it dealt with gray iron pipe, also known as cast iron. Using 12-inch in this example, the internal diameter was sized at 12 inches, and wall thicknesses were calculated using the physical and metallurgical properties of gray iron. This resulted in a 13.20 inch outside diameter. The use of iron pipe became so widespread that the outside diameters of iron pipe were adopted as industry standards. Fittings, valves, hydrants, and other pipe joints were designed to mate with iron pipe outside diameters.

With the advent of ductile iron in the 1950s and its resultant stronger and more robust metallurgical and physical properties, the wall could be reduced and the pipe would perform as well or better than gray iron. For the reasons noted above, the outside diameter was held constant and the wall thickness was taken from the inside, resulting in an inside diameter exceeding the nominal diameter. Later, other materials such as asbestos cement and PVC came to market. Those pipe materials' outside diameters were sized to match the industry o.d. standard. The physical properties of materials such as asbestos cement and PVC are less than gray iron, so the corresponding wall thicknesses were greater than gray iron, resulting in an inside diameter ***less*** than the nominal pipe size. Since it all started with an inside diameter equal to nominal and gray iron as a material, any material with physical and metallurgical properties less than gray iron will have a less-than-nominal inside diameter. Similarly, any material with physical and metallurgical properties exceeding gray iron (such as ductile iron), will have a greater-than-nominal inside diameter. Simply stated, since all standard pipe have the same o.d., stronger pipe materials allow larger inside diameters. In the case of the 12-inch example, a class 350 cement lined ductile iron pipe has an inside diameter of 12.52 inches, and a DR 18 PVC pipe has an inside diameter of 11.65. In the case of PCCP pipe, governed by AWWA C301, the inside diameter is typically equal to nominal and steel joint rings mate with whatever connection is present, often a flange. Steel pipe, governed by AWWA C200 and sometimes used in the largest diameters, also generally carries the nominal as the inside diameter and its bells, spigots, and flanges are sized as necessary. Table 3 below shows a comparison of inside diameters of various pipe materials.

Table 3. Actual internal diameters of various distribution and transmission main pipe materials[v]

Nominal Size (inches)	Ductile Iron (1)	PVC (2)	Asbestos Cement (3)	PCCP (4)	Steel (5)	HDPE (6)
6	6.28	6.09	5.85	-		5.57
8	8.43	7.98	7.85	-		7.31
10	10.46	9.79	10.00	-		8.96
12	12.52	11.65	12.00	-		10.66
14	14.55	13.50	14.00	-		12.35
16	16.61	15.35	16.00			14.05
18	18.69	17.20	-	18.00		15.74
20	20.75	19.06	-	20.00		17.44
24	24.95	22.76	-	24.00	24.00	20.83
30	31.07	28.77	-	30.00	30.00	25.83
36	37.29	34.43	-	36.00	36.00	32.29
42	43.43	40.73	-	42.00	42.00	38.41
48	49.63	46.49	-	48.00	48.00	44.47

(1) From AWWA C150, Table 5. Lowest pressure class with C104 cement mortar lining.
(2) Iron o.d., AWWA C900 and C905. DR 18 for 6"-24", DR 21 for 30"-36", and DR 25 for 42"-48".
(3) From AWWA C400-93.
(4) From AWWA C301.
(5) From manufacturers' information.
(6) From AWWA C906. DR 11 for 6"-30", DR 13.5 for 36", DR 15.5 for 42", and DR 17 for 48".

Figure 5 shows the percentage difference in cross sectional area of ductile iron pipe compared to PVC pipe for 16-inch and smaller and compared to PCCP or steel for 18-inch and larger, based on the inside diameters noted above.

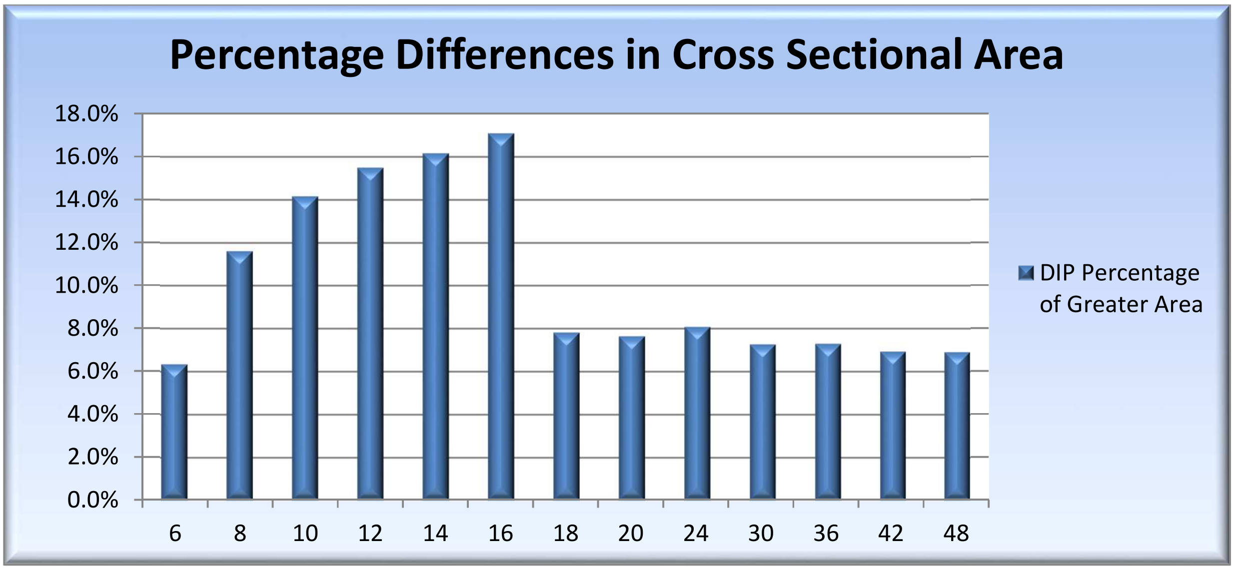

Figure 5. Percentage differences in cross-sectional area between ductile iron pipe and PVC / PCCP or steel

Water – Energy Nexus

The water – energy nexus has been a big topic lately. In their 2012 State of the [Water] Industry report, Black and Veatch reports that "Energy accounts for as much as 30% of utility budgets and more than 85% of water utility greenhouse gas emissions."[vi] To further examine this topic, this paper will model and estimate annual pumping costs for the Huntsville water system using its actual pipe materials and lengths. A second calculation of modeled annual pumping costs will then be made using DR 18 PVC for all diameters of 16-inch and smaller and PCCP or steel (nominal i.d.) for all diameters 18 inches and larger. The modeled pumping costs and energy differences and their implications will then be compared and contrasted.

Numerous papers, presentations, and studies are conducted related to pump selection and pump efficiencies as a means of reducing the significant energy required to deliver water. Those are all worthwhile and valuable, but the energy savings available through use of larger-than-nominal-diameter pipe materials yields tremendous results of greater value and impact.

Pumping Costs

Factors affecting the cost of pumping include cross sectional area, coefficient of friction, power cost, and pump efficiency. The preceding paragraphs discuss differences in cross sectional area. Let's look now at coefficients of friction.

Cement lining was developed by AMERICAN Cast Iron Pipe in 1922 and first supplied as an in situ process with Charleston Public Works in Charleston, South Carolina.[vii] It was developed in response to tuberculation, a form of internal corrosion in which minerals in the water stick to the exposed bare iron. Engineers at AMERICAN discovered that those tuberculation deposits would not stick to a cement mortar surface. It was so successful so quickly that it soon became the norm for iron pipe, and a standard was developed. In 1929, the American Standards Association issued a tentative standard for cement mortar linings.[viii] That standard is today known as AWWA C104, *Cement-Mortar Lining for Ductile Iron Pipe and Fittings*. The C Factor, or Hazen-Williams coefficient of friction, associated with cement mortar linings is 140. The long-term consistency of 140 has been challenged from time to time, but in situ flow tests have repeatedly confirmed the value.[ix] A number of studies confirming this have been published down through the years in *Journal AWWA* and other publications. Table 4 below shows in-service flow tests of several new and older cement mortar lined iron pipelines.

Table 4. Flow tests of in-service cement mortar lined iron pipe[x]

Location	Diameter (nominal inches)	Length (feet)	Age (years)	Hazen-Williams C Factor
Corder, MO	8	21,400	1	145
Bowling Green OH	20	45,600	1	143
Chicago, IL	36	7,200	12	151
Safford, AZ	10	23,200	16	144
Tempe, AZ	6	1,235	24	144
Seattle, WA	8	2,686	29	139
Concord, NH	12	500	36	140

The Hazen-Williams coefficient of friction for PVC pipe is generally agreed to be 150 and is generally agreed to remain constant as well. The higher the C factor, the less friction between the fluid and the surface. To be clear, these energy comparisons credit a lower friction value for PVC pipe as compared to iron pipe. We will see from the pumping cost calculations that the larger inside diameter of iron pipe more than offsets the lower friction value (higher C factor) of PVC pipe. The C factor for mortar lined PCCP will be the same as for mortar lined iron pipe, 140. The C factor for HDPE will be 155, also a widely agreed upon value.

Modeled pump efficiencies, power costs, and other values in the equations will be the same irrespective of the pipe materials.

Pumping costs through a pipeline are a function of power cost, pump efficiency, and head loss as reflected in the following equation:

$$\text{Pumping Cost} = 1.65\ HL * Q * (a / E)$$

Where HL = head loss in feet per thousand feet of pipeline

Q = flow rate in gallons per minute

a = power cost in dollars per kilowatt hour

E = efficiency of pump system as a fraction of 1

Head Loss in feet per thousand feet of pipeline is determined by:

$$H_L = 1{,}000\ \left[\frac{V}{0.115C(d)^{0.63}}\right]^{1.852}$$

Where V = velocity in feet per second

C = flow coefficient (C factor)

d = actual internal diameter in inches

Using velocity to determine flow rate,

$$Q = V * 2.448 * d^2$$

Where V = velocity in feet per second

d = actual pipeline internal diameter in inches

Power costs vary across the country. Factors related to power costs are regulatory requirements, the cost of fuel to generate the power, etc. Power costs in Huntsville are $0.09381 per kilowatt - hour. Figure 6 shows commercial electric power costs by state as reported by the U.S. Energy Information Administration.[xi]

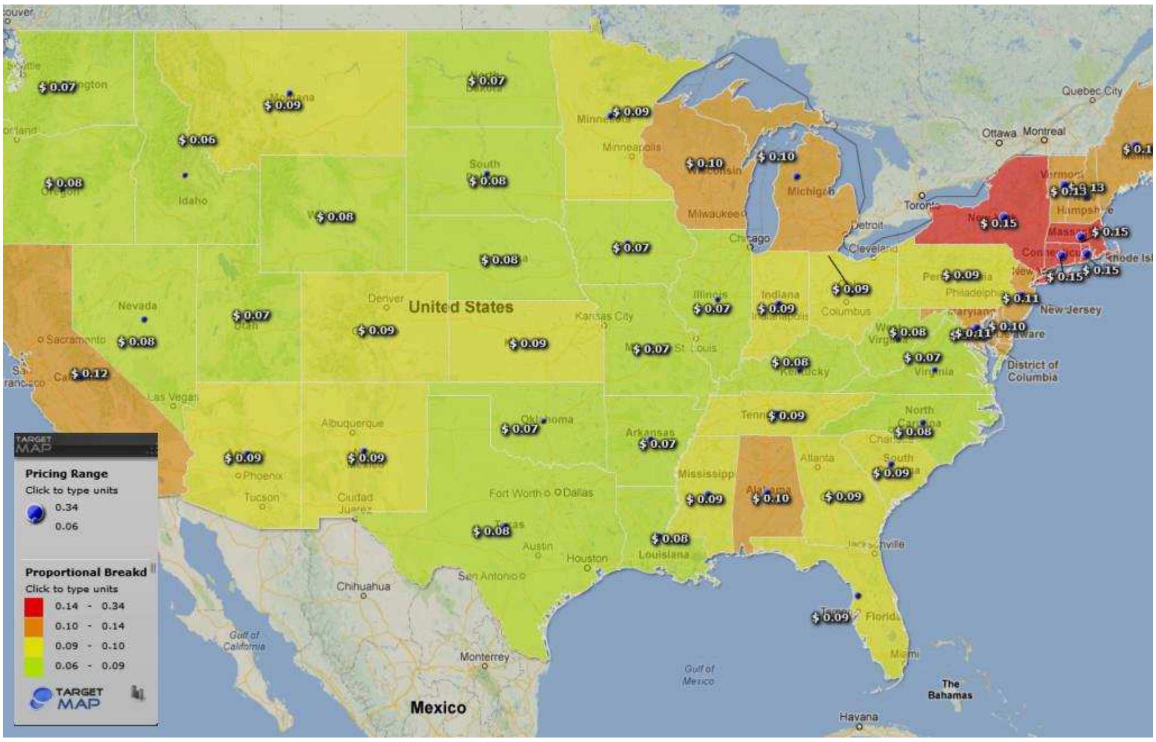

Figure 6. Commercial electric power costs by state

Pump efficiencies vary depending on manufacturer, condition, age, and other factors. A reasonable pump efficiency is 70%, and since the same efficiency is used across the board, it's a uniform variable, just as power cost.

Finally, a reasonable modeling velocity is 4 feet per second. In a 6-inch ductile iron line, that's 386 gallons per minute. In a 42-inch transmission line that will feed many smaller distribution lines, that's 18,469 gallons per minute. The variety of diameters in the Huntsville system and the production of 13 billion gallons per year are consistent with the 4 foot per second velocity.

Using the local Huntsville power cost of $0.09381 per kilowatt - hour, pump efficiency of 70%, and velocity of 4 fps, and applying these equations to the as-built transmission and distribution network of the Huntsville water system as shown in the following table, the annual pumping cost for the system is $7,529,528. Actual costs may vary given actual conditions, but proportional savings will be reflective nonetheless.

Table 5. Calculated pumping cost of as-built Huntsville Utilities water network

					Pumping cost based on as-built piping material (6-inch pipe and larger)							
Size		Material	Length (feet)		GPM	Pipe ID	C Factor	Velocity (fps)	Head Loss (feet)	Pump hours/ day	$/KWH	**Yearly PC
6		Asbestos	25262		335	5.85	140	4.0	244	24	$0.09381	$18,078.93
6		Gray Iron	1851995		357	6.04	140	4.0	17232	24	$0.09381	$1,361,165.88
6		Ductile Iron	1327303		386	6.28	140	4.0	11801	24	$0.09381	$1,007,724.91
6		HDPE	3867		304	5.57	155	4.0	33	24	$0.09381	$2,200.22
6		PVC	120078		363	6.09	150	4.0	974	24	$0.09381	$78,203.48
8		Gray Iron	294093		644	8.11	140	4.0	1940	24	$0.09381	$276,310.41
8		Ductile Iron	1393135		696	8.43	140	4.0	8785	24	$0.09381	$1,351,791.77
8		HDPE	2726		523	7.31	155	4.0	17	24	$0.09381	$1,945.32
8		PVC	19775		624	7.98	150	4.0	117	24	$0.09381	$16,132.05
10		Gray Iron	25862		999	10.1	140	4.0	132	24	$0.09381	$29,173.12
10		Ductile Iron	168802		1071	10.46	140	4.0	828	24	$0.09381	$196,052.41
10		PVC	17006		939	9.79	150	4.0	79	24	$0.09381	$16,449.40
12		Gray Iron	141969		1438	12.12	140	4.0	586	24	$0.09381	$186,419.47
12		Ductile Iron	482444		1535	12.52	140	4.0	1918	24	$0.09381	$650,870.77
12		PVC	238		1329	11.65	150	4.0	1	24	$0.09381	$266.12
14		Gray Iron	749		1961	14.15	140	4.0	3	24	$0.09381	$1,118.97
14		Ductile Iron	5881		2073	14.55	140	4.0	20	24	$0.09381	$8,992.39
16		Gray Iron	21495		2573	16.21	140	4.0	63	24	$0.09381	$35,963.10
16		Ductile Iron	176757		2702	16.61	140	4.0	505	24	$0.09381	$301,798.75
18		Gray Iron	107463		3254	18.23	140	4.0	276	24	$0.09381	$198,279.07
18		Ductile Iron	195564		3421	18.69	140	4.0	487	24	$0.09381	$368,404.28
20		Gray Iron	404		4023	20.27	140	4.0	1	24	$0.09381	$814.30
20		Ductile Iron	4839		4216	20.75	140	4.0	11	24	$0.09381	$9,945.53
24		Ductile Iron	172130		6096	24.95	140	4.0	306	24	$0.09381	$412,507.32
30		Ductile Iron	70757		9453	31.07	140	4.0	97	24	$0.09381	$203,576.60
36		Ductile Iron	154703		13616	37.29	140	4.0	172	24	$0.09381	$518,194.02
42		Ductile Iron	1011		18469	43.43	140	4.0	1	24	$0.09381	$3,845.06
48		Ductile Iron	64299		24119	49.63	140	4.0	51	24	$0.09381	$273,304.14
	Totals		6850607	Feet								$7,529,527.80
			1297	Miles								

Energy Values

Dividing by the power cost of $0.09381 results in a total annual kilowatt – hour value of 80,263,597.

The United States Environmental Protection Agency website has a conversion feature that translates annual kilowatt – hours into equivalent tons of carbon dioxide emissions resulting from the generation of those kilowatt-hours. The calculated theoretical 80,263,597 kilowatt-hours used to pump Huntsville's water would result in the emission of 62.424 tons of carbon dioxide.[xii]

Let’s now compare the energy required to deliver the same volume of water through a modeled system constructed of PVC pipe for sizes 16-inch and smaller and nominal-diameter PCCP or steel in diameters 18-inch and larger. Note the flow velocity differences compared to the baseline of 4 fps in the as-built model. Note, too, 6-inch PVC is actually bigger than 6-inch gray cast iron, so an energy savings is realized with 6-inch PVC compared to 6-inch gray cast iron. With 27% of the footage in the Huntsville system being 6-inch gray cast iron having an inside diameter smaller than PVC, iron pipe as a whole overcomes a substantial pre-existing disadvantage in this analysis. Again, this model pumps the same required volume through a modeled alternative system built with materials of different internal diameters.

Using the same power cost of $0.09381 per kilowatt - hour, pump efficiency of 70%, and flow volume, and applying the same equations to the actual as-built transmission and distribution network of the Huntsville water system as if it were not built of iron, as shown in the following table, the annual modeled pumping cost for the system would be $8,196,527.

That’s a difference of $666,999 per year.

Dividing that difference by the power cost of $0.09381 results in a total annual kilowatt – hour difference of 7,110,105. This is the additional energy that would be required if the system were built of DR 18 PVC and PCCP or steel.

Using the United States Environmental Protection Agency website conversion feature cited previously results in that difference in annual kilowatt – hours being equivalent to an additional 5.530 tons of carbon dioxide emissions.

Table 6. Pumping cost of modeled PVC / PCCP / steel Huntsville Utilities water network

					Theoretical pumping cost if PVC used for 6-inch through 16-inch and PCCP for 18-inch and larger							
Size		Material	Length (feet)		Pipe Material	Pipe ID	C Factor	Velocity (fps)	Head Loss (ft)	**Yearly PC		Difference
6		Asbestos	25262		PVC	6.09	150	3.7	176.5	$13,080.68		$4,998.25
6		Gray Iron	1851995		PVC	6.09	150	3.9	14,568.0	$1,150,747.71		$210,418.17
6		Ductile Iron	1327303		PVC	6.09	150	4.3	12,061.8	$1,030,000.64		($22,275.73)
6		HDPE	3867		PVC	6.09	150	3.3	22.5	$1,513.69		$686.52
6		PVC	120078		PVC	6.09	150	4.0	973.8	$78,203.48		$0.00
8		Gray Iron	294093		PVC	7.98	150	4.1	1,847.3	$263,080.21		$13,230.21
8		Ductile Iron	1393135		PVC	7.98	150	4.5	10,099.5	$1,554,040.11		($202,248.34)
8		HDPE	2726		PVC	7.98	150	3.4	11.7	$1,348.53		$596.80
8		PVC	19775		PVC	7.98	150	4.0	117.0	$16,132.05		$0.00
10		Gray Iron	25862		PVC	9.79	150	4.3	135.3	$29,883.72		($710.60)
10		Ductile Iron	168802		PVC	9.79	150	4.6	1,005.4	$238,182.45		($42,130.03)
10		PVC	17006		PVC	9.79	150	4.0	79.3	$16,449.40		$0.00
12		Gray Iron	141969		PVC	11.65	150	4.3	625.4	$198,912.90		($12,493.42)
12		Ductile Iron	482444		PVC	11.65	150	4.6	2,396.8	$813,490.48		($162,619.71)
12		PVC	238		PVC	11.65	150	4.0	0.9	$266.12		$0.00
14		Gray Iron	749		PVC	13.5	150	4.4	2.9	$1,238.23		($119.26)
14		Ductile Iron	5881		PVC	13.5	150	4.6	24.9	$11,397.91		($2,405.52)
16		Gray Iron	21495		PVC	15.35	150	4.5	72.5	$41,274.20		($5,311.10)
16		Ductile Iron	176757		PVC	15.35	150	4.7	652.9	$390,035.28		($88,236.53)
18		Gray Iron	107463		PCCP	18	140	4.1	293.1	$210,928.39		($12,649.32)
18		Ductile Iron	195564		PCCP	18	140	4.3	585.0	$442,483.71		($74,079.42)
20		Gray Iron	404		PCCP	20	140	4.1	1.0	$869.26		($54.96)
20		Ductile Iron	4839		PCCP	20	140	4.3	12.8	$11,898.77		($1,953.24)
24		Ductile Iron	172130		PCCP	24	140	4.3	369.7	$498,367.03		($85,859.71)
30		Ductile Iron	70757		PCCP	30	140	4.3	115.5	$241,468.69		($37,892.09)
36		Ductile Iron	154703		PCCP	36	140	4.3	204.3	$615,128.36		($96,934.33)
42		Ductile Iron	1011		PCCP	42	140	4.3	1.1	$4,526.13		($681.07)
48		Ductile Iron	64299		PCCP	48	140	4.3	60.3	$321,578.51		($48,274.38)
	Totals		6850607	Feet						$8,196,526.62		($666,998.82)
			1297	Miles								

Environmental Impact of Energy Differences

The operational differences in cost and power have both financial and environmental impact. Let's look first at the environmental impact. Iron pipe is made of recycled ferrous products, a critical dimension in the sustainability equation. The Institute for Market Transformation to Sustainability has recognized ductile iron pipe with its independent, third party Sustainable Gold rating known as SMaRT.[xiii] This is based on public health and environmental safety, renewable energy and energy reduction, the use of recycled materials, reclamation and sustainability, manufacturing innovation, and a toxin-free environment. Iron pipe is the only pressure pipe to be certified by any independent sustainability organization.

Now let's consider the environmental impact of 5.530 fewer tons of carbon dioxide annual emissions. According to the United States Environmental Protection Agency, those tons of emissions are equivalent to the following:[xiv]

- 1,045 passenger vehicles on the road
- 562,392 gallons of gasoline
- 66 tanker trucks of gasoline
- 690 homes' electrical energy consumption
- 21.6 railcars of coal
- 11,666 barrels of oil

Financial Impact of Energy Differences

We've shown the modeled annual power cost savings of $666,999. According to the Black and Veatch report cited earlier, energy can be 30% of a utility's operating expenses. If that is true for Huntsville, these savings represent a 3% savings in total overall operational expenses. Any time a 3% savings in total overall operational expenses can be achieved, someone has done a good day's work!

The present value of those future annual savings for just 30 years at 3% is $13,073,475. The present value of those future savings for just 30 years at 4% is $11,533,769. Those present values for 50 years, a very reasonable expectancy with durable iron pipe, are $17,161,727 and $14,328,596 at 3% and 4%, respectively. By using iron pipe, Huntsville has undoubtedly saved tens of millions of dollars throughout their history since the availability of smaller-than-nominal-diameter pipe materials such as asbestos-cement, PVC, and HDPE.

Four percent interest could be paid on bonds of $16,674,975 with those annual savings.

At $75,000 annually, that's a personnel head count of almost nine.

Irrespective of actual costs, it's a 9% savings in the second-highest expense of the utility, energy.

Conclusion

Huntsville Utilities' decision to use iron pipe has not only resulted in long term dependability, safe and reliable delivery of drinking water, a tough product that protects the public water supply, and numerous other practical benefits, but it has also resulted in significant annual cash flow savings of as much as

$666,999 and energy savings of 7,110,105 kilowatt – hours of energy, both of which contribute to the financial health of the utility and to the quality of life for those served in the area.

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[i] Huntsville Space and Rocket Center website. http://www.rocketcenter.com/overview
[ii] Huntsville Water System Website. http://www.hsvutil.org
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