Life Cycle Cost Analysis for Pipelines

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Abstract

The cost of a pipeline is more than its design, material, and installation cost; more than its operational cost; more than its depreciation cost; more than its service life; and more than the revenue from its salvage value. The cost of a pipeline is all that and more.

Beyond the financial cost, there is an environmental impact of raw materials and manufacture, transportation, construction, and operation.

A specific high-level case study analysis of a 24-inch diameter pipeline will be presented here, and methods will be identified for use in evaluating other diameters and alternatives. These models and criteria will provide utilities and design engineers a set of tools to evaluate the total life cycle cost associated with a water transmission pipeline.

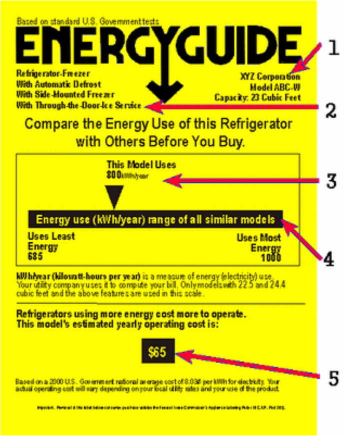
This paper evaluates financial, environmental, and other costs and provides a roadmap for decision-making early in the pipeline design process so that decades from now, future generations will look back at the wisdom, good stewardship, and quality engineering behind a sustainable infrastructure project serving the public good.

Introduction

Most of us are familiar with the concept of life cycle cost, either from an everyday practical viewpoint, if not from a formal financial analysis viewpoint. Briefly, life cycle cost analysis considers the entire sum of the costs to purchase, build or install, operate or use, and also recognizes residual value at end of life. These costs are often normalized in the form of present worth.

Consider a car, and many of us do this every time we make an auto purchase. Life cycle cost analysis would consider the purchase price, the cost of insurance, the cost of fuel, the projected cost of maintenance, the expected mileage, and re-sale value when a replacement car is purchased. We all know we can purchase a more expensive car and have a lower life cycle cost. Many of us have done so, are comfortable with it, and would never consider the cheapest cost-to-purchase option.

Consider, too, household appliances. We all examine the bright yellow stickers with annual electricity costs, shown in Figure 1, and often purchase a higher-priced water heater or air conditioning system in order to save on annual energy costs. Many of us have replaced windows in our homes with higher-quality brands in order to save energy and maintenance costs. Some choose more-expensive brick than siding in order to avoid painting expenses and gain thermal benefits. The material options are endless and probably surprisingly familiar if you made an exhaustive list.


Based on standard U.S. Government tests

ENERGYGUIDE

Refrigerator-Freezer
With Automatic Defrost
With Side-Mounted Freezer
With Through-the-Door-Ice Service

XYZ Corporation
Model ABC-W
Capacity: 23 Cubic Feet

Compare the Energy Use of this Refrigerator with Others Before You Buy.

This Model Uses
800 kWh/year

Energy use (kWh/year) range of all similar models

Uses Least Energy 685

Uses Most Energy 1000

kWh/year (kilowatt-hours per year) is a measure of energy (electricity) use. Your utility company uses it to compute your bill. Only models with 22.5 and 24.4 cubic feet and the above features are used in this scale.

Refrigerators using more energy cost more to operate. This model's estimated yearly operating cost is:

$65

Based on a 2000 U.S. Government national average cost of 8.03¢ per kWh for electricity. Your actual operating cost will vary depending on your local utility rates and your use of the product.

Figure 1. The popular annual energy guide found on many appliances.

In the public infrastructure arena, why are some road surfaces concrete and some asphalt? Why are some bridges steel and some concrete? Why do some buildings use aluminum wiring; and others, copper? Why are some power poles wood and others concrete or steel? At the root of all this, life cycle cost analysis has a role and should be practiced, but often is not.

Today, we will examine factors involved in life cycle cost analysis of water pipelines, and then illustrate a comparison with a 30,000 foot 24-inch diameter pipeline, comparing ductile iron with PVC, two popular and familiar materials.

This is a broad review, will exclude the smaller and more debatable line items, and will be clearly conclusive.

Life Cycle Cost Factors

The first item to consider is the cost of engineering design. Does one material require more detailed analysis such surge and fatigue? Is one product more resilient or robust, possessing more capacity outside normal operating margins? What are the inherent safety factors? Are the safety factors even well known and easily calculated? Does an increase in one operational area such as pressure reduce capacity in another operational area such as trench load? If a new road needed to be built above the pipeline, could one material handle it and another not? If the line needed to operate at a higher pressure in 20 years, could it do so? What about trench design? Does one material require special attention to bedding and backfill in order to have the trench support called for in its Standards? Is imported backfill needed? If so, what is the cost of that, and also the environmental impact of it? Are inspection services required for one material and not another to ensure proper bedding and backfill? Some materials require more detailed engineering analysis than others. For example, surge and fatigue which will be examined later.

Next is the cost of the material, the cost of the pipe itself. That's about the easiest and least debatable item in all of today's factors, but there is more to it than one may first realize. For example, appurtenances associated with the base pipe material vary widely. Tangential factors can include joint adaptors at connections to valves, sleeves when service connection taps are required, cost and especially effectiveness of different restraining systems, accessories required for one material but not the other such as tracer wire for PVC or polywrap for iron. There is more to a project's total cost of material than the cost of the base material.

Next is the cost to operate a pipeline. Some products are cheap to purchase and expensive to operate and maintain. Others are expensive to purchase but economical to operate and maintain. I am reminded of my father's comment, "You can't afford to buy it if you can't afford to own it." At the top of operational costs is pumping cost. Several factors go into pumping cost. One is how many gallons per day do you plan to deliver through the line, the flow rate? Another factor is the diameter, because that determines the velocity which water must flow to deliver the required volume. Another is the friction between the pipe wall and the water, the C Factor, the Hazen-Williams flow coefficient. Just as C Factors differ between materials, so do inside diameters. Another is the cost of electricity to run the pumps and the efficiency of those pumps, but those are independent of pipe material. This is all very important because energy costs - essentially pumping costs – account for as much as 30 percent of utility budgets, often a water utility's second largest expense behind salaries and wages. (Black and Veatch Engineers, 2012) Another dimension of operating costs is maintenance. What is the break rate? What is the cost to repair one type of pipe compared to another type of pipe? What is the nature of failure? Is it sudden and catastrophic, or is it slow and with warning? When repairs are necessary, is special care or precaution required? Can the line remain in service while being repaired?

Next is life expectancy of the various options. Do all models of cars each have a 200,000 mile life? Do all tires last the same 40,000 miles? Do all pipeline materials perform and last the same number of years? Of course not, and these differences matter and have associated costs. Two strong resources for service life expectancy are AWWA's *Buried No Longer* report, (American Water Works Association, 2015) and a University of Michigan life cycle framework. (Menassa, 2016)

And then, there is salvage value. When it comes time to retire from service or replace your pipeline, can you get any value for it? Can it be recycled? Is there environmental impact related to its retirement from service?

Practical Evaluations

Let's now compare more directly ductile iron and PVC concerning the above factors.

Design, Construction, and Inspection

Concerning design, both PVC and ductile iron are governed by flexible design theory, and PVC is more flexible, allowing it to more readily flex from surges. However, PVC also has a significantly lower yield point, below which it must remain to not be affected by fatigue. These are not simple matters. In fact, McPherson says of PVC pipe, "Fatigue analysis is complicated …" (McPherson, 2018) Further, John Plattsmier, Chair of the A21 Standards Committee said,

> In all reality, ductile iron and welded steel pipe will not fail due to fatigue. That cannot be said of other materials, so cyclic loading due to starting and stopping of pumps, external traffic loads, and other transient events needs to be considered. (Plattsmier, 2018)

To evaluate PVC system fatigue in the design and engineering stage as urged by pipeline design experts McPherson and Plattsmier costs money.

Figure 2 shows stress-strain diagrams for both PVC and ductile iron on a single pair of axes. Resiliency and fatigue of both materials is discussed in the 2019 ASCE Pipelines presentation *What is Pipeline Resilience?* (Gaston, What is Pipeline Resilience?, 2019)

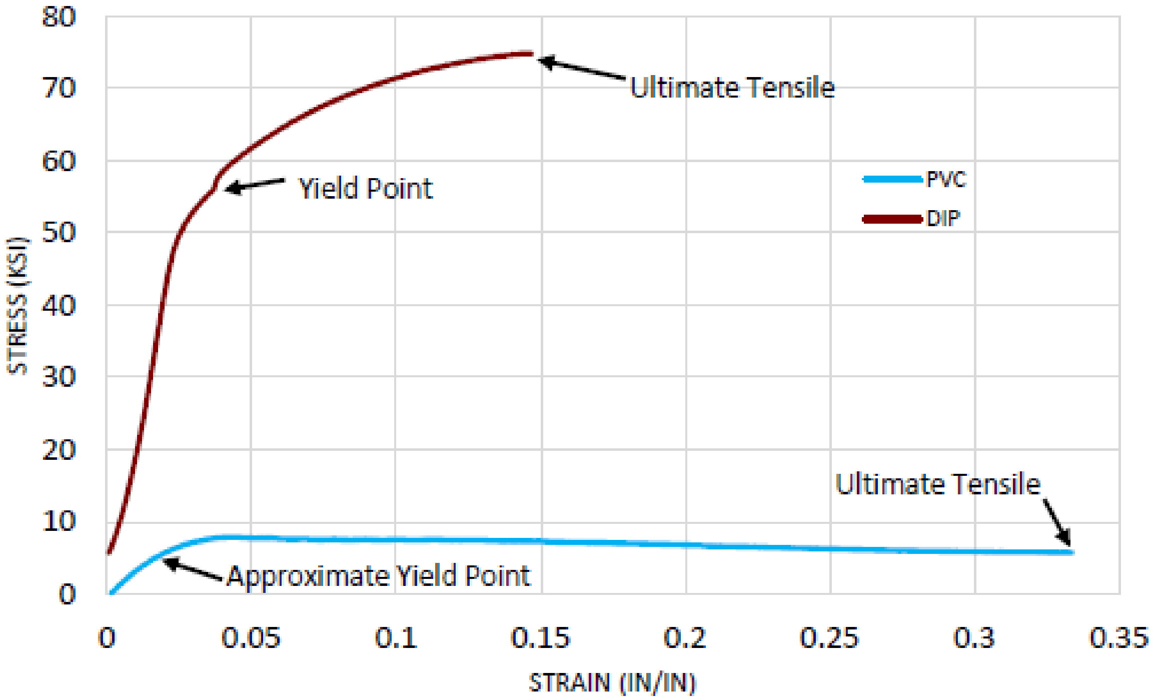
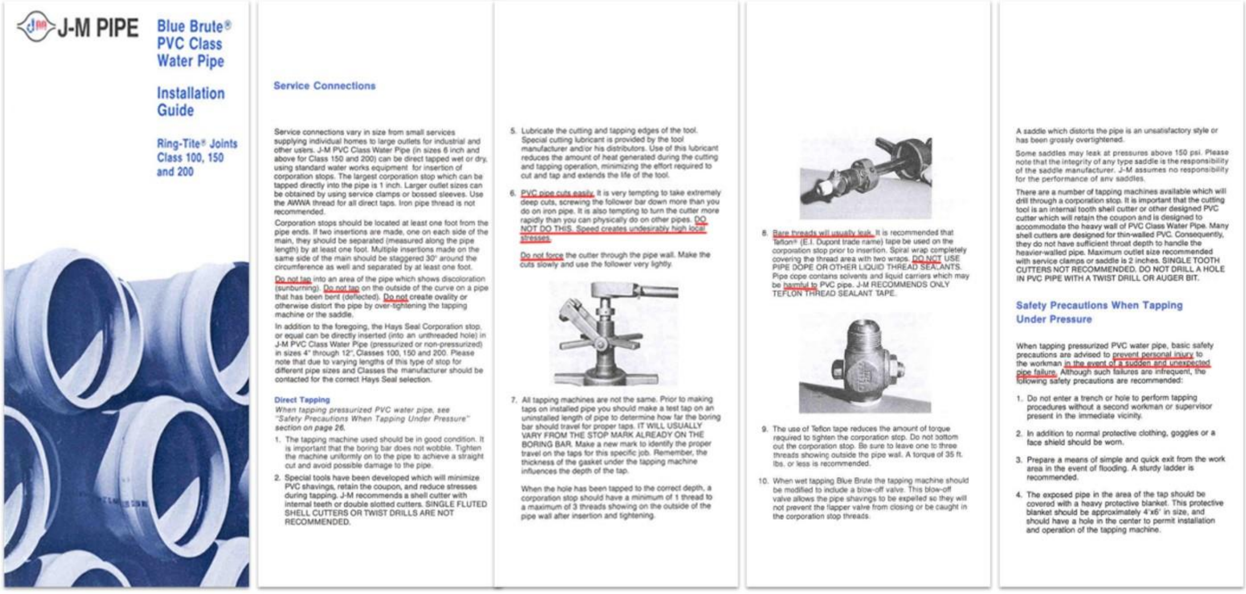


Figure 2. Stress-strain diagram comparing fatigue and resilience properties of PVC and iron. (Tabitha H. Crocker, 2019)

On the other hand, ductile iron has a 100 psi surge allowance in all her design factors and a safety factor of 2.0 is applied to that, meaning there is 200 psi of surge in the design of all ductile iron pipelines within AWWA Standards. (American Water Works Association, 2014)

Concerning bedding and backfill, both are important for all pipe materials, and care is to be taken in all construction scenarios. However, due to its lower yield point and other strength factors, the margins for PVC are tighter and, according to PVC literature more care to trench construction should be attended. (American Water Works Association, 2018)

Concerning inspection, it’s important for all pipe materials and all construction sites. However, a review of product literature will show a plethora of warnings and cautions related to the use of PVC pipe. Perhaps most prevalent is the warning against “over-belling,” pushing the spigot too far into the bell, (PVC Pipe Association, 2019), stressing the spigot through telescoping, and contributing to the possibility of splitting the entire pipe length.



J-M PIPE

Blue Brute®
PVC Class
Water Pipe

Installation
Guide

Ring-Tite® Joints
Class 100, 150
and 200

Service Connections

Service connections vary in size from small services supplying individual homes to large outlets for industrial and other users. J-M PVC Class Water Pipe (in sizes 6 inch and above for Class 150 and 200) can be direct tapped wet or dry, using standard water works equipment for insertion of corporation stops. The largest corporation stop which can be tapped directly into the pipe is 1 inch. Larger outlet sizes can be obtained by using service clamps or bossed sleeves. Use the AWWA thread for all direct taps. Iron pipe thread is not recommended.

Corporation stops should be located at least one foot from the pipe ends. If two insertions are made, one on each side of the main, they should be separated (measured along the pipe length) by at least one foot. Multiple insertions made on the same side of the main should be staggered 30° around the circumference as well and separated by at least one foot.

Do not tap into an area of the pipe which shows discoloration (sunburning). Do not tap on the outside of the curve on a pipe that has been bent (deflected). Do not create ovality or otherwise distort the pipe by over-tightening the tapping machine or the saddle.

In addition to the foregoing, the Hays Seal Corporation stop, or equal can be directly inserted (into an unthreaded hole) in J-M PVC Class Water Pipe (pressurized or non-pressurized) in sizes 4" through 12", Classes 100, 150 and 200. Please note that due to varying lengths of this type of stop for different pipe sizes and Classes the manufacturer should be contacted for the correct Hays Seal selection.

Direct Tapping

When tapping pressurized PVC water pipe, see "Safety Precautions When Tapping Under Pressure" section on page 26.

1. The tapping machine used should be in good condition. It is important that the boring bar does not wobble. Tighten the machine uniformly on to the pipe to achieve a straight cut and avoid possible damage to the pipe.
2. Special tools have been developed which will minimize PVC shavings, retain the coupon, and reduce stresses during tapping. J-M recommends a shell cutter with internal teeth or double slotted cutters. SINGLE FLUTED SHELL CUTTERS OR TWIST DRILLS ARE NOT RECOMMENDED.

5. Lubricate the cutting and tapping edges of the tool. Special cutting lubricant is provided by the tool manufacturer and/or his distributors. Use of this lubricant reduces the amount of heat generated during the cutting and tapping operation, minimizing the effort required to cut and tap and extends the life of the tool.
6. PVC pipe cuts easily. It is very tempting to take extremely deep cuts, screwing the follower bar down more than you do on iron pipe. It is also tempting to turn the cutter more rapidly than you can physically do on other pipes. DO NOT DO THIS. Speed creates undesirably high local stresses.

   Do not force the cutter through the pipe wall. Make the cuts slowly and use the follower very lightly.
7. All tapping machines are not the same. Prior to making taps on installed pipe you should make a test tap on an uninstalled length of pipe to determine how far the boring bar should travel for proper taps. IT WILL USUALLY VARY FROM THE STOP MARK ALREADY ON THE BORING BAR. Make a new mark to identify the proper travel on the taps for this specific job. Remember, the thickness of the gasket under the tapping machine influences the depth of the tap.

   When the hole has been tapped to the correct depth, a corporation stop should have a minimum of 1 thread to a maximum of 3 threads showing on the outside of the pipe wall after insertion and tightening.
8. Bare threads will usually leak. It is recommended that Teflon® (E.I. Dupont trade name) tape be used on the corporation stop prior to insertion. Spiral wrap completely covering the thread area with two wraps. DO NOT USE PIPE DOPE OR OTHER LIQUID THREAD SEALANTS. Pipe dope contains solvents and liquid carriers which may be harmful to PVC pipe. J-M RECOMMENDS ONLY TEFLON THREAD SEALANT TAPE.
9. The use of Teflon tape reduces the amount of torque required to tighten the corporation stop. Do not bottom out the corporation stop. Be sure to leave one to three threads showing outside the pipe wall. A torque of 35 ft. lbs. or less is recommended.
10. When wet tapping Blue Brute the tapping machine should be modified to include a blow-off valve. This blow-off valve allows the pipe shavings to be expelled so they will not prevent the flapper valve from closing or be caught in the corporation stop threads.

A saddle which distorts the pipe is an unsatisfactory style or has been grossly overtightened.

Some saddles may leak at pressures above 150 psi. Please note that the integrity of any type saddle is the responsibility of the saddle manufacturer. J-M assumes no responsibility for the performance of any saddles.

There are a number of tapping machines available which will drill through a corporation stop. It is important that the cutting tool is an internal tooth shell cutter or other designed PVC cutter which will retain the coupon and is designed to accommodate the heavy wall of PVC Class Water Pipe. Many shell cutters are designed for thin-walled PVC. Consequently, they do not have sufficient throat depth to handle the heavier-walled pipe. Maximum outlet size recommended with service clamps or saddle is 2 inches. SINGLE TOOTH CUTTERS NOT RECOMMENDED. DO NOT DRILL A HOLE IN PVC PIPE WITH A TWIST DRILL OR AUGER BIT.

Safety Precautions When Tapping Under Pressure

When tapping pressurized PVC water pipe, basic safety precautions are advised to prevent personal injury to the workman in the event of a sudden and unexpected pipe failure. Although such failures are infrequent, the following safety precautions are recommended:

1. Do not enter a trench or hole to perform tapping procedures without a second workman or supervisor present in the immediate vicinity.
2. In addition to normal protective clothing, goggles or a face shield should be worn.
3. Prepare a means of simple and quick exit from the work area in the event of flooding. A sturdy ladder is recommended.
4. The exposed pipe in the area of the tap should be covered with a heavy protective blanket. This protective blanket should be approximately 4'x6' in size, and should have a hole in the center to permit installation and operation of the tapping machine.

Figure 3. Installation warnings are an invisible cost.

So – does it cost more to design a PVC pipeline compared to a ductile iron pipeline? I’d suggest it does because of fatigue, bedding and backfill, and installation requirements.

Material Cost

Next, is the cost of the pipe. Plastic PVC is cheaper, and that is an area of appeal to some. A 24-inch DR 18 PVC pipe costs about $54.58 per foot today. It moves up and down often related to the cost of petroleum-based feedstocks imported from Asia, but that’s a fair quote as of October, 2019. A fair price for 24-inch class 200 cement lined ductile iron is $68.32 per foot.

That’s a difference of $13.74 in favor of PVC. But it also costs materials and labor to ***install*** the pipe. Installation costs vary greatly depending on the setting. A cross-country installation through farmland will be much less than an urban environment with pavement, traffic control, limited hours, conflicting utilities, and more. Most experienced industry personnel will allow that PVC needs better bedding and backfill resulting in higher installation costs. However, in the interest of objectivity and more-than-fair mindedness, let’s consider the cost of installation for both materials to be the same and to be 1.5 times the cost of the PVC pipe material. With those general but reasonable assumptions, and with PVC’s $54.58 material cost, its installed cost is $54.58 plus $81.87, or $136.45. Ductile iron’s installed cost is then its material cost of $68.32 plus an installation cost of $81.87, resulting in an installed cost of $150.19.

This is an important point to understand. While the cost difference of the materials is $54.58 vs. $68.32, a 20 % difference, the installed costs are $136.45 vs. $150.19, only a 9% difference. Installation is a significant leveler, and operations will be even more so.

Figure 4. Installation costs vary depending on the setting.

Operational Costs

The most significant operational expenses are pumping costs. Two major determinants to pumping costs are inside diameter and Hazen-Williams coefficients of friction. Why do nominally same-sized pipe of different materials have different inside diameters? That's a great question, and it is answered in detail in the proceedings of the 2016 ASCE Pipelines conference in Kansas City in a presentation titled *Energy Efficiency through Material Selection*. (Scott & Gaston, 2016) In the interest of brevity, a 24-inch diameter class 200 cement lined ductile iron pipe has an inside diameter of 24.95 inches, and a 24-inch DR 18 plastic PVC pipe has an inside diameter of 22.76 inches. Table 1 below shows a comparison of inside diameters of numerous pipe materials.

Table 1. Actual inside diameters of various distribution and transmission main pipe materials. (American Water Works Association, 2009)

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, latest revision. Lowest pressure class with C104 cement mortar lining.
(2) Iron o.d., AWWA C900 and C905, latest revisions. 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, latest revision.
(5) From manufacturers’ information.
(6) From AWWA C906, latest revision. DR 11 for 6”-30”, DR 13.5 for 36”, DR 15.5 for 42”, and DR 17 for 48”.

These differences in inside diameter are shown graphically in Figure 5 where the percentage difference in cross sectional area of ductile iron pipe is compared to that of PVC pipe, with ductile iron having the larger area.

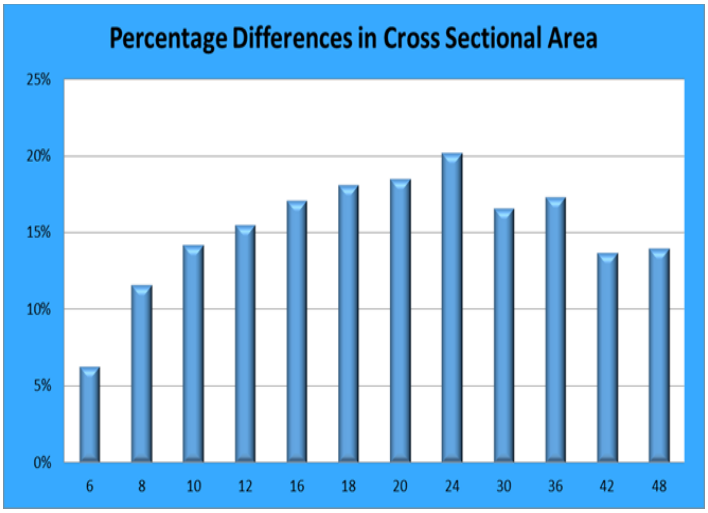


Figure 5. Percentage differences in cross-sectional flow area between ductile iron pipe and PVC pipe.

A second major determinant to pumping costs is the Hazen-Williams flow coefficient. Cement lining was developed in 1922 and first supplied as an in situ process with Charleston Public Works in Charleston, South Carolina. (Miller, 1965) Cement lining was developed in response to tuberculation, a form of internal corrosion in which minerals in the water stick to the exposed bare iron and tubercles form from the iron. AMERICAN Cast Iron Pipe pioneered cement linings and facilitated that original Charleston, South Carolina, in situ application. (Chaplin, 2005) Cement lining soon became the norm for iron pipe, and in 1929 the American Standards Association issued a standard for cement mortar linings. (American Water Works Association, 2013) 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 value of 140 for cement mortar lined iron pipe has been a recent focus of dispute by the PVC industry, but in situ field tests support the long-term resilience of 140. (Ductile Iron Pipe Research Association, 2012) A number of studies confirming this have been published down through the years in *Journal AWWA* and other publications. (Gaston, Pipe Inside Diameter Key to Energy Efficiency, 2014) Table 2 below shows in-service flow tests of several new and older cement mortar lined iron pipelines.

Table 2. Flow Tests of In-Service Cement Mortar Lined Iron Pipe

Location	Diameter (Nominal Inches)	Length (Feet)	Age (Years)	Hazen-Williams C Factor
Corder, Missouri	8	21,400	1	145
Bowling Green, Ohio	20	45,600	1	143
Chicago, Illinois	36	7,200	12	151
Safford, Arizona	10	23,200	16	144
Tempe, Arizona	6	1,235	24	144
Seattle, Washington	8	2,686	29	139
Concord, New Hampshire	12	55	36	140

(Ductile Iron Pipe Research Association, 2006)

Whether the long-term cement mortar C Factor is 140, 145, or 135, it clearly does not deteriorate over time and advertising photos of tuberculated iron pipe without cement mortar linings are at best disingenuous. In fact, today's high-speed cement linings in ductile iron pipe likely have a C Factor higher than 140. Figure 6 shows just how smooth today's ductile iron pipe cement mortar linings are.

Figure 6. Modern high-speed cement linings have a smooth inside surface proven to remain smooth for decades with no trend or hint of deterioration.

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 more advantageous friction value for PVC pipe as compared to iron pipe, but we will see from the pumping cost calculations that the larger inside diameter of iron pipe more than offsets the lower friction value of PVC pipe. In reality, recent and current improvements in high-speed lining processes are producing C Factors better than 140, but that's a topic for a different day.

Let's now look specifically at the pumping cost differences between ductile iron and PVC for our 24-inch 30,000 foot example. A complete outline of pumping cost formulae and calculations can be found in a variety of water industry publications, and for a good outline of them and the process, I would suggest the *Journal AWWA* June 2014 issue and its article entitled *Pipe Inside Diameter Key to Energy Efficiency*. (Gaston, Pipe Inside Diameter Key to Energy Efficiency, 2014)

Power costs vary across the country. Figure 7 shows domestic commercial electric power costs in 2018. It differs regionally, and the national average is 10.58 cents per kW-hour. (United States Chamber of Commerce, 2019) Factors related to power costs include local regulatory requirements, the source and cost of fuel to generate the power, etc. A conservative power cost for an analysis of this nature is $0.10 / kW-hour, ten cents per kilowatt-hour. That's lower than the average, but higher than some areas, therefore, a more-than-fair cost for this analysis.

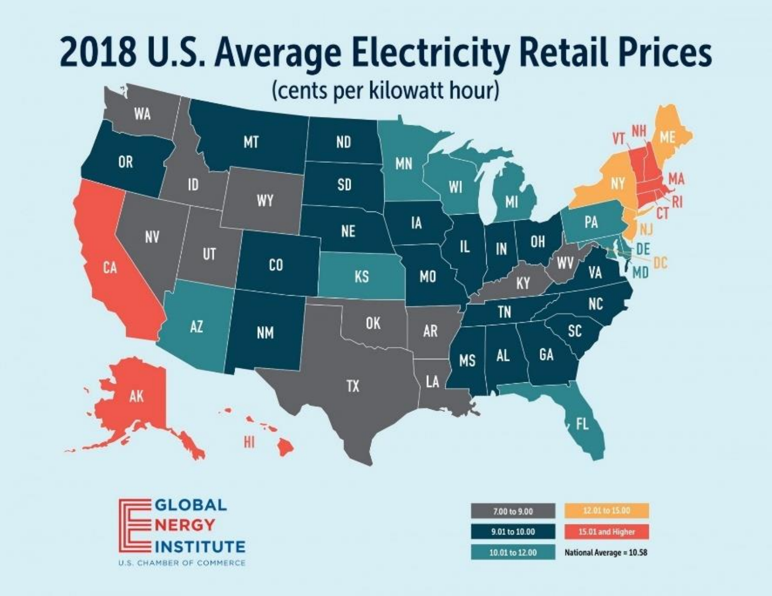


Figure 7. Electricity costs in 2018 across the United States.

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

If power costs are higher than $0.10 and pump efficiencies are less than 70%, ductile iron pipe will fare even better in this comparison.

Velocity and Flow Rate

Finally, a reasonable modeling velocity is 4 feet per second. In a 24-inch pressure class 200 ductile iron line, that’s 6,095 gallons per minute, or roughly 8.8 MGD. (ICENTA, 2016)

For this example, we are using a 30,000-foot, 24-inch diameter, cement-lined, class 200 ductile iron pipe with a 24.94-inch inside diameter, and a C Factor of 140. A comparison will be made against the same footage of PVC DR 18 pipe with an inside diameter of 22.76 inches and a C Factor of 150. Valves are not considered, but full port-opening resilient wedge gate valves as compared to butterfly valves have been shown to have much less head loss and to be commensurately more efficient. (Scott & Gaston, 2016)

As an aside, the design pressure of Class 200 ductile iron pipe is 600 psi, and every 24-inch ductile iron pipe is required by AWWA Standards to be proof-tested to 500 psi, and AMERICAN proofs this item to 75% yield before it leaves our factory, 805 psi for this diameter and class combination. Since the yield point of

PVC is approximately 6,500 psi, depending on temperature, 24-inch DR 18 plastic PVC pipe will experience fatigue at approximately 765 psi, a lower pressure than what ductile iron is proof-tested. Whether hot or cold, the ambient environment may compromise the performance of PVC pipe.

Using a power cost of $0.10 per kW-h, pump efficiency of 70 percent, flow rate of 6,095 gallons per minute, and applying these equations to 30,000 feet of 24-inch diameter pipe, the annual pumping cost through ductile iron pipe is $76,639. If that same line were made of DR18 PVC with its smaller inside diameter, and even considering the possibility of a slightly smoother surface and C Factor of 150, the annual pumping cost would be $105,085. As shown in Table 3, the annual savings for this relatively short line and considering only the pipe is $28,446.

Table 3. Annual Pumping Costs for 30,000 Feet of Ductile Iron Pipe Compared to PVC.

Comparison of 24-inch Ductile Iron and PVC Pumping Costs										
Size	Pipe Material.	Length (feet)	GPM	Pipe I.D.	C Factor	Velocity (fps)	Head Loss	Pump Hrs/Day	$ / KWH	Annual Cost
24	Ductile Iron	30,000	6096	24.95	140	4.0	53.3	24	$0.10	$76,639
24	PVC	30,000	6096	22.76	150	4.8	73.2	24	$0.10	$105,085
Ductile Iron Annual Savings										**$28,446**

These annual savings are shown in bar graph form in Figure 8. Remember, these are annual savings, and they will compound as we will soon evaluate.

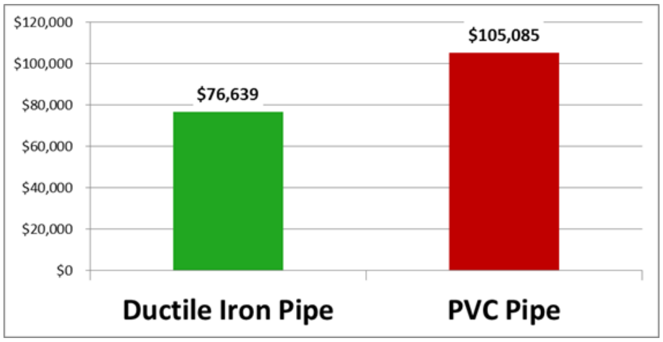


Figure 8. Annual pumping costs through the two comparative materials.

This does not take into account savings from lower maintenance costs, or the longer life of the iron line, and a host of other benefits associated with the use of iron pipe and listed earlier.

Using a present worth calculator and the data and values shown in Table 4, a present worth value for the annual pumping cost savings of $61.42 per foot in favor of ductile iron is determined, a total of $1,842,743. (Ductile Iron Pipe Research Association, 2019) This would be like a yellow sticker comparing annual energy costs of an iron vs. a PVC pipeline, similar to an MPG rating between two truck brands or between a truck and a car. In this case, the tougher one also has the better operating costs.

Table 4. Factors used to determine annual pumping cost savings and associated present worth related to the use of ductile iron instead of PVC pipe. (Ductile Iron Pipe Research Association, 2019)

Values in Determining Pumping Cost Savings		
	24-inch Ductile Iron Class 200	**24-inch PVC DR 18**
Inside Diameter	24.95 in	22.76 in
Velocity	4.0 fps	4.81 fps
Flow Volume	6,095 gallons per minute, or roughly 8.8 MDG	
C Factor	140	150
Head Loss	1.78 ft/1000 ft	2.45 ft/1000 ft
Power Cost	$0.10 / kilowatt-hour	
Pump Efficiency	70%	
Pump Operation	24/7	
Annual Power Cost	$76,645	$105,526
Annual Savings with Ductile Iron	$28,881	
Design Life	100 Years	
Rate of Return	4%	
Electricity Inflation	3%	
Present Worth Savings with Ductile Iron	**$1,842,743**	
Per Foot Present Worth Savings with Ductile Iron	**$61.42**	

Summary

As shown early on in this paper, there are many factors in life cycle costing. Many of those factors are subject to debate and respected differences of opinion.

Considering only material costs, installation costs, and pumping costs - and ignoring the more debatable design costs, maintenance costs, service lives, and salvage values, each of which also favors iron pipe - we see in this 30,000 foot 24-inch diameter example, the life cycle cost of ductile iron pipe having a higher material cost is less, more economical and affordable, and a better value for ductile iron pipe. Table 5 sums the broad factors for the two materials.

Table 5. Summary of life cycle costs for ductile iron and PVC, per foot.

Per Foot	**24-inch Ductile Iron Class 200**	**24-inch PVC DR 18**
Material Cost	$68.32	$54.58
Installation Cost	$81.87	$81.87
Pumping Cost Present Worth Delta	Zero	+ $61.42
Net Life Cycle Cost	$150.19	$197.87
Life Cycle Cost Advantage for Ductile Iron Pipe	**$47.68**	

This life cycle advantage for ductile iron is actually conservative. The longer life of iron pipe and the resultant expense of replacing the PVC line is not considered, nor are the higher maintenance and repair costs. Each of these are substantiated by both *Buried No Longer* and the University of Michigan study. In other words, ductile iron has even higher value than shown here with these objective numbers.

Energy and Environmental Impact

Also, none of this takes into account the environmental benefits of lower pumping costs and the annual, on-going carbon reduction resulting from those energy savings. In this example, those are annually equal to 288,810 kilowatt-hours. This is equivalent to the annual CO_2 emissions of 22,981 gallons of gasoline, 20,062 gallons of diesel, 223,272 pounds of coal, or 473 barrels of oil. It equals annually the carbon sequestered by 240 acres of forest land. (Environmental Protection

Agency, 2019) That is a substantial environmental impact from the specification choice of a modest municipal pipeline and likely of interest to rate-paying citizens.

Further, and increasingly of interest and value, none of this takes into account that ductile iron pipe is made of recycled iron and steel while PVC is made of petroleum-based feedstock, much of which is imported from Asia.

Conclusions

Just because a material may have higher purchase cost, it does not necessarily have a higher operational nor, especially, higher life cycle cost. To the contrary, many times and in many different arenas, the higher initial-cost option provides the greater long-term value and lower life cycle cost. In other words, oftentimes, the higher-cost material has within it better value resulting in an advantageous life cycle cost.

Ductile iron pipe is good for performance, good for rate payers, and good for the environment. In this example and many others, ductile iron pipe has the better life cycle cost when compared to plastic PVC pipe.

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