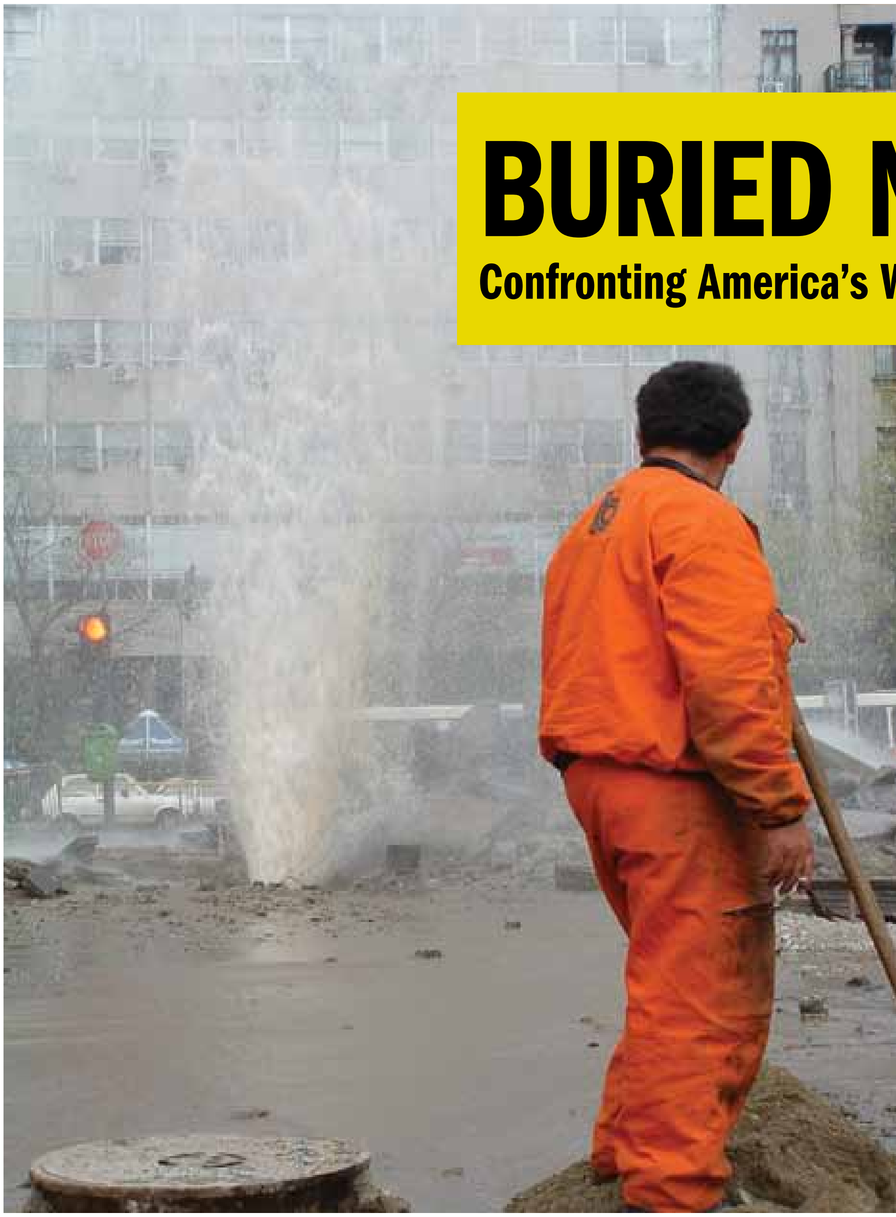
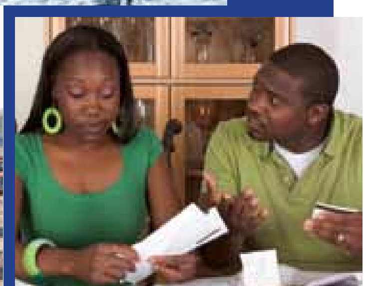
BURIED NO LONGER:

Confronting America's Water Infrastructure Challenge





American Water Works Association

The Authoritative Resource on Safe Water®

Acknowledgments

This report was developed by the American Water Works Association under the direction of its Water Utility Council, through Stratus Consulting in Boulder, Colorado. Significant portions of the analyses described in this report were initiated or developed by John Cromwell, who unfortunately passed away before this project was completed. John was a true visionary, a wonderful friend and colleague, and an ardent believer in promoting sound management of water system infrastructure. We hope this report does proper service to John's intent, integrity and passion. Special recognition is also due to Bob Raucher, who completed the work with great attention to detail, patience and outstanding professionalism.

Haydn Reynolds is the developer of the Nessie Model and managed all the empirical investigations in this report. His continued engagement in the development of this report has been exemplary, as has been his willingness to address the many questions involved in the transition of the final report preparation from John Cromwell to Bob Raucher and others at Stratus Consulting. Finally, but not least, a number of AWWA utility members did significant work on this project, including Dave Rager (who chairs the Water Utility Council), Mike Hooker (who was WUC chair when the report was initiated), Aurel Arndt (who chairs the advisory work group on this project), and Joe Bella, John Sullivan, Richard Talley, Robert Walters, and Dave Weihrauch, all of whom made significant contributions as members of the advisory work group.

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Introduction. A new kind of challenge is emerging in the United States, one that for many years was largely buried in our national consciousness. Now it can be buried no longer. Much of our drinking water infrastructure, the more than one million miles of pipes beneath our streets, is nearing the end of its useful life and approaching the age at which it needs to be replaced. Moreover, our shifting population brings significant growth to some areas of the country, requiring larger pipe networks to provide water service.

As documented in this report, restoring existing water systems as they reach the end of their useful lives and expanding them to serve a growing population will cost at least $1 trillion over the next 25 years, if we are to maintain current levels of water service. Delaying the investment can result in degrading water service, increasing water service disruptions, and increasing expenditures for emergency repairs. Ultimately we will have to face the need to "catch up" with past deferred investments, and the more we delay the harder the job will be when the day of reckoning comes.

In the years ahead, all of us who pay for water service will absorb the cost of this investment, primarily through higher water bills. The amounts will vary depending on community size and geographic region, but in some communities these infrastructure costs alone could triple the size of a typical family's water bills. Other communities will need to collect significant "impact" or development fees to meet the needs of a growing population. Numerous communities will need to invest for replacement **and** raise funds to accommodate growth at the same time. Investments that may be required to meet new standards for drinking water quality will add even more to the bill.

Although the challenge to our water infrastructure has been less visible than other infrastructure concerns, it's no less important. Our water treatment and delivery systems provide public health protection, fire protection, economic prosperity and the high quality of life we enjoy. Yet most Americans pay less than $3.75 for every 1,000 gallons of safe water delivered to their taps.

This report demonstrates that as a nation, we need to bring the conversation about water infrastructure above ground. Deferring needed investments today will only result in greater expenses tomorrow and pass on a greater burden to our children and grandchildren. It's time to confront America's water infrastructure challenge.

The Era of Infrastructure Replacement. More than a decade ago the American Water Works Association (AWWA) announced that a new era was dawning: the replacement era, in which our nation would need to begin rebuilding the water and wastewater systems bequeathed to us by earlier generations. Our seminal report—*Dawn of the Replacement Era*—demonstrated that significant investments will be required in coming decades if we are to maintain the water and wastewater systems that are so essential to our way of life.

The *Dawn* report examined 20 water systems, using a relatively new technique to build what came to be called a "Nessie Curve" for each system. The Nessie Curve, so called because the graph follows an outline that someone likened to a silhouette of the Loch Ness Monster, revealed that each of the 20 water systems faced unprecedented needs to rebuild its underground water infrastructure—its pipe network. For each system, the future investment was an "echo" of the demographic history of the community, reflecting succeeding generations of pipe that were laid down as the community grew over many years. Most of those generations of pipe were shown to be coming to an end of their useful service lives in a relatively compressed period. Like the pipes themselves, the need for this massive investment was mostly buried and out of sight. But it threatens our future if we don't elevate it and begin to take action now.

The present report was undertaken to extend the *Dawn* report beyond those 20 original cities and encompass the entire United States. The results are startling. They confirm what every water utility professional knows: we face the need for massive reinvestment in our water infrastructure over the coming decades. The pipe networks that were largely built and paid for by earlier generations—and passed down to us as an inheritance—last a long time, but they are not immortal. The nation's drinking water infrastructure—especially the underground pipes that deliver safe water to America's homes and businesses—is aging and in need of significant reinvestment. Like many of the roads, bridges, and other public assets on which the country relies, most of our buried drinking water infrastructure was built 50 or more years ago, in the post-World War II era of rapid demographic change and economic growth. In some older urban areas, many water mains have been in the ground for a century or longer.

Given its age, it comes as no surprise that a large proportion of US water infrastructure is approaching, or has already reached, the end of its useful life. The need to rebuild these pipe networks must come on top of other water investment needs, such as the need to replace water treatment plants and storage tanks, and investments needed to comply with standards for drinking water quality. They also come on top of wastewater and stormwater investment needs which—judging from the US Environmental Protection Agency's (USEPA) most recent "gap analysis"—are likely to be as large as drinking water needs over the coming decades. Moreover, both water and wastewater infrastructure needs come on top of the other vital community infrastructures, such as streets, schools, etc.

Prudent planning for infrastructure renewal requires credible, analysis-based estimates of where, when, and how much pipe replacement or expansion for growth is required. This report summarizes a comprehensive and robust national-level analysis of the cost, timing, and location of the investments necessary to renew water mains over the coming decades. It also examines the additional pipe investments we can anticipate to meet projected population growth, regional population shifts, and service area growth through 2050.

This analysis is based on the insight that there will be "demographic echoes" in which waves of reinvestment are driven by a combination of the original patterns of pipe investment, the pipe materials used, and local operating environments. The report examines the reinvestment demands implied by these factors, along with population trends, in order to estimate needs for pipe replacement and concurrent investment demands to accommodate population growth.

Although this report does not substitute for a careful and detailed analysis at the utility level as a means of informing local decisions, it constitutes the most thorough and comprehensive analysis ever undertaken of the nation's drinking water infrastructure renewal needs. The keys to our analysis include the following:

1. Understanding the original timing of water system development in the United States.
2. Understanding the various materials from which pipes were made, and where and when the pipes of each material were likely to have been installed in various sizes.
3. Understanding the life expectancy of the various types and sizes of pipe ("pipe cohorts") in actual operating environments.
4. Understanding the replacement costs for each type and size of pipe.
5. Developing a probability distribution for the "wear-out" of each pipe cohort.

Methodology

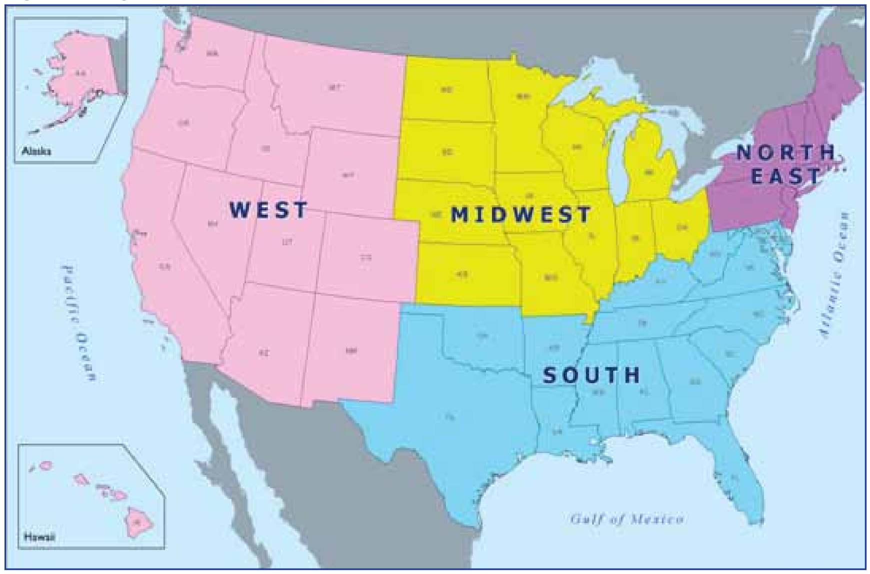
For this report, we differentiated across four water system size categories*:

- Very small systems (serving fewer than 3,300 people, representing 84.5% of community water systems).
- Small systems (3,300 to 9,999 served, representing 8.5% of community water systems).
- Medium-size systems (10,000 to 49,999 served, representing over 5.5% of systems). And,
- Large systems (serving more than 50,000 people, representing 1.5% of community water systems).

** Note that the water system size categories used in this analysis are not identical to the size categories USEPA uses for regulatory purposes. Note also that although data were analyzed based on these four size categories, some of the graphs that accompany this report combine medium-size and small systems. This is done for simplicity in the visual presentation, when the particular dynamics being represented are closely similar for medium-size and small systems.*

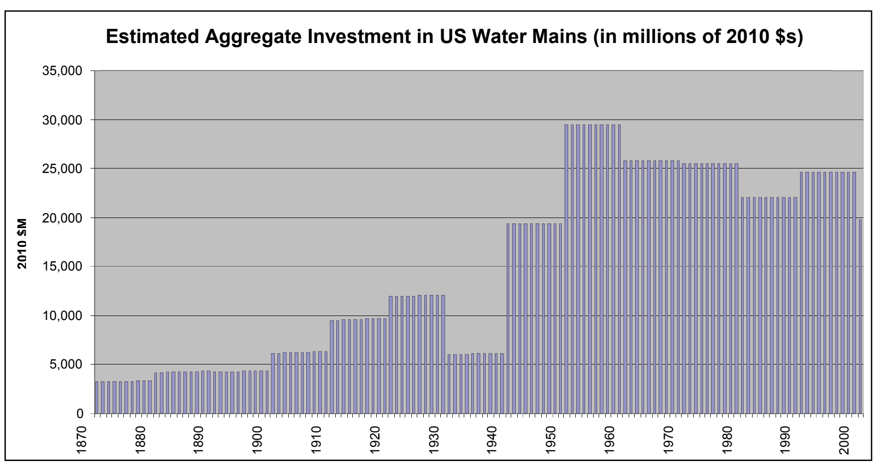
Next, we divided the country into four regions (Northeast, Midwest, South, and West), as shown in Figure 1. These regions are not equal in population, but they roughly share certain similarities, including their population dynamics and the

Figure 1: Regions Used in This Report



historical patterns of pipe installation driven by those dynamics. Data published by USEPA, the water industry, and the US Census Bureau were tapped to obtain a solid basis for regional pipe installation profiles by system size and pipe diameter. The US Census Bureau has produced a number of retrospective studies of the changes in urban and rural circumstances between 1900 and 2000 that proved especially useful in this analysis. The report also used the AWWA Water/Stats database, the USEPA Community Water Supply Survey, and data from the 2002 Public Works Infrastructure Survey (PWIS) as essential inputs in the analysis.

Figure 2: Historic Investment Profile for All US Water Systems, 1850-2000



In addition, we conducted a limited survey of professionals in the field concerning pipe replacement issues and other relevant "professional knowledge." The national aggregate for the original investment in all types and sizes of pipes is shown in Figure 2, while Figure 3 shows the aggregate current replacement value of water pipes by pipe material and utility size, totaling over $2.1 trillion.

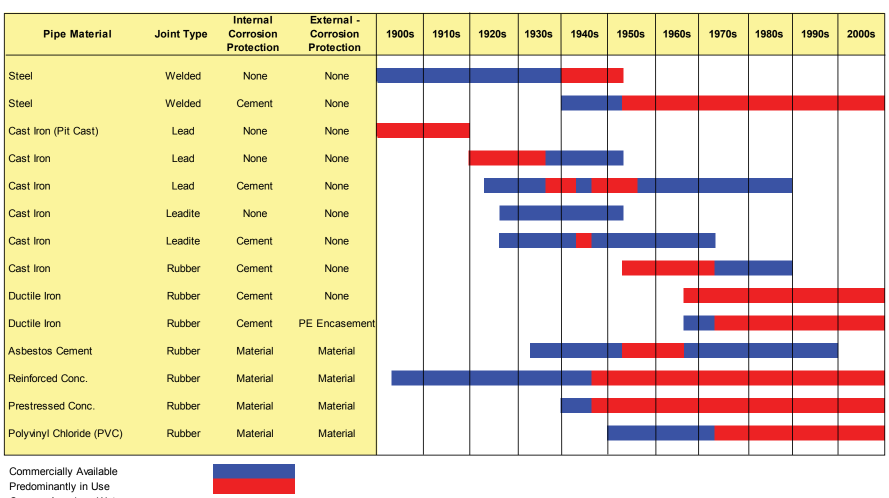
Figure 3: Aggregate Replacement Value of Water Pipes by Pipe Material and Utility Size (millions 2010 $s)

Region	CI	CICL	DI	AC	PV	Steel	PCCP	TOTAL
Northeast Large	48,958	8,995	5,050	2,308	1,875	335	0	67,522
Northeast Medium & Small	66,357	61,755	28,777	26,007	16,084	5,533	6,899	211,411
Northeast Very Small	14,491	15,992	10,661	7,281	7,937	329	462	57,152
Midwest Large	37,413	9,151	3,077	2,504	1,098	784	512	54,539
Midwest Medium & Small	74,654	92,106	51,577	37,248	30,506	8,682	11,152	305,925
Midwest Very Small	37,597	28,943	25,464	12,428	19,720	601	828	125,581
Southeast Large	30,425	28,980	29,569	21,229	14,936	9,337	7,227	141,703
South Medium & Small	54,772	98,608	140,079	103,659	102,804	21,394	17,160	538,475
South Very Small	43,183	24,998	49,791	34,529	47,823	1,461	1,244	203,028
West Large	15,448	16,055	28,949	14,774	14,723	7,443	6,215	103,607
West Medium & Small	15,775	50,145	70,355	50,541	48,885	12,276	9,806	257,782
West Very Small	16,344	11,199	17,910	13,166	17,245	545	453	76,862
Total	455,416	446,927	461,258	325,674	323,637	68,719	61,957	2,143,589
CI: cast iron; CICL: cast iron cement lined; DI: ductile iron; AC: asbestos cement; PV: polyvinyl chloride; PCCP: prestressed concrete cylinder pipe								

Finally, we used historical data on the production and use of seven major types of pipe with 14 total variations (Figure 4) to estimate what kinds of pipe were installed in water systems in particular years. This was validated by field checking with a sample of water utilities as well as checking against the original Nessie analysis. Together these steps resulted in the development of 16 separate inventories (four regions with four utility sizes in each region), with seven types of pipe in each inventory, *thus providing the most comprehensive picture of the nation's water pipe inventory ever assembled.* Note that in some of the report's graphs, "long-" and "short-lived" versions of certain pipe materials are combined, for purposes of visual simplicity in the presentation.

In order to consider growth, it was also necessary to examine population trends across rural, suburban, and urban settings over the past century. US Census Bureau

Figure 4: Historic Production and Use of Water Pipe by Material



Source: American Water


projections of demographic trends allowed the development of infrastructure need profiles for growth through 2050 in each of the regions and utility size categories (for the latter purpose, city size was used as a proxy for utility size).

The study generally assumes that utilities continue efforts to manage the number of main breaks that occur per mile of pipe rather than absorb increases in pipe failures. That is, the study assumes utilities will strive to maintain current levels of service rather than allow increasing water service outages. We assume that each utility's objective is to make these investments at the optimal time for maintaining current service levels and to avoid replacing pipes while the repairs are still cost-effective. Ideally, pipe replacement occurs at the end of a pipe's "useful life"; that is, the point in time when replacement or rehabilitation becomes less expensive in going forward than the costs of numerous unscheduled breaks and associated emergency repairs.

With this data in hand and using the assumptions above, we projected the "typical" useful service life of the pipes in our inventory using the "Nessie Model"™. The model embodies pipe failure probability distributions based on many utilities' current operating experiences, coupled with insights from extensive research and professional experiences with typical pipe conditions at different ages and sizes, according to pipe material. The analysis used seven different types of pipe in three diameters and addressed pipe inventories dating back to 1870. Estimated typical service lives of pipes are

Figure 5: Average Estimated Service Lives by Pipe Materials (average years of service)

Derived Current Service Lives (Years)	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	Steel	Conc & PCCP
Northeast Large	130	120	100	110	50	80	80	100	100	100
Midwest Large	125	120	85	110	50	100	85	55	80	105
South Large	110	100	100	105	55	100	80	55	70	105
West Large	115	100	75	110	60	105	75	70	95	75
Northeast Medium & Small	115	120	100	110	55	100	85	100	100	100
Midwest Medium & Small	125	120	85	110	50	70	70	55	80	105
South Medium & Small	105	100	100	105	55	100	80	55	70	105
West Medium & Small	105	100	75	110	60	105	75	70	95	75
Northeast Very Small	115	120	100	120	60	100	85	100	100	100
Midwest Very Small	135	120	85	110	60	80	75	55	80	105
South Very Small	130	110	100	105	55	100	80	55	70	105
West Very Small	130	100	75	110	60	105	65	70	95	75

LSL indicates a relatively long service life for the material resulting from some combination of benign ground conditions and evolved laying practices etc.
SSL indicates a relatively short service life for the material resulting from some combination of harsh ground conditions and early laying practices, etc.

Figure 6: Aggregate Needs for Investment in Water Mains Through 2035 and 2050, by Region

2011-2035 Totals			
(2010 $M)	**Replacement**	**Growth**	**Total**
Northeast	$92,218	$16,525	$108,744
Midwest	$146,997	$25,222	$172,219
South	$204,357	$302,782	$507,139
West	$82,866	$153,756	$236,622
Total	**$526,438**	**$498,285**	**$1,024,724**

2011-2050 Totals			
(2010 $M)	**Replacement**	**Growth**	**Total**
Northeast	$155,101	$23,200	$178,301
Midwest	$242,487	$36,755	$279,242
South	$394,219	$492,493	$886,712
West	$159,476	$249,794	$409,270
Total	**$951,283**	**$802,242**	**$1,753,525**

reflected in Figure 5. Note that the *actual* lives of pipes may be quite different in a given utility. Because pipe life depends on many important local variables as well as upon utility practices, predicting the actual life expectancy of any given pipe is outside the scope of this study. Many utilities will have pipes that last much longer than these values suggest while others will have pipes that begin to fail sooner. However, these values have been validated as national "averages" by comparing them to actual field experience in a number of utilities throughout the country. The model also includes estimates of the indicative costs to replace each size category of pipe, as well as the cost to repair the projected number of pipe breaks over time according to pipe size.

The analysis of pipe replacement needs is compiled in the Nessie Model by combining the demographically based pipe inventories with the projected effective service lifetimes for each pipe type. This yields an estimate of how much pipe of each size in each region must be replaced in each of the coming 40 years. Factoring in the typical cost to replace these pipes, we derive an estimate of the total investment cost for each future year. The model then derives a series of graphs (the Nessie curves) that depict the amount of spending required in each future year to replace each of the different pipe types by utility size and region. Aggregating this information, we derived the dollar value of total drinking water infrastructure replacement needs over the coming 25 and 40 years for each utility size category per region, and for the United States.

Key Findings

1. The Needs Are Large. *Investment needs for buried drinking water infrastructure total more than $1 trillion nationwide over the next 25 years*, assuming pipes are replaced at the end of their service lives and systems are expanded to serve growing populations. Delaying this investment could mean either increasing rates of pipe breakage and deteriorating water service, or suboptimal use of utility funds, such as paying more to repair broken pipes than the long-term cost of replacing them. Nationally, the need is close to evenly divided between replacement due to wear-out and needs generated by demographic changes (growth and migration).

Over the coming 40-year period, *through 2050, these needs exceed $1.7 trillion.* Replacement needs account for about 54% of the national total, with about 46% attributable to population growth and migration over that period.

Figure 6 (previous page) shows aggregate needs for investment in water mains through 2050, due to wear-out and population growth.

2. Household Water Bills Will Go Up. Important caveats are necessary here, because there are many ways that the increased investment in water infrastructure can be allocated among customers. Variables include rate structures, how the investment is financed, and other important local factors. But the level of investment required to replace worn-out pipes and maintain current levels of water service *in the most affected communities could in some cases triple household water bills.* This projection assumes the costs are spread evenly across the population in a "pay-as-you-go" approach (See "The Costs Keep Coming" below). Figures 7 and 8 illustrate the increasing cost of water that can be expected by households for replacement, and for replacement plus growth, respectively. The utility categories shown in these figures are presented to depict a range of household cost impacts, from the least-to-the-most affected utilities.

Figure 7: Costs per Household for Water Main Replacement by Utility Size and Region

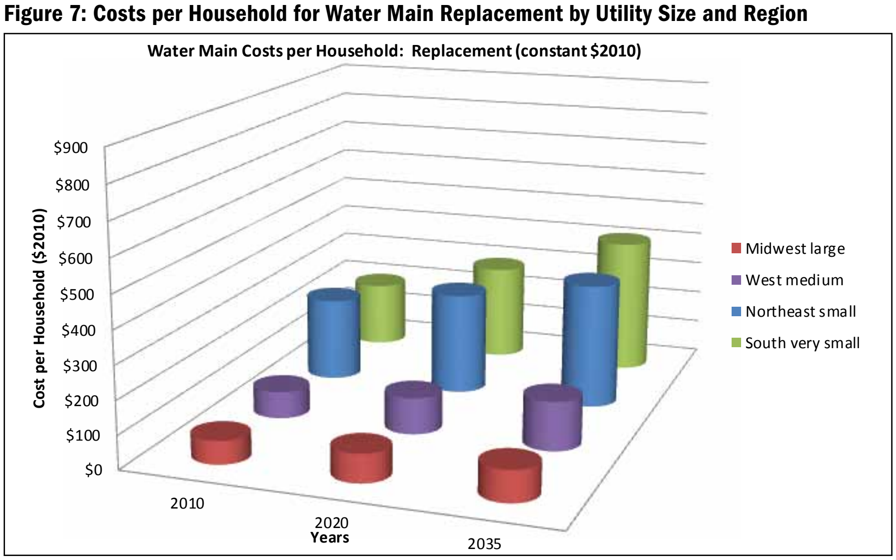
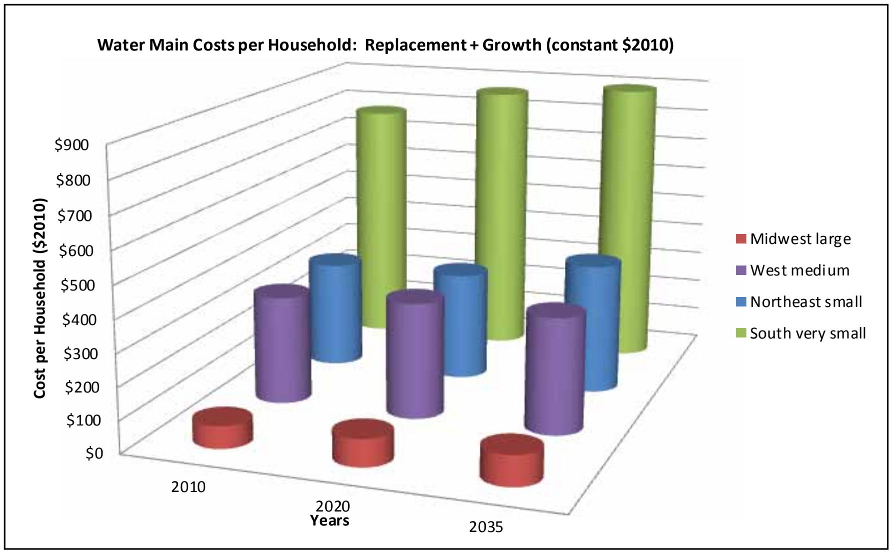


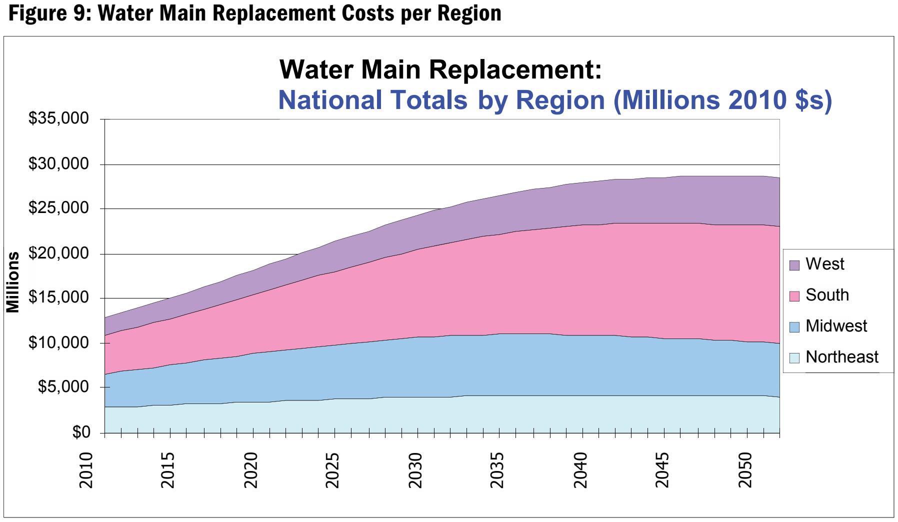
Figure 8: Costs per Household for Water Main Replacement Plus Growth



With respect to the cost of growth, other caveats are important. Many communities expect growth to pay or help pay for itself through developer fees, impact fees, or similar charges. In such communities, established residents will not be required to shoulder the cost of population growth to the extent that these fees recover those costs. *But regardless of how the costs of replacement and growth are allocated among builders, newcomers, or established residents, the total cost that must be borne by the community will still rise.*

3. There Are Important Regional Differences. The growing national need affects different regions in different ways. In general, the South and the West will face the steepest investment challenges, with total needs accounting for considerably more than half the national total (see Figures 6 and 9). This is largely attributable to the fact that the population of these regions is growing rapidly. In contrast, in the Northeast and Midwest, growth is a relatively small component of the projected need. However, the population shifts away from these regions complicate the infrastructure challenge, as there are fewer remaining local customers across whom to spread the cost of renewing their infrastructure.

Figure 9: Water Main Replacement Costs per Region

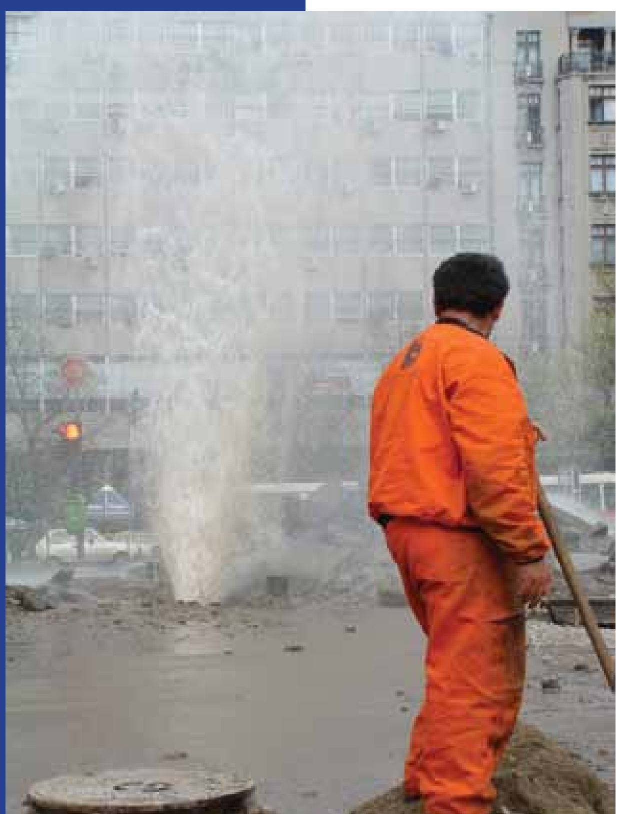


This regional perspective reveals the inherent difficulty of managing infrastructure supply and demand. Although water pipes are fixed in place and long-lasting, the population that drives the demand for these assets is very mobile and dynamic. People move out of one community, leaving behind a pipe network of fixed size but with fewer customers to support it. They move into a new community, requiring that the water system there be expanded to serve the new customers.

4. There Are Important Differences Based on System Size.

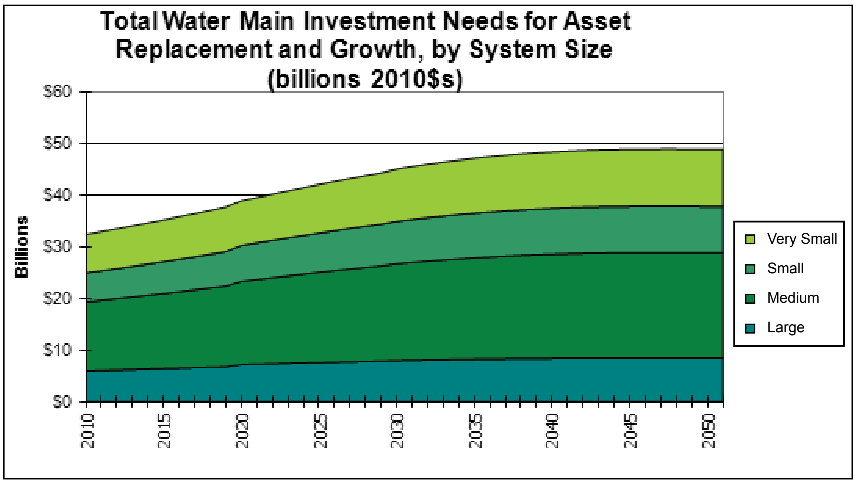
As with many other costs, *small communities may find a steeper challenge ahead on water infrastructure.* Small communities have fewer people, and those people are often more spread out, requiring more pipe "miles per customer" than larger systems. In the most affected small communities, the study suggests that a typical three-person household could see its drinking water bill increase by as much as $550 per year above current levels, simply to address infrastructure needs, depending as always on the caveats identified above.

In the largest water systems, costs can be spread over a large population base. Needed investments would be consistent with annual per household cost increases ranging from roughly $75 to more than $100 per year by the mid-2030s, assuming the expenses were spread across the population in the year they were incurred. Figure 10 illustrates the differing total costs of required investment by system size.



5. The Costs Keep Coming. The national-level investment we face will roughly double from about $13 billion a year in 2010 to almost $30 billion annually by the 2040s for replacement alone. If growth is included, needed investment must increase from a little over $30 billion today to nearly $50 billion over the same period. This level of investment must then be sustained for many years, if current levels of water service are to be maintained. *Many utilities will have to face these investment needs year after year, for at least several decades.* That is, by the time the last cohort of pipes analyzed in this study (predominantly the pipes laid between the late 1800s and 1960) has been replaced in, for example, 2050, it may soon thereafter be time to begin replacing the pipes laid after 1960, and so on. In that respect, these capital outlays are unlike those required to build a new treatment plant or storage tank, where the capital costs are incurred up front and aren't faced again for many years. Rather, infrastructure renewal investments are likely to be incurred each year over several decades. For that reason, *many utilities may choose to finance infrastructure replacement on a "pay-as-you-go" basis rather than through debt financing.*

Figure 10: Total Water Main Replacement and Growth Needs by System Size



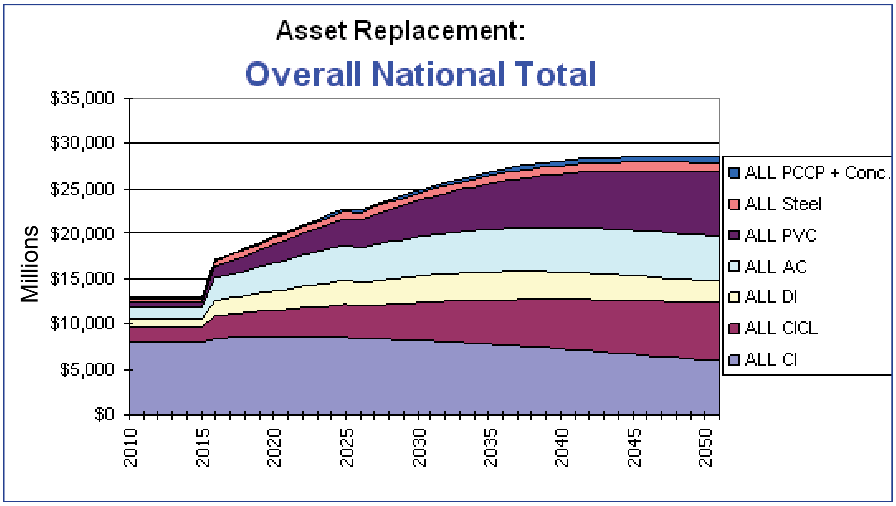
6. Postponing Investment Only Makes the Problem Worse.

Overlooking or postponing infrastructure renewal investments in the near term will only add to the scale of the challenge we face in the years to come. Postponing the investment steepens the slope of the investment curve that must ultimately be met, as shown in Figure 11 (next page). It also increases the odds of facing the high costs associated with water main breaks and other infrastructure failures. The good news is that *not all of the $1 trillion investment through 2035 must be made right now.* There is time to make suitable plans and implement policies that will help address the longer-term challenge. The bad news is that the required investment level is growing, as more pipes continue to age and reach the end of their effective service lives.

As daunting as the figures in this report are, the prospect of not making the necessary investment is even more chilling. Aging water mains are subject to more frequent breaks and other failures that can threaten public health and safety (such as compromising tap water quality and fire-fighting flows). Buried infrastructure failures also may impose significant damages (for example, through flooding and sinkholes), are costly to repair, disrupt businesses and residential communities, and waste precious water resources. These maladies weaken our economy and undermine our quality of life. As large as the cost of reinvestment may be, **not** undertaking it will be worse in the long run by almost any standard.

This suggests that a crucial responsibility for utility managers now and in the future is to develop the processes necessary to continually improve their understanding of the "replacement dynamics" of their own water systems. Those dynamics should be reflected in an Asset Management Plan (AMP) and, of course, in a long-term capital investment plan. The 2006 AWWA Report *Water Infrastructure at a Turning Point* includes a full discussion of this issue.

Figure 11: Effect of Deferring Investment Five Years with a Ten-Year Make-Up Period



Conclusion

Because pipe assets last a long time, water systems that were built in the latter part of the 19th century and throughout much of the 20th century have, for the most part, never experienced the need for pipe replacement on a large scale. The dawn of the era in which these assets will need to be replaced puts a growing financial stress on communities that will continually increase for decades to come. It adds large and hitherto unknown expenses to the more apparent above-ground spending required to meet regulatory standards and address other pressing needs.

It is important to reemphasize that there are significant differences in the timing and magnitude of the challenges facing different regions of the country and different sizes of water systems. But the investments we describe in this report are real, they are large, and they are coming.

The United States is reaching a crossroads and faces a difficult choice. We can incur the haphazard and growing costs of living with aging and failing drinking water infrastructure. Or, we can carefully prioritize and undertake drinking water infrastructure renewal investments to ensure that our water utilities can continue to reliably and cost-effectively support the public health, safety, and economic vitality of our communities. AWWA undertook this report to provide the best, most accurate information available about the scale and timing of these needed investments.

It is clear the era AWWA predicted a decade ago—the replacement era—has arrived. The issue of aging water infrastructure, which was buried for years, can be buried no longer. Ultimately, the cost of the renewal we face must come from local utility customers, through higher water rates. However, the magnitude of the cost and the associated affordability and other adverse impacts on

communities—as well as the varying degrees of impact to be felt across regions and across urban and rural areas—suggest that there is a key role for states and the federal government as well. In particular, states and the federal government can help with a careful and cost-effective program that lowers the cost of necessary investments to our communities, such as the creation of a credit support program—for example, AWWA's proposed Water Infrastructure Finance and Innovation Authority (WIFIA).

Finally, in many cases, difficult choices may need to be made between competing needs if water bills are to be kept affordable. Water utilities are willing to ask their customers to invest more, but it's important this investment be in things that bring the greatest actual benefit to the community. Only in that spirit can we achieve the goal to which we all aspire, the reliable provision of safe and affordable water to all Americans.

Additional Information and Resources.

A full and robust infrastructure analysis is an indispensable tool for decision making by water and wastewater utilities. This report does not substitute for such detailed local analysis for purposes of designing an infrastructure asset management program for individual utilities.

Additional information is available from AWWA concerning asset management. Particular attention should be given to the WITAF reports *Dawn of the Replacement Era, Avoiding Rate Shock, Thinking Outside the Bill* and *Water Infrastructure at a Turning Point.* In addition, Manual M1, *Principles of Water Rates, Fees, and Charges*, and the AWWA Utility Management Standards may be helpful. For more information, visit the AWWA Bookstore at **www.awwa.org/store.**

A number of graphs and figures from this report are also available through the AWWA website at **www.awwa.org/infrastructure.** They include:

Estimated Distribution of Mains by Material
Northeast and Midwest
South and West

Proportion of 2010 Systems Built by Year
Northeast
Midwest
South
West

Investment for Replacement Plus Growth, by Region and Size of Utility

Northeast
Large
Medium
Small
Very Small

Midwest
Large
Medium
Small
Very Small

South
Large
Medium
Small
Very Small

West
Large
Medium
Small
Very Small

Household Cost of Needed Investment by Region and Size of Utility

Northeast
Large
Medium
Small
Very Small

Midwest
Large
Medium
Small
Very Small

South
Large
Medium
Small
Very Small

West
Large
Medium
Small
Very Small

www.awwa.org/infrastructure

Estimated Distribution of Mains by Material Over Time
Northeast & Midwest Regions

	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (SSL)	AC (LSL)	PVC	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	AC (LSL)	Steel	Conc & PCCP
	<6 inch diameter								6-10 inch diameter								>10 inch diameter						
1870	100%								100%								100%						
1880	100%								100%								100%						
1890	100%								100%								100%						
1900	100%								100%								100%						
1910	100%								100%								100%						
1920	100%								100%								100%						
1930	50%	30%	20%						50%	30%	20%						50%	30%	20%				
1940	20%	60%	20%						20%	60%	20%						20%	40%	20%			20%	
1950		60%				20%	20%			60%				20%	20%			40%			10%	20%	30%
1960		50%			10%	20%	20%			50%			10%	20%	20%			35%		5%	10%	20%	30%
1970		20%			40%			40%		20%			40%			40%				50%		20%	30%
1980				25%	30%			45%				25%	35%			40%				60%		15%	25%
1990				50%	5%			45%				50%	5%			45%				60%		15%	25%
2000				55%				45%				55%				45%				60%		15%	25%
2010				55%				45%				55%				45%				60%		15%	25%
2020				55%				45%				55%				45%				60%		15%	25%
2030				55%				45%				55%				45%				60%		15%	25%

Steel and PCCP pipe not in widespread use in sizes under 10 inches.

CI: cast iron; CICL: cast iron cement lined; DI: ductile iron; AC: asbestos cement; PV: polyvinyl chloride; PCCP: prestressed concrete cylinder pipe

The regions are combined because they share similar dynmaics for this distribution.

Note:
"LSL" indicates a relatively long service life for the material resulting from some combination of benign ground conditions and evolved laying practices etc.

"SSL" indicates a relatively short service life for the material resulting from some combination of harsh ground conditions and early laying practices etc.

Estimated Distribution of Mains by Material Over Time
South & West Regions

	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	AC (LSL)	Steel	Conc & PCCP
	<6 inch diameter								6-10 inch diameter								>10 inch diameter						
1870	100%								100%								100%						
1880	100%								100%								100%						
1890	100%								100%								100%						
1900	100%								100%								100%						
1910	100%								100%								100%						
1920	100%								100%								100%						
1930	50%	30%	20%						50%	30%	20%						50%	30%	20%				
1940		70%	30%							70%	30%							50%	30%			20%	
1950		25%				40%	35%			25%				40%	35%			40%			15%	25%	20%
1960		25%		2%	3%	40%	30%			25%		2%	3%	40%	30%			40%		5%	10%	25%	20%
1970		10%		10%	10%	40%		30%		10%		10%	10%	40%		30%				45%	10%	25%	20%
1980				25%	25%			50%				30%	30%			40%				60%		20%	20%
1990				45%	5%			50%				50%	5%			45%				60%		20%	20%
2000				50%				50%				50%				50%				60%		20%	20%
2010				50%				50%				50%				50%				60%		20%	20%
2020				50%				50%				50%				50%				60%		20%	20%
2030				50%				50%				50%				50%				60%		20%	20%
Steel and PCCP pipe not in widespread use in sizes under 10 inches.																							
CI: cast iron; CICL: cast iron cement lined; DI: ductile iron; AC: asbestos cement; PV: polyvinyl chloride; PCCP: prestressed concrete cylinder pipe																							

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Note:
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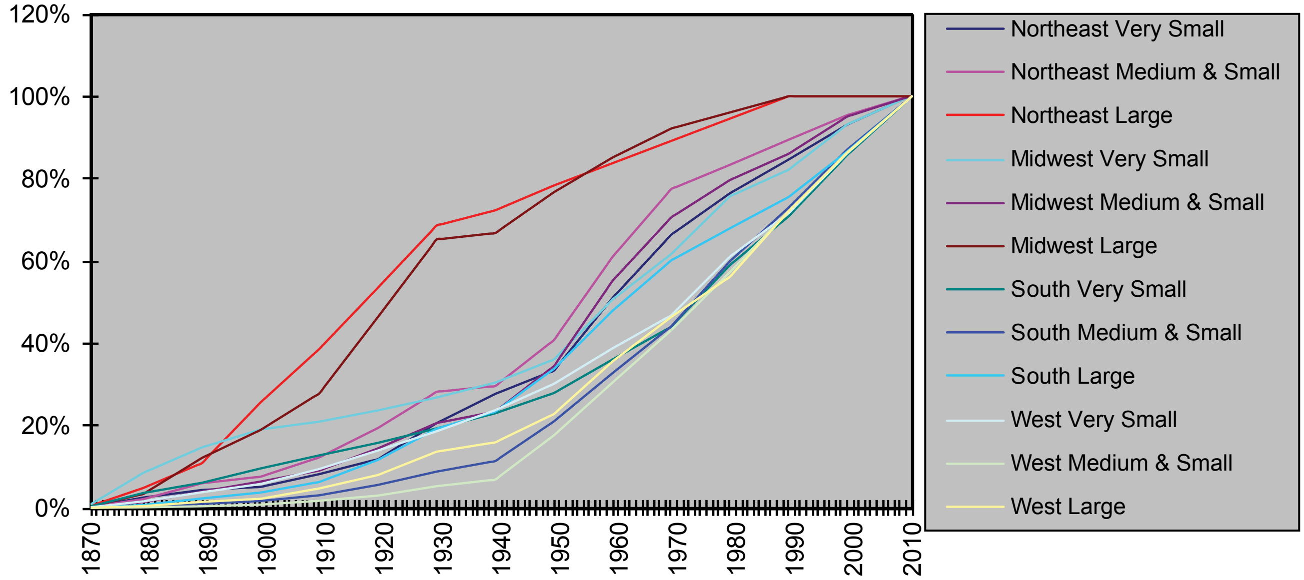
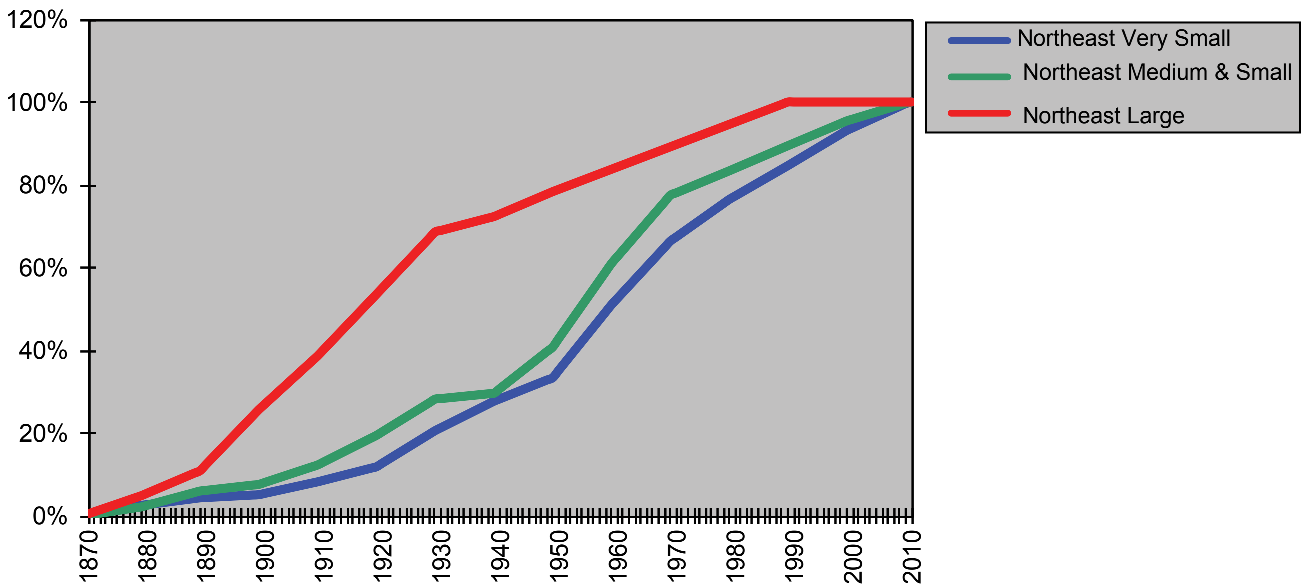
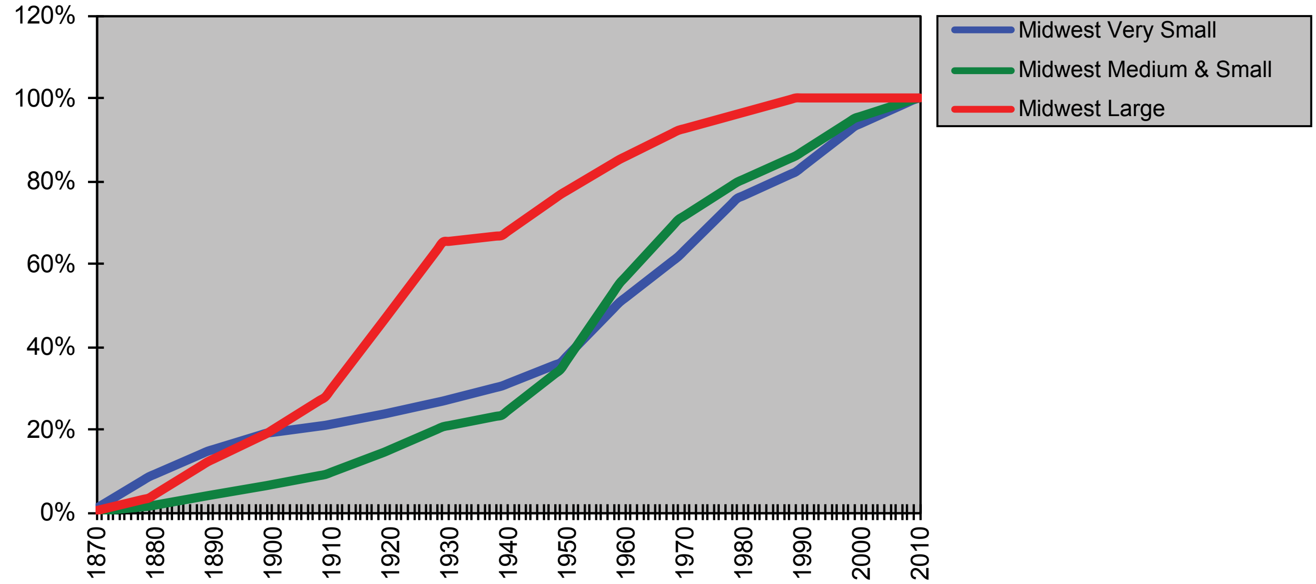
Proportion of Current System Built by Decade: All Regions



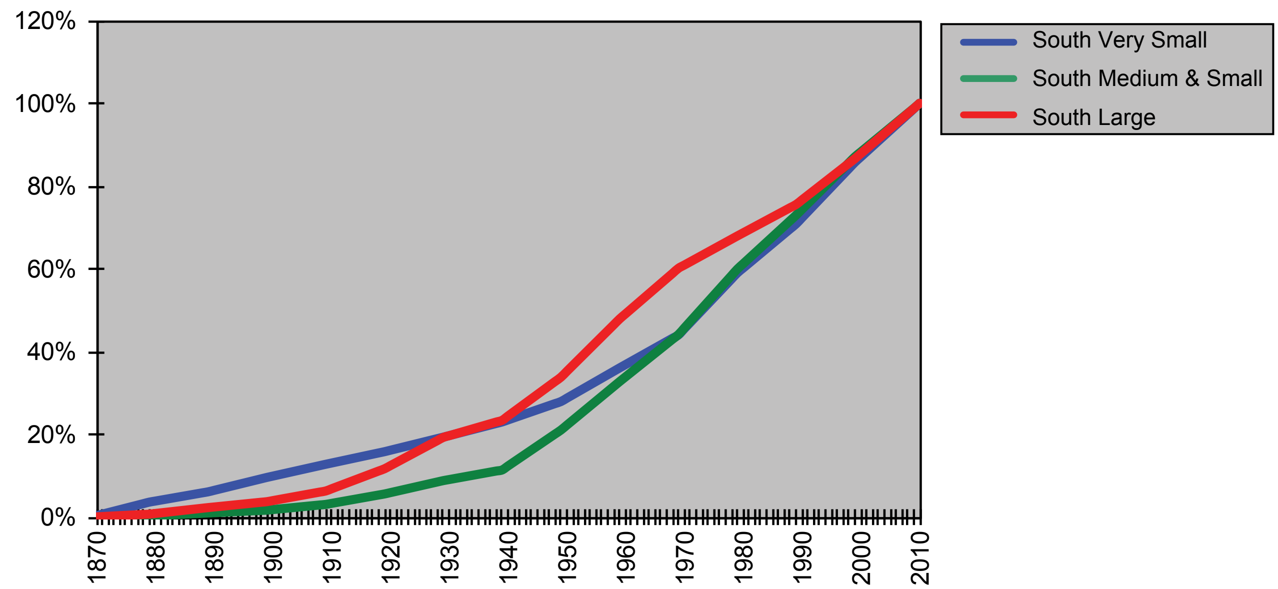
Proportion of Current System Built by Decade: Northeast



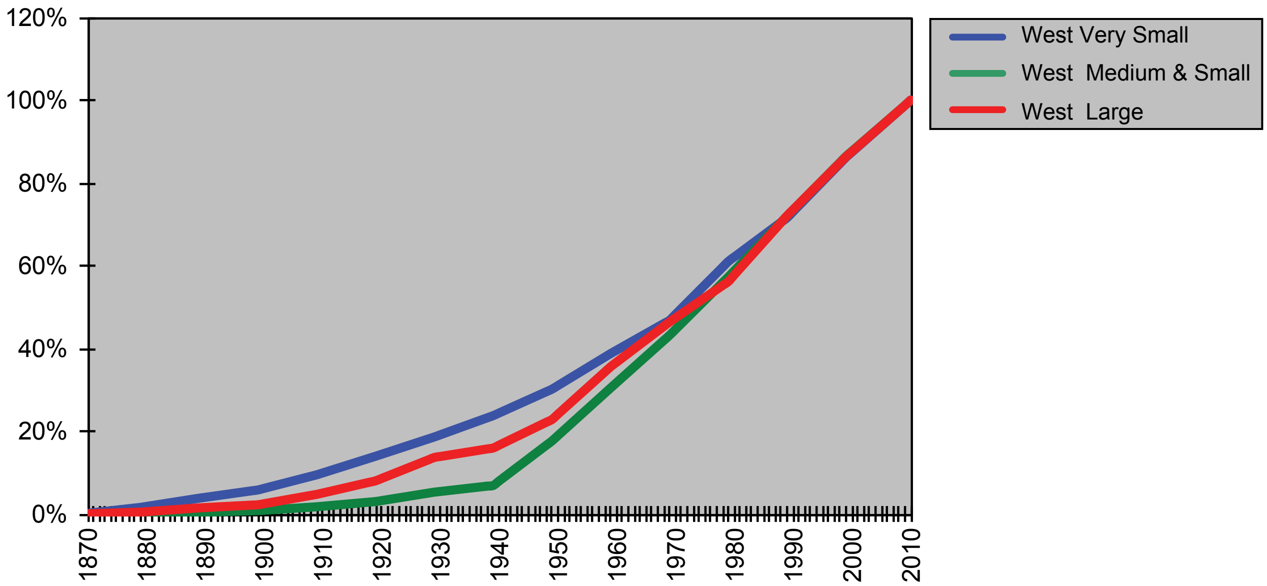
Proportion of Current System Built by Decade: Midwest

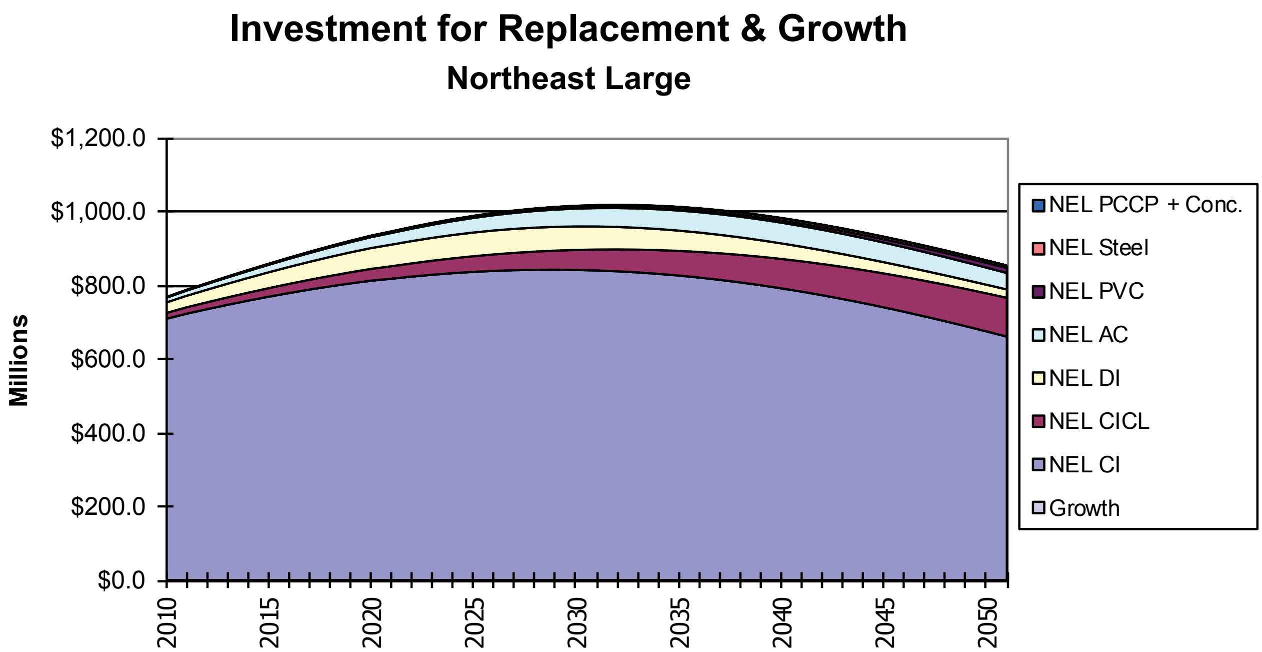


Proportion of Current System Built by Decade: South



Proportion of Current System Built by Decade: South





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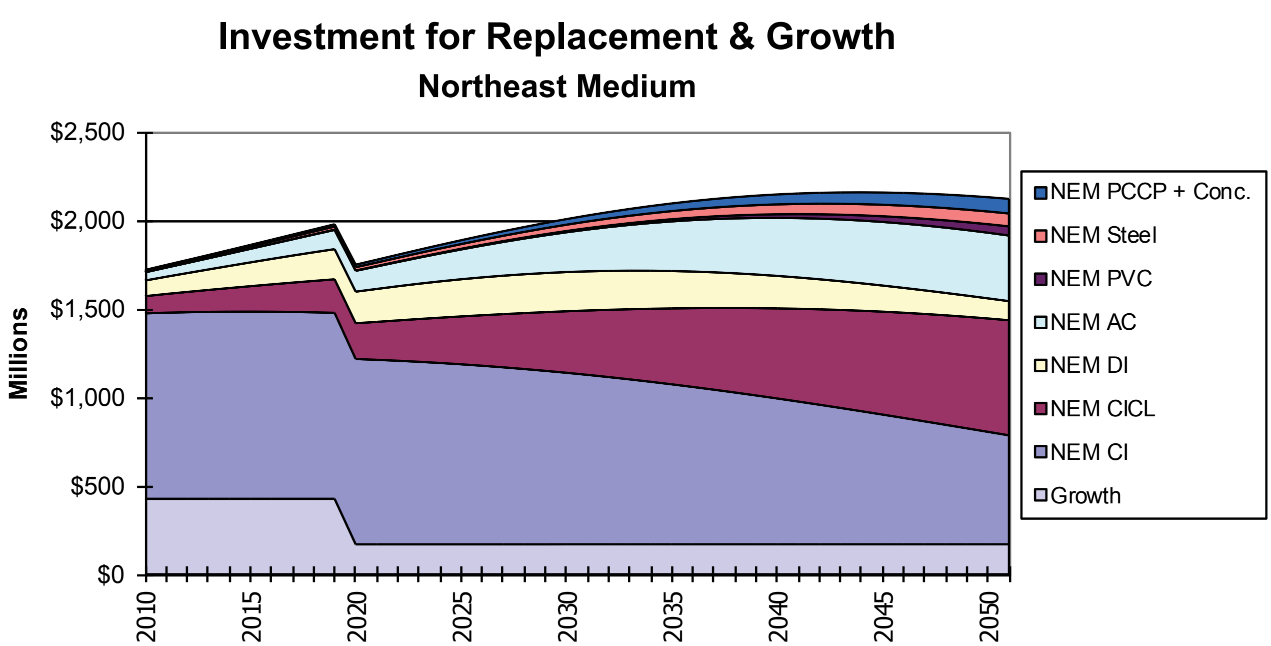

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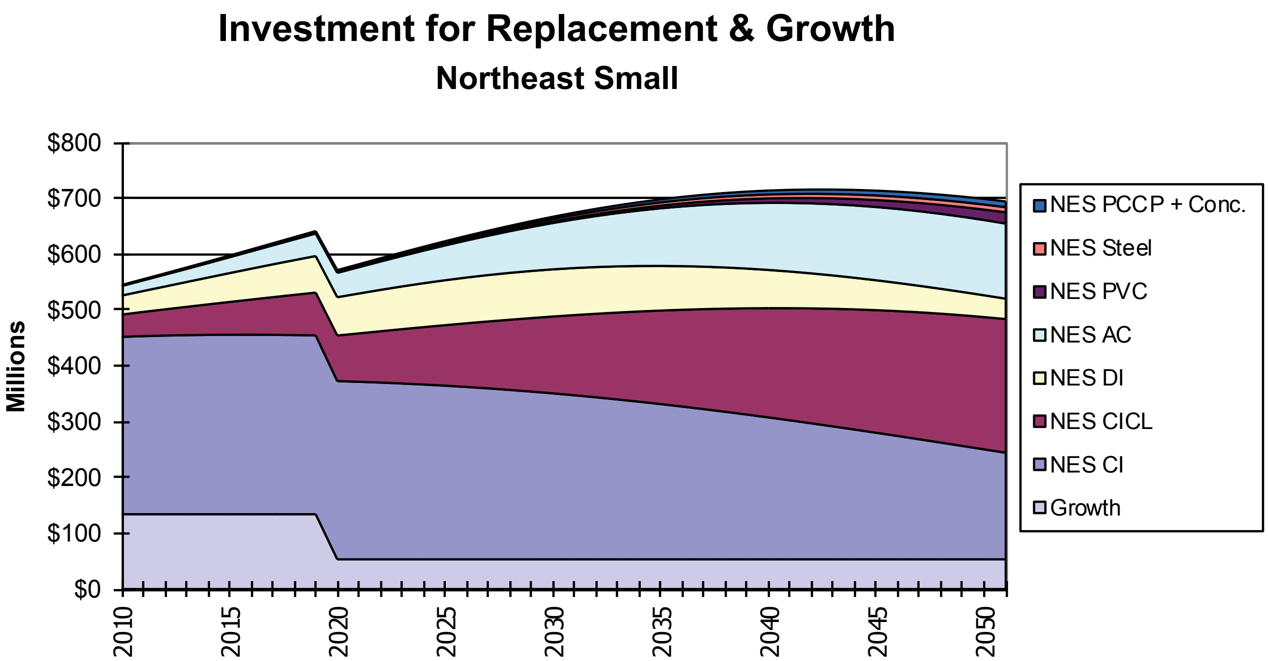
The charts show needs for replacement of particular types of pipe and for growth (see the keys below and to the right of the chart). An artifact of the model and US Census data result in an apparent upward or downward "spike" in growth-related needs between certain decades. In reality, the apparent sudden shift in growth-related needs will be spread more evenly over the years bridging each decade to the next.



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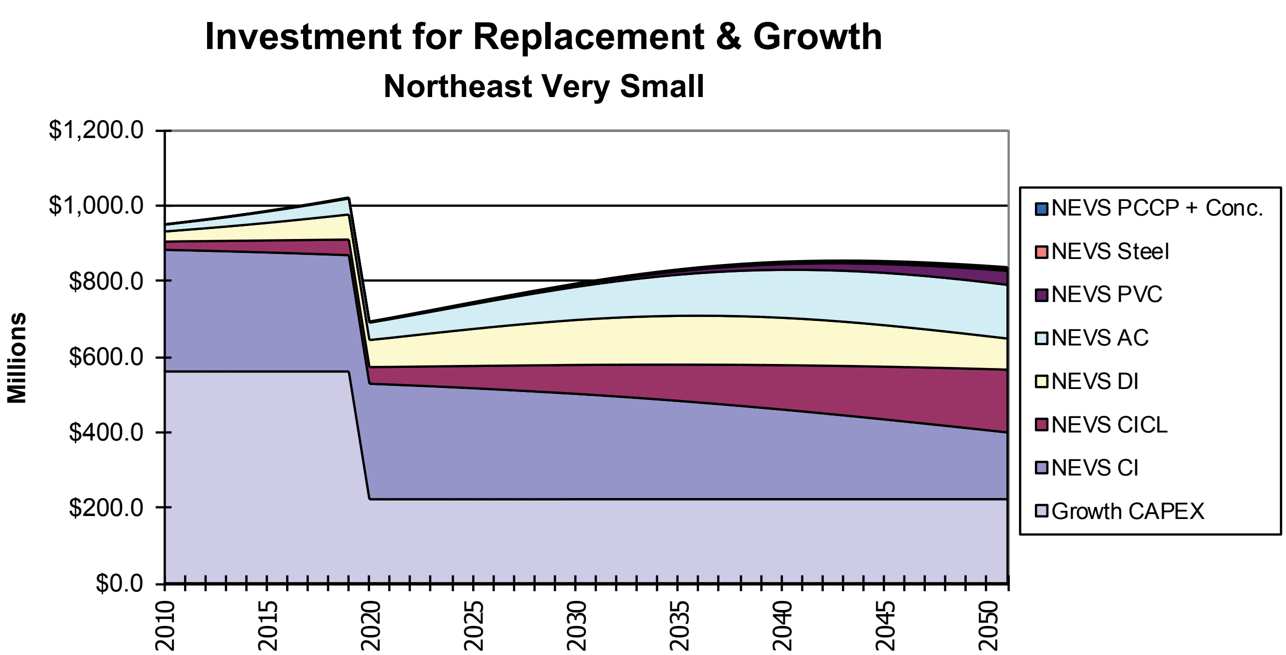

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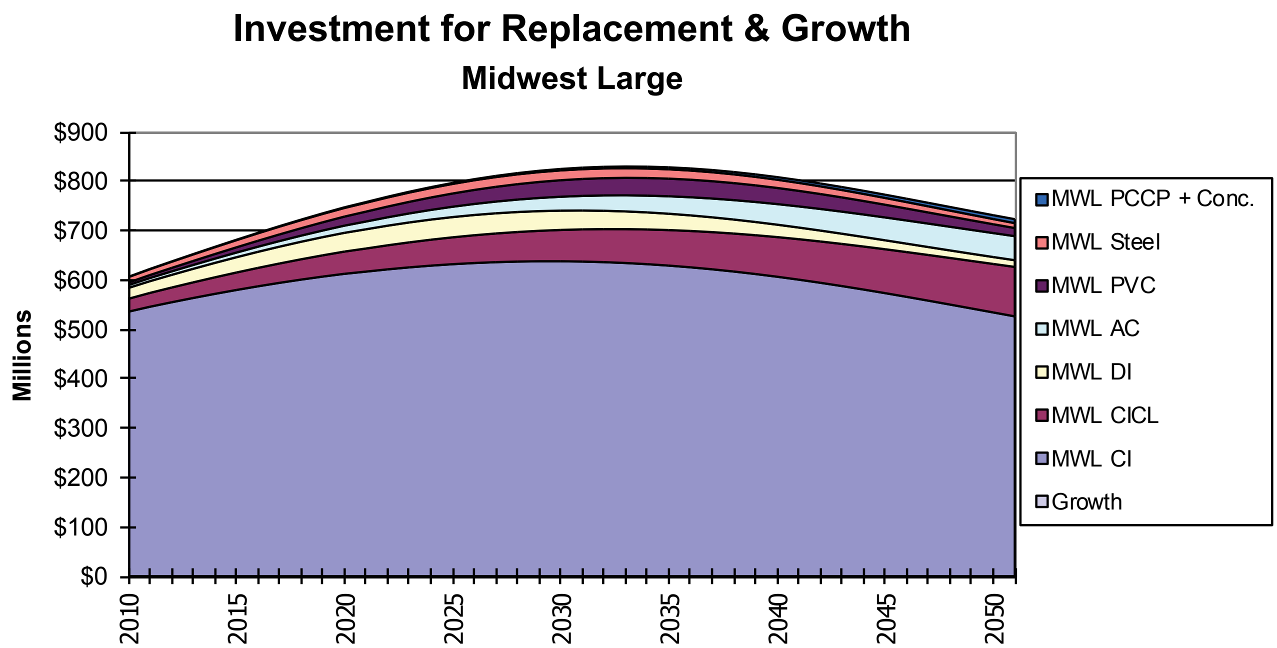

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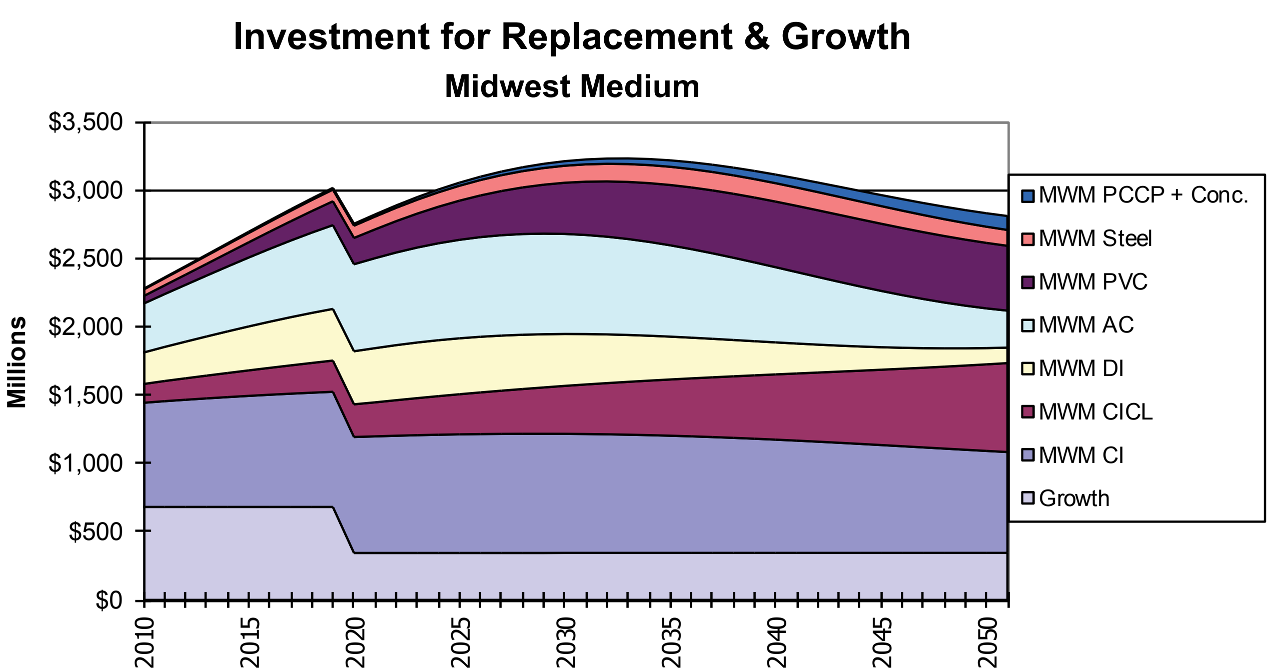

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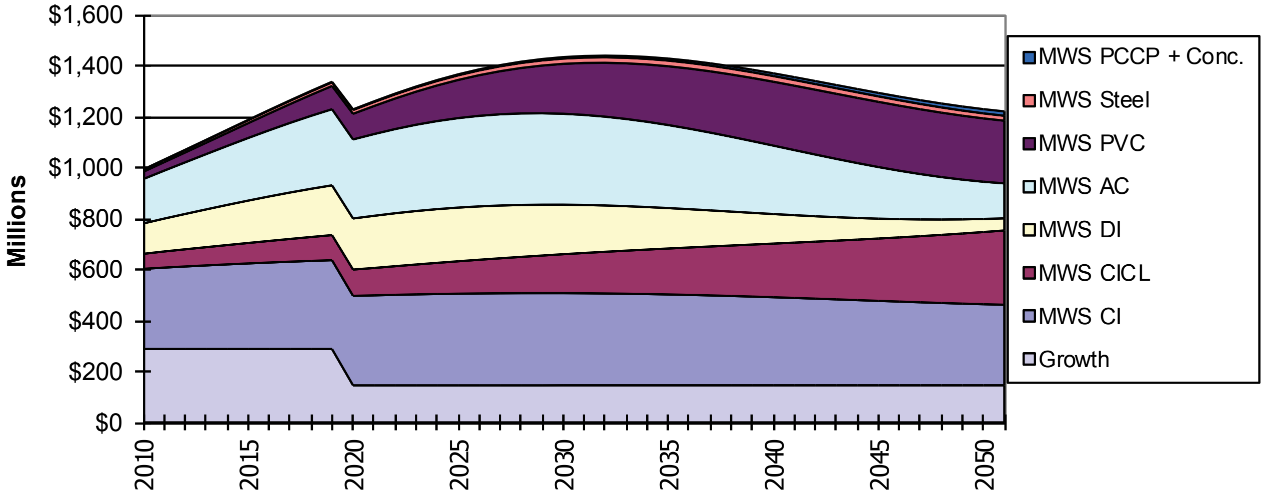
Investment for Replacement & Growth

Midwest Small



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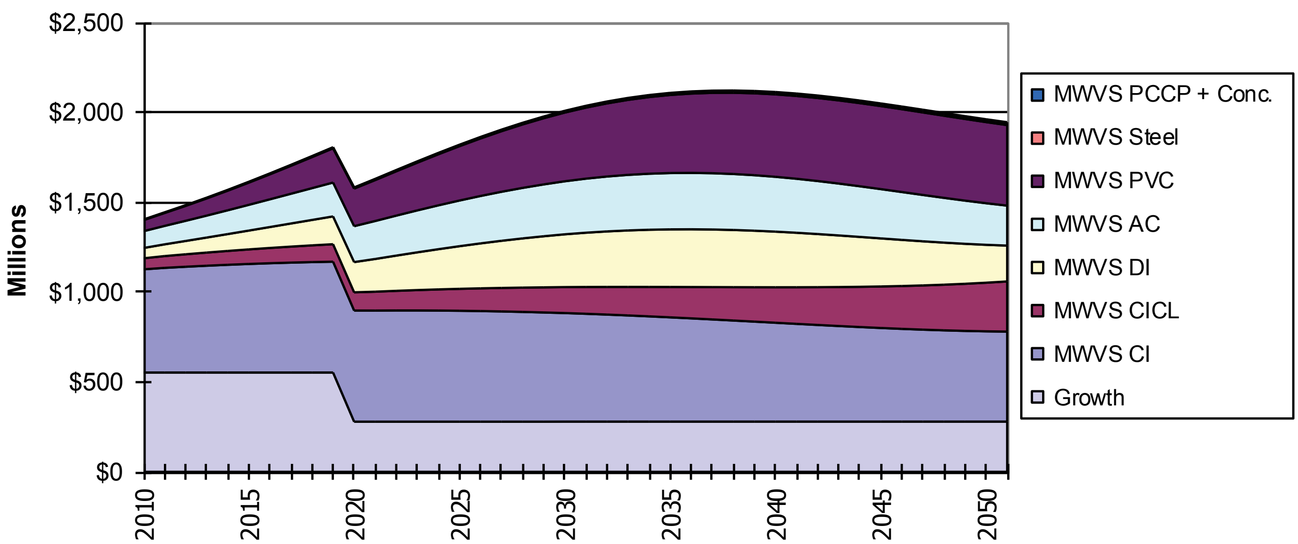
Investment for Replacement & Growth

Midwest Very Small



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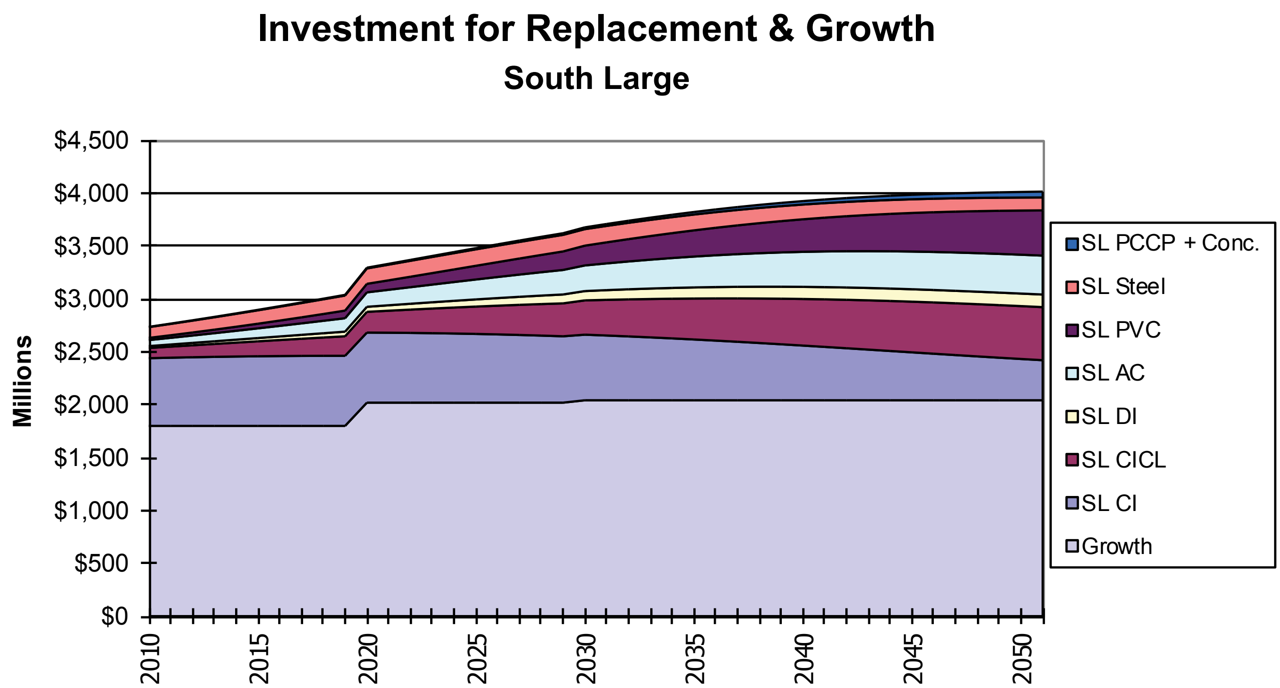

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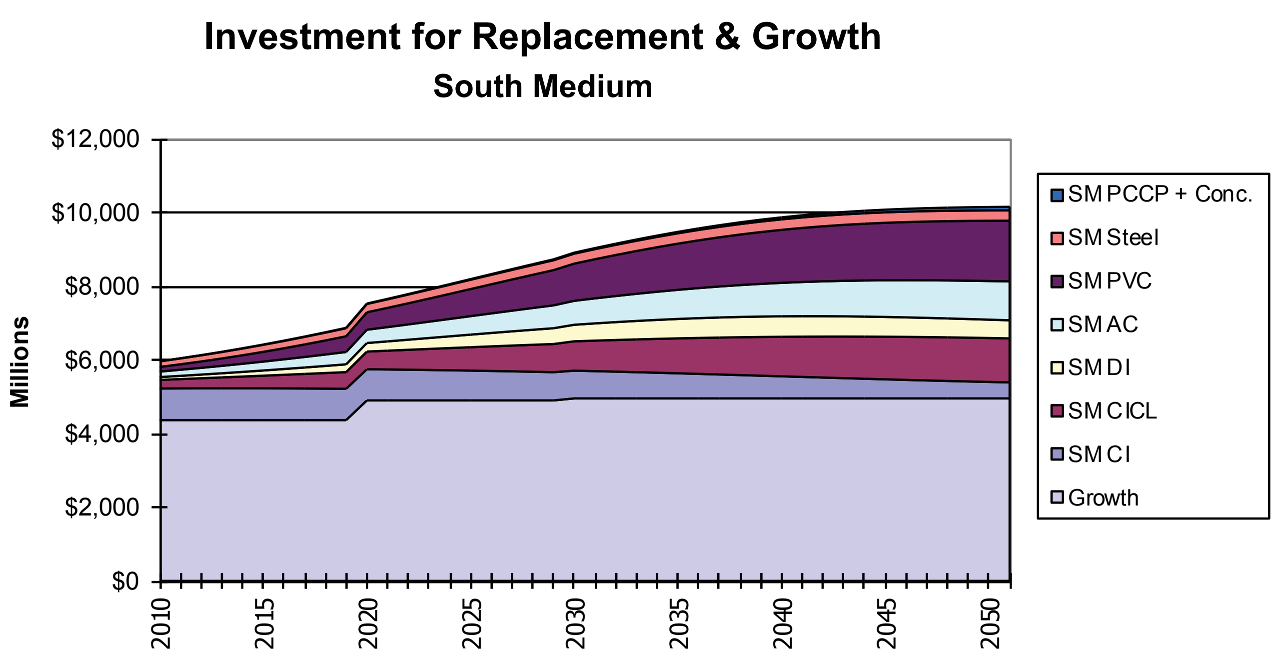

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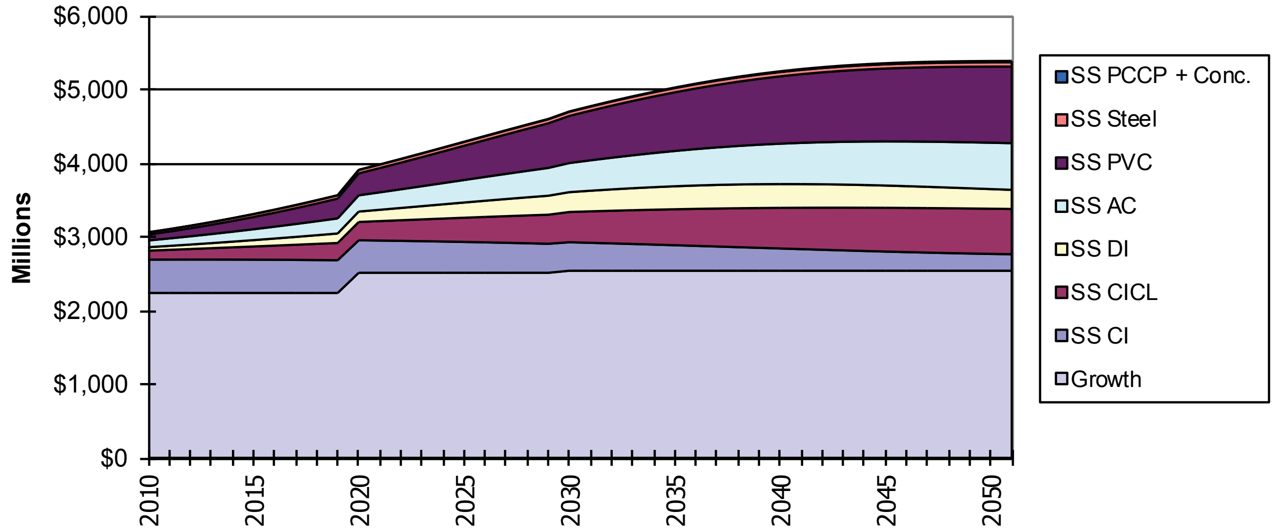
Investment for Replacement & Growth

South Small



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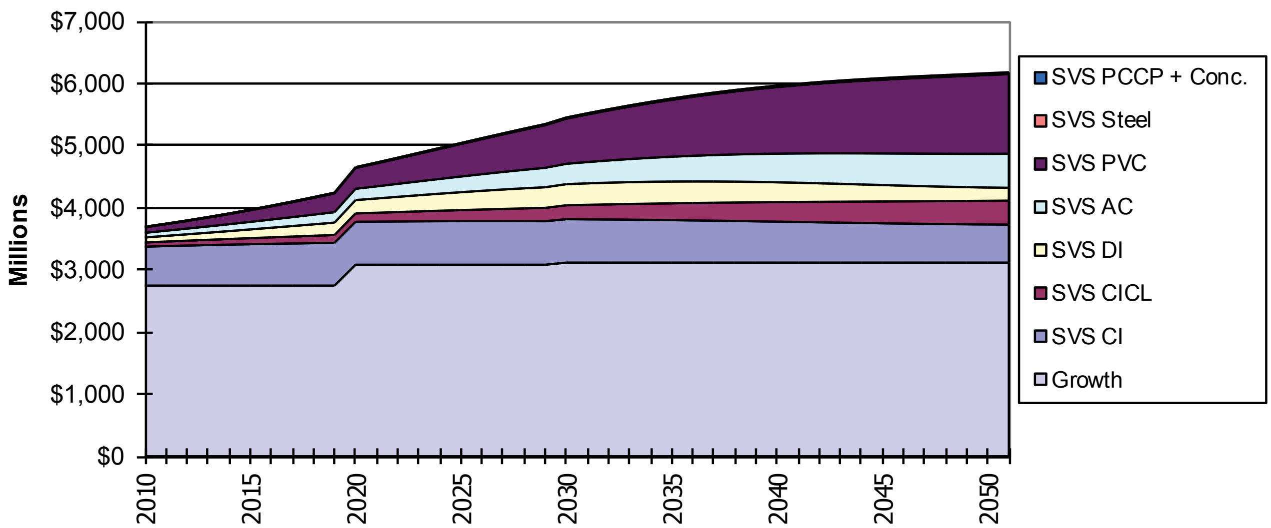
Investment for Replacement & Growth

South Very Small



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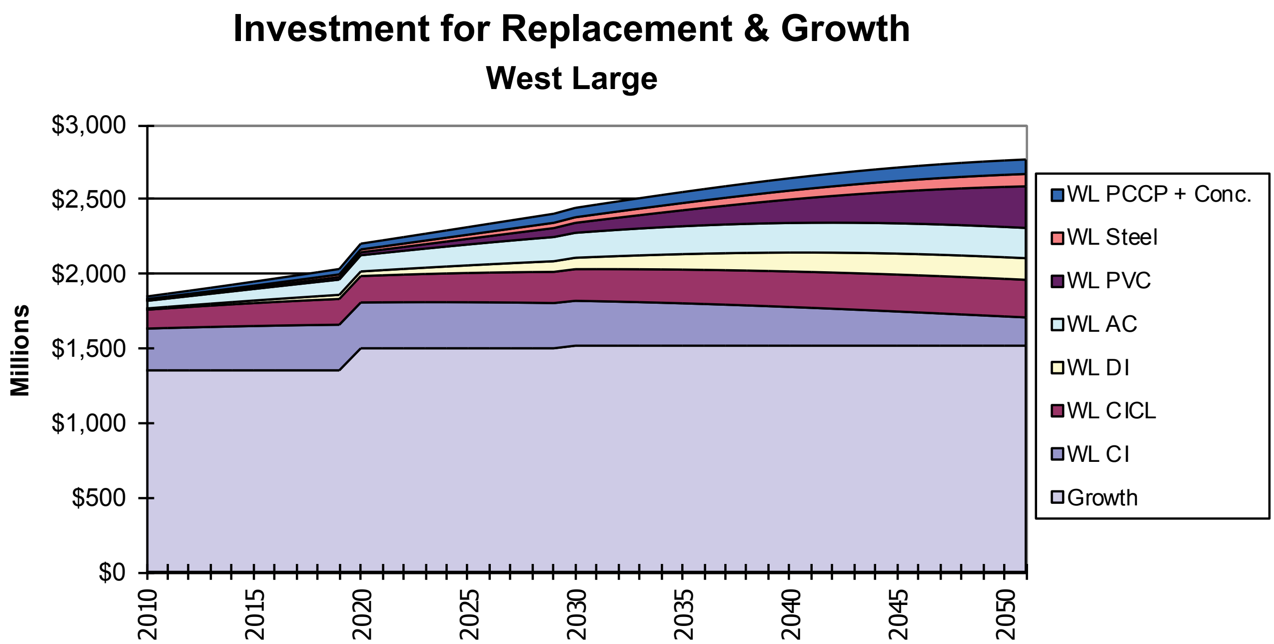

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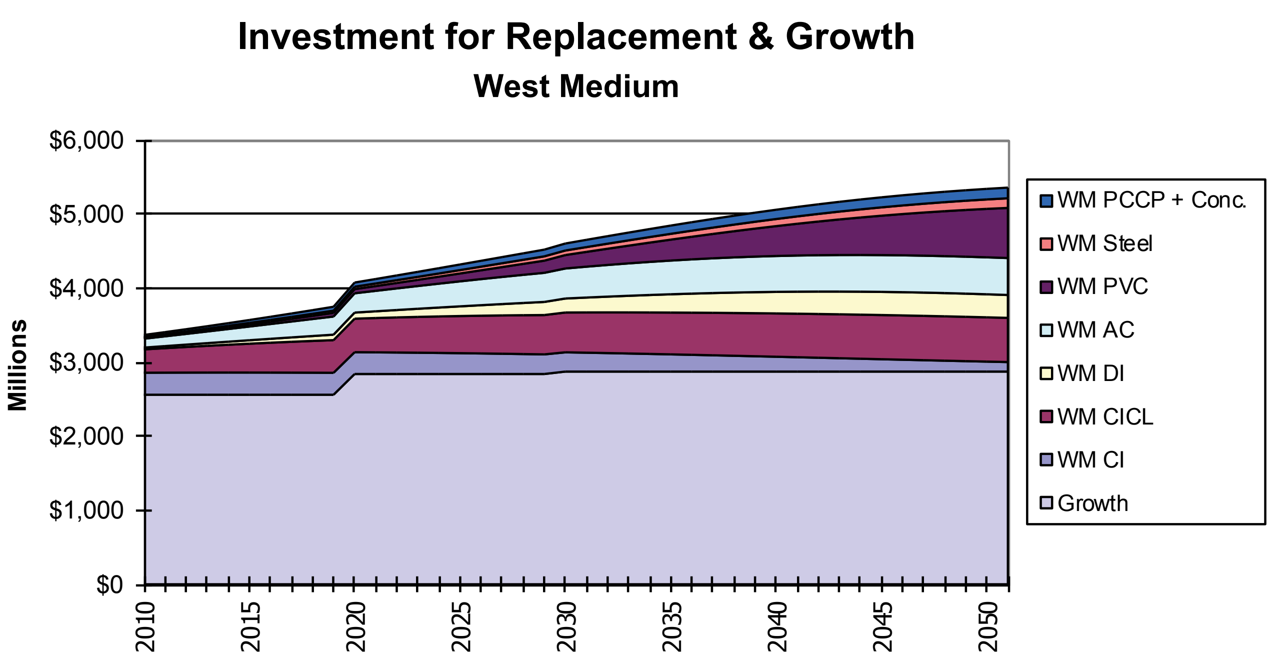

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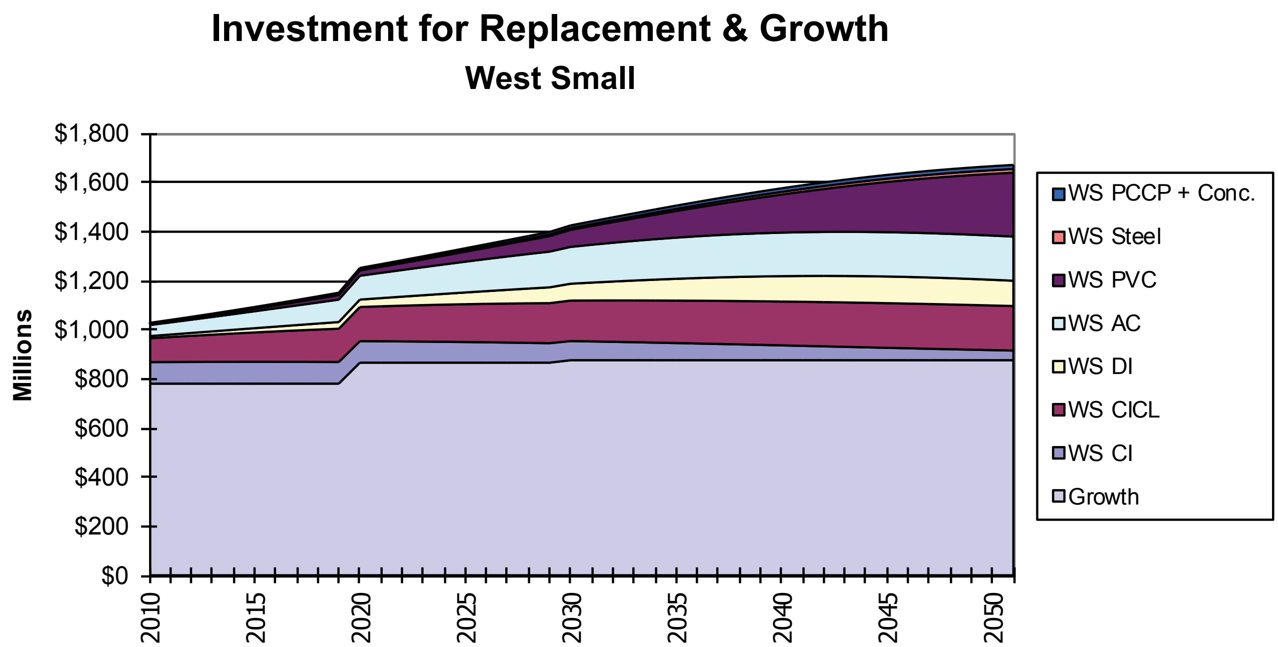

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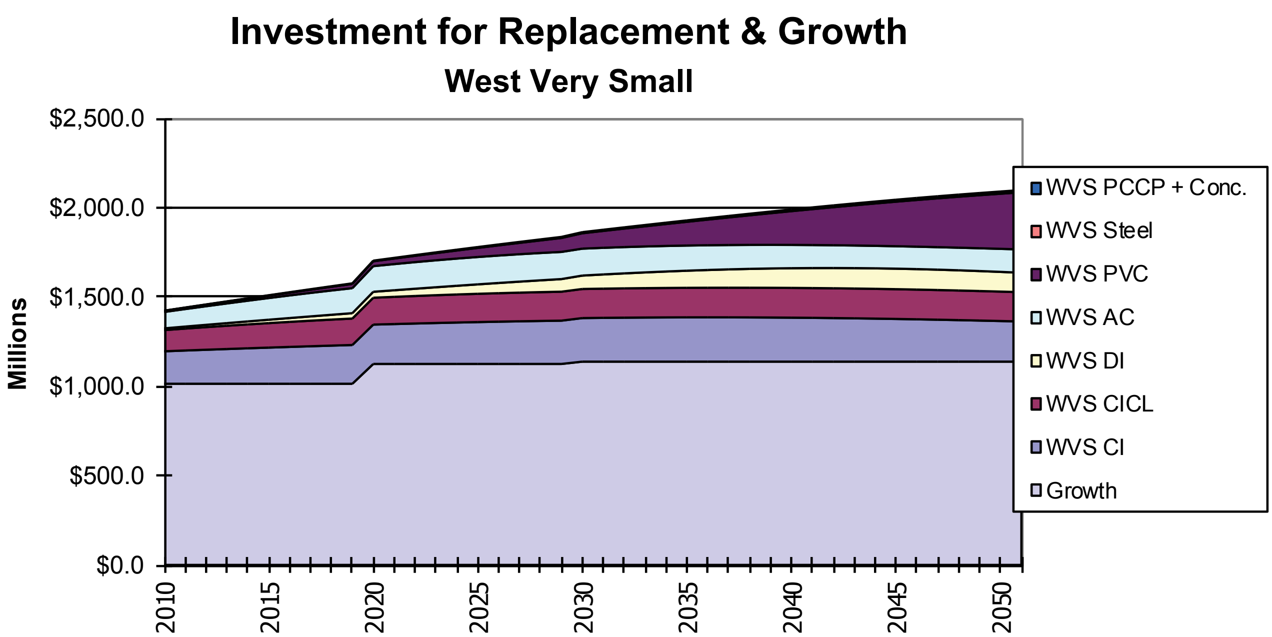

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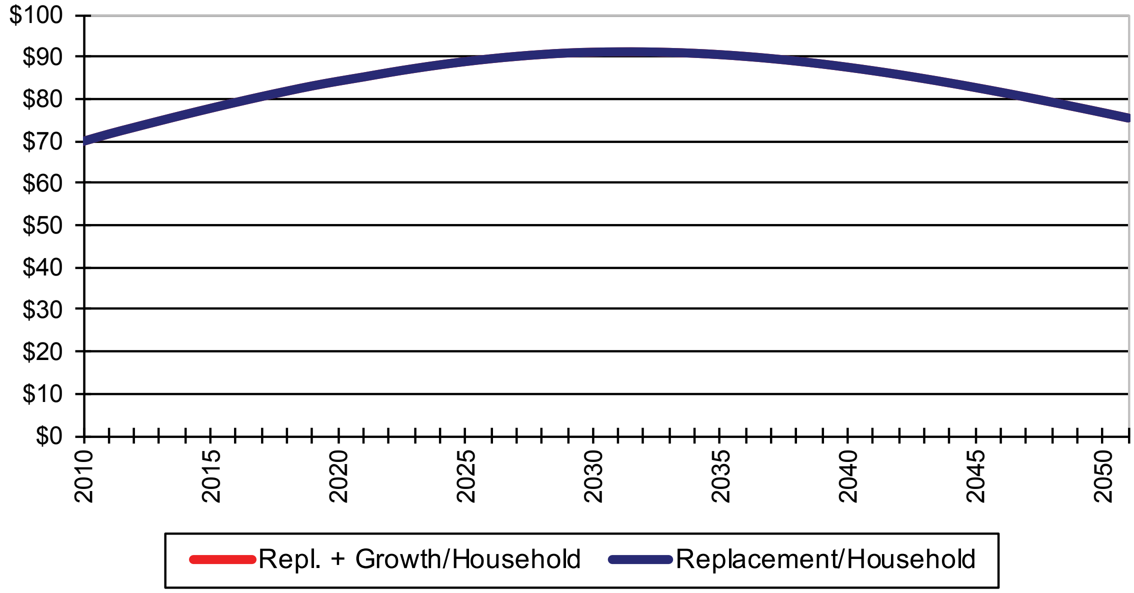
Household Cost of Needed Investment for Replacement Plus Growth*

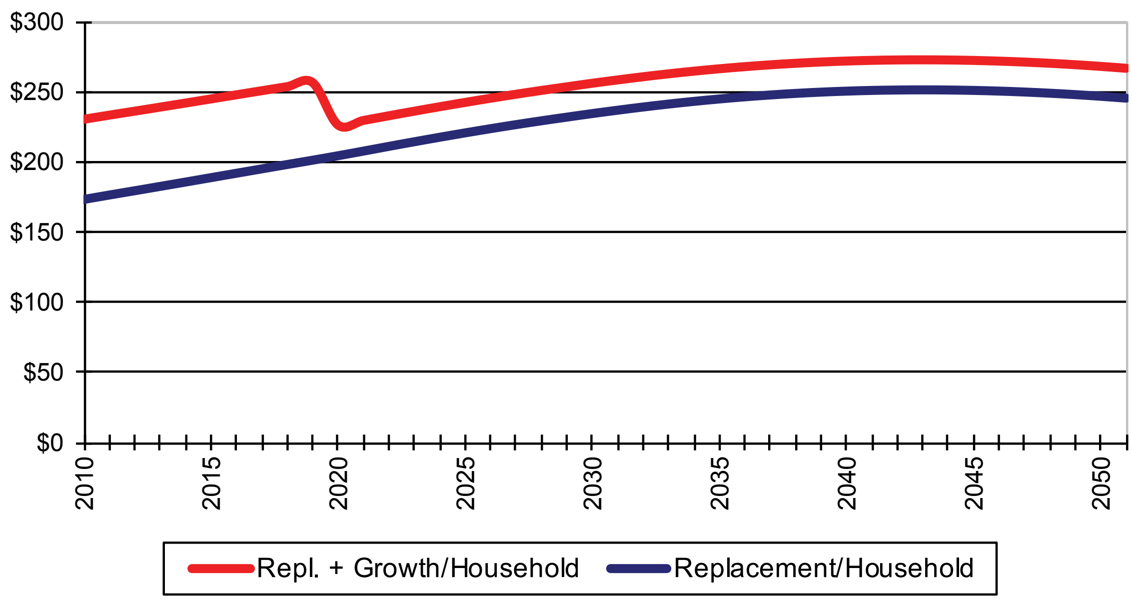
Northeast Large



**This assumes costs are spread evenly across households of 2.6 persons each, based on data from the US Census.*

Household Cost of Needed Investment for Replacement Plus Growth*

Northeast Medium



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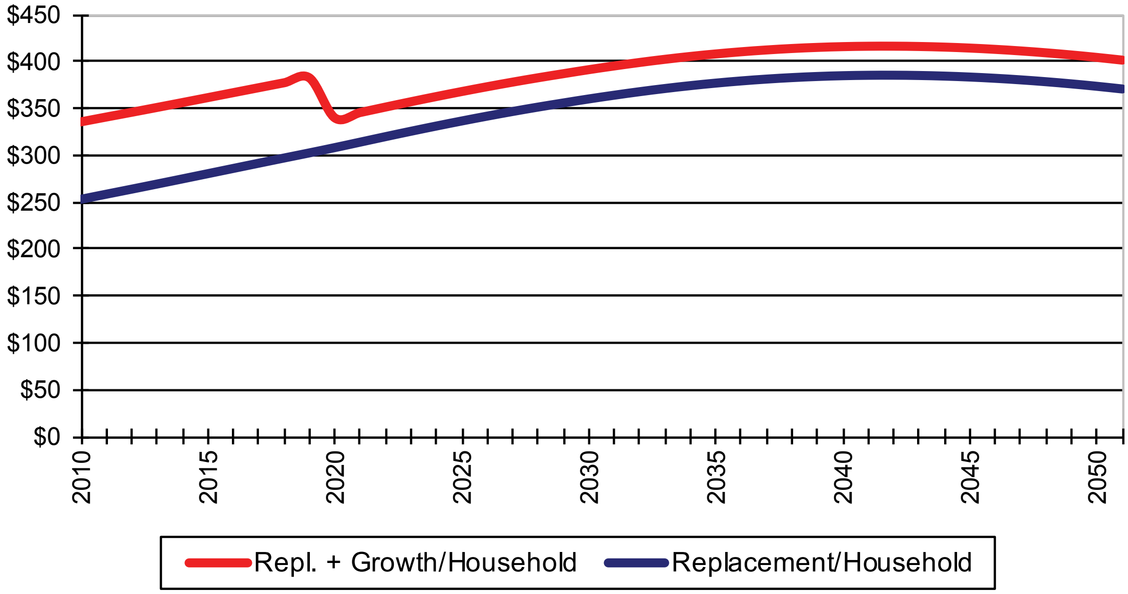
Household Cost of Needed Investment for Replacement Plus Growth*

Northeast Small



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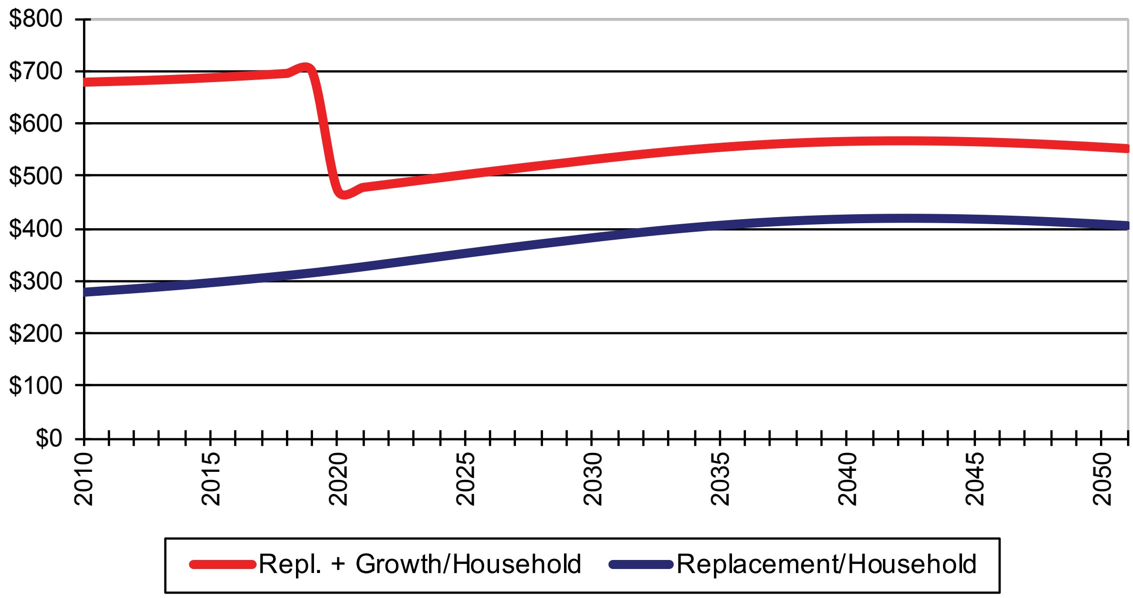
Household Cost of Needed Investment for Replacement Plus Growth*

Northeast Very Small



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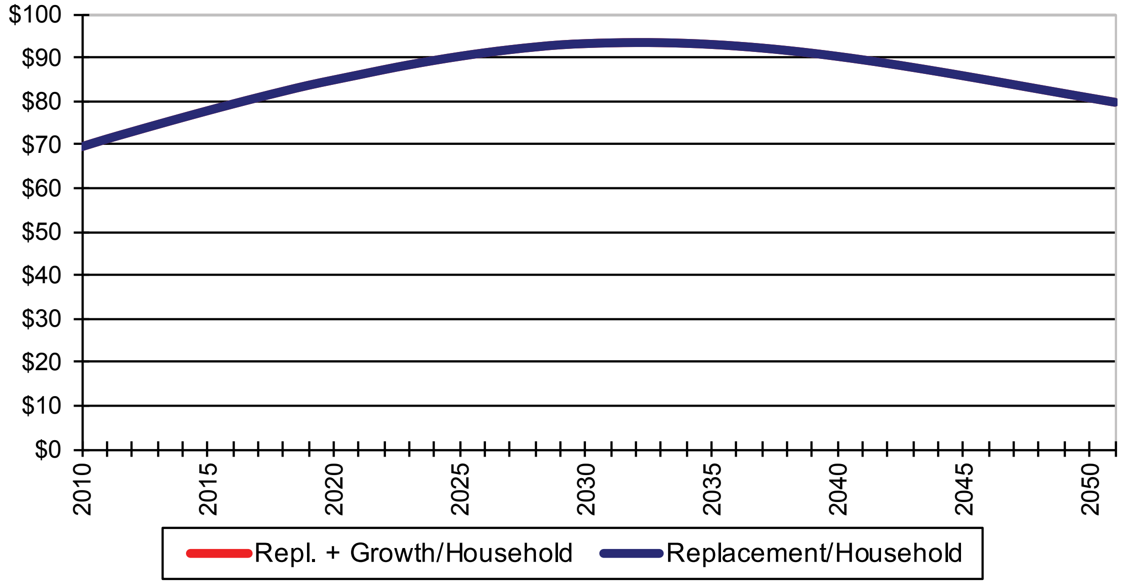
Household Cost of Needed Investment for Replacement Plus Growth*

Midwest Large



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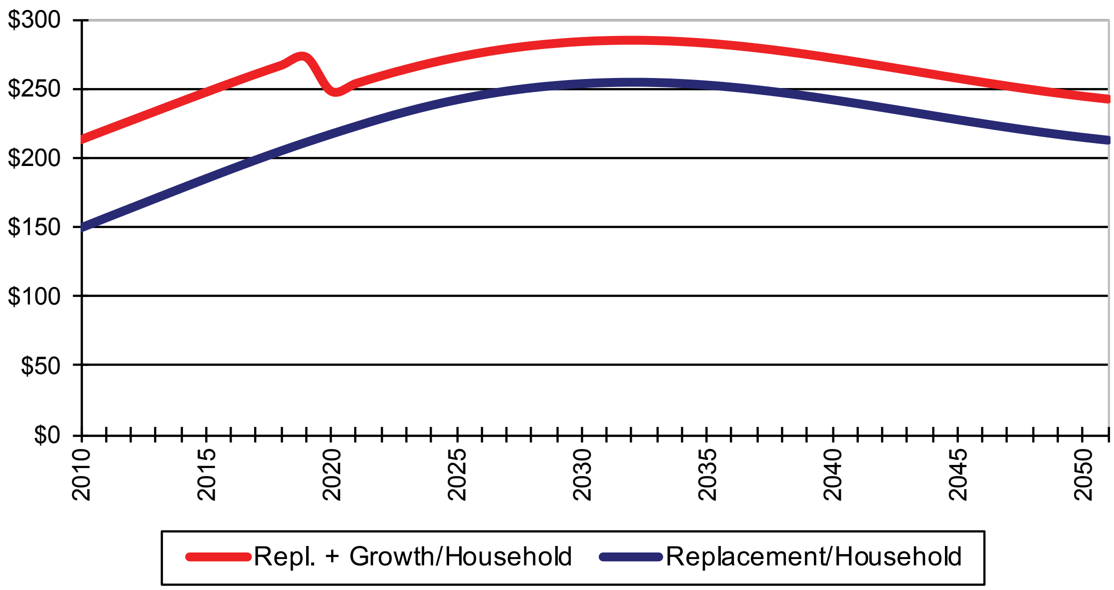
Household Cost of Needed Investment for Replacement Plus Growth*

Midwest Medium



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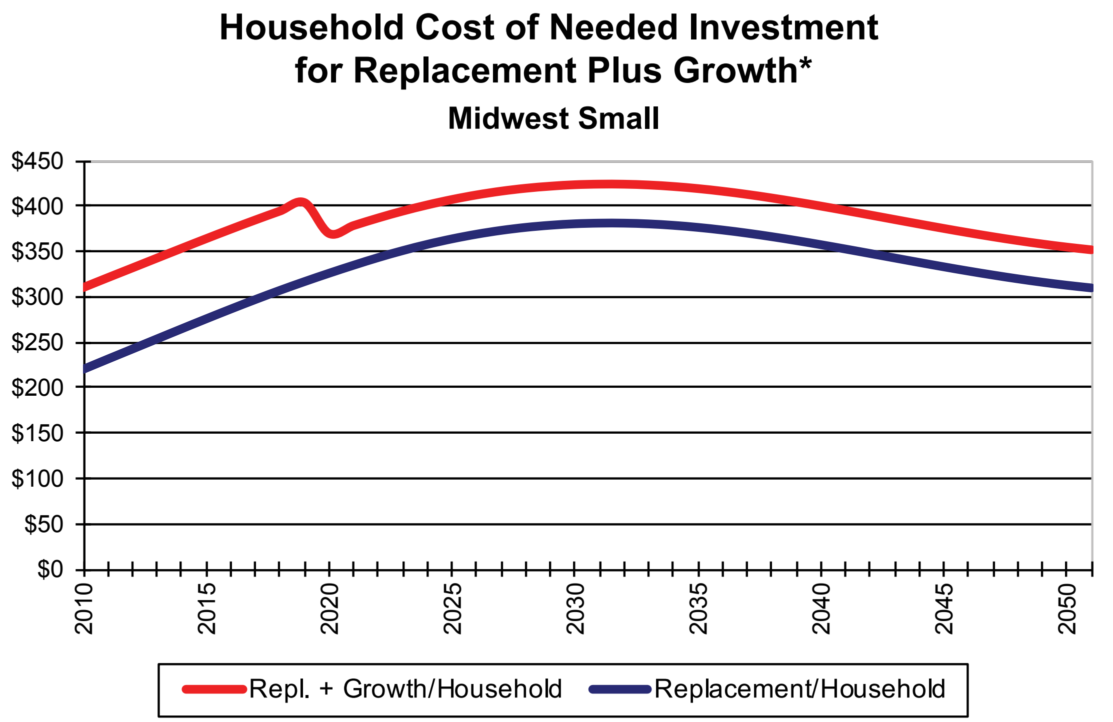

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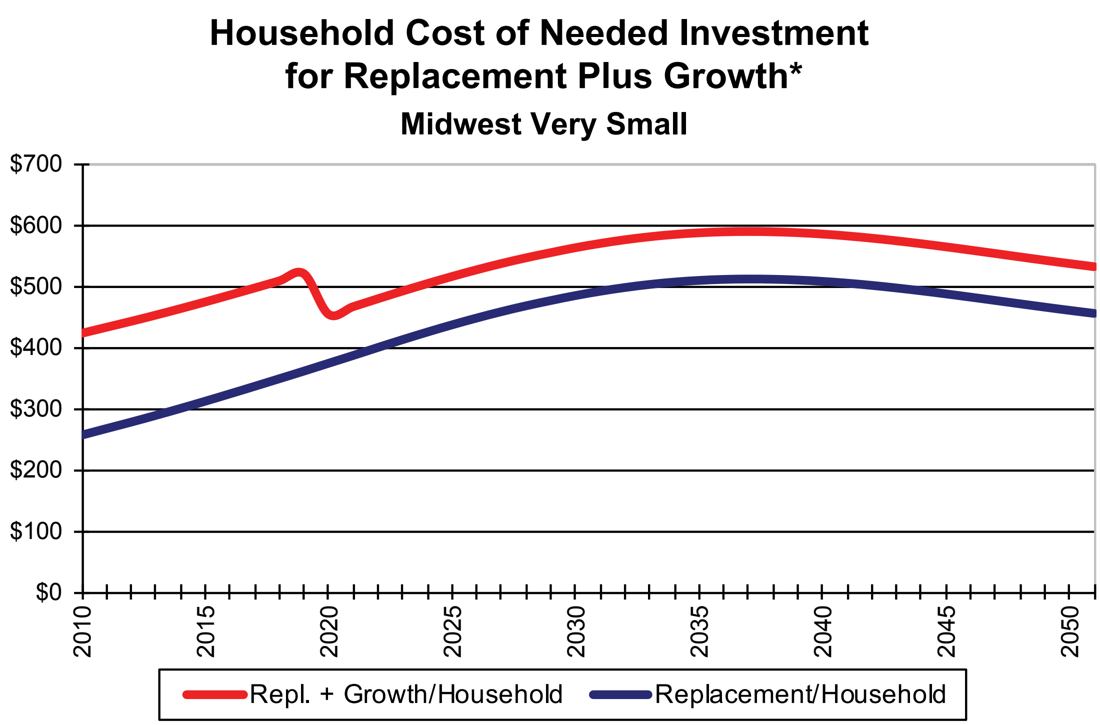

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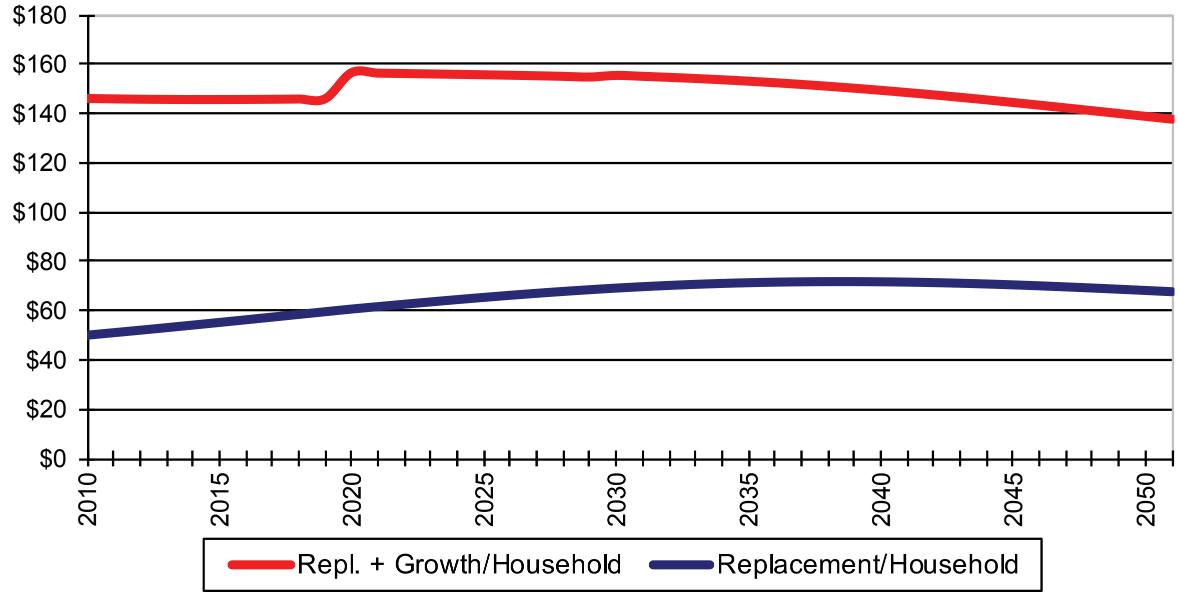
Household Cost of Needed Investment for Replacement Plus Growth*

South Large



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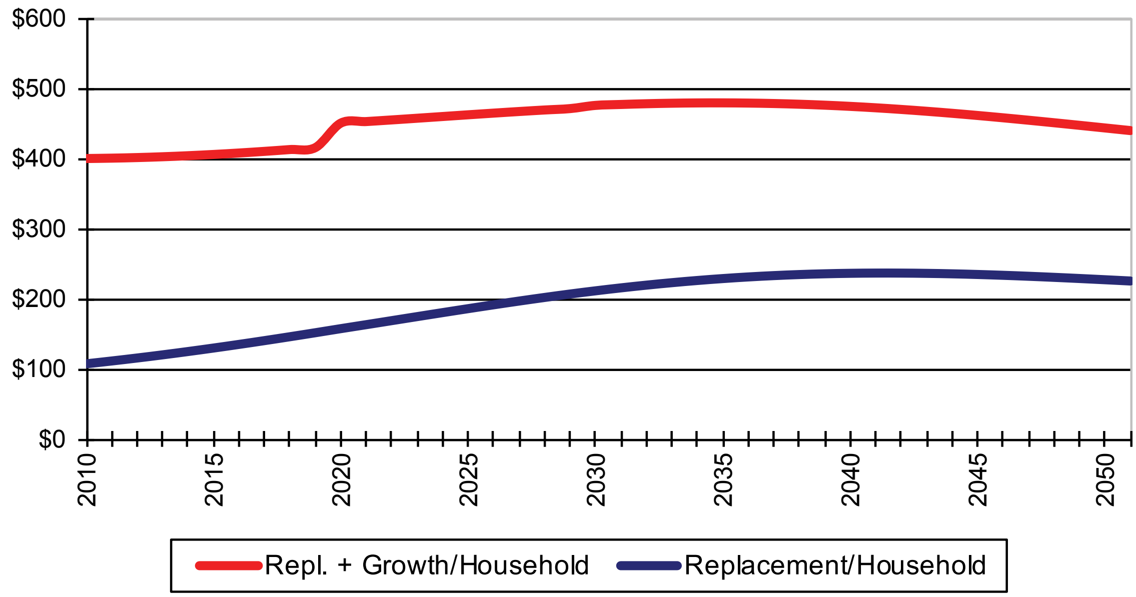
Household Cost of Needed Investment for Replacement Plus Growth*

South Medium



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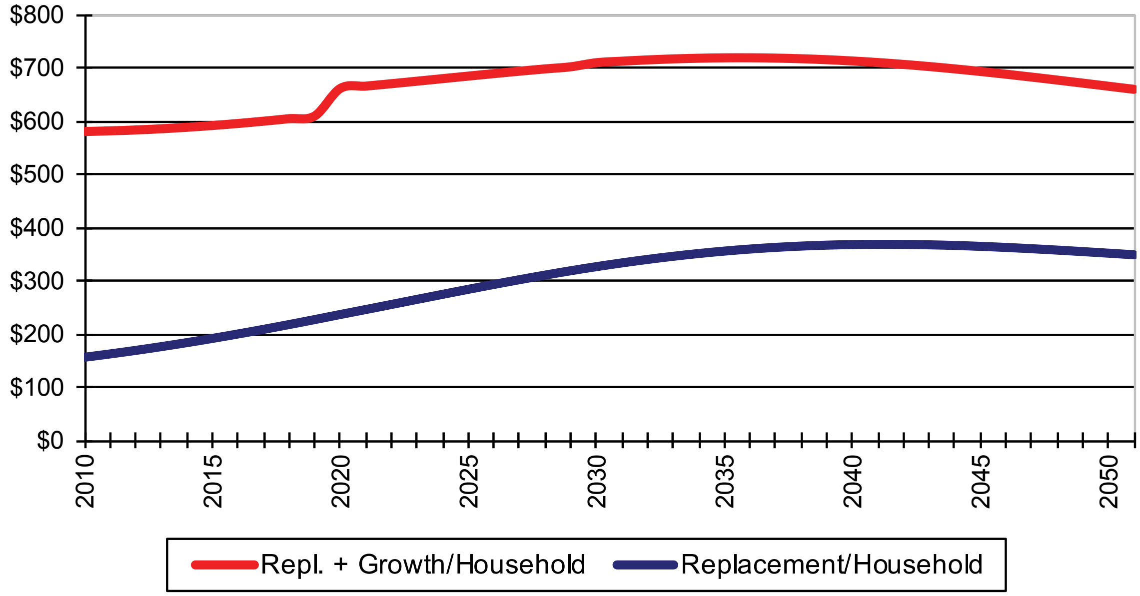
Household Cost of Needed Investment for Replacement Plus Growth*

South Small



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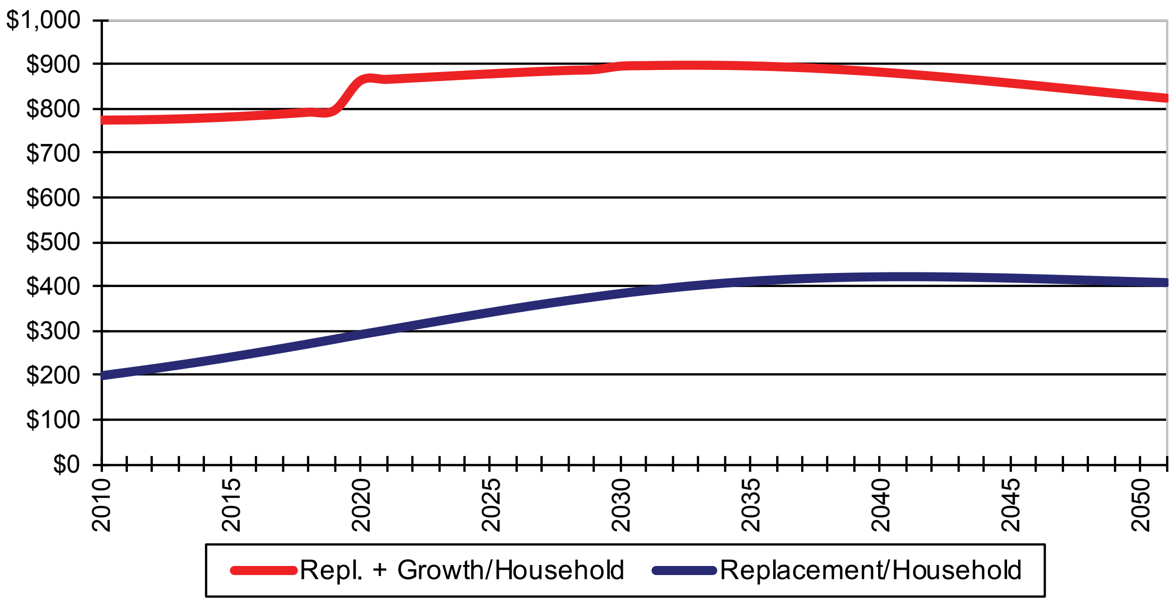
Household Cost of Needed Investment for Replacement Plus Growth*

South Very Small



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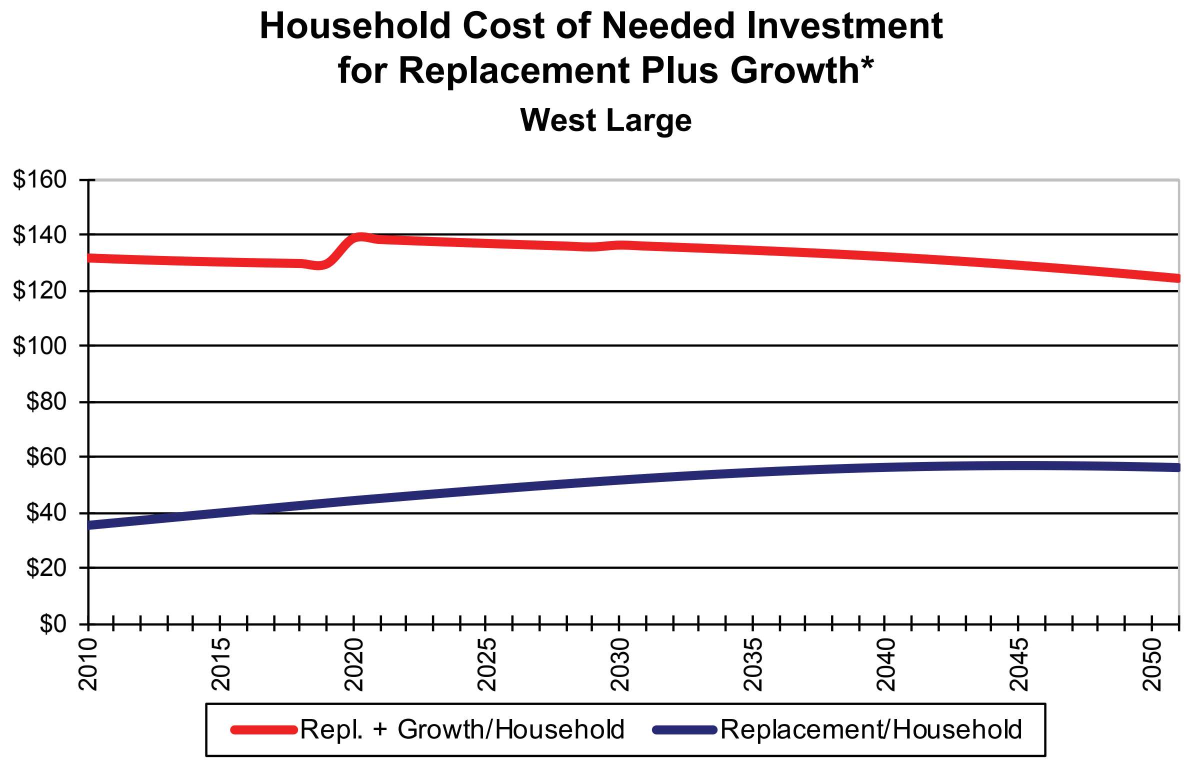

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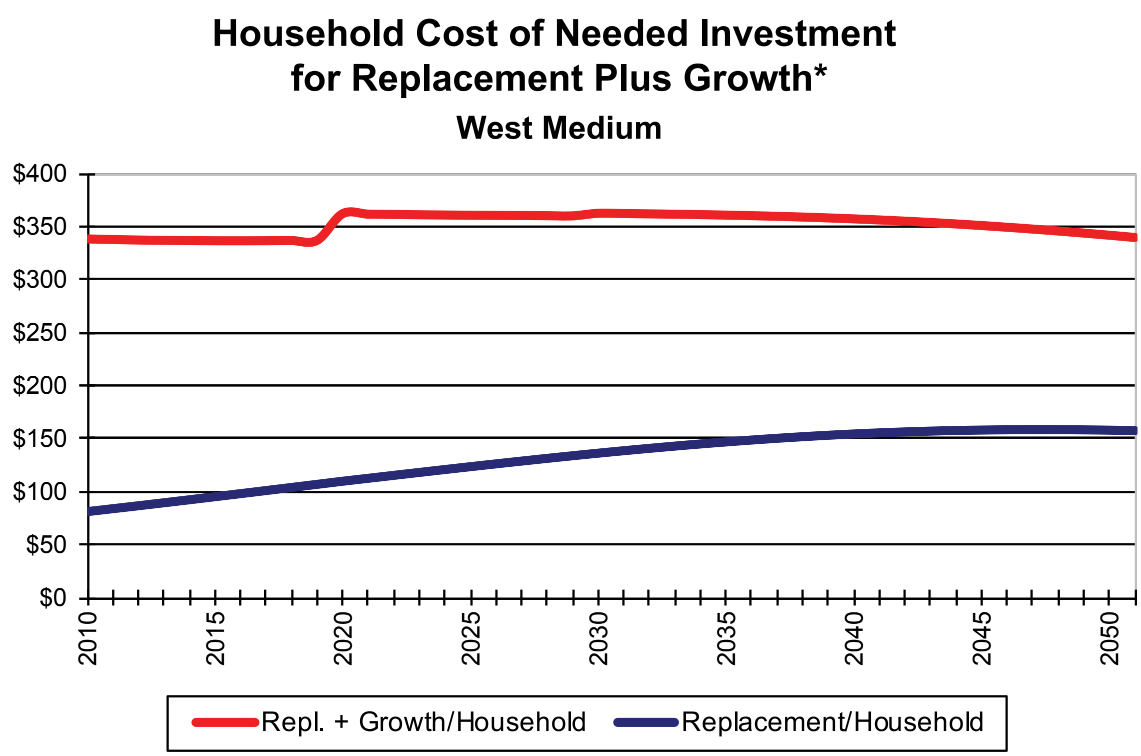

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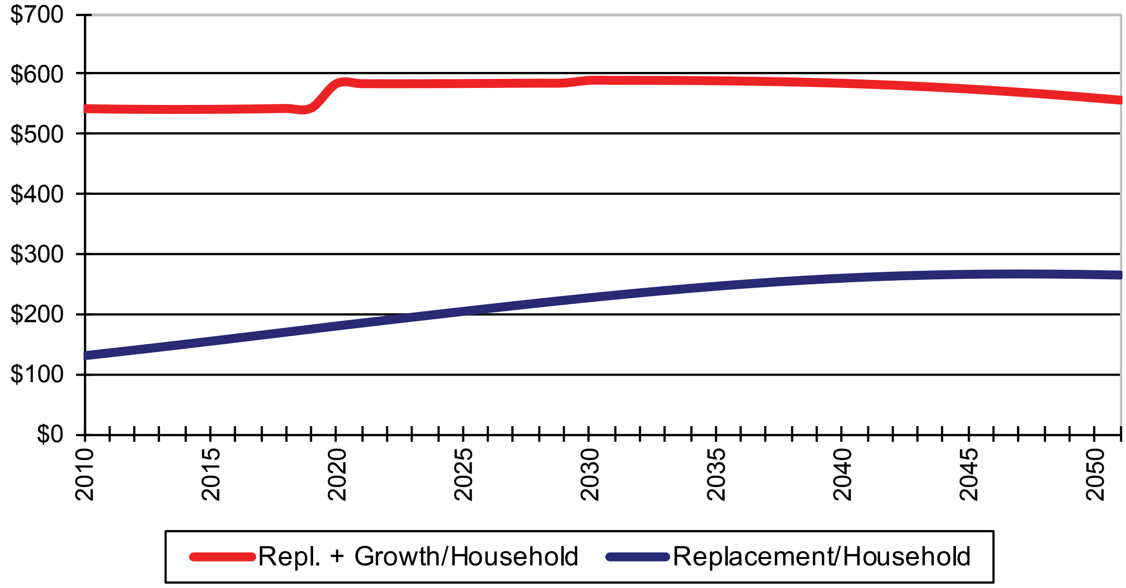
Household Cost of Needed Investment for Replacement Plus Growth*

West Small



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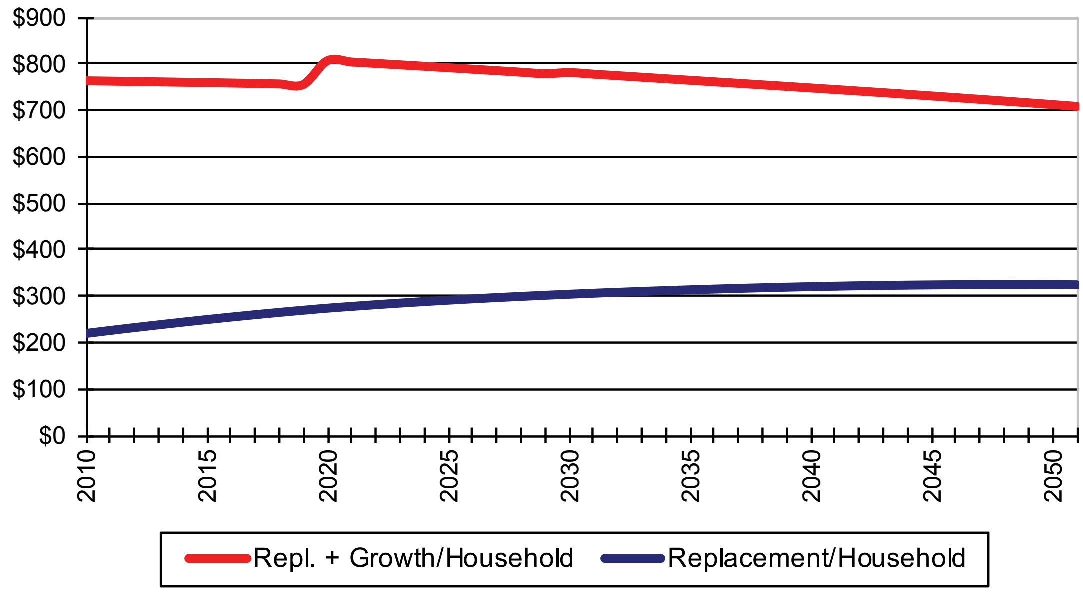
Household Cost of Needed Investment for Replacement Plus Growth*

West Very Small



**This assumes costs are spread evenly across households of 2.6 persons each, based on data from the US Census.*

The charts show per household costs for replacement, and for replacement plus growth. The model assumes costs are spread evenly over households averaging 2.6 persons per household in accordance with US Census data. An artifact of the model and US Census data result in an apparent upward or downward "spike" in growth-related needs between certain decades. In reality, the apparent sudden shift in growth-related needs will be spread more evenly over the years bridging each decade to the next."