Over a Decade with ATCO:

A Case Study of Bimodal MDPE/HDPE Gas Pipe Applications

A paper prepared by

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Purpose

ATCO has safely constructed and operated more than 2,300 miles (3,700 km) of bimodal medium density polyethylene (MDPE) and high density polyethylene (HDPE) distribution gas pipelines since the first installation in 2007. This paper highlights the superior material properties of bimodal PE pipe and ATCO's key learnings in switching from unimodal to bimodal PE piping system installation. It also provides a sample plan to successfully implement bimodal PE piping systems based on ATCO's experience.

Bimodal PE piping systems have superior resistance to slow crack growth (SCG) and rapid crack propagation (RCP), significantly prolonging their expected useful service life over that of unimodal PE piping systems. Overall, ATCO has had to make only small procedural changes to transition from unimodal to bimodal PE pipe installation and operation. There have been no incidents with significant consequences caused by the transition, in large part due to a well-communicated and coordinated implementation plan.

About ATCO Natural Gas

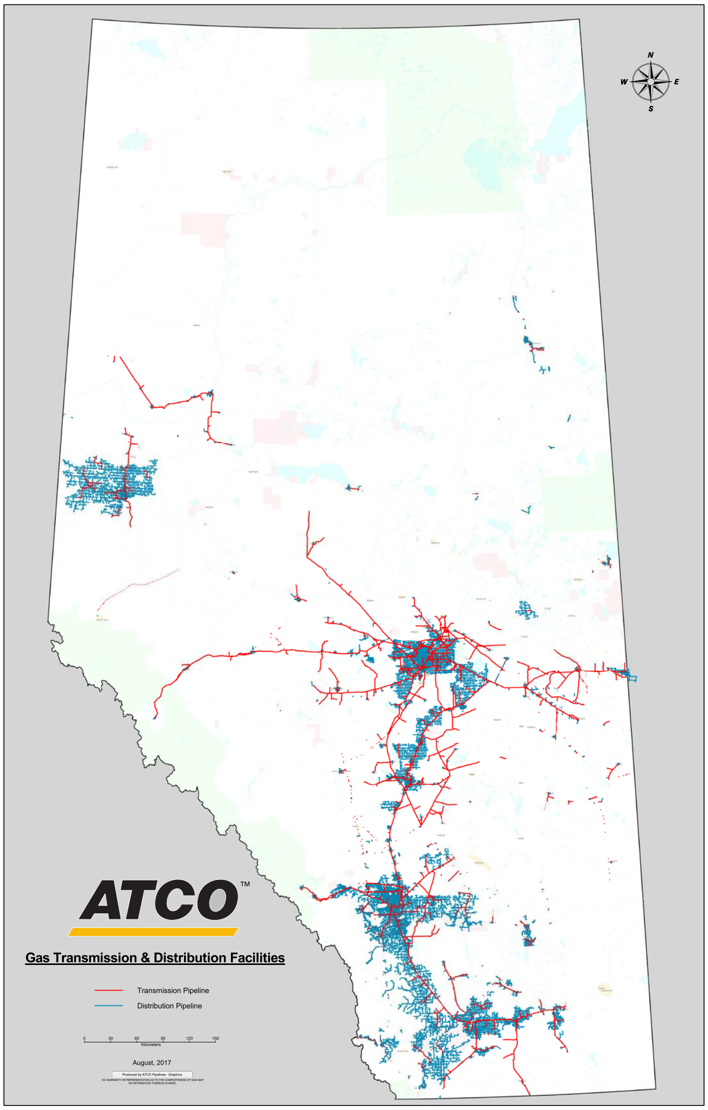
ATCO Natural Gas delivers natural gas to over 1.14 million residential customers and 102,000 commercial and industrial customers in approximately 290 municipalities throughout Alberta, Canada. Figure 1 provides a view of ATCO's natural gas facilities in Alberta. These facilities include over 40,000 km of distribution gas piping systems, 77% of which are PE. ATCO first installed PE pipe in 1960.

Bimodal PE Pipe Implementation at ATCO

ATCO introduced bimodal HDPE pipe into its systems in 2007 for its 12" (323 mm) applications and increased the standard dimension ratio (SDR) from 13.5 to 17.[1] Bimodal PE was chosen for its longer predicted lifespan, partially attributed to its improved resistance to SCG failure mode in addition to the initial cost savings from switching to thinner walled pipe. At the time, bimodal resins were about 10% more expensive than unimodal resins per unit weight (large diameter pipe is priced primarily by weight), but the thinner wall resulted in a cost savings of approximately 6.8% per meter. By 2011, the bimodal resins' higher critical pressures would allow the thinner walled pipe systems to be operated at pressures up to 90 psi (630 kPa) if desired.[2]

Bimodal PE pipe also has superior resistance to RCP failure mode and considerably lower critical temperature values, both of which are particularly important in colder climates such as Alberta's.

Figure 1: ATCO Natural Gas Distribution and Transmission Facilities (2017)



[1] The exception to ATCO's typical pipe dimensions is use of bimodal HDPE SDR 11 pipe in systems with pressures above 90 psi.

[2] ATCO's piping design pressures are determined using the calculation in CSA Z662 for HDB-rated materials. The design factor is 0.45 for PLUS compounds such as CONTINUUM™ DGDA-2420 NT, CONTINUUM™ DGDA-2490 NT, and CONTINUUM™ DGDA-2492 NT Bimodal Polyethylene Resins, which are the bimodal PE pipe materials used by ATCO.

In 2012, ATCO introduced bimodal HDPE pipe for its 6” (168 mm) and 8” (219 mm) applications and increased the standard dimension ratio (SDR) for these sizes from 11 and 13.5, respectively, to 17. This resulted in cost savings of approximately 18.5% and 6.7% per meter.

Following a successful transition to bimodal HDPE pipe use, ATCO introduced bimodal MDPE pipe into its systems in 2014 for smaller diameter applications, i.e., 1¼" (42 mm), 2" (60 mm), 3" (88 mm), and 4" (114 mm). To date, the SDRs for these sizes remain unchanged at 11. The drivers for this change were: (1) the need to approve a new MDPE resin alternative because production was discontinued for of one of ATCO’s two approved MDPE resins; and (2) greater awareness of the superior properties of bimodal PE. An evaluation of pipe produced from CONTINUUM™ DGDA-2420 NT Bimodal Polyethylene Resin, ATCO’s only approved bimodal MDPE resin, found that only small procedural changes were required to produce acceptable electrofusion and butt fusion joints while no procedural changes were required for use of mechanical fittings or squeeze-offs. These changes are detailed in the “Key Learnings for Bimodal PE Pipe Installation” section of this paper.

ATCO still uses unimodal MDPE resins for its smallest diameter applications, ½" (15 mm) and ¾" (26 mm), due to desire to maintain socket fusion as a repair method. Bimodal PE socket fusion, which would support a transition to bimodal MDPE resins for ½" and ¾" pipe sizes, is currently undergoing evaluation at ATCO as an option.

Polytubes, with its manufacturing facility located in Edmonton, Alberta, has been ATCO’s primary bimodal PE pipe supplier since 2007.

Material Property Advantages of Bimodal PE Pipe

When ATCO started to qualify bimodal PE pipe for use in its systems, CONTINUUM™ DGDA-2420 NT, CONTINUUM™ DGDA-2490 NT, and CONTINUUM™ DGDA-2492 NT Bimodal Polyethylene Resins offered significantly better resistance to SCG and RCP than traditional unimodal MDPE/HDPE products of the time because they had been developed with a unique molecular architecture. In 2021, the same resins still offer the best in class performance. These high performance resins extrude well on conventional equipment, have good melt strength, and can cross-fuse with various pipe grades commonly available on the market.

To understand the performance improvements over unimodal PE, one must consider that, historically, many PE pipe failures are related to the SCG mechanism. SCG is characterized in three different phases:

1. Crack incubation and initiation. This is generally the longest of the three phases.
2. Crack propagation.
3. Instability and ductile yielding. This phase is relatively short.

The biggest improvement of the bimodal architecture is in the crack propagation portion of the lifetime.

The durability improvements of the bimodal material over the more traditional unimodal material came from focus on the second phase, crack propagation, of the SCG mechanism. This was accomplished through the resin’s bimodal design where more comonomer is incorporated in the higher molecular weight (MW) species thus increasing the comonomer effectiveness in creating tie molecules. Optimized reactor design and process conditions granted large scale manufacturability of resins with optimized component molecular weights. Specifically, high comonomer incorporation in molecules at greater than 150,000 MW.

Specific comonomer placement yielded durability improvements in not only SCG, but RCP and notch sensitivity as well. RCP is a phenomenon that has been known and researched for several years. While this failure mode is quite rare, when it happens, it is catastrophic. RCP, as its name implies, is a very fast fracture. Crack speeds up to 600 ft/s (180 m/s) have been measured and can travel up to 800 ft (240 m) of pipe. While it can be difficult to predict when RCP failure will happen, the probability is dependent on these factors:

- Increase in pipe size/wall thickness
- Increase in internal pressure
- Decrease in temperature
- Increase in resistance to RCP of the PE material

CONTINUUM™ DGDA-2420 NT, CONTINUUM™ DGDA-2490 NT, and CONTINUUM™ DGDA-2492 NT Bimodal Polyethylene Resins were shown to have significant improvement in RCP performance over typical unimodal counterparts. In general, there is about a ten-fold difference. This was achieved by specific placement of comonomers in the high molecular weight region of the polymer. The end result of increased performance and durability gave greater flexibility to utility system designers, thus allowing for increase in operating pressure.

Over a Decade of Successful Service with Bimodal PE Pipe

ATCO installs and operates bimodal PE pipe in urban and rural systems with the following maximum operating pressures: 18 psi (124 kPa), 20 psi (138 kPa), 30 psi (207 kPa), 50 psi (345 kPa), 60 psi (414 kPa), 80 psi (552 kPa), and 100 psi (690 kPa). ATCO's system pressures don't normally exceed 80 psi; its generally approved bimodal PE pipe dimensions are as listed in Table 1. This table also provides the total estimated installed lengths of bimodal PE pipe for each pipe size.

Notably, ATCO installed a 6" SDR 7 bimodal HDPE pipe in an oil sands area near Fort McMurray in 2007. With this resin, the pipe would normally have a 240 psi design pressure, but, due to potential oil exposure, a chemical derating factor of 0.5 was applied in the design pressure calculation. The pipe is currently operated at 100 psi.

From 2015 to 2020, aproximately 48% of bimodal PE pipe installation at ATCO has been installed to replace vintage steel and plastic systems, 30% to serve new growth, and the remaining 22% to repair (hitlines, water erosion, etc.) or relocate pipe.

ATCO has had no incidents with significant consequence caused by use of bimodal PE pipe and fittings. In general, the integrity performance and risk profile of ATCO's gas distribution plastic piping systems is improving. This is evidenced primarily by the overall downward trend in number of leaks as well as the removal of higher-risk materials such as vintage PE.

Key Learnings for Bimodal PE Pipe Installation

In ATCO's experience with installing bimodal MDPE/HDPE piping systems and unimodal MDPE piping systems, several differences have been noted between bimodal and unimodal PE:

- **Electrofusion:** For joining 4" and smaller PE pipe, ATCO currently uses unimodal MDPE, bimodal MDPE, and bimodal HDPE electrofusion fittings. For joining 6" and larger pipe, ATCO uses bimodal HDPE electrofusion fittings and, occasionally, unimodal HDPE electrofusion fittings. There are no differences in ATCO's electrofusion procedure when using unimodal MDPE vs. bimodal MDPE vs. bimodal HDPE electrofusion fittings.

  Bimodal PE is harder than unimodal PE and may be more difficult to hand scrape, which can lead to chatter marks or gouges. With adequate training and practice, the hand scraping technique can be adjusted to avoid gouging or removing excessive material. Mechanical scrapers comparatively remove smaller depth and thinner width ribbons, but scrapers can be selected and/or adjusted to achieve desired scraping depth.

  Electrofusion fittings are used to join pipe with dissimilar SDRs, such as 13.5 to 17, since ATCO does not allow butt fusion in these situations even though it is commonly practiced within the industry.

Table 1: ATCO's Typical Bimodal PE Pipe Nominal Dimensions and Corresponding Installed Lengths*

Nominal Diameter in. (mm)	SDR	Nominal Wall Thickness in. (mm)	Nominal Inside Diameter in. (mm)	Coil, Reel, or Stick	Total Installed Length mi. (km)
MDPE					
1¼ (42.2)	10	0.17 (4.22)	1.33 (33.76)	Coil, Reel	280 (450)
2 (60.3)	11	0.22 (5.49)	1.94 (49.34)	Coil, Reel, Stick	1,398 (2,250)
3 (88.9)	11	0.32 (8.08)	2.86 (72.74)	Reel, Stick	157 (252)
4 (114.3)	11	0.41 (10.39)	3.69 (93.66)	Reel, Stick	268 (432)
Total	2,103 (3,384)				
HDPE					
6 (168.3)	17	0.39 (9.91)	5.85 (148.50)	Stick	102 (164)
8 (219.1)	17	0.51 (12.90)	7.61 (193.32)	Stick	83 (134)
12 (323.9)	17	0.75 (19.05)	11.25 (285.79)	Stick	44 (71)
Total	229 (369)				
MDPE + HDPE Total	**2,332 (3,753)**				

*Total estimated installed lengths as of January 1, 2021.

- **Butt fusion:** Bead development for bimodal PE is harder to assess during the fusion process, so there is some reliance on timing the fusion for bimodal PE whereas for unimodal PE the fuser can go by solely watching for the top of the bead to reach 12 o'clock before removing the iron and applying interfacial pressure. A bimodal PE bead forms by leading up with a round edge rather than a sharp edge, which is common with unimodal PE. Post-fusion, bimodal PE beads generally have a flatter appearance than unimodal PE beads.

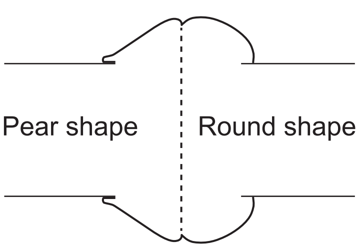
  In training and qualifying fusers, ATCO requires round bead rollover (beads that roll back far enough to touch the pipe completely, as shown in Figure 2) on both the inside and outside of the pipe/fitting. When ATCO first started installing bimodal MDPE piping systems using manual butt fusion machines, many fusers initially struggled to consistently produce round beads. Pear-shaped beads, which were commonly produced and considered to be a visual failure at the time, resulted from what was considered to be insufficient interfacial pressure or by using an iron that was too hot. However, fusers have continually shown to overcome these challenges with adequate training and practice. Because round bead rollover is harder to achieve with bimodal PE, ATCO no longer considers it be a visual failure as it is now recognized not to be indicative of fusion quality.

  Compared to unimodal PE, bimodal PE requires increased manual or machine gauge pressure for comparable pipe dimensions. For manual butt fusion, this is particularly noticeable for 3" and 4" pipe/fitting sizes. PPI TR-33 Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Pipe can be used for guidance when selecting appropriate gauge pressures. In ATCO's experience, fusing time is generally longer for bimodal PE than it is for unimodal PE; for 6" and larger pipe, fusing time is at least doubled.

  ATCO has observed a significant reduction in cold fusion failures with bimodal PE as compared to unimodal PE,[3] though it is unclear at this point to what this can be attributed.

  Bimodal PE feels stickier on the iron than unimodal PE. Though not an issue, fusers may notice this difference.

Figure 2: Butt Fusion Bead Shape for Unimodal PE vs. Bimodal PE



- **Socket fusion (½", ¾"):** Though ATCO has not yet approved socket fusion for bimodal PE pipe, in-house and external party testing has shown that socket fusion of unimodal/bimodal PE pipe to bimodal MDPE pipe can be performed successfully using bimodal HDPE couplings but not unimodal MDPE couplings. It should be noted that ATCO fuses at a lower temperature (425-450°F) than industry standard (500°F), which may have an impact on success. Two concerns that came up during testing were issues with cold ring grip (due to increased "slipperiness" of the pipe) and safety concerns with burning hands due to the amount of heat retained in the bimodal PE materials.

- **Mechanical joints:** ATCO's mechanical tee and coupling installation procedures did not change with transition to bimodal PE pipe. Some installers notice that bimodal PE pipe has a more slippery feel than unimodal PE pipe when stabbing the pipe into mechanical couplings, but it is not an issue.

  Mechanical fittings, particularly stab fittings, are used as ATCO's preferred option to join bimodal PE pipe to vintage[4] unimodal PE pipe, though fusion may be used in lower risk situations if mechanical fittings are not suitable.

- **Squeeze-off:** It can be harder to achieve 100% shut-off with bimodal PE pipe than with unimodal PE pipe. This is due to the extra time it takes for cold flow relaxation to take place within the material. This issue can be overcome with supplemental squeezing,[5] utilizing a second squeeze-off point, or using tapping and stopping equipment as an alternative.

- **Horizontal directional drilling (HDD):** ATCO has had several incidents of bimodal HDPE SDR 17 pipe buckling (flattening) while pulling the pipe back through the drill holes, with the thinner pipe wall as the main contributing factor. Likely causes of the failures were excessive drill depth and/or non-uniform drill path. ATCO continues to drill SDR 17 pipe but now takes greater care during pullbacks to not over-stress the pipe. For many drills, a heavier-walled pipe may be incorporated into the design as well.

- **Bending/handling:** Bimodal HDPE pipe is stiffer in colder weather due to the higher density of these materials, i.e., PE 4710 vs. PE 3608, which can impact bending or uncoiling. When ATCO switched to bimodal HDPE pipe for its 6" and larger applications, it was beneficial that ATCO was already purchasing only stick pipe for these sizes as standard practice. For changing pipe direction, elbow fittings are used in place of bending pipe, though slight pipe deflections are commonplace.

[3] The reduction in cold fusion is observed in butt fusion samples provided by fusers as part of obtaining and maintaining their fusion certification; in-service failures due to cold fusion are generally rare at ATCO.

[4] In ATCO's systems, vintage (pre-1978) unimodal PE pipe is considered to be pipe that is likely to have been produced prior to when the industry introduced and widely accepted chemical improvements in resins, i.e., better branching to significantly increase environmental stress crack resistance.

[5] Supplemental squeezing is allowing the squeeze-off tool to sit for a period of time, usually one minute per diameter inch, after reaching the maximum squeeze-off pressure before squeezing again to the maximum pressure to complete the squeeze-off.

As with many product changes, there are growing pains that must be worked through before the “new normal” is achieved. ATCO’s experience with transitioning from installing unimodal to bimodal PE piping systems has proven that it can be achieved successfully, i.e., without disruptions to work continuity and while ensuring employee and public safety, system integrity, and system reliability.

Implementation Plan

The key to overcoming concerns and recognizing the full benefits of implementing bimodal PE pipe installation, operation, and maintenance is a well-communicated and coordinated plan. A sample plan, which is largely based on ATCO’s successful implementation of bimodal HDPE pipe, is listed in Table 2.

Table 2: Implementation Plan for Bimodal PE Pipe

Step	Action	Comments
1	Set up task force with representatives from impacted stakeholder groups to create and assign Management of Change action items.	Establish stakeholder involvement early on for better success.
2	Contact other users and seek advice from resin suppliers and pipe manufacturers.	Discuss with peers through involvement at AGA Plastics Materials Committee. Multiple suppliers are now producing bimodal PE pipe, as listed in Plastics Pipe Institute (PPI) TR-4 HDB/HDS/SDB/PDB/MRS Listed Materials.
3	Define scope of piping and fittings to be transitioned.	
4	Complete buried pipe design calculations to confirm suitability for design conditions.	If increasing SDR, can incorporate conservatism into calculations to increase confidence.
5	Communicate pertinent information to designers and construction/operations groups.	
6	Draft new pipe specifications.	
7	Select resin/pipe suppliers via bidding process.	Supplier/manufacturer qualification via quality management system review and onsite manufacturing facility audit is recommended.
8	Purchase minimum order of bimodal PE pipe and fittings for testing and evaluation.	This is for procedure and fuser qualifications and emergency stock for repairs. Can also purchase bimodal PE pipe for first year of installation projects.
9	Draft updates to fusion procedures for bimodal PE pipe/fittings.	
10	Conduct fusion trials on existing and bimodal PE materials as per current industry recommended practices.	
11	Evaluate and approve new fittings, equipment, and tooling for use as required.	
12	Establish final fusion procedures for bimodal PE pipe/fittings and qualify initial fusers.	This will enable rapid deployment for the first projects.
13	Complete first projects to install bimodal PE pipe and fittings.	These projects will require special fuser certification to minimize impact on fusion quality.
14	Evaluate initial installations.	Evaluate for ease of handling and installation, supply chain issues.
15	Communicate findings from evaluations of initial installations to designers and construction/operations groups.	
16	Set up contractual agreements with fitting suppliers. Establish good inventory practices.	
17	Determine contractual obligations related to tooling, etc., for contract construction crews.	
18	Update fuser training courses, and complete training to update fuser certification to ensure fusers are competent and qualified to install new pipe and fittings.	Hands-on training will ensure fusers gain familiarity with installation differences.
19	Update tracing, trackability, and quality control processes.	
20	Design roll-out.	Work with stakeholders. Determine if a soft launch is beneficial, i.e., limit transition to only some crews or areas at first to work through problems that may be encountered prior to rolling out to all crews and areas.
21	Communicate and implement roll-out.	

For more information, visit www.dow.com and www.atco.com.

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