Australian Vinyls

PVC Pipe

Why it's the Best Pipe for Moving Water

Nigel Jones – Technical Manager,
Australian Vinyls (nigel.jones@av.com.au)

Think Pipes.
Think PVC
Sustainability and performance

Agenda

- **What is PVC**
- **PVC Pipe in Perspective**
  - History
  - Technology
  - Types
- **PVC Pipe's Advantages**
  - Performance advantages
  - Environmental aspects
  - Comparison with Other Pipe Types
- **Future Opportunities**

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What is PVC

- Most plastics are 100% hydrocarbon-based – derived from non-renewable resource (oil, gas)
- PVC is different –
  A chlorinated hydrocarbon
- **57%** of PVC by weight comes from **salt**

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What is PVC

- Poly Vinyl Chloride, or ‘Vinyl’
- First discovered in 1838
- Commercialisation from 1928 – 30
- Rubber replacement during WWII
- Today, about 15% of the plastics market worldwide
- Product of both Chlor-Alkali and petrochemical industries (largest consumer of Chlorine ~35 – 40% of world production)

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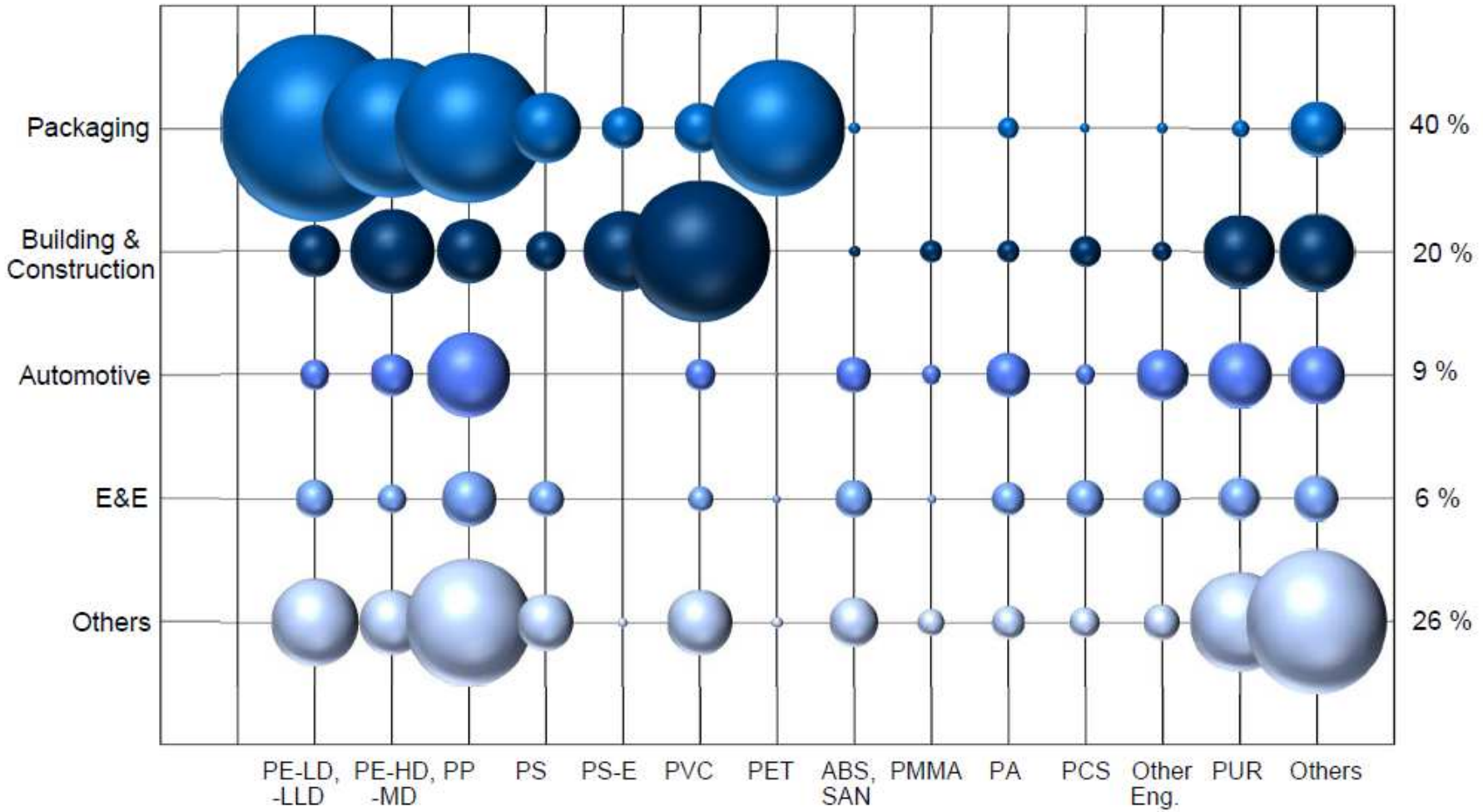
PVC: Largest market share of B&C plastics in Europe

Demand total in 2014: 47.8 Mio t

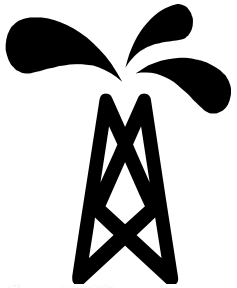


Source: PlasticsEurope

We use ethylene and salt to make great products

Salt
+
Ethylene

→ EDC → VCM → PVC
+
additives



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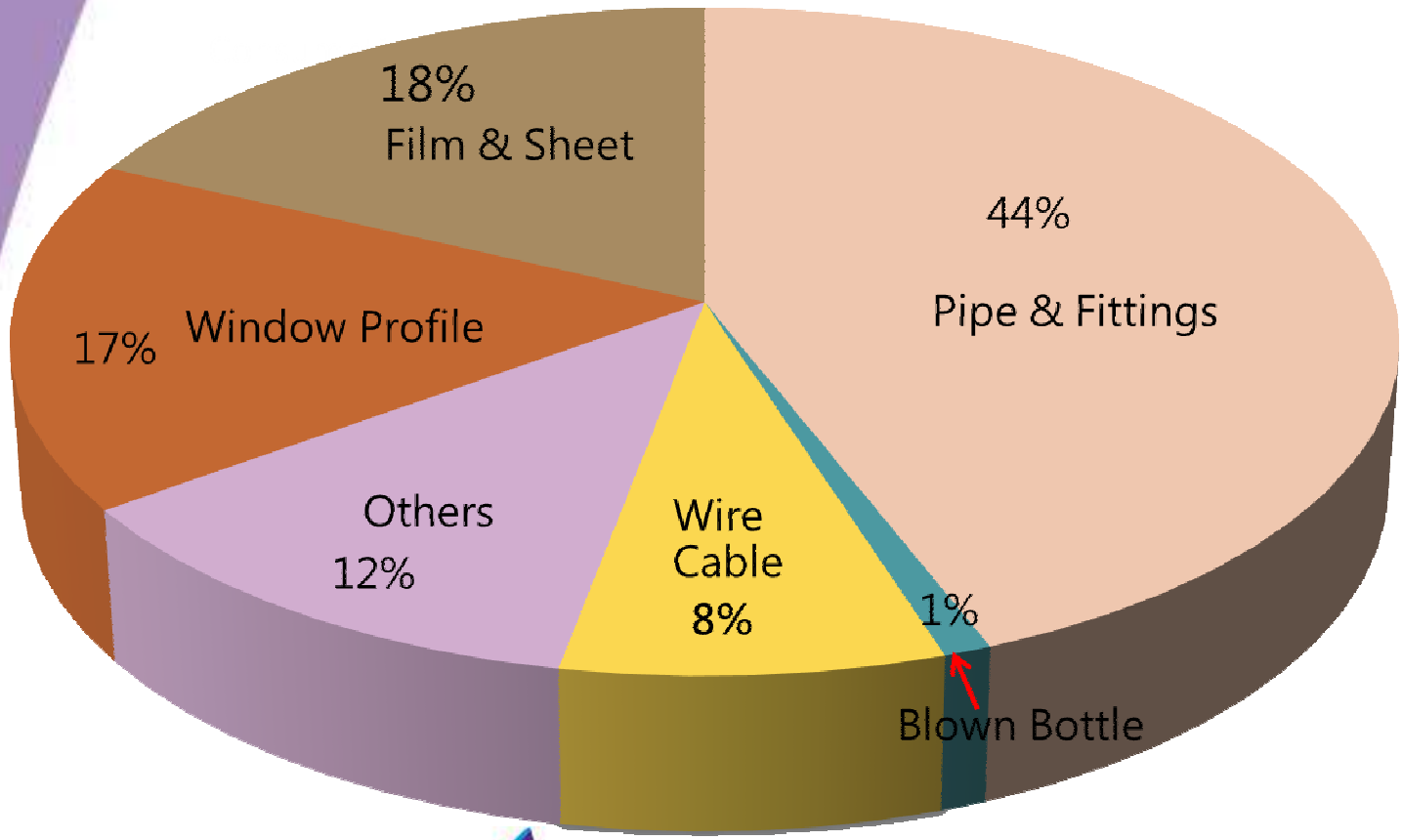
2017 Global PVC Usage



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Source: Formosa Plastics Corp

PVC Formulating

- PVC is like flour, fairly useless by itself, very useful when mixed with other additives
- Key additives include
  - Heat Stabilisers
  - Fillers
  - Impact Modifiers
  - Plasticisers
  - Colour

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PVC Pipe Formulating

- PVC pipe will contain the following additives
  - PVC resin
  - Heat Stabilisers
  - Fillers
  - Impact Modifiers
  - Lubricants
  - Processing aids
  - Colour/Pigment

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PVC Pipe Additives – PVC Resin

- Generally medium Molecular Weight resin (K66 – 67, pbar 1020 – 1080 range typical)
- Most important feature is consistency
- Important properties include
  - Molecular weight
  - Apparent or bulk density
  - Porosity or cold plasticiser absorption
  - Particle size distribution
  - Residual vinyl chloride monomer

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PVC Pipe Additives – PVC Resin

- PVC resin is manufactured from VCM, which can be produced by two different methods
  - Ethylene based
  - Carbide/Acetylene based
- The environmental impacts of the Carbide/Acetylene process are significantly higher, in particular
  - Mercury emissions: Mercury based catalysts used to manufacture carbide/acetylene based VCM are a major source of Mercury emissions to the environment (estimated to be 1000+ tons per year)[1]

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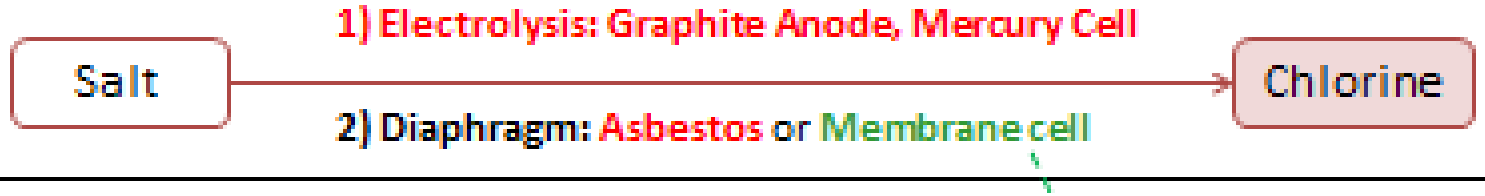
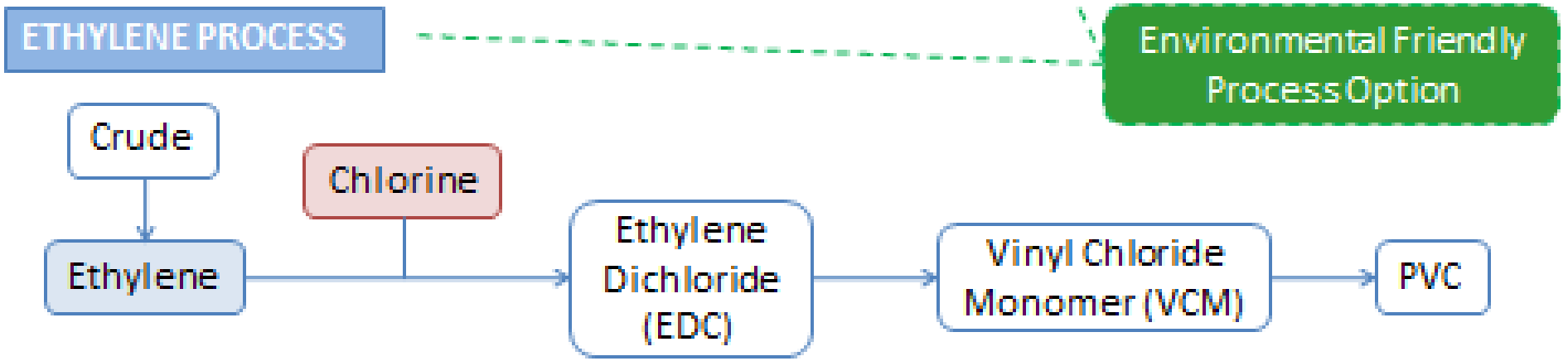
1. Literature Review and Best Practice Guidelines for the Life Cycle of PVC Building Products, Issued by the Green Building Council of Australia

PVC Production Process

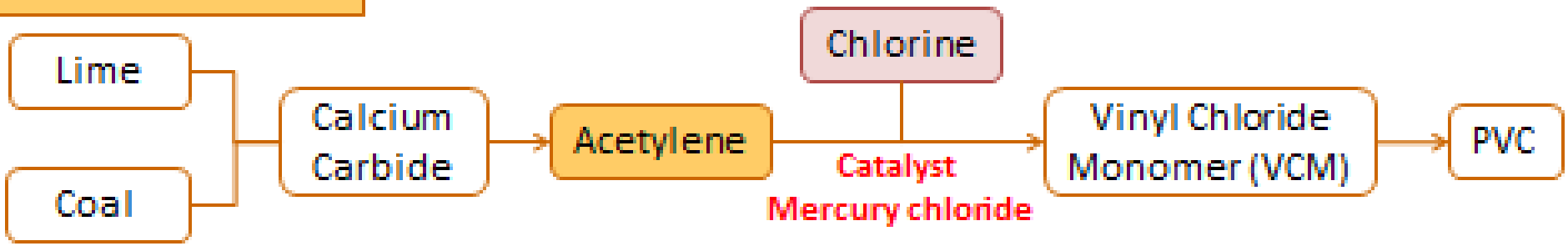
CHLOR-ALKALI PROCESS



ETHYLENE PROCESS



ACETYLENE PROCESS



updated 14.10.2015

PVC Pipe Additives – PVC Resin

- Acetylene based VCM uses large quantities of coal and significantly more water than ethylene based product
- Carbide/Acetylene VCM phased out in most parts of the world except for China. >80% of PVC resin produced in China uses Carbide/Acetylene VCM
- Whilst not banned in Australia, Carbide/Acetylene based PVC is almost never used due to environmental pressure

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PVC Pipe Additives – Heat Stabilisers

- Added to prevent PVC resin thermally degrading during processing
- Historically Lead or Tin based
  - Numerous water quality tests have proven Lead stabiliser to be safe for use in drinking water pipe
- Modern technology has replaced Lead with Ca/Zn or organic based stabilisers
  - Safer during production of pipes

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PVC Pipe Additives - Fillers

- Calcium Carbonate fillers added to increase stiffness and reduce cost
  - Fine particle size (1 – 2μm) ground Calcium Carbonate (Omyacarb 1T is industry standard in Australia)
  - Stearate coated
  - Loading
    - Pressure pipe <5%
    - DWV (sewer) pipe ~15%
    - Stormwater pipe ~20%

Note: Filler loading limited by product standards

  - Excess loading leads to faster extruder wear, poor quality (brittle) pipe
  - Ultrafine precipitated Calcium Carbonates can enhance physical properties

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PVC Pipe Additives – Impact Modifiers

- Added to increase impact strength and ductility of pipe
- Typically not used in standard PVC pressure pipe
- Chlorinated Polyethylene (CPE) used in Modified pressure pipe
- Often used in non-pressure pipe to increase impact strength

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PVC Pipe Additives – Others

- Lubricants and processing aids added to assist with extrusion of pipe
- Pigment added to give desired colour to pipe and also UV protection
  - Australian PVC pipe must contain minimum 1.5phr of Rutile Titanium Dioxide (requirement of product standards)

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PVC Pipe History

- New, but it's not
- Oldest known pipe >80 years old (Berlin, Germany)
- In use in Australia for over 50 years
- Exhumation projects
  - http://www.pipa.com.au/index.php?option=com_content&view=article&id=88&Itemid=1
- Produced up to 1500mm diameter

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PVC Pipe Technology

- Pressure pipe
  - PVC-U (unplasticised)
  - PVC-M (modified)
  - PVC-O (oriented)
- Non-pressure pipe
  - Foam Core / Sandwich Construction
  - Corrugated
- Electrical / Telecommunications conduit
  - Foam Core / Sandwich Construction

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PVC Pipe Standards

- Pressure pipe
  - PVC-U AS/NZS 1477
  - PVC-M AS/NZS 4765
  - PVC-O AS/NZS 4441 (based on ISO16422)
- Non-pressure pipe
  - DWV AS/NZS 1260
  - Stormwater AS/NZS 1254
- Electrical / Telecommunications Conduit
  - AS/NZS 2053

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PVC Pressure Pipe

- PVC-U is traditional pressure pipe, most common type worldwide
- In Australia, all 3 different types of PVC pressure pipe used
- PVC-M is most common type used in Australia
- PVC-O also commonly used for domestic water supply pipe (100 – 300mm range)

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PVC-M Pressure Pipe

- Developed in South Africa for use in underground mines
- PVC-M has been used for around 18 years in Australia
- Typically modified with ~5% CPE (Chlorinated Polyethylene) modifier
- More ductile/less brittle than PVC-U
- Produced up to 630mm diameter
- Undergoes severe impact test (falling weight from 20m)
- Accepted by all water authorities in Australia
- More difficult to produce – higher scrap rates than PVC-U
- PIPA technical note https://www.pipa.com.au/sites/default/files/document/attachment/tn015.pdf

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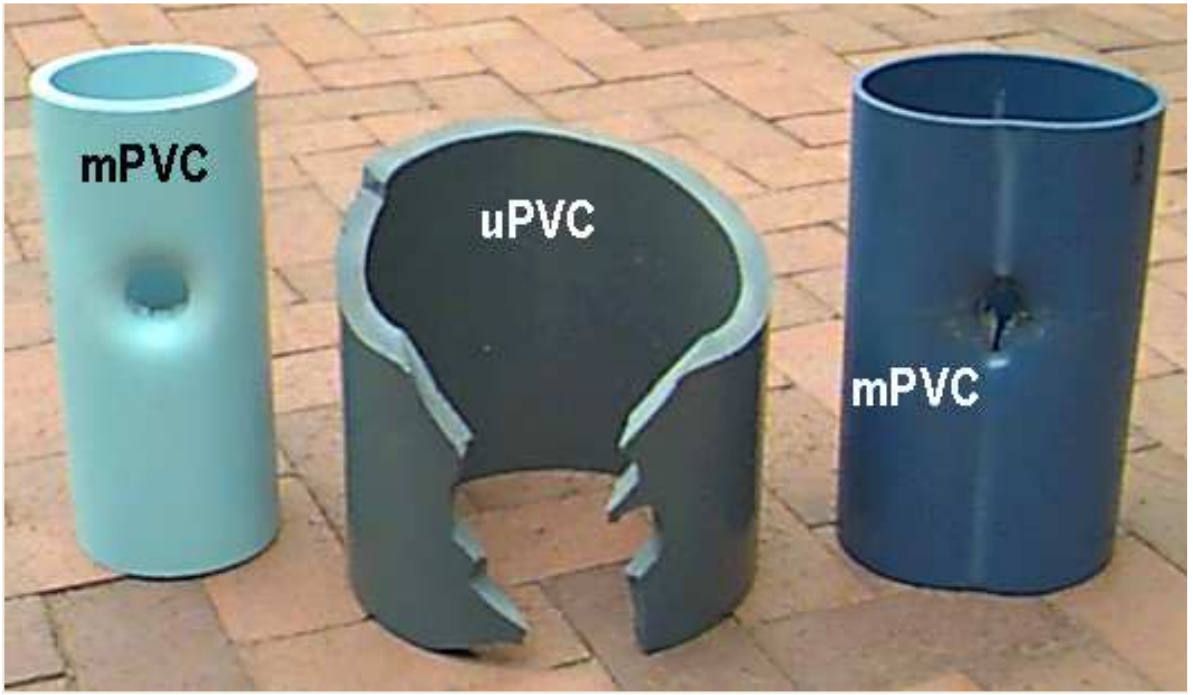
PVC-M Pipes



PVC-O Pipe Technology

- Has been successfully used in Australia for 30+ years
- In-line orientation technology allows rapid production
- Is widely used in Australia for water supply in 100 – 300mm diameter range
- Several technologies available, including Beier, KraussMaffei Berstorff, Molecor, Rollepaal and Wavin
- Videos
  - Ipex Bionax (http://www.youtube.com/watch?v=Oa0c5usOoJ4)
  - Molecor (http://www.youtube.com/watch?v=1B8hXStwToo)
  - Think Pipes. Think PVC (http://www.thinkpipesthinkpvc.com.au/extreme-field-testing-of-pvc-o)

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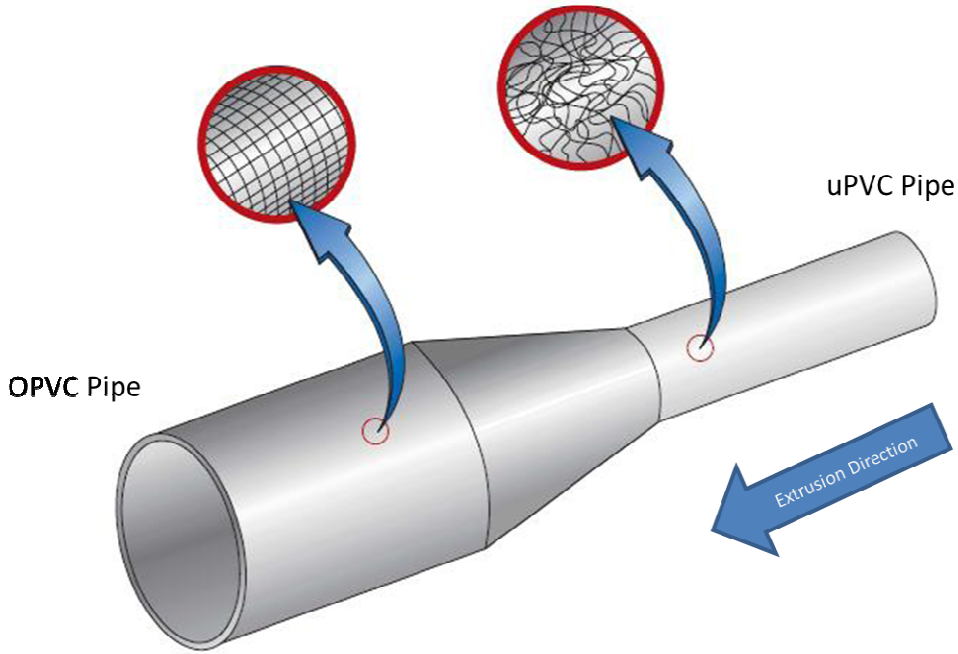
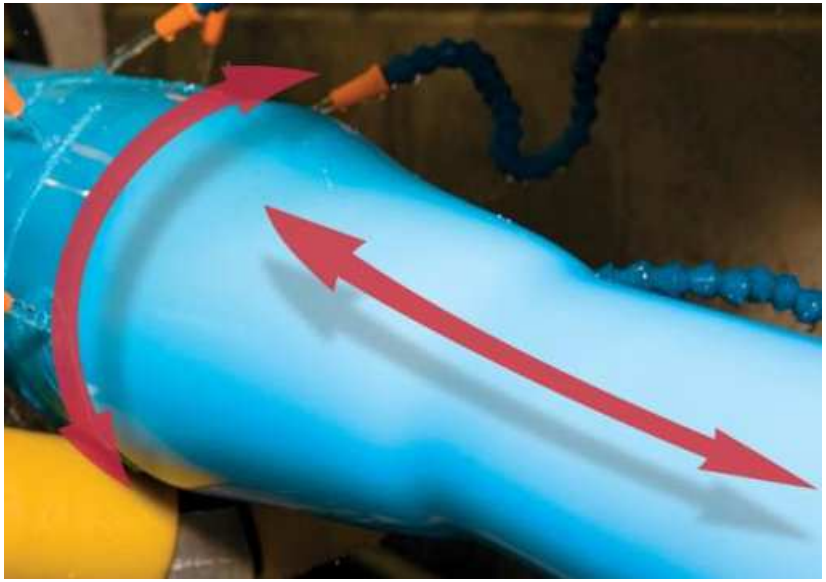
O-PVC Pipes





PVC Pipe Technology

Pressure pipe comparisons[1]

Pipe Type	Weight Per Length (relative to PVC-O)	Tensile Strength (MPa)	Design Coefficient (Safety Factor)	Hydraulic Capacity (% relative to PVC-O)	Installation Costs (% relative to PVC-O)	Environmental Impact[2]
PVC-U	**2**	**~45**	**2**	**78**	**100**	**Medium**
PVC-M	**1.4**	**~40**	**1.4**	**90**	**100**	**Med - Low**
PVC-O	**1**	**~75**	**1.6**	**100**	**100**	**Low**
PE	**2**	**~28**	**1.25**	**65**	**200**	**Medium**
Ductile Iron	**6**	**High when new (>400)** **~0 after ageing**	**High when new (3)** **~0 after ageing**	**82**	**150 - 200**	**High**

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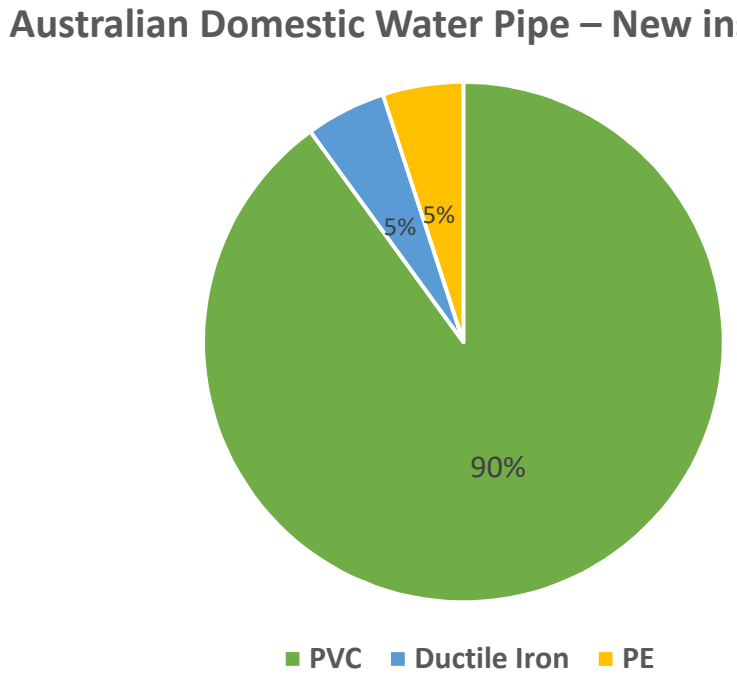
Notes:

1. Typical figures for 200 – 250mm diameter pipe Based on mix of Australian and EU data

2. Based on Embodied energy, lifetime CO2 emissions, resource requirements, installation and performance


PVC-U
c 1990
PVC-M
c 2000
PVC-O
c 2010

Pipe Types used for Domestic Water Supply



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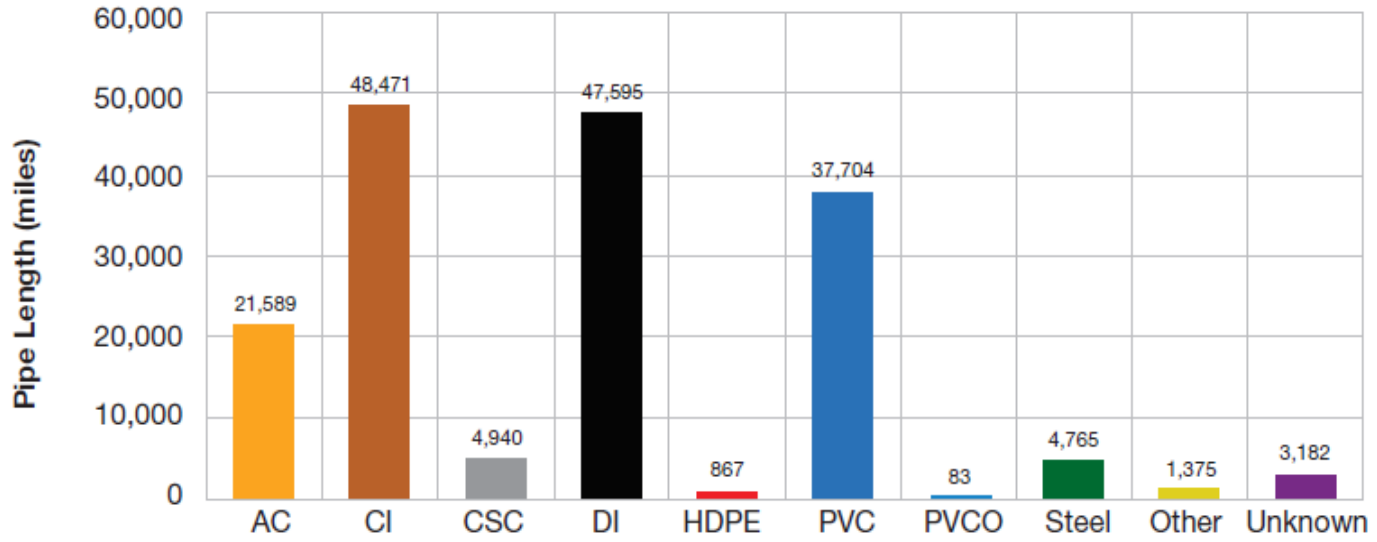
Based on 100mm – 300mm diameter pipe.
Source: Plastics Industry Pipes Association

Pipe Types used for Domestic Water Supply - USA

FIGURE 9: LENGTH OF PIPE SEPARATED BY MATERIAL TYPE FROM THE BASIC SURVEY



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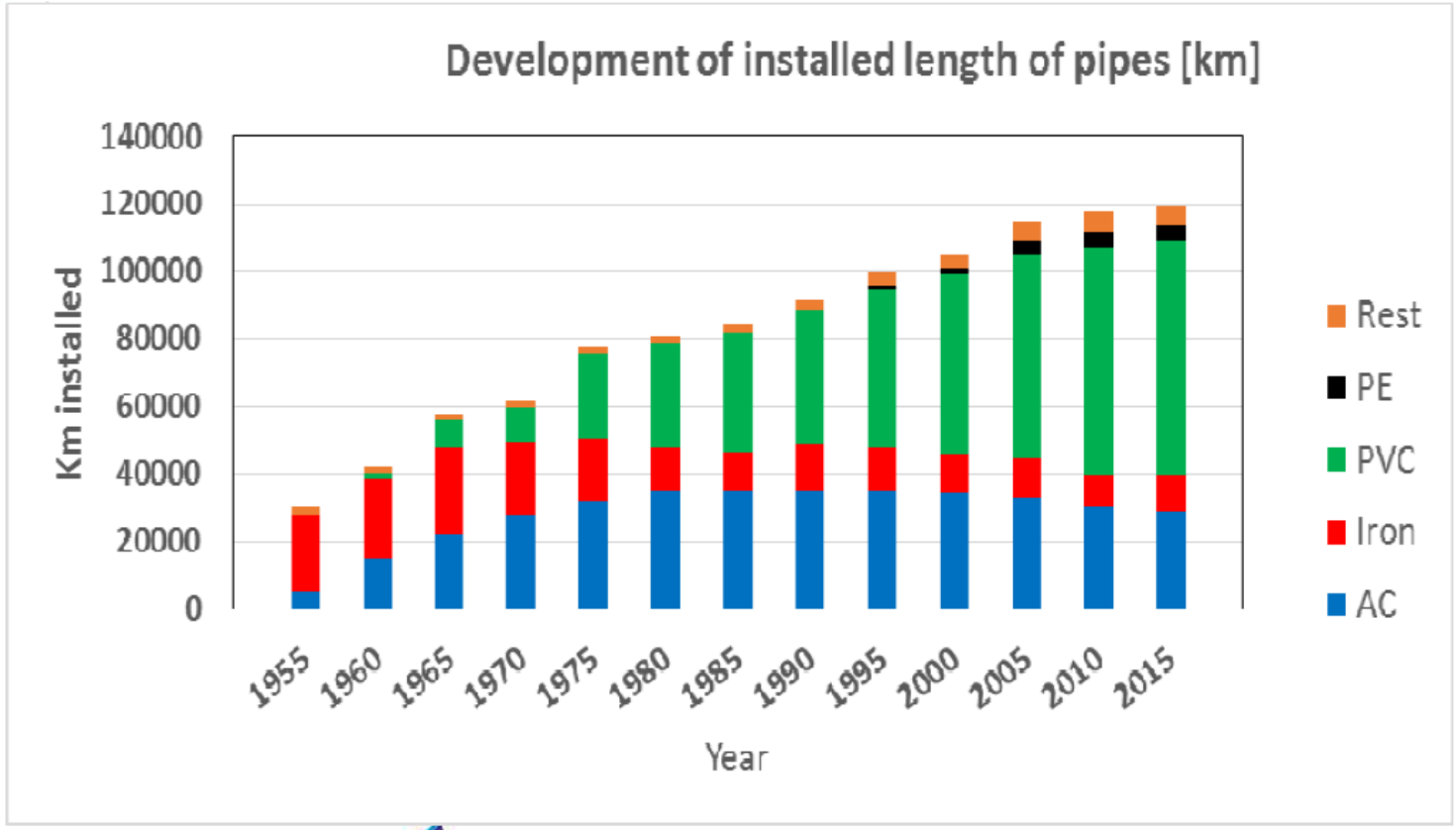
Source: Folkman, Steven, "Water Main Break Rates In the USA and Canada: A Comprehensive Study" (2018).*Mechanical and Aerospace Engineering Faculty Publications*. Paper 174. https://digitalcommons.usu.edu/mae_facpub/174

Pipe Types used for Domestic Water Supply - Netherlands



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Source: **THE EXPERIENCE WITH THE USE OF UPVC PIPES IN VARIOUS BURIED APPLICATIONS. Frans Alferink.** Wavin Overseas, The Netherlands **Proceedings of the 18th Plastic Pipes Conference PPX, September 12-14 2016, Berlin, Germany**

PVC Pipe Technology

- Non-pressure pipe
  - Example of foam core pipe (100mm DWV pipe)

  - Typical density of foam core = 0.6 – 0.7g/cm^3
  - ~40% lighter than solid wall equivalent
  - Core often contains recyclate

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PVC Non-pressure Pipe – Market Share

- DWV (Drain, Waste and Vent pipe = sewer pipe)
  - PVC market share >90%
- Stormwater Pipe
  - Within property, PVC has virtually 100% market share
  - Outside property, <5%. Concrete is #1, PP growing
  - Only significant market left for concrete and they defend it vigorously
  - No technical issues with using PVC pipe under ground load
- Electrical / Telecommunications Conduit
  - Within building, PVC >95%, outside building shared between PVC and PE

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Source: Plastics Industry Pipe Association

PVC Pipe's Advantages

PVC has intrinsic advantages for a piping material

- **Right balance of mechanical properties**
  - Excellent compromise between stiffness and flexibility:
    - Stiff enough to withstand traffic load
    - Flexible enough to resist natural movements of the ground. (data from Christchurch NZ earthquakes)
- **Chemical resistance**
  - Most resistant of all pipe types to chemicals, water disinfectants and corrosion

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PVC Pipe's Advantages

- **UV resistance**
  - All PVC pipe manufactured in Australia must contain minimum loading of UV protection (TiO2)
- **Fire resistance**
  - Very hard to get PVC pipe to burn
- **Material efficiency**
  - Most sustainable pipe

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PVC & PE Comparison

Compared to PVC, PE pipe

- Has a higher effect on water taste[1]
- Is more susceptible to biofilm growth[1]
- Requires higher levels of Chlorination to prevent biofilm[1]
- Degrades due to oxidation from Chlorination (temperature dependency)[2]
- Causes higher levels of contaminants in water such as antioxidant degradation products and other VOC's[3]
- Has lower resistance to hydrocarbon permeation[4]

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1. B. Rabaud, J. Baron, A. Ragot, A. Bruchet and K. Glucina, Suez-Environnement/Eau de Paris – "**What Is The Risk Of Plastic Pipe Long-Term Degradation On Water Quality?",**
poster presentation at Plastic Pipes XVI, Barcelona, 2012
2. DUVALL.D.E & EDWARDS.D.B, Engineering Systems Inc. Illinois, USA – "**Oxidative Degradation of HDPE Pipes due to Exposure to Water Disinfectants**", presented at Uni-Bell 2012 Annual Meeting
3. Skjevrak.I, Due.A, Gjerstad.K.O, Herikstad.H, Regional Food Control Authority, Norway – "**Volatile organic components migrating from plastic pipes (HDPE,PEX and PVC) into drinking water**", Water Research 37 (2003) 1912–1920
4. AWWA Publication – Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets, 2008

PVC & PE Comparison (cont)

Compared to PVC, PE pipe

- Is more difficult to join and more susceptible to joint failure
- Is slower to install
- Is expected to have a shorter lifetime
- Has lower hydraulic capacity – higher pumping costs
- Is more expensive

PE makes great pipe – it's just that PVC makes better pipe for water distribution

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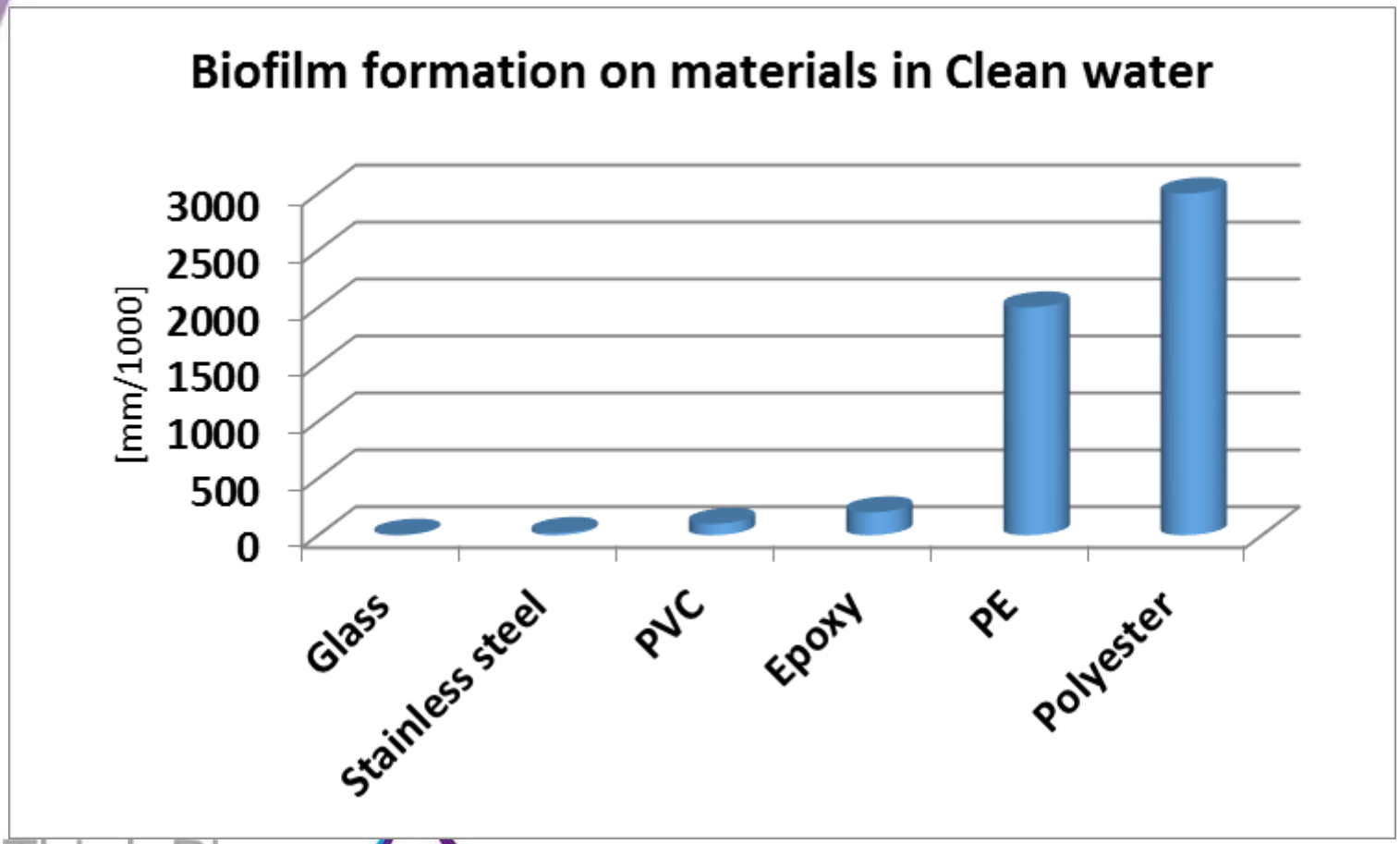
PVC & PE Comparison (cont)



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Source: THE EXPERIENCE WITH THE USE OF UPVC PIPES IN VARIOUS BURIED APPLICATIONS.Frans Alferink.Wavin Overseas Proceedings of the 18th Plastic Pipes Conference PPXVIII, September 12-14, 2016, Berlin, Germany

PE Pipe Failures

- Recent failures in Australia
  https://ceed.wa.edu.au/wp-content/uploads/2017/09/17-015-Wong.Water-Corp.PE-PIpe-Failure.pdf
- Extensive history of researched and documented failures in the USA
  http://hdpefailures.com/pipe%20failures.html
- Southern France failures
  POLYMER ENGINEERING AND SCIENCE—-2009

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Duvall & Edwards Conclusions (USA)

“CONCLUSIONS

The data clearly show that the chlorine-based disinfectant chemicals commonly used in potable water systems degrade the inside wall surface of polyethylene pipes. Most of the failed pipes have been from areas with **warmer ground temperatures**. The increased temperature alone would affect the lifetime of the pipe, even without oxidation of the inner surface.

It has historically been estimated that crack initiation time comprises approximately 90 percent of the pipe’s lifetime. The degraded inner surface of the pipes can greatly shorten the crack initiation time. Thus, oxidation of the pipe’s inner surface leads to premature failures.”

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PE Pipe Failures

- Southern France Failures - Conclusions

  “It appears that DOC, which is a radical in ground state, is reactive with phenolic antioxidants and with polyethylene. It is able to initiate oxidation radical processes leading to chain scission. This latter is responsible for polymer embrittlement and premature failure. In natural aging conditions
  (temperature 15°C, DOC concentration 0.15 ppm, hoop stress of few MPa), lifetimes can be of the order of 10 years, sometimes shorter, against 50 years expected value.”

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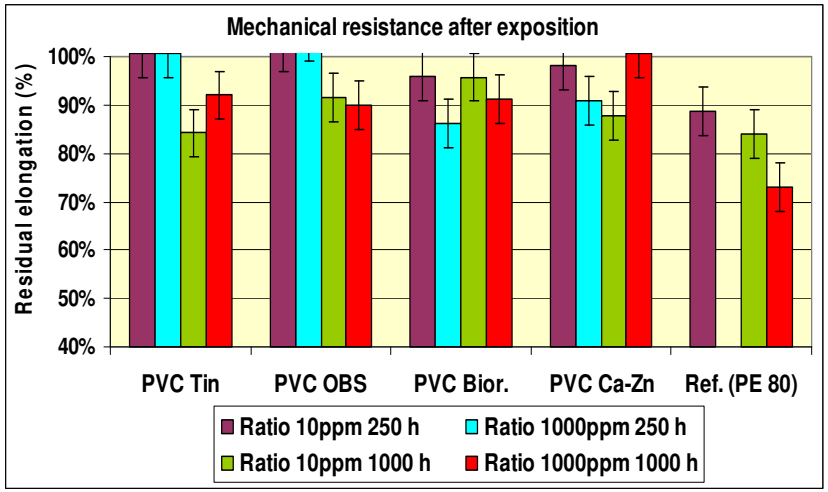
Chemical Resistance

- Effect of hypochlorite on PVC and PE



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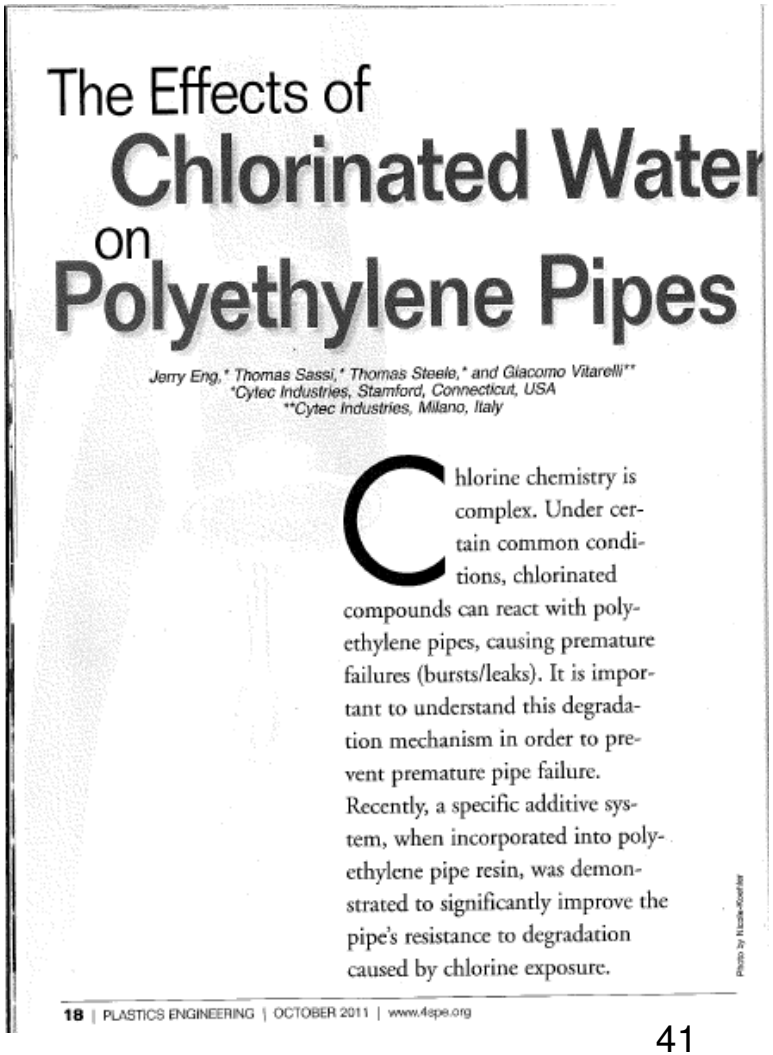

The Effects of Chlorinated Water on Polyethylene Pipes

Jerry Eng,* Thomas Sassi,* Thomas Steele,* and Giacomo Vitarelli**
*Cytec Industries, Stamford, Connecticut, USA
**Cytec Industries, Milano, Italy

Chlorine chemistry is complex. Under certain common conditions, chlorinated compounds can react with polyethylene pipes, causing premature failures (bursts/leaks). It is important to understand this degradation mechanism in order to prevent premature pipe failure. Recently, a specific additive system, when incorporated into polyethylene pipe resin, was demonstrated to significantly improve the pipe's resistance to degradation caused by chlorine exposure.

PVC & PE Pipe - Jointing

Factor	PE Pipe	RRJ PVC Pipe
Electric power requirement	Yes. Minimum of 2.5kVA generator	No power required
Weather conditions / Environment	Jointing must be protected from heat, dust and rain. Preferably under a shelter.	Jointing can occur under all weather conditions
Time to prepare and make joint	29 minutes / joint	1 minute / joint
Skill required for joining	Operator must be trained and certified by a Registered Training Organisation	No special skills required
Specialised equipment or consumables	Generator, welding machine, electrofusion couplings, alcohol wipes, pipe clamps, re-rounding tool, peeling tool or scraper.	Pipe lubricant and clean rag

PVC and PE Pipe Cost Comparison – Sewer Pipe

Cost / Kilometre	PE	PVC
Excavation	=	=
Embedment	=	=
Pipe laying labour	=	=
Joint making / welding labour	$ 6,000	$ 208
Pipe	$16,680	$ 9,400
Electrofusion couplings	$ 5,010	$ 0
Consumables and fuel	$ 668	$ 12
TOTAL	**$28,358**	**$ 9,620**
Cost difference	**+195%**	**-66%**

Based on 100mm DWV pipe

Source: Australian Pipe Industry

PVC vs. Ductile Iron Pipe Comparison

- Pipe 1 : Ductile Iron

Max pressure : 35 bar (when new !)

- Pipe 2 : PVC

Max pressure : 16 bar (always !)

PVC pipe: true strength and sustainability begin with corrosion resistance.

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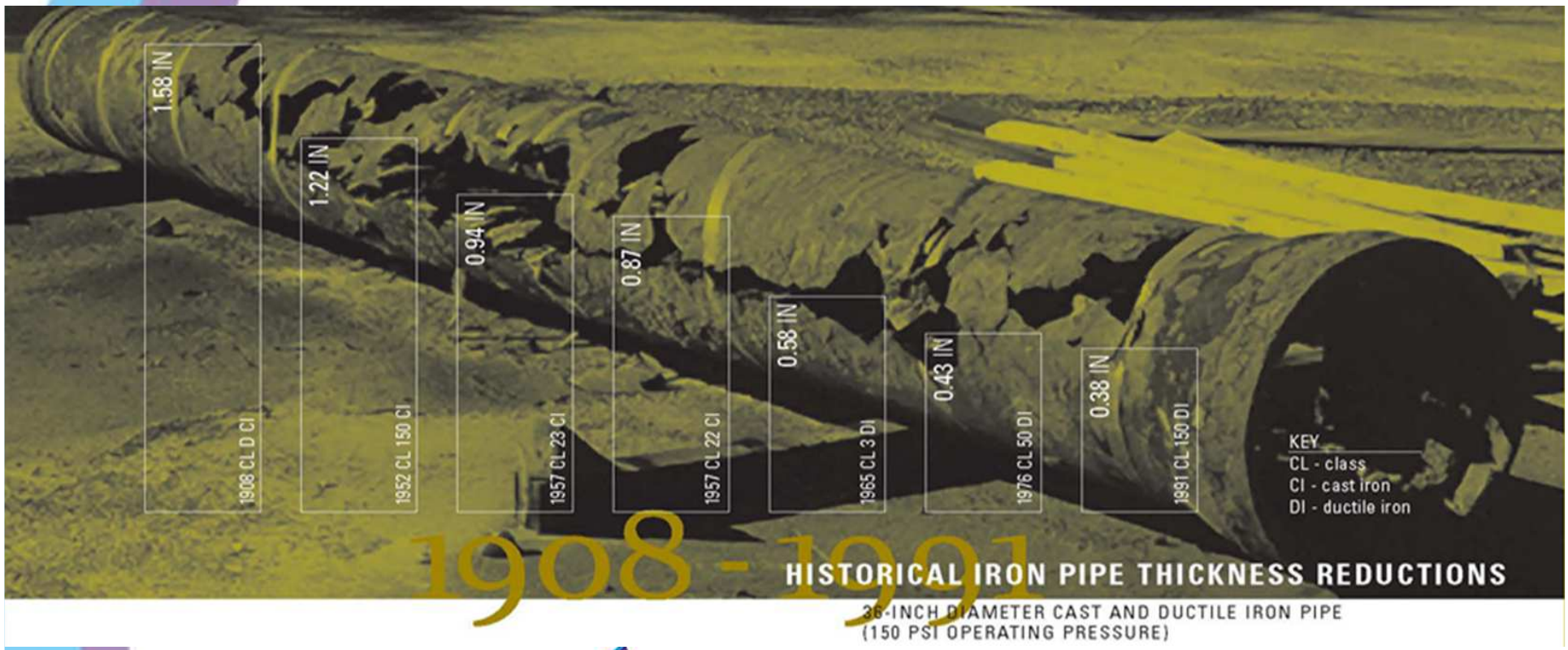
Changes in Iron Pipe Wall Thickness



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Failure rates of Different Pipe Types: Australian data

	Av. fail rate (per 100km/yr)	Data source
	Australian water authorities	
PVC	4.3	1
PE	7.8	1
Ductile Iron	9.5	2
Asbestos Cement	54.0	2
Cast Iron	59.7	2

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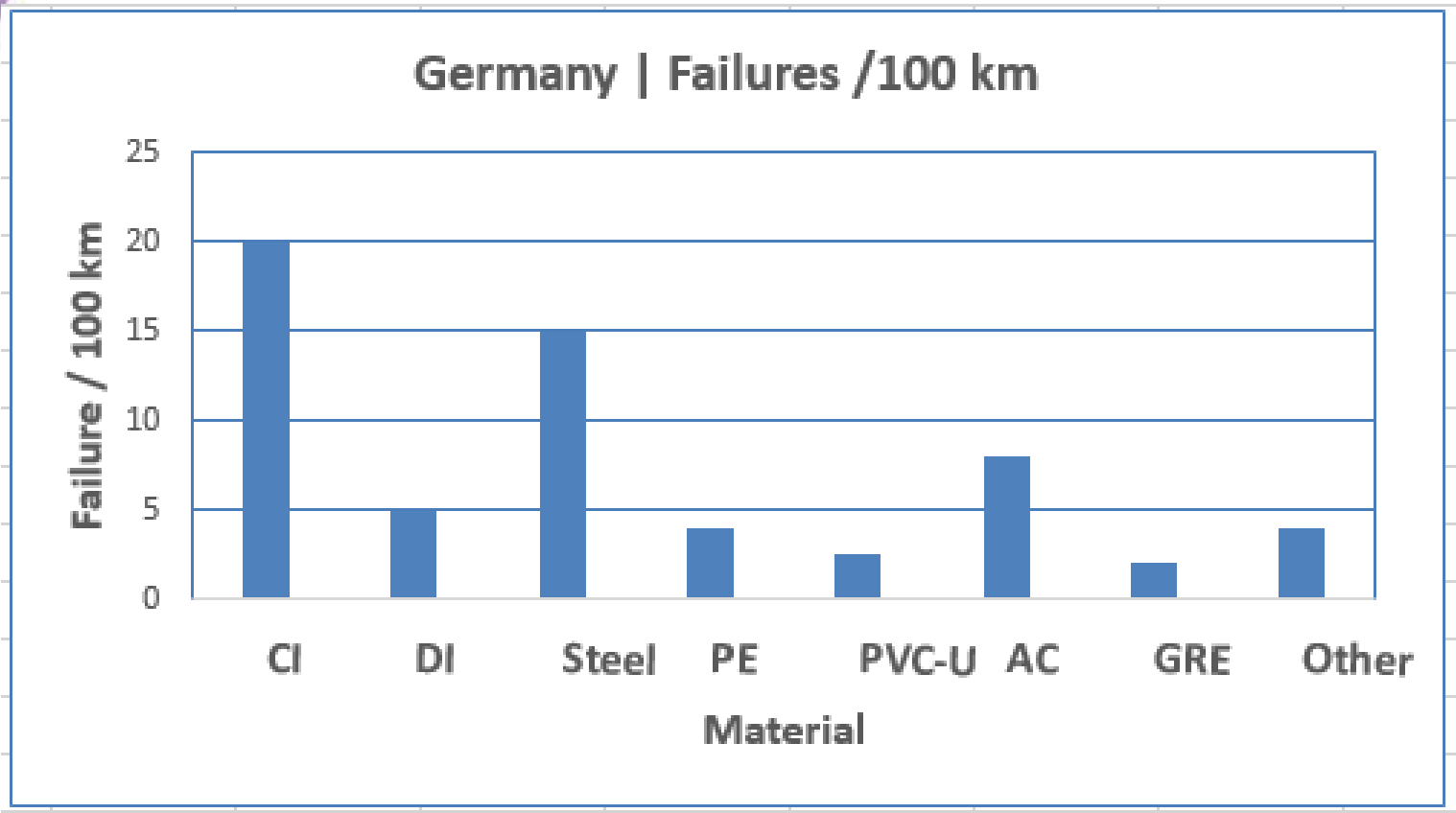
1. CSIRO reports "Long Term performance of PE/PVC pipes" (2005/7)
2. CSIRO PARMS Asset management software (2007)

Failure rates of Different Pipe Types: Europe



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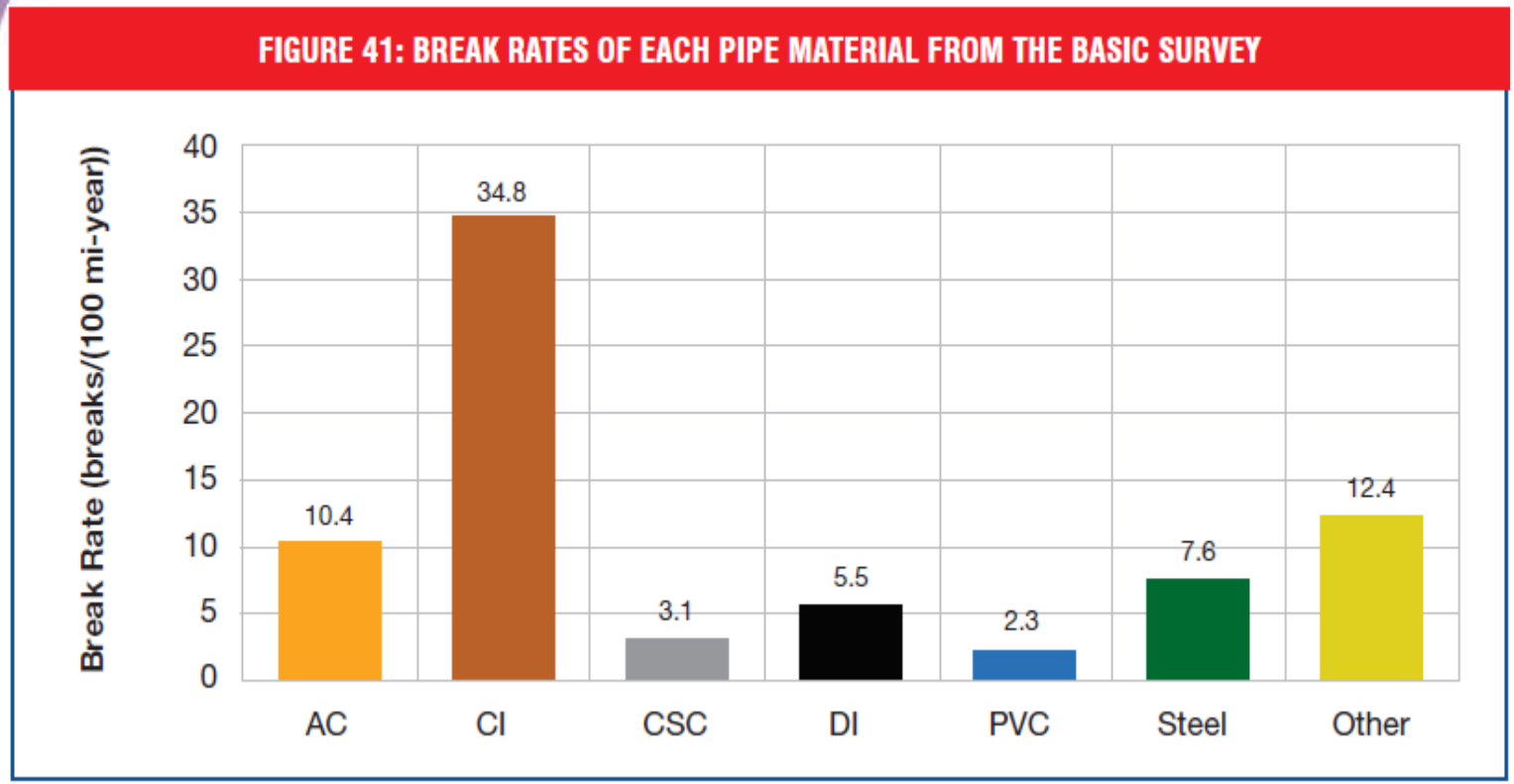
Source: Frank Dietzsch, Dr. Günter Walther. „Netz-und Schadenstatistik Wasser, Ergebnisse aus die Jahrne 2010 bis 2012“ , Energie|Wasser Praxis, 7/8/2014

Failure rates of Different Pipe Types: USA



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Source: Water Main Break Rates In the USA and Canada: A Comprehensive Study – 2018 Update
Dr Steven Folkman, *Utah State University*
Available at https://digitalcommons.usu.edu/mae_facpub/174/

PVC Pipe and the Triple Bottom Line

Based on social, ecologic and economic impacts, PVC pipe is the clear winner

Social	Ecologic	Economic
Lowest failure rates[1]	57% from salt	Lowest cost pipe
Best ROI for consumer	No hazardous RM's[2]	Lowest installed cost
Faster installation	Lowest embodied energy	Lowest op. cost
Safer to install	Recyclable	Lowest maint. costs

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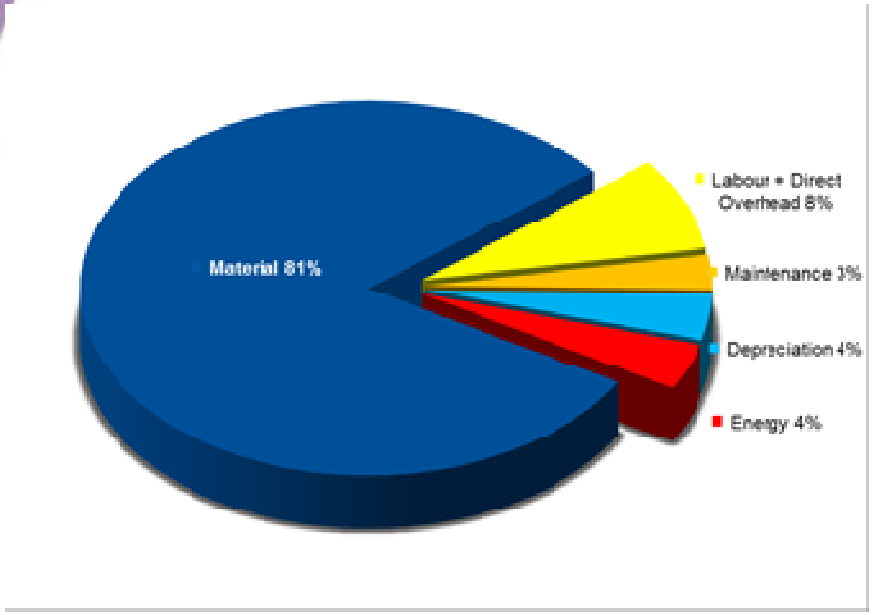
1. Based on North American (National Research Council Canada), German and Australian (CSIRO) research
2. All pipe produced in Australia is heavy metal free

PVC Pipe and the Triple Bottom Line



Typical cost break down of plastic pipe

PVC pipe uses less material than alternatives

- More economic
- More sustainable - less demand on finite raw materials
- Best performing

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Source: Rollepaal B.V. Netherlands
Proceedings of the 18th Plastic Pipes Conference
PPXVIII, September 12-14, 2016, Berlin, Germany

PVC Pipe CSF's

- **Compliance to Relevant Pipe Standard**
  - Quality, Quality, Quality
- **Joining**
  - Constrained elastomeric seal for pressure pipe (e.g. Hultec Reiber Ring)
- **Installation**
  - Most failures with PVC pipe happen in first few years due to poor installation[1,2]
  - AS2032, AS2566 (design and installation guidelines)
  - PIPA guidelines (https://www.pipa.com.au/sites/default/files/document/attachment/tp005.pdf)

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1. Folkman.S., Utah State University – "Water Main Break Rates In the USA and Canada – A Comprehensive Study", April 2012
2. https://sourceable.net/underground-pipes-hampered-by-poor-soil-support/#

PVC Pipe Installation
Minimum Depth

TABLE 5.1

MINIMUM COVER OVER PIPE

Loading condition	Minimum cover m
Not subject to vehicular loading	0.30
Subject to vehicular loading—	
(a) no carriageway;	0.45
(b) sealed carriageways;	0.60
(c) unsealed carriageways	0.75
Pipes in embankments or subject to construction equipment loads	0.75

Source: AS/NZS2032.2006 – Section 5.3.1

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Future Opportunities

- Large diameter pressure pipe for water trunk mains
  - Molecor PVC-O up to 800mm diameter
  - Diamond Plastics (USA) 1500mm PVC-U
- Major water infrastructure and irrigation projects

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Future Opportunities

- Trenchless Applications
  - PVC has the widest range of options for trenchless installations
    - Fusible PVC (Underground Solutions)
    - Spiral Winding (Sekisui Rib Loc)
    - Segmental Sliplining (Iplex Restrain)
    - Fold & Form/Close Fit Liner
    - Heavy Walled Jacking Pipe

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PVC - The Best Choice

PVC Pipe: Best Performing
Best Environmentally
Most Economic

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