Abstract
Recent R&D on pipeline coatings is discussed, and the main R&D issues at this time in the area of pipeline coatings are identified.

Following are the main priorities for R&D at this time:

- Field applied coatings, both repair and joint coatings;
- Effects of minor variations in surface preparation on long-term coating performance;
- Relationship between application temperature and coating performance;
- Effect of compaction produced by backfilling on coating performance;
- Effects of physical and chemical soil forces on coating performance;
- Development of tests to evaluate repair coatings;
- Development of an industry-wide database on historical performance of older and modern coatings;
- Effects of microbial species on coating performance; and
- Methodologies for evaluation and qualification of external pipeline coatings for construction (-45°C) and usage (150°C) at extreme temperatures.

Introduction
Coating performance depends on the events taking place during the five stages of the coating lifetime:

1. Manufacture,
2. Application,
3. Transportation,
4. Installation, and
5. Field operation.

Objectives of R&D are to clarify the following issues:

1.
2.
3.
4.
5.
• What are the chemical and electrochemical conditions and their changes under realistic pipeline environments?
• What are the conditions that are independent of coating type?
• What are the conditions that depend on coating type?
• What are the failure modes of coatings on an operating pipeline?
• How are the failure modes identified?
• How accurate are the field monitoring techniques?
• Do the standard tests simulate the chemical and electrochemical conditions of the field environments?
• Do the standard laboratory tests simulate the failure modes in the field?
• Are the acceleration effects (e.g., aging, extreme CP potential, and elevated temperature) in the laboratory tests relevant to field conditions?
• What information from the laboratory data could be transferred to field performance?
• What are the assumptions to be made to transfer the data?
• How is the validity of the prediction of field performance monitored and verified in the field?

The state-of-the-art on our understanding of performance of pipeline coatings is discussed in this white paper, along with R&D to be performed to address the issues.

**Manufacture of Chemical Components**

Figure 1 lists the coatings used in different time periods in the twentieth century4-64. A comprehensive laboratory analysis of factors leading to coating failure63 and loss of adhesion64 has been performed. Some of the earliest coatings applied are still in service and are still available for application on new pipelines. Over a decade ago, the concept of polyurea spray elastomer technology was introduced. This new application was based on the reaction of an isocyanate component with an amine blend. Advances in both the chemistry and application equipment for coatings have enabled continuous evolution of coatings.

**Coating Chemistry**

The relationship between coating chemistry and corrosion protection is not clear. Objective investigations have been undertaken in the past to advance the knowledge of cathodic protection systems and the disbonding of coatings on buried pipelines by focusing on the electrochemical reactions and chemical changes that occur in the environment at the steel surface and to characterize, using Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS), the surface chemistry of steel samples taken from areas where the coating was disbonded. Simple test procedures have been developed to assess65:

1. The degree of reaction (cure) of the applied FBE coating,
2. The adhesive bond strength of the coating to the steel pipe substrate, and
3. The void content of the coating created by bubble entrapment or gas formation during application.

All investigations were carried out using FBE coating as the model system66-72.

Filling the gaps in knowledge requires that the manufacturers be willing to disclose not only the coating formulations but also the ratios in which the different components are present in the
formulations. Within the composition range of generic coatings, the formulations change widely without any significant change in the corrosion protection properties. Although a relationship between coating chemistry and corrosion protection is important, any attempt to fill this gap will involve significant R&D.

- The relationship between coating chemistry and corrosion protection is not clear.

**Laboratory Evaluation**
Evaluation of existing coatings is the first important step in the development of future coatings. Several methods have been used over the years to evaluate the tests. Table 1 presents a list of standard tests that can be used to evaluate coatings. It is not entirely clear which laboratory tests should be used to evaluate a particular property of a given coating and which laboratory tests are suitable for specific coatings.

- Consolidation of laboratory methods to develop generic tests, leading to specific test methods for specific coatings, should be considered.

**Long-Term Prediction**
Current and potential distributions inside the crevice of a simulated disbonded coating with a holiday during cathodic protection (CP) of steel were measured experimentally\(^7\). Based on the comparison of experiments and numerical simulation of a cathodically protected buried pipe with coating failures, a model was developed. The agreement between the results demonstrates that numerical simulations are acceptable for cathodic protection systems in high-resistivity media\(^7\). The two and three-dimensional boundary element mathematical models have been developed to model the performance of CP designs. The model offers a convenient tool to quantify the performance of a CP system and allows the user to determine the influence of relevant parameters (e.g., soil resistivity, coating damage, and anode type and spacing). The model can also be used as an educational tool to identify the factors that control CP performance under different operating conditions\(^7\).

A boundary element mathematical model was used to assess the influence of cathodic protection (CP) design parameters on performance of a parallel-ribbon sacrificial anode CP system for coated pipelines. The model accounted for current and potential distributions associated with discrete holidays on coated pipelines that expose bare steel to the environment. Case studies, based on the CP system used to provide protection to the Trans-Alaska pipeline, were selected to show conditions under which a given CP system will and will not protect a pipe\(^7\).

The General Electromigration Model (GEM) has been used with modifications for electrochemical kinetics\(^7\). The cathodic hydrogen evolution rate and anodic iron dissolution rates were both found to affect the pH inside the crevice. The model also predicted that formation of iron carbonate, observed extensively in some pipeline failures, occurs under a specific combination of iron dissolution rate and hydrogen evolution rate. GEM provides a unique modeling tool because it is flexible enough to test the effects of a variety of environmental conditions as input parameters and because its predictions of solid mineral
formation in crevices can be tested against field experience. The changes in crevice pH and potential were measured experimentally using microelectrodes.

The occurrence of corrosion and stress corrosion cracking (SCC) under a disbonded coating on a pipeline is determined by a variety of factors including groundwater composition, soil conditions, presence of alternating wet/dry conditions, coating type, cathodic protection, and operating conditions. The Transient Electrochemical Coupled TRANsport (TECTRAN) code predicts the time evolution of the environment under a disbonded coating. However in all the modeling work, the plurality of coatings has not been addressed. In one study, it was determined that for the coating thicknesses examined and over the time period observed, coal tar enamel and polyethylene tape acted as inert barriers, and no permeation or ionic migration through these coatings was observed. The FBE exhibited slight ionic migration and was found to be cation selective.

Electrochemical Impedance Spectroscopy (EIS) is a good tool to investigate the deterioration of coating on a metal. For gas pipelines, the equivalent circuit parameters in the presence of disbonded coatings have been well established. Model parameters are coating thickness and the area under disbonded coating. A coated pipeline can be modeled as a sequence of simple equivalent circuits, which can be handled using standard theory to yield the observed impedance in terms of the values of the circuit elements in the line. The proposed models have been tested to verify their applicability for predicting sites of corrosion in buried pipelines. The effect of a few geometrical and physical parameters has been investigated, and results have been compared with the output of laboratory and field measurements. In some cases, the adjustment of literature parameters has been enough to obtain good agreement of field and laboratory data; modification of the equivalent circuit has, however, been found to be necessary. Future work in this field is promising.

Electrochemical impedance spectroscopy provides two very important pieces of information: the change in capacitance of the organic film that relates to water uptake and the deviation from purely capacitive behavior of the film.

Development of virtual pores in the coating or disbonding of an electrolyte-saturated film at the onset of corrosion causes deviation from capacitive behavior. For either case, conducting paths develop parallel to the coating. Qualification of these conduction paths predicts coating life in corrosive environments as shown by the few available studies that have actually compared impedance data to long-term exposure. Research to evaluate the nature of the shorting process would provide valuable insight into the degradation of the protective properties of organic coatings. Despite some transmission-line models, little understanding exists on the relationship of the low-frequency data to the protective properties of organic coatings.

Low cost computing power is having its impact on all areas. In recent years, the use of microprocessors in the design of instrumentation has brought computing power into the hands of people working in quality control. These analytical techniques are now being applied to coatings, particularly for coating thickness assessment when continuous processing is applicable.
• A comprehensive model to predict long-term performance of coatings should be developed based on carefully controlled laboratory experiments as well as from field experience with older coatings, such as coal tar and asphalt, and modern coatings, such as FBE and urethane, using the power of modern computers and intelligent systems, e.g., artificial neural networks.

**Temperature Effect**
In some applications, one of the critical properties of external organic coatings is resistance to high temperature. It has been found that most organic coatings have problems at temperatures higher than 80°C. There is a need for high-temperature performance in oil and gas pipelines, especially near compressor stations for natural gas transmission and in the transport of higher viscosity crude oils. The operating temperatures of pipelines extend to 150°C. Applicators, coating manufacturers, and owners are working to overcome the challenges associated with high temperatures. Currently no industry standards exist to test high temperature coatings. Manufacturers are developing high temperature coatings based on in-house testing. It is recognized that conventional test methods, such as cathodic disbondment, may not be appropriate. The primary challenge is to obtain adequate flexibility with high temperature performance. For this reason, design criteria for high temperature test methods and for life prediction need to be established.

The criteria for testing coatings for higher temperature applications are not the same as those for lower temperature application. For example, coatings with good cathodic performance, adhesion, barrier properties, impact resistance, and flexibility will protect the pipeline over the lifetime. At elevated temperatures, cathodic disbondment performance may not be relevant if the coated pipe is insulated. But good adhesion, barrier properties, flexibility, and resistance to movement at higher temperatures are necessary.

The question, is not “How do we design the perfect high temperature coating?” Rather it is “How do we know that we have designed it?”

• Based on a systematic study, the temperature limits of existing tests should be explored, and tests to evaluate products for elevated temperature applications should be developed.

**Application**
In general, conditions are better for application of coatings in the mill than in the field. Most modern coatings are applied in the mill.

• Whereas many of the issues of mainline coatings are well understood and standards for mainline coatings have been developed, there is now a need to focus on field applied coatings, both repair and joint coatings.

**Surface Preparation**
Resistance of a coating to disbondment is a property affecting all forms of corrosion; an intact coating that prevents contact of electrolyte with the steel surface will mitigate all forms of corrosion. Studies show that inadequate grit blasting can increase corrosion and stress corrosion cracking susceptibility by creating stress raisers at embedded mill scale. Grit blasting produces anchor patterns suitable for adherence of coatings.
A study of atmospheric exposure of cold applied coal tar enamel coatings revealed that systems applied to wire-brushed surfaces, primed or unprimed, failed within one year. On the other hand, the same systems on sandblasted surfaces, with and without primers, were in satisfactory condition after five years’ exposure in the same environment.

Studies have concluded that visual evaluation (degree of blistering, rusting and creep of blistering and corrosion from a scratch) is not sufficient to predict the effect of surface condition on coating properties.

An investigation on the effect of surface contamination included a study of the presence of varnish or previous coating on the pipe, phosphoric acid treatment, water, and grit or shot quality. The presence of contaminants on the pipe surface was identified using EDAX (X-ray energy dispersion analysis), optical and electron microscopy analysis, grit and water conductivity, and acid wash location. The results indicate that all varnished pipes presented high cathodic disbonding (above 17 mm). This high cathodic disbonding was attributed to varnish particles located on the anchor pattern of the pipe surface. It was also found that the phosphoric acid application after blasting gives better adhesion and less cathodic disbonding. This has been attributed to the surface active pattern provided by the acid that gives better interaction between the pipe surface and FBE.

Based on R&D to evaluate the performance of FBE coatings on contaminated and uncontaminated surfaces with and without phosphoric acid treatment, the following conclusions were drawn: Acid wash treatment greatly improves the performance in CD tests if the surface was initially contaminated. Chloride contamination is the most difficult type of contamination to remedy due to pitting corrosion.

Based on adhesion ratings after hot-water immersion, the maximum tolerance levels of FBE coatings applied over contaminated steel surfaces were at the threshold limit values: chloride (5 µg/cm²), sulphate (7 µg/cm²), nitrate (9 µg/cm²), and ferrous ion (24 µg/cm²). Accelerated performance testing of FBE coatings on ion-contaminated steel substrates revealed that the following coating parameters are functions of contaminant ion concentration: (1) tensile bond strength after hot-water immersion, (2) blister size and density after hot-water immersion, and (3) degree of disbondment after accelerated cathodic disbonding. One study of FBE coating performance was conducted using coupons removed from contaminated production pipe. The steel coupons with contaminations higher than a threshold level failed in the hot-water immersion test, whereas those with lower levels of contamination passed the test.

The use of water jetting and water cleaning has increased recently with advances in equipment technology, the continued concerns with dusting caused by abrasive blast cleaning, and a heightened awareness of the need for chemically clean substrates. NACE 5/SSPC-SP 12 was introduced in 1996 (as an update to NACE Standard RP0172) to describe levels of cleaning using water for substrates to be painted. The NACE and SSPC abrasive blast cleaning standards are well known in the coatings industry, and field inspectors are very familiar with their use and interpretation. Additionally, the blast cleaning standards clearly describe one end condition of the substrate to be painted. In contrast, NACE 5/SSPC-SP 12 describes four end conditions of the...
substrate for visible cleanliness and three conditions for non-visible cleanliness. As a result, the specifier must make specific choices when invoking NACE 5/SSPC-SP 12.

A review paper on the surface preparation standards in various countries was published recently with the intention of determining whether there is a prevailing or common standard in use. Discussions with users in Europe, United Kingdom, Middle East, Japan, Australia and Venezuela have revealed a trend away from national standards towards International Standards. Grit blasting increased the disbonding resistance of coal-tar enamel and FBE coatings, but did not increase the cathodic disbonding resistance of polyethylene tape. Grit blasting also beneficially alters the corrosion potential of the pipe.

Whereas the effects of different surface preparation techniques are well established, the tolerance in the variation within the surface preparation specification is not clear. This aspect is especially important because there are limitations on the control of surface preparation that is possible in the field.

- The effects of minor variations in surface preparation on long-term coatings performance need to be established.

**Temperature Effects**
The intercoat adhesion of coatings cured using cross-linkers depends on both temperature and humidity. The addition of thinner aggravates intercoat adhesion failure. The conversion of the amine to amine carbamate salts at or near the surface, resulting in incomplete curing at the interface, is responsible for intercoat adhesion failure.

The rate of reaction between the amine and the epoxy prepolymer, and the humidity level, are key factors in the intercoat adhesion of epoxy coatings. At appropriate temperatures of application, the rate of reaction between the amine and the epoxy prepolymer is rapid, causing the formation of coatings with good intercoat adhesion. However, at lower temperatures, the rate of the cross-linking reaction is decreased, allowing moisture to permeate the coating and solubilize the amine. In its solubilized form, the amine reacts with carbon dioxide to form stable carbamate salts incapable of reacting with the epoxy prepolymer. In addition, the degree of cross-linking also depends on the RH level to determine the degree of solubilization of the amine that can be converted to the carbamate salt. The appropriate level of applying the coating is generally determined by the glass transition temperature.

- The relationship between application temperature and coating performance needs to be established.

**Installation of Pipeline**
During installation, minor coating damage is bound to occur for various reasons. It is very important to ensure that the pipe coating is adequately tested and that all defects are repaired.
Stockpiled Coating
The breakdown of powder polyester coatings when exposed to UV radiation (270-390 nm, peak ~313 nm) has been explored by monitoring changes in their ion transport properties using impedance spectroscopy. EIS demonstrated that one manifestation of weathering was the development of an increased level of porosity in the films that could be measured quantitatively. The results from impedance spectroscopy were supported by SEM and gloss loss measurements.89

The effect of UV on stockpiled coatings is well known. The extent to which stockpiling affects coating performance is not known.

- Influence of stockpiling on coating performance should be established.

Joint Coating
Historically, the major problems associated with field applied coatings were directly related to the sensitivity of prevailing environmental conditions, such as substrate cleanliness and preparation, and application technique. In addition to good "in service" performance, systems should be easy to apply and tolerant to environmental conditions. While pipeline coating plants have been developed to apply advanced coatings to strict specifications, specifications for coatings applied to field joints have not received the same emphasis.

The increase in use of high quality and expensive pipeline coatings has heightened the need for field joint coating systems to match the quality of factory coatings. A comparison should be made between the different field joint coating systems in terms of technical characteristics, cost, and ease of application in the field. Because of the lack of international standards, pre-qualification trials and production testing in the field are important.

- A systematic study on the effects of field conditions and variations of procedure during the application of joint coatings, including the field performance of the coating, is recommended. This study should include the cohesive and adhesive strength of joint coatings.

Backfilling
There are several factors relating to backfilling that influence coatings. These are soil type, drainage, topography, temperature, and electrical conductivity. The Canadian Energy Pipeline Association (CEPA) has classified the soils in Canada into seven (7) types (Table 2). Even though backfilling is very important, no systematic experimental data are currently available on the effect of backfilling on coating performance.

Fine backfill around the pipe is used to protect the pipe from heavy and sharp rocks or other objects. In addition, the system can include a layer of geotextile fabric just above the fine backfill as additional protection against damaging rocks.90

In very rocky areas, pipeline-construction operations sometimes dictate that an external impact-resistant or barrier material be applied over the pipe to protect the coating from damage during backfilling. The use of a specific backfill, such as compacted sand, is often specified. As an alternate, a barrier coating of concrete or urethane foam can be applied over the coating.
Although high resistance and resistivity are normally associated with a propensity for shielding of cathodic protection current, the resistivity of a barrier material and the corrosion rates and polarization characteristics of the underlying steel are important when considering the potential for shielding and the protection capability of the barrier material.\(^9\)

- Realistic backfill impact testing that includes a method to evaluate the compaction produced by backfilling should be carried out to determine the effect of backfilling on coating performance.

**Soil Forces**
Shear properties of pipeline coatings with elastomeric adhesives are frequently measured in the laboratory. These measurements are expected to correlate with the ability of the coating to withstand the forces of soil burial and movement. The parameters of the laboratory methods are based on calculations of soil forces on pipeline coatings from an analytical model and from finite element analysis.\(^9\)

An apparatus was designed and built to carry out peel and sheer tests at different temperatures. The peel test procedure allows for the measurement of shear strength, which is directly comparable to shear stress sustained by coatings on buried pipelines. The results have shown significant differences between the adhesion properties of individual products. The shear and peel strengths of the coatings are strongly affected, as shown by an exponential drop with increasing temperature. The results conform to an Arrhenius relationship between temperature and the peel and shear strengths.\(^9\)

In one project, existing test methods were examined to determine their applicability to horizontal directional drilling (HDD) and slip boring loads. Two generally applicable methods were identified, Technical Inspection Services' (TISI) Gouge Test and Taber Abraser Test (ASTM D 4060). Both these methods are related to the soil conditions, for which the rotary abrasion tester has been designed. The results can be used to predict coating wear during HDD installation through rock.\(^9\)

- Focused effort to understand soil forces (both physical and chemical) on coating performance will provide useful information for developing strategies to protect coatings.

**Construction of Frontier Pipelines in Extreme Temperatures**
In the near future, the construction of northern pipelines for transmission of natural gas will begin in North America. Construction in the harsh northern climate (temperature as low as \(-45^\circ\text{C}\)) and remote location will impose unique challenges with respect to pipeline protective coatings. Methodologies for evaluating and selecting pipeline coatings for use in northern pipelines will have to be developed, considering the extreme climatic conditions to which the coated pipe may be subjected before it is installed and before operation begins. It is critical that the design of coatings be adequate to protect the pipelines under long-term, severe environmental conditions, including the extreme climatic conditions that will apply in the North before the pipe is installed and operation begins.
• Recommended practices for evaluating coatings for northern pipelines need to be developed and incorporated in standards

Field Testing of Coatings

Repair Coatings
A number of factors that are important in the performance of mainline coatings are also important for repair coatings, including: cathodic disbondment, adhesion, resistance to moisture penetration, impact resistance, penetration resistance, performance at service temperature, abrasion resistance, soil stress, burn-back resistance, chemical resistance, and general handling behavior. In addition, because the repair coatings are applied in the field, the factors discussed in joint coatings are also important. In spite of the importance of repair coatings, no special tests or procedures have been developed to evaluate them.95

Correct material selection can provide substantially improved coating performance and economy. No specific method for repair coating selection exists. The development of field-proven, reliable criteria for selecting and evaluating repair coatings is essential in order to make the best use of available materials and processes. The development of accelerated tests that closely resemble actual field application and service conditions would be useful in the realistic evaluation of repair coatings.

• Tests to evaluate repair coatings, including evaluation of cohesion within the repair coating and adhesion to the mainline coating and to steel pipe, should be developed.

Field Performance

Monitoring
Several techniques are available to detect defects in coatings on buried pipelines. A critical review and evaluation of the Pearson survey, close interval survey, coating conductance parameter, electromagnetic current attenuation, and dc voltage gradient methods have been provided, with the advantages and disadvantages of each method identified.96 An instrumented pipeline pig designed to locate disbonded external coating on operating gas pipelines has been evaluated.95 The results from each method are assessed in terms of defining the need for coating refurbishment and in providing the parameters needed to establish the most cost-effective route to control pipeline corrosion.

The Elastic Wave vehicle has the potential to detect disbonding as well as areas where the coating has been removed.98,99

The development of instrumentation for field testing and inspecting coatings has been accelerated by the use over the last ten years of microprocessor electronics. Such designs are now entering the fourth generation and have included many user features which make the assessment of coatings easier and more accurate than was previously possible. These features include storage of data, statistical analysis, hard copy printout and high accuracy in hand-held
fully portable and rugged units, suitable for use in the most hazardous environments. The most recent improvements have been realised by providing the transducer or probe with electronic intelligence so that its characteristics can be closely matched for optimum accuracy and flexibility. A major benefit of this approach is that the measurement transducer can be of any type and the data output from the electronics can be made to fit a standard format display instrument. In this way, it is possible to make a general purpose kit with a diverse set of measurement modules for a range of tests, such as temperature, humidity, surface profile, and adhesion, as well as a full range of coating thickness modules, using electromagnetic induction and eddy currents for applications that range from thin coatings on small components up to very thick coatings on large structures.

It is becoming more common for gas transmission pipelines to share a common corridor with electric power-transmission lines. Electrical energy that is magnetically coupled from the power line often results in an ac voltage being developed between the pipeline steel and the earth that surrounds the pipeline100.

EIS can be used to measure coating degradation, corrosion under coatings, and cathodic delamination. The EIS method deserves further investigation for measurement of the degradation of coatings during field exposure.

- Development of a remote, accurate monitoring technique to evaluate the status of the coating will greatly enhance pipeline integrity and decrease the number of pipeline incidents caused by corrosion.

**Feedback**
In spite of the close interaction between pipeline owners and coating suppliers at the time of installation of pipe, feedback on coating performance, whether positive or negative, is not, in general, readily available.

- Development of an industry-wide coating database to share the experience of older and modern coatings is an essential logical step to develop an integrity management program. Continuous updating and sharing of such a database will be very useful.

**Operational Conditions**
In general, pipeline operational conditions vary considerably. Among all the various conditions, temperature is quite important. In spite of the well-known temperature variations of pipelines and seasonal fluctuations, no systematic study on the effect of temperature on coatings has been carried out.

- The performance of coatings should be compared at constant and fluctuating temperatures.

**Ground Effects**
Although coatings are routinely evaluated for resistance to a variety of ground factors (e.g., soil stresses), few coatings have been developed with consideration given to their resistance to microbiologically influenced corrosion (MIC). Increased numbers of bacteria at some corrosion sites have been observed. A model, for the development of a site where MIC occurs, indicates
that, in the first phase, soil stresses cause disbondment of the coating, leaving adhesive/primer exposed to the invading water on the pipe surface. Blisters, filled with water, form in the residual coating components on the pipe surface. As the MIC community forms and grows, pitting corrosion begins in those local areas, effectively “fixing” the anodes. In the final phase, periodic exposure to oxygen results in secondary transformation of the corrosion products (siderite and ferrous sulfides) to iron (III) oxides.

Early studies performed in the GRI MIC program demonstrated that a very high percentage of external MIC occurred in connection with disbonded coatings and followed the same general pattern as classic examples of MIC associated with disbonded coatings. The general consensus is that holidays will occur in most coatings by one or more mechanisms (mechanical, chemical, and biological) and that holidays and disbonded coatings offer sites for MIC to occur\textsuperscript{101}. Studies have also shown that levels of bacteria are high on all types of coatings and in all holidays regardless of the level of CP and the pH in the holidays (which ranged from 4.5 to 11.9).

The effects of CP on MIC cannot be assessed simply by measuring the numbers of bacteria. Instead, chemical and site specific factors (e.g., corrosion potential of the steel in the soil) must be taken into account.

A "first-cut" MIC profile was developed to aid in determining which sites were most likely to be susceptible to external MIC. This profile included soil, chemical, biological, metallurgical and operational factors, such as level of CP.

Several reports in the literature have confirmed the utilization of certain pipeline coatings by microorganisms. Microorganisms have the potential to enhance coating disbondment rates as well as contribute to pipeline corrosion as a result of coating biodegradation. Tests used parameters such as coating weight loss and enumeration of microbial cells to assess the biodegradation of coatings. Uncertainties in causes of weight change occur because weight loss can result from solubilization of coating constituents and weight gain can be caused by water absorption. Enumeration is not a measure of activity since microorganisms can be active without increasing their numbers. Thus, enumeration cannot produce direct and quantitative results.

• An objective study to develop a method that monitors microbial population and coating biodegradation will clarify the effects of microbes on coatings.

**Summary**

The following R&D issues have been identified as top priorities\textsuperscript{102}:

• Whereas most of the issues surrounding mainline coatings are well understood and the standards for mainline coatings are recognized, the focus should now be on field applied coatings, both repair and joint coatings.
• The effects of minor variations in surface preparation on long-term coatings performance need to be established.
• The relationship between application temperature and coating performance needs to be established.
• Methods to evaluate the compaction produced by backfilling should be developed to determine the effect of backfilling on coating performance.
• Focused effort to understand soil forces (both physical and chemical) on coating performance will help develop strategies to protect coatings.
• Tests specifically to evaluate repair coatings, including evaluation of cohesion within the repair coating and adhesion to the mainline coating and to steel pipe, should be developed.
• Development of an industry-wide coating database to share the experience of older and modern coatings is an essential logical step to develop an integrity management program. Continuous updating and sharing of such a database will be very useful.
• An objective study to develop a method that monitors microbial population and coating biodegradation will clarify the effects of microbes on coatings
• Methodologies for evaluation and qualification of external pipeline coatings for construction (−45°C) and usage (150°C) at extreme temperatures need to be developed.

Acknowledgements

The authors gratefully acknowledge the support of the Pipeline Research Council International (PRCI) in carrying out the review described in this white paper. Numerous helpful discussions with the chair of the Ad Hoc PRCI committee, Howard R. Mitschke of Shell Global Solutions (US) Inc., are acknowledged. Meetings with the Ad Hoc Committee were most beneficial in helping to achieve the objectives of this project.

References


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94. J.D.Hair, PRCI project PR-003-9715, “Coating Requirements for Pipeline Installed by Horizontal Drilling and Slip Boring”.
Fig. 1: Pipeline Coatings in Canada

- Coal Tar
- Wax & Vinyl Tape
- Asphalt
- Polyethylene Tape
- Yellow Jacket
- Fusion Bonded Epoxy
- 3-Layer
- Composite
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## Table 2: CEPA - Soil Type Description

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<th>Description</th>
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<td>Alluvium</td>
<td>Various textures, utilized in this classification for mountainous areas only</td>
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<tr>
<td>Waterways</td>
<td>Lakes, swamps, rivers, ditches</td>
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<td>Gaciofluvial</td>
<td>Sandy and/or gravel textures</td>
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<td>Moraine Till</td>
<td>Variable soil texture, variable size range of stones sand and gravel clay and silt &gt;1m to bedrock</td>
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<td>Organic</td>
<td>Organic over clay</td>
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<tr>
<td>Lacustrine</td>
<td>Clayey to silty fine textured soils</td>
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<td>Organic over gravel</td>
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<td>Creeks and Streams</td>
<td>Clay bottom (generally &lt;5m in width)</td>
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