Technology and Pilot Testing Evaluation Process

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Contents

Executive Summary

The goal of this project is to provide guidance, in the form of templates with supporting discussion, to the design of pilot tests so that the results of the testing provide an unambiguous indication of the suitability of the technology for the intended purpose. A key concept in this document is that the design and evaluation of a pilot test must be conducted with an understanding of the commercial scale system.

The goals of a pilot test program may include one or more of the following:

- Proof of concept of a new process
- Proof concept of a new type of equipment
- Demonstration of an existing technology in a new application
- Develop information for confirming or scaling up to a commercial design:
    - Consumables (e.g. chemicals, power)
    - Equipment sizing criteria (e.g. membrane flux)
    - Rates of fouling/scaling

The criteria used for the design and evaluation of the pilot test are derived from the goals. These criteria become the basis for formalizing the Success Criteria of the pilot test program. If the testing is conducted by a technology provider, the Success Criteria should be incorporated into the Terms and Conditions of the pilot program contract.

1) Pre-pilot Preparation for Discussions with Technology Providers

The first step towards evaluating a new technology or existing technology from a new supplier is to have a sound understanding of your operational requirements, current costs and accepted commercial models. Some of the key areas to consider are:

- Water Quality and Characterization
- Commercial Considerations
    - Cost Basis
    - Water Treatment Costs
    - Scale-up Costs

The following sections cover each of these topics.

a) Feed Water Characterization and Treated Water Quality

Feed Streams

Source water, flowback and produced water quality can vary drastically depending on location, hydraulic fracturing fluids used and method of application. The typical water analysis shown in Figure 1 is not sufficient for most water treatment technology and pilot test evaluations.

CATIONS			ANIONS		
Ion	mg/L	meq/L	Ion	mg/L	meq/L
Na	17300	752	Cl	32340	911
K	230	5.88	HCO3	130	2.12
Ca	2340	117	SO4	81.0	1.69
Mg	195	16.0	CO3	<0.50	<0.02
Ba	27.5	0.401	OH	<0.50	<0.03
Sr	101	2.30			
Fe	0.46	0.0164			
H+					

Total Dissolved Solids (mg/L)	
Measured	53000 (Calculated)
Relative Density: 1.039	Refractive Index: 1.339
Conductivity (uS/cm): 80200	Resistivity (ohm-m) @25°: 0.12
Total Hardness as CaCO3 (mg/L): 6600	Total Alkalinity as CaCO3 (mg/L): 110
Total Fe (mg/L): 13.9	Total Mn (mg/L): 5.65
Observed pH: 6.62	H2S Spot Test: FALSE

Logarithmic Patterns of Dissolved Ions (meq/L)

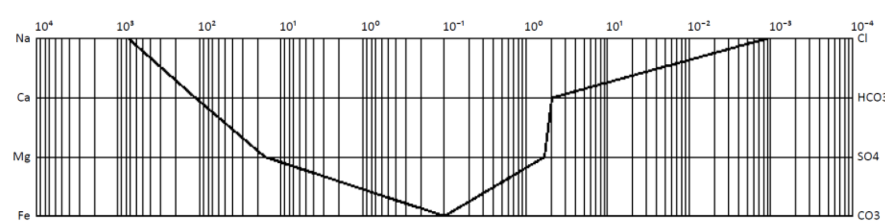

Figure 1: Typical Water Analysis

A complete and current characterization is essential. It will not be necessary to continuously monitor most of these constituents during the pilot. It may not even be necessary to measure them if they do not contribute to waste or by-products and are not predicted to interfere with the treatment process. However, it is important to have a full characterization so that these decisions can be made as part of the assessment of the technology.

A complete characterization should include:

- Major anions (chloride, bromide, fluoride, sulfate, nitrate, nitrite, bicarbonate, carbonate)
- Major cations (sodium, calcium, magnesium, potassium)
- Metals (total and dissolved, including barium and strontium)
- Volatile organic carbon (VOCs)
- Oil & Grease
- Total Organic Carbon (TOC)
- Total Inorganic Carbon (TIC)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- Dissolved gases (H_2S, O_2, ammonia)
- pH
- Alkalinity
- Naturally Occurring Radioactive Material (NORMs)
    - Lead -210 (Bq/L)
    - Radium-226 (Bq/L), Radium-228 (Bq/L)
    - Thorium-228(Bq/L), Thorium-230 (Bq/L), Thorium-232 (Bq/L)
    - Uranium-238(Bq/L)
    - Gross Alpha (pCi/L), Gross Beta (millirems/year)
- Bacteria
    - Sulfate Reducing Bacteria (SRB)
    - Acid Producing Bacteria (APB)
    - Iron Related Bacteria (IRB)
- Residuals from Hydraulic Fracturing fluids
    - e.g. Boron

Further characterization of the organics would include:

- Phenol
- Surfactants
- Benzene, Toluene, Ethylbenzene, Xylenes
- F1 (C6-C10), F2 (C>10-C16), F3 (C16-C34)
- Total PAH

An ion balance should be performed to indicate if the analysis is complete and correct. A balance within 5% is considered good. A balance within 10% is considered acceptable.

The extent of the characterization depends on the objectives of the treatment and the hydraulic fracture fluid type (refer to the following section on the Treated Water Stream)

Notes:

- Ideally, characterizations are based on more than one sample. This should ensure that a grab sample does not coincide with operational abnormality and enhance statistical accuracy of the data.
- Some parameters should be measured in the field at the time of sampling. These include Fe^{+2}, pH, H_2S, TSS.
- Low concentrations of certain species can become problematic for waste disposal or emissions (e.g. VOCs, H_2S, NORMs)

Treated Water Stream

The specification of the treated water stream determines its suitability for the intended purpose. For example, residual iron or residual crosslinkers in flowback or produced water can interfere with the preparation of fresh hydraulic fracture fluids. In these examples, the treated water specification should include these parameters. In addition, the specification must take into consideration the unintended effects of the treatment. Preparing the specification for the treated water stream and predicting the unintended consequences requires a thorough characterization of the feed stream.

- **Identifying the targeted constituents:** This requires a good understanding of the purpose of the treatment. Examples:
  - Reuse of the water for preparing hydraulic fracture fluid requires knowing the type of fracture fluid and the constituents which impact that fluid. This is discussed in the PTAC report *Fracturing Fluid Flowback Reuse Feasibility Study and Decision Tool - Manual and Decision Tree*. For example, the requirements for a cross-linked fluid are more stringent than for a slickwater fluid. Refer to Appendix B for water quality specifications for different hydraulic fracture fluids.
  - Compliance with regulations for surface storage
  - Reuse for another purpose, such a 10 pound brine (used as a drilling fluid).

- **Selecting the limits for important constituents:** For example, a specification for a treatment process which removes iron and which requires a concentration below that which is actually required may eliminate candidate treatment processes, or lead to a pilot which is unnecessarily deemed a failure.

- **Constituents which are not targeted, but can impact the treatment process or the intended purpose:** These constituents can impact the system in several ways and are easy to miss during the technology evaluation and design:
  - Side reactions which interfere with the treatment process or create fouling or scaling. An example is where organics precipitate and foul a membrane or filter. Side reactions are possible whenever chemicals or oxidants are added to the process, where the pH or temperature is changed, and where the stream is concentrated.

  - A treatment process which results in a water which has non-targeted constituents which interfere with the intended process. For example, a pH outside of an acceptable range or where a treatment chemical has been added which may interfere with the intended use.

- **Constituents which are not targeted, but can result in air emissions or difficult to dispose by-products. The treated water is the primary product. By-products are any non-primary outflow stream from the treatment process:**
  - Air emissions: any process which changes the pH, temperature, uses gases for treatment, oxidizes constituents, or uses a change in phase may result in air emissions. The vents from tanks open to the atmosphere can result in air emissions as the tank is filled. Air emissions may create objectionable odours. Air emissions are discussed further below.
  - By-products: any process which uses precipitation, separation, or concentration will generate by-products. By-products are discussed further below.

- **Constituents which are not targeted and which are not important:** For example, it is not advantageous for the specification to require a low concentration of sodium and chloride if the intended purpose is not affected by the presence of dissolved salt.

b) Commercial Evaluation Inputs

The commercial context generally refers to the question “what does the water treatment cost?” That question begs a second question: “compared to what?” Understanding the basis for the answer to the second question, which can be considered the Cost Basis, will avoid potentially unnecessary effort and expense.

Cost Basis

The goal of establishing a cost basis is to have an “apples to apples” comparison. Examples:

- If the goal is to select from one of several different alternative technologies, where the operating costs are relatively small compared to the annualized capital cost, then a comparison of installed cost may be appropriate.
- If the goal of investigating a water treatment technology is to reduce the cost of an ongoing operation, then a comparison of cost on a dollars per cubic meter of water treated may be appropriate.
- If the goal is to outsource water treatment, then a comparison of the internal and outsourced cost on a dollars per cubic meter basis should be considered.

When the basis of a comparison is an internal cost for water, the challenge is identifying and quantifying the costs. In some cases, portions of the capital costs associated with water treatment are treated as an expense and in other cases capitalized.

For reference, different business models for establishing a cost basis are discussed in a later paragraph in this section.

Central Processing Facility (CPF), Pad-based, and Mobile Systems

Water treatment for hydraulic fracturing operations may be centralized in a processing facility or be conducted at the point of production, depending on the location and available infrastructure. Location for a new technology should be touched on early in discussions with technology providers to ensure that both parties are not making assumptions about available (or unavailable) infrastructure, including utilities and access.

The location of the water treatment, and the expected duration of its use, impacts how the capital cost of the equipment is allocated. This can range for more than 10 years in a CPF to a few weeks for a mobile system.

Business Models

There are many variations of business models. Depending on the model the supplier can be a technology provider or a supply team consisting of a technology provider, a construction company, and an operating company. The following descriptions are intended to illustrate the basic types to indicate the difference in responsibility for capital and operating costs between the supply team and the producer, which impacts the cost of water treatment.

(1) Equipment Sale (ES)
This model requires the technology provider to source, procure, and deliver all equipment. The producer is responsible for installation of the equipment, including providing all materials not included in the equipment supply, and ongoing operation and maintenance costs.

(2) Design Build (DB)
This model requires the technology provider to source, procure, deliver, and install all equipment. This model is also referred to as Turnkey. The technology provider often works with a construction company for the installation. The producer is responsible for ongoing operation and maintenance costs.

(3) Design Build Operate Maintain (DBOOM)
This model functions as a dedicated service model between a supply team and the producer. The supply team often consists of a technology provider working with a construction company for the installation and an operating company for the operation and maintenance. The ownership of the plant remains with supply team. The contract between the supply team typically includes guarantees for the supply of the service from the supply team and a guarantee of payment, even when the service is not required, for a fixed term.

These mutual guarantees and the fixed term are the differences between this model and a Merchant Plant model.

Note: a Merchant Plant is one where the technology or service is provided on an as-needed and first-come-first-served basis at a cost that is negotiated on a case-by-case basis. There are no guarantees for the availability of the service or the price.

If the producer takes ownership of the plant immediately, then model 3 becomes a Design Build Operate Maintain (DBOOM). If the producer takes ownership and all operational responsibilities of the plant after some period of time, then model 3 becomes a Design Build Own Operate Maintain Transfer (DBOOMT). Once transferred, the Producer will be responsible for all operational and maintenance costs.

2) Technology and Commercial Evaluation

The design of the pilot test takes into consideration the expectations of the performance of the technology at the commercial scale. This section presents the basic elements of the commercial scale evaluation and how those elements influence the design of the pilot test. The discussion supports the items shown in the templates. The design of the pilot is linked to the commercial scale technology and the discussion in these sections includes references to both.

a) Process Flow Diagram

One of the most important tools for a technology and eventual pilot evaluation is the process flow diagram (PFD). The PFD shows the major components in the system. A variant of the PFD is the Process Control Diagram, which is a PFD with the primary control loops for flow, pressure, temperature, etc. included. In addition to showing the flows in and out of the system, the PFD shows flows within the system between the major components. This distinguishes the PFD from a "black box" diagram, where only the flows in and out of the system are shown.

The extent to which internal flows are shown is often subject to concerns about intellectual property confidentiality. A review of the internal flows is desirable for two reasons. First, it provides further insight into whether the claims about the technology are reasonable. Second, it provides guidance for process measurements and sample collection and analysis during the pilot.

The streams in and out of the system required for a technology and eventual pilot evaluation are described below and include flow rate, temperature, pressure, and characteristics. A test of the completeness of the information is preparation of a heat and mass balance.

Feed Stream

The feed stream represents the water which will be treated. In addition to providing information about the constituents which the treatment is intended to change, it is important to provide a full characterization of the feed stream so that the fate of all constituents can be evaluated. For example, hardness removal may be the goal of a treatment technology and the feed characterization would focus on hardness data. Hardness removal will usually also capture radium compounds and may result in a hazardous waste so it is important to have data on NORMs. Another example is the use of electro-coagulation for bacteria removal. Organics in the feed stream may foul the electrodes in the unit so it is important to have organic matter identified and characterized.

Variability of the constituents in the feed stream, both in identity and concentration, must be considered. Examples include ammonia and H_2S.

As noted in the discussion on feed characterization, it will usually not be necessary to analyze for every constituent identified in the characterization. Those constituents which become important are ones that:

- Are indicators of the effectiveness of the treatment
- May interfere with the treatment process – the technology provided must identify those constituents
- Have potential to affect emissions or by-product streams in a negative way (e.g. odorous air emissions or hazardous by-products)
- Have the potential to foul, scale, or corrode equipment

Treated Water Stream

The treated water stream is discussed in detail in Section 1)a). The considerations outlined there are important for the technology evaluation.

Utilities and Chemicals

Utilities and chemicals are a cost and practicality issue and includes availability, transport, storage, and hazards evaluation.

(1) Utilities, including:
  (a) Power (voltage)
  (b) Fuel (diesel, natural gas)
  (c) Steam
  (d) Compressed air
(2) Chemicals, including:
  (a) Commodity materials
  (b) Proprietary Products
  (c) Quantity
  (d) Characteristics
  (e) Health, Safety, and Environment Considerations
    (i) Toxicity
    (ii) Handling and Storage
    (iii) Containment requirements

By-Products, Waste Streams and Air Emissions

Air Emissions

Any process which changes the pH, temperature, uses gases for treatment, oxidizes constituents, or uses a change in phase may result in air emissions. The vents from tanks open to the atmosphere can result in air emissions as the tank is filled. Air emissions may create objectionable odours.

Regulatory Requirements

In B.C, permits and regulations generally refer to larger industrial facilities that are required to report their emissions due to their size or production capacity. There are no apparent specific requirements for pilot plant air emissions under the BC Environmental Management Act. Guidance can be found by looking at the B.C. Oil and Gas Waste Regulation which states authorization is given to discharge air contaminants from small operations, subject to conditions. Most water treatment pilot plants would be classified as small operations. The conditions which apply set limits for H_2S concentrations, odours from tank vents, and give the authorities the right to demand additional information. In the event a permit is necessary, the issuance of a permit or approval is based upon a multi-step process found in B.C.'s *Waste Discharge Authorizations* document.

Reporting requirements for Alberta also vary depending on the substance released, size, and nature of the facility. The Alberta Energy Regulator (AER) *Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting* contains the requirements for flaring, incinerating, and venting in Alberta at all upstream petroleum industry wells and facilities. There is no reference to pilot or test facilities. Guidance can be found in the directive under Section 8.2 pertaining to "Limitations of Venting Gas Containing H_2S or Other Odorous Compounds". No reference is made to the size of the facility in regards to air emissions, however the directive states 'venting and/or fugitive emissions must not result in any offensive hydrocarbon odours outside the lease boundary that, in the opinion of the AER, are unreasonable either because of their frequency, their proximity to surface improvements and surface development (as defined in *Directive 056*), their duration, or their strength'. Specific limits are set for H_2S, SO_2, and benzene and dispersion modeling is required under certain conditions. The directive also states that venting must not result in exceedances of the Alberta Ambient Air Quality Objectives (AAAQO) outside of the lease boundary. The EPEA publishes a *Guide to Content for Industrial Approval Applications* which describe the details required for an approval application in Alberta.

Table 1 provides a summary of the ambient air quality objectives of substances which may be released from a water treatment operations. The summary was compiled from the Ambient Air Quality Objectives published by the British Columbia, Alberta, and Saskatchewan. This guide is not exhaustive and users should refer to original Ambient Air Quality Objectives as published by the respective provinces.

Air Emissions Monitoring

In accordance with the BCOGC Regulations and the AER, emissions released below the ambient air quality objectives threshold do not require continuous monitoring. Due diligence must be taken and sensors may be required to measure and document substances released and ensure they do not exceed air quality objectives. The Environmental Management Act (EMA) of B.C. and Environmental Protection and Enhancement Act (EPEA) of Alberta provide more detail on objectives to manage air emissions.

Table 1: Acceptable Limits for Ambient Air Quality Objectives

Acceptable Limits for Ambient Air Quality Objectives				
Substance	**µg m^{-3} (AB)**	**µg m^{-3} (BC)**	**µg m^{-3} (SK)**	**Expected Release (µg m^{-3})**
Ammonia				
1-hour average	1,400			
Benzene				
1-hour average	30			
24-hour average	3			
Carbon monoxide				
1-hour average	15,000	14,300	15,000	
8-hour average		5,500	6,000	
24-hour average	6,000			
Chlorine				
1-hour average	15			
Chlorine dioxide				
1-hour average	3			
Ethylbenzene				
1-hour average	2,000			
Hydrogen chloride				
1-hour average	75			
Hydrogen sulphide				
1-hour average	14		15	
24-hour average	4		5	
Methanol				
1-hour average	2,600			
Nitrogen dioxide				
1-hour average	300			
24-hour average	45			
Ozone (ground level)				
1-hour daily maximum	160	160	160	
8-hour average		123		
Particulate Matter				
Fine - 2.5 microns or less				
24-hour average	30	25		
Total Suspended				
24-hour average	100	120	120	
Annual geometric mean	60	60	70	
Phenol				
1-hour average	100			
Sulphur dioxide				
1-hour average	450	200	450	
24-hour average	125		150	
30-day average	30			
Annual average	20		30	
Toluene				
1-hour average	1,880			
24-hour average	400			
Xylenes				
1-hour average	2,300			
24-hour average	700			

µg m^{-3} is the weight, in micrograms, of the substance in one cubic meter of air.

By-Products (Waste)

By-product streams must be identified, characterized, and classified before a disposal option is selected. By-product streams should be identified on the Process Flow Diagram (PFD). It is not uncommon that the PFD does not include all of these streams. For reference, to help identify the potential sources of by-products, any process which uses precipitation, separation, or concentration will generate by-products. The by-products will become a waste stream when it is desired to dispose of them off-site.

After the disposal option is selected, the specific analyses required for acceptance of the waste at the disposal facility, and the requirements for transporting the by-product, can be identified.

Characterization

Characterization identifies the waste's physical, chemical, and toxicological characteristics. The waste must then be compared to regulatory requirements in order to classify the waste as DOW or non-DOW. This is an essential step in order to properly handle and dispose of the waste.

Typical constituents of concern from hydraulic fracture flowback are barium, strontium, radiological species, and benzene, toluene, ethyl-benzene, and xylenes.

Classification

Alberta regulations classify oilfield wastes as either a dangerous oilfield waste (DOW) or non-dangerous oilfield waste (non-DOW). At a federal level, waste is generally given the designation of hazardous/non-hazardous. It is the responsibility of the waste generator to determine the appropriate waste classification.

Note: The classification is based on a comparison of the waste's physical, chemical, toxicological, and radiological characteristics to regulatory requirements.

Transportation on Public Roads

Transportation procedures are outlined by the Transportation of Dangerous Goods Regulations (TDGR) based on the waste classification. The *Alberta User Guide for Waste Managers* (Tables 3 & 4) can be used as reference to identify waste that contains special provisions and restrictions and/or fall within TDG Classes Column 1-9, which are prohibited wastes.

In some cases, manifest documentation may be required, depending on the nature of the waste. Manifest documentation, along with other waste-related information, must be provided to both the waste hauling services and the proper oilfield waste management facility.

Disposal Facility Requirements

In Alberta, the AER maintains an approved *Oilfield Waste Management Facilities* list containing the facility name, location and type of waste that can be processed. Waste facilities' main concern is whether the waste is classified as a hazardous or non-hazardous waste. There are separate procedures and regulations to follow depending on if the waste is a solid or liquid.

AER Directive 058 describes the *Properties of Dangerous Oilfield Wastes (Table 4.1a)*. The properties in Table 4.1a, in addition to those in Table 4.1b, define the criteria for hazardous waste.

The *Alberta User Guide for Waste Managers* can be referenced for a more exhaustive list of both solid and liquid hazardous waste. These are classified as dangerous oilfield wastes and cannot be immediately disposed of at Alberta landfills. Should the waste type not be listed on the references above, the generator may use their previous knowledge of a waste stream to determine if it is hazardous or not. This may be supported with analytics performed by approved accredited laboratories. If the exact waste stream description cannot be identified, a unique description can be specified in accordance to waste acceptance protocols accompanied by supporting analytics.

In British Columbia, hazardous waste must be managed according to the Environmental Management Act and the Waste Discharge Regulation. Facilities such as Tervita provide a *Solid Waste Acceptance Protocol* which can be followed to assist in identifying acceptable solid waste and analytical testing requirements for each waste stream or type. This protocol describes examples of acceptable waste, prohibited waste, and landfill disposal criteria.

b) Equipment

Materials of Construction

The materials of construction for pilot plants may not be suitable for a commercial facility but will serve the purpose of a pilot test. Conversely, materials of construction which are suitable for commercial equipment may not be suitable for the intermittent operation of a pilot plant.

The parameters to consider are dissolved gasses (oxygen (O_2), hydrogen sulfide (H_2S), carbon dioxide (CO_2)), chloride (Cl), pH, and temperature. The operating conditions to consider are start-up, shutdown, inspection, and the chemicals used for cleaning.

In general, carbon steel will be corroded if:

- dissolved O_2 is present
- the pH is below neutral
- H_2S or CO_2 are present

Dissolved O_2 may not be expected in a commercial operation. However, the intermittent operation of a pilot plant, the opening of equipment for inspection, and tanks which are open to the atmosphere can result in dissolved O_2 and corrosion. Another consideration is that the corrosion may not be an issue for the pilot equipment, but the resultant dissolved iron may interfere with the treatment process.

316 stainless steel is subject to localized corrosion (pitting, crevice, and stress cracking) to varying degrees depending on the combination of dissolved O_2, Cl, pH, and temperature. However, while 316 stainless steel may not be suitable for a commercial plant, the initiation period for localized corrosion may allow its use in a pilot plant.

Non-metallic materials are attractive because they are resistant to most forms of inorganic corrosion. Most non-metallics are limited to temperatures below 90^{o}C. Epoxy lined Fibre-Reinforced Plastic (FRP) can be used to temperatures of 110^{o}C.

Site Preparation

Road Access Requirements

At the proposed water treatment location, it would be useful to be familiar with the access conditions. Aspects to consider include:

- Can the site be accessed year-round?
- Is the site access suitable for all types of delivery vehicles?

Space Requirements

Space requirements for primary and auxiliary equipment require consideration. A plot plan should be provided. In the case of limited space availability at the site, the delivery and installation requirements (e.g the use of cranes) should also be identified in advance.

Secondary Containment

Secondary containment is required for chemicals and possibly for the treatment equipment itself. Secondary containment can be avoided if chemicals are stored in double walled tanks and if the pilot equipment has built-in containment.

Others Special Considerations

It is possible that there are special and unusual site considerations for a particular technology not covered in this report. These could include special requirements for chemical storage, installation or ongoing operations after start-up. These unusual requirements are often identified upon careful review of a *Daily Operations Description*, to be provided by the technology provider. This is discussed in more detail in the next section.

Fixed or Mobile

Pilot test equipment is generally mobile, with the ability to quickly move from one site to another. The commercial scale equipment may also be mobile or be designed as more permanent or semi-permanent system. This should be confirmed with the technology provider.

c) Operator Requirements

The operator prerequisites should be provided. This includes details on operator education level and if additional training is required. In order to assess if additional operators will be necessary, it is also useful to understand how frequently the system requires attention or if the equipment can run unattended.

- Operator training
    - Is additional training required to operate the new equipment?
    - Is there an expected level of education?
- Attention
    - Does the system run unattended?
        - If not, how frequently, in a 24 hour period, is action required?

d) Commercial Considerations

Water Treatment Cost

After establishing the Cost Basis (see Section 1)b) and reviewing the technology, it is necessary to collect the information required to develop the water treatment capital and operating costs. The costs must take into consideration:

- What is the treatment capacity of the process at the commercial scale?
- Is the treatment fixed in a Central Processing Facility (CPF), located temporarily or permanently on a pad, or mobile?
- Utilities, chemicals, waste disposal
- Site preparation
- Number of operators
- Number of shifts

Scaling Up Costs from Pilot to Commercial

Pilot plants are typically intended to demonstrate a technology, such as electro-coagulation, a treatment process, such as physical chemical treatment followed by filtration, or to confirm a design parameter, such as membrane flux. Intensive costs, such as chemical dosing, can be scaled to a commercial plant. Intensive design parameters, such as membrane flux, can be used to size commercial equipment. Equipment costs do not generally scale up from a pilot plant to a commercial plant. It is necessary to understand the commercial plant costs as part of the evaluation process for deciding to proceed with a pilot test.

3) Conducting a Pilot

Once the Technology and Commercial Evaluations have been completed and the decision to conduct a pilot has been reached, careful consideration of numerous aspects is required, ranging from process flow analyses to code compliance. The following sections summarize these areas and include:

- Process Flow Diagram Analysis
  - Feed Stream
  - Treated Stream
  - By-Products and Waste Streams
  - Utilities and Chemicals
- Design and Equipment Reviews
  - Materials of Construction
  - Electrical and Mechanical Code Compliance
  - Site Preparation and Secondary Containment
  - Operator Requirements
  - HAZOP
- Process Monitoring and Data Collection
- Sampling and Analyses
- Test Protocols
- Daily Operations Description
- Terms and Conditions for Test Agreements
- Scope of Responsibilities
- Schedule
- Insurance
- Other personnel on site

a) Process Flow Diagram Analysis

The process flow analysis for the commercial scale and pilot scale is identical. Refer to Section 2)a) for details.

b) Design and Equipment Reviews

Materials of Construction

The materials of construction take into account the variables and aspects previously described in Section 2)b).

Electrical and Mechanical Codes and Certification

Electrical

New pilot (not yet fabricated)

All electrical systems must be compliant with CSA code (Canadian Standards Association) and be stamped and approved by a CSA-certified inspector.

If the pilot will be fabricated in Canada, it is beneficial to have the inspector conduct an intermediate inspection before fabrication is complete. This will alleviate the need for rework and subsequent schedule delays.

If the pilot, or parts of the pilot equipment, are fabricated outside of Canada, CSA approval and stamps will be required as part of the customs documentation. Obtaining CSA approval outside of Canada can take time and schedules should take this into account.

Existing pilot

If the pilot unit has already been fabricated (in Canada), the electrical engineering drawings and CSA inspection approval report should be readily available for review.

If the pilot was fabricated outside of Canada, obtaining CSA approval may require rework or replacement of components, leading to additional cost and time.

Mechanical

Pilot plants which arrive at customs without consideration of mechanical code compliance can result in extensive delays and additional costs. The following discussion is relevant to Alberta and serves as guidance for other provinces.

CSA Standard B51-09 paragraphs 6.1, 7.1, and 8.1 specify that the standards governing the design, construction, installation, inspection, testing, and repair of boilers, pressure vessels, and piping shall be the ASME Code.

Pressure Equipment is defined in the Alberta Safety Codes Act S01 (Act) as "a thermal liquid heating system and any containment for an expansible fluid under pressure, including, but not limited to, fittings, boilers, pressure vessels and pressure piping systems, as defined in the regulations."

ABSA (Alberta Boilers Safety Association) is a regulatory authority and administers Alberta's pressure equipment safety programs under the Safety Codes Act, and has the authority to enforce pressure equipment safety as set out in the legislation, including registration of pressure equipment as required by the Act. Pressure equipment is registered when ABSA is satisfied that a design meets the requirements of this Regulation.

Depending on operating temperature and pressure, size, and volume, some pressure equipment is exempt from registration. ABSA provides the Codes Act Flow Chart (AB-508) to help determine if a pressurized item is subject to the Safety Codes Act and what requirements apply. The examples below have been copied from the regulations:

- a pressure piping system having an aggregate internal volume not exceeding 500 litres are exempt from the requirement to have the design registered
- a pressure vessel or pressure piping system that is fully vented or operating with one or more pressure relief devices with set pressure not exceeding 103 kilopascals and sized so that the operating pressure cannot exceed 103 kilopascals
- Pressure piping that does not exceed DN 50, that has a maximum allowable working pressure not exceeding 1035 kilopascals, that has a design temperature between minus 29 degrees Celsius and 186 degrees Celsius, that contains air, nitrogen, argon, carbon dioxide, steam or hot water, and that is constructed to the applicable ASME Code, is exempt from all the other requirements of this Regulation except Section 35

Note: These are examples only and should not be used as an exhaustive interpretation of the regulations. The pilot provider should conduct a thorough review of the regulations to ensure compliance.

New pilot (not yet fabricated)

If the pilot will be fabricated in Canada, a review of the process components (operating temperatures and pressures) should be conducted to determine if registration is required for piping and vessels and if CRNs (Canadian Registered Number) are required for vessels and fittings. If there is any ambiguity, then the relevant regulatory body should be consulted.

Existing pilot

If the pilot unit has already been fabricated (in Canada), then design approval and registration from the appropriate regulatory body as well as CRNs (Canadian Registered Number) for vessels and fittings should be available for review.

If the pilot unit was fabricated outside of Canada, then a review of the process components (operating temperatures and pressures) and the relevant pressure vessel regulations should bring to light if any of the equipment requires registration as pressure vessels or piping. If there is any ambiguity, then the relevant regulatory body should be consulted.

Regulatory Bodies

Vessels and piping registration is completed through one or more of the following regulatory bodies:

- ABSA (Alberta Safety Authority)
- BCSA (British Columbia Safety Authority)
- TSASK (Technical Safety Authority of Saskatchewan)

Notes:

1. *It can be very difficult and time-consuming to obtain registration for existing pilot units fabricated outside of Canada.*
2. *There are exceptions to the regulations based on operating conditions. A careful review of the regulations is strongly encouraged.*
3. *Registration with more than one authority may be required if the pilot will be used in different provinces.*

Site Preparation and Secondary Containment

Site preparation includes space and access requirements, along with secondary containment. The pilot considerations for these aspects are the same as those for the commercial technology. Refer to Section 2)b) for more details.

Operator Requirements

The same considerations that are given to operator requirements at the commercial scale are also accounted for at the pilot level. Refer to Section 2)c).

HAZOP

A review of pilot design aspects and operational safety in the form of a HAZOP is recommended.

Note: A pilot HAZOP should focus on ensuring operational safety for temporary facilities. It may not be necessary to follow company-specific design practices that are not code-related, are measures taken for very unlikely events or are in place to manage risk for large quantities/flows not representative of the pilot operating conditions.

Participation in the HAZOP by both the representatives from the Technology Provider and the Host Company will lead to better collaboration and improve understanding of the pilot equipment and operating conditions.

HAZOP follow-up should be identified by the end of the review, including

- HAZOP report, including action items and responsible parties
- Implementation deadline for recommended changes
- Follow-up report documenting changes
- Sign-off persons (ideally one representative from both the Host Company and Technology Provider)

c) Process Monitoring and Data Collection

Careful and planned data collection and process monitoring is critical for assessing the suitability and success of a technology. The critical parameters should be identified as well as the frequency and acceptable methods for measuring or determining those parameters. Proper selection of process instrumentation plays an important role in the method for measuring and determining critical parameters.

As examples, flux is important for assessing the separation ability of a membrane-based technology, the TSS level in injected fluids plays can have a detrimental effect on tight formations and power consumption for thermal treatments can be significant. Identification of the critical parameters needs to take into account not only the technology itself but also the **source and treated water specifications** and geological formations.

The data collection may be manual or automated. In either case, it is best to generally outline how the data will be managed and reported during the evaluation phase of a new technology.

d) Sampling and Analysis

Sampling requires advance planning, in particular with respect to sampling locations. The grab points must be representative of the process streams and be able to support the determination of the critical parameters. For example, for a membrane-based technology, sampling points should include immediately upstream and downstream of the membrane and if power consumption is critical, then measurements should be made during normal and peak conditions. In addition, sampling frequency, equipment, container types and personal protective equipment (PPE) should be considered.

Analyses are typically a combination of in-field measurements and third party laboratory analyses. The breakdown between in-field and laboratory analyses should be provided, with an emphasis on evaluating key parameters on site. The key parameters will vary from site to site, depending on the water quality requirements and presence of trace constituents. For example, if TSS is critical, then an onsite method for determination should be implemented since sample ageing between the time of sampling and the time of analysis at a third party laboratory can have a significant impact on the results.

e) Test Protocols

A Test Protocol should be included for any pilot testing program. This can be a brief document which outlines distinct testing programs. For example, if the technology removes residual gel from gel-based flowback using a specialty chemical, then a testing protocol could include variations in the chemical concentration under different temperature and flow conditions. It is best to layout in advance the proposed combination of variables and how long the evaluation period is for each test.

Note: During pilot testing, test protocols can change rapidly based on evolving results. Involved parties need to remain flexible with respect to quick changes. This does not detract from the value in developing a plan prior to start-up as the test protocols will help focus thinking around testing goals.

Finally, every technology has its limitations and pilot testing is an excellent opportunity to discover those boundaries. “Pushing the limits”, without compromising material or structural integrity, is strongly recommended.

f) Daily Operations Description

A Daily Operations Description is a short document (typically one to two pages) which provides an overview of day-to-day activities involved in operating the equipment. This document is not a detailed engineering Control Philosophy, rather it will bring to light many of the aspects already outlined in this report and any other technology-specific aspects that may require special considerations for site preparation, operator requirements, consumables handling, storage, disposal, etc.

g) Terms and Conditions for Test Agreements

A Test Agreement between the selected Technology Provider and the Host Company should be initiated as soon as possible. In addition to covering legal aspects of the Technology Provider-Host Company relationship, this document will also address most of the details from subsequent sections as well. For this reason, drafting of the Terms and Conditions for the Test Agreement should begin early on in the process.

The key Terms and Conditions that all Test Agreements should include are:

- Data and Results Ownership
- Ownership of Improvements
- Licences
- Proof of Outcome
- Confidentiality
- Dispute Resolution

Aspects such as Scope of Responsibilities, Schedule and Test Protocols are often included as Appendices to the Test Agreement.

Note: Standard Terms and Conditions typically used for Contractors and Sub-contractors often either a) do not include many of these key aspects or b) are one-sided in wording. It is important to include reciprocity in all aspects to protect both the Host Company and the Technology Provider.

Data and Results Ownership

If the case where the Host Company pays for the pilot, the ownership of the data and results is most often jointly owned, with the understanding that each party will provide approval regarding how and to what degree the results are published. In the case where the Technology Provider pays for the pilot, they will likely maintain ownership of data and results with an agreement to share results. Note that in this case, there is the risk that the Technology Provider may withhold information about the testing.

Ownership of Improvements

Improvements can be divided roughly into two categories

a) Improvements to the Technology, as provided by the Technology Provider
b) Improvements unrelated to the Technology which may arise during the course of pilot testing

In case a), the improvements are owned by the Technology Provider.

In case b), the improvements are generally owned by the Host Company.

Because of the aforementioned distinction, it is important to clearly define both the term 'Technology' and 'Improvements' in the Test Agreement.

Licences

If the technology is typically provided with a licence and the Host Company finances the pilot testing, then the Test Agreement may include provision for a future licence arrangement. This may take the form of

- a reduced licence fee for the first or first several commercial units that the Host Company could purchase in the future.
- an exclusive licence for a set term.

If the Technology Provider pays for the pilot, then the Test Agreement is unlikely to include incentives for reduced or exclusive licences.

Proof of Outcome

The Test Agreement should outline mutually agreed upon Success Criteria. Examples include the Treated Water Specification, Chemical Consumption, Utility Consumption, By-Product Characteristics and Volumes, Air Emissions, etc.

Confidentiality

Confidentiality clauses are standard in Test Agreements. Several aspects to keep in mind are:

- Term
- Actions in event of a breach of confidence
- Conditions under which each party may disclose confidential information to third parties.

Dispute Resolution

Dispute resolution, in the event of breach of contract, should be reviewed for:

- Who bears the costs
- Jurisdiction

h) Scope of Responsibilities

A clear outline of the scope of responsibilities helps define budgets and alleviate disputes once the Test Agreement is executed. The parties responsible for the equipment and operation will depend on the nature of the Test Agreement, primarily who will finance the project.

Responsibilities should include, but are not limited to:

- Site Preparation
- Mobilization, Installation and Demobilization
- Utilities Connections
- Consumables
- Waste Disposal
- Operations

Site preparation

Site preparations include laying of rigmats, secondary containment installation or repositioning of existing equipment.

Mobilization, Installation and Demobilization

The party responsible for mobilization and demobilization of equipment as well as the mechanical and electrical installation of the test equipment should be clearly indentified.

Utilities connections

Responsibility for the power and water connections, including the necessary hoses, cables and piping should be included.

Consumables

The party providing consumables required during pilot testing (chemicals, filters, etc.) should be identified.

Waste disposal

Responsibility for the disposal of waste, either on-site or off-site to third party facilities should be included.

Operation

Operation of the pilot includes:

- Repair and maintenance
- Hiring and training of operators
- Accommodations for remote locations
- HSE Compliance

The responsible parties for each of these areas should be identified.

i) Schedule

The testing schedule should include estimated times for:

- Mobilization
- Installation
- Start –up and commissioning
- The overall testing period
- Demobilization

j) Insurance

Standard agreements between a Host Company and Contractors include provisions for providing evidence of Commercial General Liability (CGL) and Workers Compensation (WCB).

In addition to this level of coverage, the other insurance areas to consider are Property Premiums, Boiler & Machinery insurance and Pollution Policies.

Property coverage is usually included with CGL as an add-on, but needs to be specifically requested. This insurance covers damage or loss to property due to outside forces (fire, flood, vandalism, etc.).

Another policy to seriously consider is the Boiler & Machinery insurance which covers accidental breakdown of a piece of equipment with accompanying physical damage that is of such magnitude or is sufficiently serious to necessitate repair or replacement of the equipment or part of the equipment. This policy should also include any rental equipment during the course of the pilot testing.

> *Note: Careful review of rental equipment agreements is recommended to determine if the supplier or user are liable for potential damages.*

A Pollution Policy covers sudden and accidental spills. These policies can cover a wide variety of scenarios including clean-up, fines, personal injury, etc. The selected policy will depend heavily on the nature of a potential spill, location, secondary containment available and potential clean-up costs.

Discussions with insurance providers can be challenging as most do not understand new technologies and/or pilot testing. In preparation for discussing insurance, it is best to have the following documentation ready:

- Description of the process at a high level. Include key equipment
- Plot plan
- List of modules and rental equipment
- List of safety-related aspects, including a list of chemicals
- Description of operator activities (normal and for repair & maintenance)
- Description of waste handling
- Location and time-frame

Note: the focus of all the aforementioned documentation should be on safety (the inherent safety of the equipment, operating procedure, waste handling, etc.). Insurance providers are heavily focused on risk and are far less interested in technical details.

k) Other personnel on site

Application Process

When a new Technology Provider is coming on site for the first time, most companies have an application process. The turn-around for approval on these applications can be as fast as a week, but is generally longer. The Technology Provider should be made aware of the application requirements and time frame for approval as soon as possible to avoid schedule delays.

Contact persons for spills or fires during non-operating hours

The Technology Provider should provide a 24-hour emergency response list of contact people. This list should be available to the Host Company's on-site personnel.

Training (WHMIS, TDG, H_2S alive)

The training requirements for operators will vary depending on the location and nature of the equipment. Examples include WHMIS, TDG, H_2S Alive and Confined Entry. The external Technology Provider must ensure all personnel have all necessary safety tickets required for daily operations. These must be presented upon request and copies stored in personnel files.

Training (site-specific)

All operators who are new to the site require a site-specific orientation to procedures and equipment. This will include site-specific heavy machinery up to and including emergency exit procedures.

Conclusions

The goals of a pilot test program may include one or more of the following:

- Proof of concept of a new process
- Proof concept of a new type of equipment
- Demonstration of an existing technology in a new application
- Develop information for confirming or scaling up to a commercial design:
    - Consumables (e.g. chemicals, power)
    - Equipment sizing criteria (e.g. membrane flux)
    - Rates of fouling/scaling

The criteria used for the design and evaluation of the pilot test are derived from the goals. These criteria become the basis for formalizing the Success Criteria of the pilot test program. If the testing is conducted by a technology provider, the Success Criteria should be incorporated into the Terms and Conditions of the pilot program contract.

The evaluation of the pilot program results is a comparison between the Success Criteria and the testing results and analysis. There are two levels of success. The first level is when the correct amount and type of data and results were obtained to conduct an assessment of the technology. The second level is when the results meet or exceed the expectations in the Success Criteria.

Finally, all pilot tests will have unexpected findings and outcomes. In many cases, the unexpected things provide valuable information. The common factor to capturing the benefits of the expected and the unexpected is the maintenance of thorough and complete records of observations.