Unconventional Resource Development

Understanding the Reservoir and Applying Technological Innovation to Create Opportunities

November 2013

Dawson Energy Advisors Ltd.
**Topics to be Discussed**

- Foundation of Unconventional Reservoirs
- Exploration Strategies – A critical aspect for success
- Reservoir Properties
  - Hydrocarbon Generation and Storage
  - Permeability Pathways and Fracability
- Accessing the Reservoir
  - Drilling Technologies
  - Hydraulic Fracture Stimulations
  - Microseismic Tools and Observations
- Opportunities for Unconventional Resources in Mexico
- Role of Government
  - Lease Tenure and Royalties
  - Stakeholder Issues
  - Pace of Development
Topics to be Discussed

Foundation of Unconventional Reservoirs

Exploration Strategies – A critical aspect for success

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  Permeability Pathways and Fracability

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Opportunities for Unconventional Resources in Mexico

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  Pace of Development
Smaller Reservoirs Easier to Develop

High Quality

Larger Reservoirs More Difficult to Develop

Medium Quality

Lower Quality

Modified from Schmezl, 2009

Coalbed Methane

Decreasing Reservoir Quality

Tight Gas

Gas Shales

Tight Oil

Gas Hydrates

Increasing Cost to Develop

Increasing Technology Requirements

1000 md

100 md

1 md

0.1 md

0.001 md

0.00001 md
Note: Natural Gas from Coal reservoirs are classified as unconventional due to type of gas storage.
The shift from conventional to unconventional reservoirs reflects a change in grain size from higher permeability, coarser grained rocks towards very fine grained rocks with low permeability.

Reservoir variability both vertical and geographically can lead to the development of “sweet spots” of higher permeability in the finer grained reservoir rocks.

Core photos courtesy of Canadian Discovery
Organic-rich Black Shale
- High TOC & high adsorbed gas
- Low matrix Sw
- High matrix Sg
- Gas stored as free & adsorbed
- Mature Source Rock

Silt - Laminated Shale or Hybrid
- Gas stored in shale and silt
- Low to moderate TOC
- Higher permeabilities in silty layers

Highly Fractured Shale
- Low TOC & low adsorbed gas
- High matrix Sw
- Low matrix Sg
- Gas stored in fractures
- Shale is the source rock

From Hall, 2008

Shale is just not Shale
Resource play development is a statistical play

Recognition that within the oil or gas field there are going to be both high volume and low volume producers.

Rely on statistical average to achieve project economic return on investment.

Understanding reservoir properties will decrease the risk of completing low volume producing wells.

First Year Production Average (MMcf/d)

From Southwestern Energy, 2009
Conventional vs Continuous or Unconventional Type Accumulations

- Lateral pervasiveness of hydrocarbon bearing strata results in large accumulations.
- The identification and development of the higher permeability “sweet spots” is an important consideration in the overall project economics.
- Resource plays can be considered a statistical play where there will be a range of producibility well profiles, and a large number of wells are required in order to achieve economic success.
Fundamental Differences

- Conventional reservoir areas constrained by geological boundaries
- Within the unconventional reservoir area are sweet spots of higher productivity
- Most wells in unconventional reservoir are productive but some may not meet economic thresholds
- Unconventional reservoirs require significant number of wells to achieve statistical thresholds of economic production
Much of the prospective reservoir area contains productive hydrocarbons but not necessarily at economic rates.

The identification of the “sweet spots” of potentially higher productivity wells is an important element of economic success.

A strong understanding of reservoir properties and the heterogeneity of the reservoir across the lease block helps in defining the presence and location of the sweet spots.
Other Aspects of Unconventional Resource Development

Risk of Success
Conventional Reservoirs

Risk of Success
Unconventional Reservoirs

Much of the risk is concentrated in the front end geoscience exploration and the ability to locate natural gas reservoirs of economic size.

Risk is concentrated in the ability to produce economic volumes from laterally pervasive deposits of natural gas where the risk of finding hydrocarbons is low.
Shale gas exploration is capital intensive with large volume of investment in the early stages and return on investment throughout the life of the project.

To achieve economic production companies require:
- Strong commodity prices
- Ideally existing infrastructure (pipelines, processing facilities etc.) to lower capital costs
- Advanced technologies to optimize productivity while lowering costs
- Availability of equipment and materials in sufficient quantity and stability of supply

![Typical Investment Profile for Unconventional Resource Development](image)

From Shell E&P Technology, 2009
Conventional Reservoirs

Decline rates of production may follow three types of curves and generally are less than 20% per year.

Unconventional Reservoirs

Commonly steep decline rates up to 75 – 85% in the first 18 months of production.
Other Aspects of Unconventional Resource Development

- Production declines are relatively steep (60 to 80% in the first year)
- Companies are compelled to be on a drilling treadmill to offset production declines while at the same time growing production
- As a result, large land tracts of mineral tenure are required to allow for the planning of an inventory of drillable locations
Observations about successful North American shale gas exploration projects

- Shale gas exploration is capital intensive requiring several hundreds of millions of $$$ of investment before commercial production of scale is achieved

- Integration of geology and engineering disciplines to recognize the influence of geology on engineering design and ultimate productivity

- Exploration and development will take a number of years to reach thresholds of production

- A well established exploration strategy is necessary to ensure that:
  - Reservoir properties that will influence production are identified
  - Optimum completion technologies are applied to demonstrate repeatability
  - The optimal target area is identified in the lease area (sweet spot if present)
  - Capital efficiency
  - Management understanding of risk, reward and time requirements
Topics to be Discussed

Foundation of Unconventional Reservoirs

*Exploration Strategies – A critical aspect for success*

Reservoir Properties
- Hydrocarbon Generation and Storage
- Permeability Pathways and Fracability

Accessing the Reservoir
- Drilling Technologies
- Hydraulic Fracture Stimulation
- Microseismic Tools and Observations

Opportunities for Unconventional Resources in Mexico

Role of Government
- Lease Tenure and Royalties
- Stakeholder Issues
- Pace of Development
Unconventional Gas Strategy is Critical to Success

Understanding the Play
- Reservoir Characterization
- Resource Assessment
- Formation Properties & Analogs

Address the Resource Play Challenges
- Which technologies, services or products are most appropriate
- Operational Risk / Cost Assessment
- Field Trials / Pilot

Build in Efficiencies of Operations and Material Management to Control Costs
- Scale of operations is usually large (program drilling and completions)
- Remote areas may add significant cost
- Bundling of Services, Concurrent / Continuous Operations
Determination of reservoir properties along with stimulation and production optimization requires a number of years of testing and pilot projects.

Pace of development is largely dependent on technical success, economics and market conditions and availability of equipment and materials.

Stage 1: Identification of UCG Resource
- Preliminary geological assessment to determine potential for hydrocarbons

Stage 2: Early Evaluation Drilling
- Vertical drilling to obtain core samples for reservoir properties along with estimation of resource potential and geographic limits of potential field

Stage 3: Pilot Project Drilling
- Early horizontal drilling to evaluate well performance with varying hydraulic fracturing technologies along with continued reservoir testing to determine engineering properties

Stage 4: Pilot Production Testing
- Advanced hydraulic fracturing testing and improvements of productivity with reduced expenditure

Stage 5: Commercial Development
- Project Reclamation

Exploration Tasks
- Determination of reservoir properties along with stimulation and production optimization requires a number of years of testing and pilot projects.
Key Variables That Influence Overall Reservoir Performance

Completion and stimulation choices will be influenced by there reservoir characteristics as well as outside factors such as technology, materials and equipment availability.
In order to be economically successful most unconventional resource play projects require the adoption of a “manufacturing” style of operations. This is to ensure that the project achieves:

- Optimization of Reservoir Production
- Employs Economies of Scale and Economic Benefits
- Continuous Improvement of Productivity while at the same time reduction in production costs
- Sufficient land base to support ongoing drilling and development plans that account for steep decline of initial production rates
- Service sector alliances that will allow continuous operations and economies of scale
The Key Questions

- Reservoir Characterization
- Reservoir modeling
- Sweet Spot identification
- Wellbore placement
- Wellbore completion

THE GOAL

MAXIMIZED

RESERVOIR

EXPOSURE

from E. Schmelzel, 2008
Pilot project testing is necessary:

- To realize continued improvement of wellbore productivity and ultimate reserve recovery
- Demonstrate technology repeatability for large scale commercial development

~35% Improvement in EUR/stage from 0.74 to 1 Bcf/stage

This type curve is based on an inventory-weighted average of approximately 150 wells.
Summary and Key Points

- Shale gas exploration and development is capital intensive and requires a well developed exploration strategy to enhance the probability of success.

- A staged exploration approach allows key reservoir knowledge to be obtained during the exploration programs prior to corporate commercial decisions being made.

- Understanding of the reservoir is critical to develop the most effective drilling and completion technologies that will improve the prospects for commercial production.

- Development of repeatability as well as production optimization is necessary before commercial development begins.

- Shale gas reservoirs are heterogeneous and there will be variability from region to region. The key is to understand the reservoir properties to be able to identify variables that will impact producibility.
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Completion and stimulation choices will be influenced by their reservoir characteristics as well as outside factors such as technology, materials and equipment availability.
Key Reservoir Properties

During early stages of shale gas exploration knowledge of primary reservoir properties is critical for drilling and completion planning

- Net Reservoir Thickness (m) – vertical position of prospective gas bearing zones
- Lateral Continuity of Reservoir and Geological Barriers
- Maturity of the Shale (Ro%) – gas generation window
- Total Organic Carbon (TOC%) – gas generation capability
- Matrix Porosity (%) – gas storage capability
- Langmuir Isotherms – gas storage capacity and saturation
- Gas Composition (% C1, C2, C3, C4)
- Reservoir Temperature (°C) – specifications of downhole completion equipment
- Matrix Composition (% SiO2) – fracability of the reservoir
- Reservoir Pressure Conditions
- Reservoir Strength (Young’s Modulus and Poisson’s Ratio)
- Reservoir Stress Conditions
Geological Characteristics and Reservoir Properties

- **Net pay and lithology**
  - TOC and thermal maturity
  - Reservoir porosity
  - Reservoir permeability
  - Reservoir stress
  - Influences on reservoir fracability
- Net pay is defined as the thickness of fine grained sedimentary rocks that have the necessary properties to store hydrocarbons.
- Not all shale beds will be prospective for hydrocarbon accumulation.
- The key property of net pay is the thickness of shale rocks that contain a sufficient volume of organic material preserved within the rock matrix.
- Due to the low density of kerogen, the potential reservoir porosity is ~2 times the volumes of TOC % in the reservoir.
Shale gas reservoirs effectively are mature source rocks

- Commonly display expanded pores and microfractures surrounding the organic matter due to an increase in volume during oil generation
- Retention of pathways of organic matter through the fine grained rock matrix
- TOC content of ~ 3% translates into reservoir porosity of ~ 6% - in North America, this is generally the lower cutoff for potential reservoirs to achieve sufficient resource in place
Gas Storage Capacity is determined by volume of organic matter (TOC %) or kerogen as well as available free space within the natural fracture system.

- Methane adsorbs onto the kerogen
- Kerogen has a low density (1.1 g/cm³), a high gamma ray response (500 to 4000 API units) and high neutron porosity (60 pu)
- Unique characteristics allow identification on petrophysical logs and can be converted to a TOC value
- Methane desorbs from kerogen and flows through the shale matrix to the natural fracture system and to the wellbore
- Critical flow pathways are necessary for methane migration

From Schlumberger
**Adsorbed Gas Analysis**

- **Micro- & Meso-Porosity (≤ 50 nm)**
  - Storage by Sorption
  - Mass Transfer by Diffusion
- **Macro-Porosity (> 50 nm)**
  - Storage by Compression and in Solution
  - Mass Transfer by Diffusion & Darcy Flow
- **Natural Fractures**
  - Storage by Compression and in Solution
  - Mass Transfer by Darcy Flow

- Isotherms measure the amount of gas adsorbed to kerogen in terms of scf/ton

- Amount of gas (Storage capacity) is a function of:
  - Kerogen content (increases with TOC)
  - Kerogen type
  - Gas composition (methane, ethane, etc)
  - Temperature
  - Reservoir pressure (increases with pressure)

**Methane Isotherm Results**

- 48.5 scf/ton
- 18.9 scf/ton

From Hall, 2008

**Calculating Total Gas Storage Capacity:**

\[ G_{st} = G_s + G_{sf} + G_{sd} \]

where:
- \( G_{st} \) = total gas storage capacity, scf/ton
- \( G_s \) = sorbed gas storage capacity, scf/ton
- \( G_{sf} \) = free gas storage capacity, scf/ton
- \( G_{sd} \) = dissolved gas storage capacity, scf/ton
The generation of hydrocarbons is a function primarily of increasing thermal maturity due to increases in temperature and pressure.

As thermal maturity increases, hydrocarbon production will shift from primarily oil to wet gas then dry gas.

Thermal maturity is commonly measured by vitrinite reflectance (% Ro).

Optimal range of thermal maturity is a vitrinite reflectance >0.5% Ro but < 3% Ro.
Geological Characteristics and Reservoir Properties

- Net pay and lithology
- TOC and thermal maturity

- Reservoir porosity
- Reservoir permeability
- Reservoir stress
- Influences on reservoir fracability
Geological Characteristics and Reservoir Properties

- Net pay and lithology
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Reservoir stress will impact:

- Orientation of existing natural fracture system within the reservoir
- Orientation of propagated fracture systems
- Vertical growth of propagated fractures
- Contribution of free gas into reservoir producibility
- Anisotropy of reservoir production

Due to depth of most shale gas reservoirs vertical stress is greater than horizontal stress resulting in propagation of vertical fractures during hydraulic stimulation
Knowledge of regional stress gradients is necessary to orientate direction of horizontal wells.
Two Island Lake shale gas development in the Horn River Basin

Note that almost all horizontal wells are drilled perpendicular to maximum horizontal stress.

Objective is to intersect as many open fractures in the horizontal leg trajectory.
Geological Characteristics and Reservoir Properties

- Net pay and lithology
- TOC and thermal maturity
- Reservoir porosity
- Reservoir permeability
- Reservoir stress

(Influences on reservoir fracability)
Fracture generation in shale gas reservoirs ideally will behave in a fracture swarm to create a series of pathways for methane migration.

Clay rich rocks will behave in a more ductile manner during fracture stimulation limiting the creation of migration pathways (induced fractures).
Even within the same formation, reservoir heterogeneity will result in variations in mineral composition resulting in differences in fracability.
The type of fracture fluid system will depend on the fracability or brittleness of the reservoir.

### Proposed Fracture Stimulation Choices Based on Britteness

<table>
<thead>
<tr>
<th>Britteness</th>
<th>Fluid System</th>
<th>Fracture Geometry</th>
<th>Fracture Width</th>
<th>Proppant</th>
<th>Fluid</th>
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<td>Slick Water</td>
<td></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
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<tr>
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<td>10%</td>
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</tbody>
</table>
Key Geological Criteria for Shale Gas Resource Determination

- Geology (Sedimentology, Petrography, H)
- Geochemistry (TOC, Maturation)
- Adsorbed Gas Analysis (Sorbed Gas Volume and Composition)
- Measured Rock Properties (Porosity, Permeability, Saturations)
- Gas In Place (Petrophysical Modeling)

Data must be collected and cross referenced to depth within the wellbore

Multiple data sets should be collected due to the vertical heterogeneous nature of the reservoir rock

Mineralogy, geochemistry, porosity, and permeability are all elements of the calculation and are required together to input into the downhole logs and model the volume, density, and maturation of the reservoir
Fracability of Reservoir is determined primarily by mineral composition

Ideally reservoir rocks will have a high silica or carbonate composition resulting in brittle behaviour.

Shale rocks that are rich in shale particularly kaolinite and smectite tend to be more ductile and do not fracture as effectively.

Most highly productive shale gas reservoirs have mineralogy with > 50-60% quartz or carbonate.
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Opportunities for Unconventional Resources in Mexico

Role of Government
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Three key technologies form the foundation upon which the unconventional resource potential in Canada has been unlocked.

- Horizontal Drilling
- Micro-Seismic Monitoring
- Multi Stage Fracturing
Evolution of Drilling Technology

- **Cost of Drilling**
  - Vertical wells
  - Vertical wells with multiple targets
  - Inclined or deviated wells
  - Horizontal multilateral wells
  - Horizontal Wells
  - Unconventional Resources

- **Increase in Reservoir Contact**

- **Time**
Drilling technology needs to be matched with the specific reservoir geometries

- Vertical reservoir targets may be best intersected using vertical or deviated wells
- Thick laterally persistent shale reservoirs are best intersected using horizontal wells or horizontal with a multi-lateral configuration

Courtesy of Halliburton
Drilling Efficiencies and Savings have been achieved through:

- Speed of drilling using new bit technology (PDC bits achieve penetration rates of up to 80 m/hr)
- Multiple drill string assemblies that reduce tripping time
- Geosteering in real time in horizontal and multilateral wells
- Automation of rig floor equipment eliminating additional manpower
- Fit for purpose rigs that can move on site without teardown
- Improved drilling fluids for solids removal and borehole stability

From Range Resources, 2010
Drilling of horizontal wells with the horizontal legs being up to 3500 m in length

Multi-stage fracture stimulations using slick water and sand to essentially “create reservoir” in rock that would not have been previously been considered reservoir quality

Wellbore design for extended lateral length (>2000 m) requires proper design including an understanding of reservoir properties, geological barriers and regional stress regimes
 Rotary Steerable Systems consideration for efficiency gain (ROP) and improved well bore quality (Logging/Completion activities).
LWD considerations for preferred placement within Duvernay Formation.
Decrease risk and reduce time on well utilizing Rotary Steerable Tools – Shale Gas Laterals

- **Decrease risk**
  - Improved borehole quality allows for casing running operations to be completed with less risk for extended reach laterals

- **Reduce time on well**
  - Eliminating orient and slide time associated with steerable motor drilling improves overall effective penetration rate

- **Position in the sweet spot**
Application of multiple wells from single drilling pads reduces surface footprint

Requires accurate downhole drilling surveys to ensure proper borehole separation between parallel horizontal legs as well as optimal reservoir drainage

Multiple wells from a single pad allow optimal materials management and cost savings through the employment of a "manufacturing process"
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Fracture stimulations are required for most unconventional resource plays due to low permeabilities of the reservoirs.

Type of fracture stimulation used is defined by:

- Depth and number of reservoirs to be stimulated
- Reservoir quality
- Type of wellbore (vertical versus horizontal)
- Fluid sensitivity
- Geomechanical properties of the reservoir
- Availability of equipment and materials
- Economic assessment of wellbore deliverability
Hydraulic fracturing operations are completed on a large scale and require specialized equipment.

Completion techniques as well as size and amount of equipment will be dependent on the depth of the reservoir, size of fracture stimulation and number of fracs designed for the well.
Fracture Stimulation Parameters

- The main purpose of fracture stimulation is to create open pathways for fluid flow within the reservoir either by creation of fractures or intersection of existing fracture systems.
- Ideally the reservoir rock should be “brittle” so that it fractures easily.
- Mineral content of the shale component will determine “fracability” of reservoir – ideally a silica rich shale is preferred.

Sheared and slickensided fractures

Open vertical fractures

This vs. that

Barnett Shale

Upper Cretaceous WCSB

From Hall, 2008
Principle of Multi-Stage Fracture Stimulations

- To effectively stimulate the entire length of the horizontal leg multi-stage fracture technology is necessary.

- Single stage stimulations tend to leave much of the intersected reservoir un-stimulated due to preferential flow of fracture fluids.

- Isolation technologies allow the horizontal leg to be divided into discrete stages that can be stimulated individually.

- Stage fracturing ensures that the maximum amount of fracture energy can be applied in a defined area thus making a more effective fracture with greater number of fractures or a greater fracture half length.

Radioactive tracer log indicates that only 3 of 6 perforations accepted fracture fluid.
Multi-Stage fracture stimulation allows more accurate placement of frac with specific volumes of frac fluid and proppant.
Understanding the Reservoir is Key to Optimizing Production and Reserve Recovery

This is achieved through continuous improvements and experimentation in drilling, completion and production techniques

From Southwestern Energy, 2009
Downhole Technologies

The mechanism by which the fracture fluid and proppant are delivered into the specific stages of the multi-stage fracturing operation is critical to the successful fracture stimulation.

There are many types of technologies that address the access to the reservoir with minimization of formation damage. These systems are built around two fundamental approaches:

- Cemented Liner
- Open Hole (non cemented liner or no liner)

Both of these approaches have advantages and disadvantages and may not be suitable under all reservoir conditions.
Proppant technology continues to address the issues of:

- Creation of fines from the proppant and reservoir
- Integrity of the proppant material under pressure and temperature

5% Fines = 60% Decrease in Fracture Flow Capacity

From Carboceramics
The object of reservoir stimulation is to maximize communication between the wellbore and the reservoir.

Reservoir communication can be in the form of intersecting existing fracture systems or creating a fracture network in the reservoir rock surrounding the wellbore.

**Definition of Stimulated Rock Volume (SRV)**

The amount of reservoir rock stimulated that contributes to the ultimate recoverable volume of natural gas produced from the wellbore.

\[
\text{SRV} = \text{fracture network height} \times \text{fracture network width} \times \text{length of stimulated lateral}
\]
Key Elements of Hydraulic Fracture Stimulation Programs

- Choosing the right technologies for the fracture stimulation is dependent foremost on the reservoir itself.
- The operator must have a good understanding of the reservoir properties in order to design the proper fracture treatment program.
- Each reservoir will have its own unique characteristics and early stage exploration activities are required to determine these reservoir properties.
- Other factors determining the choice of fracture stimulation are:
  - Availability of equipment and technology
  - Availability of fracture fluids and proppant
  - Number of stages required the total size of each stage
  - Relative cost
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Micro-Seismic to Determine Effectiveness of Stimulation

- Measures micro seismic events related to the propagation of fractures within the reservoir
- Requires one or more observation wells to allow proper mapping of location geographically and vertically of microseismic events
- Can be run independently or as permanent seismic arrays in field to be developed
- Provides a 3D image of fracture propagation that can be measured in real time during the fracture stages
- Allows fracture propagation trends to be identified and adjusted for additional stages so fractures can be contained within zone
- Identifies areas of poor fracture generation or geological barriers to effective stimulation
The validity and usefulness of microseismic data is highly dependent on the design of the microseismic program

- Observation Well Distance and number of observation sites
  - In Canada, typical distance from observation well to stimulated well are:
    - Shallow Gas – 150 m
    - Foothills Tight Sands – 700 m
- Issues
  - Same Pad Operations
  - Other Cultural Noise (e.g., Production)
  - Treatment Factors
- Viewing Angle
  - Seeing As Much Of The Fracture As Required
  - Avoiding Breaking Into The Observation Well
- Receiver Depth
  - Straddling
  - Above
Micro-seismic monitoring of the multi-stage fracture stimulation program allows:

- Visualization in real time of fracture propagation enabling adjustments to be made during the stages to ensure that the fractures are staying within zone
- Identification of previously unrecognized geological barriers
- Determination of optimal horizontal well spacing
- Determination of stimulated rock volume (SRV) for reserve determination

Dots represent individual micro-seismic events that occur during the fracturing of the reservoir

Track of the horizontal wellbore

Micro-seismic monitoring of fracture events for each staged stimulation allows the lateral and vertical envelope of the fracture stimulated rock to be determined

Courtesy of Nexen, 2011
Microseismic events can be used to calculate stimulated rock volume for reserve valuations.

Production contribution from various stages to overall wellbore production can be observed and calibrated to reservoir heterogeneity or effectiveness of stimulation techniques.
Observations From Field Activities in North America

- Microseismic Activity Is Very Limited For Rates < ~ 20 bpm
  - From An Offset Observation Well

- Higher Stimulation Rates Generate More And Larger Microseisms

- Larger Volumes Generate More And Larger Microseisms

- Microseismic Activity In Horizontal Wells Is Increased By Limiting Fracture Entrances
  - Uncemented Laterals Often Have Considerably Less Activity

- Highly Tectonic Environments Often Are Good Microseismic Candidates
  - High Stresses, Large Shear, And More Fracture Planes (Oblique)

- Thick Reservoirs Are Likely To Generate Stronger Microseisms
  - Vertical Fractures (Most Common) Will Be Larger (Larger Slip Area)
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Unconventional Resources
Geographic Setting

Northern Basins – gas prone
Southern Basins – oil prone
Eagle Ford Fm of the Maverick Basin
Geology does not stop at the Border

The prospects for unconventional hydrocarbon resources in northeast Mexico are essentially undeveloped yet have very high potential.

From USGS Geological Map of North America

The Eagle Ford geological equivalent can be found in northern Mexico in the Burgos Basin. While different, the geological equivalent strata are of similar or greater thickness and initial tests has demonstrated gas production.
Pemex has identified 5 basins that have shale gas potential:
- Chihuahua
- Sabinas
- Burgos
- Tampico/Misantla
- Veracruz

Pemex has ambitious plans to evaluate and develop the country’s shale gas potential.

One well, Emergente-1 has been completed and stimulated and an additional 2 more wells are in the planning or early stages of drilling.

From PEMEX Investor Presentation, 2012
A number of prospective shale basins have been identified.
Burgos Basin

- Southern extension of the Maverick Basin in West Texas that contains the Eagle Ford and Pearsall formations
- Covers approximately 63,000 sq km
- Eagle Ford shale ranges in thickness from 100 to 300 m
- Depth between 1000 to > 5000 m (in the east)
- TOC estimated at 5% and an Ro of 1.3%
- Resource concentration of Eagle Ford estimated at 210 Bcf/sq mile and total OGIP estimated at > 1500 Tcf
- Deeper Pearsall Formation up to 400 m of which 70 m is organically rich
- Average depth 3800 m
- TOC of 3% and Ro of 1.3%
- Resource concentration of 75 Bcf/sq mile and an OGIP estimate of 272 Tcf
Sabinas Basin

- Total area of 62,000 sq km
- Conventional gas production since 1974 with current output of 8 to 9 MMcf/d
- Structurally complex with evaporite fold structures associated with the Laramide uplift and subsequent salt withdrawal tectonics in Tertiary
- Much of basin may be too structurally complex to be considered prospective for shale gas
- Two formations Eagle Ford and deeper La Casita have some potential for shale gas resources
- Eagle Ford shale up to 300 m thick
- Estimated TOC at 4% and Ro of 1.3%
- Estimated depth of up to 3000 m but the reservoir may be underpressured
- Eagle Ford Fm estimated resource concentration of 113 Bcf/sq mile with OGIP of 218 Tcf

From EIA World Shale Gas Report
Tampico Basin

- Prospective area covers ~ 36,000 sq km
- Basin bounded by the Sierra Madre Oriental on the west and the Tuxpan Platform on the east
- Prospective shale formation is the Pimienta shale at depths from 1400 to 3000 m (mainly in the south part of basin)
- Three large NE trending geological structures dominate the center of the basin
- Conventional wells intersected thick section of Pimienta encountering up to 200 m thick but variable in thickness due to paleohighs
- Shale has TOC of about 3% and an RO of 1.3%
- OGIP estimated at 63 Bcf/sq mile with a total resource estimate of 215 Tcf

From EIA World Shale Gas Report
Tuxpan Platform

- Tuxpan platform is a basement high with overlying Cretaceous age formations of which two are prospective for shale gas
- Prospective area about 5000 sq km
- Lower Cretaceous age Tamaulipas Fm averages 68 m at a depth of 1800 to 3000 m
- Cretaceous age Pimienta Fm ranges from 140 to 350 m thickness at a depth of 2400 to 3300 m
- TOC of the Tamaulipas Fm ~ 3% with an RO of 1.25%
- Shale formation may be absent in some areas due to sub-aerial exposure and erosion
- OOGIP estimates suggest that up to 72 Bcf/sq mile for the Pimienta Fm with a total of 28 Tcf
- Tamaulipas Fm is estimated to hold 65 Bcf/sq mile of OOGIP and a total resource estimate of about 20 to 25 Tcf

From EIA World Shale Gas Report
Pemex plans for shale gas exploration

<table>
<thead>
<tr>
<th>Area / Basin</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<tbody>
<tr>
<td></td>
<td>Evaluation of prospects and test of concept</td>
<td>Geological characterization and reduction of uncertainty</td>
<td>Full scale development</td>
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<td></td>
<td>Total of wells 172</td>
<td>Total of wells 590</td>
<td>Total of wells 27,000</td>
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<td>Sabinas</td>
<td>25 wells, 90 wells, 2,700 wells</td>
<td>4,050 wells</td>
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<td>Burgos Mesozoico</td>
<td>30 wells, 100 wells, 4,050 wells</td>
<td>13,500 wells</td>
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<tr>
<td>Tampico-Misantla</td>
<td>80 wells, 240 wells, 13,500 wells</td>
<td>10 wells, 50 wells, 1,350 wells</td>
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<tr>
<td>Veracruz</td>
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<td>Chihuahua</td>
<td>10 wells, 50 wells, 1,350 wells</td>
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Imports of low cost natural gas from Texas negatively impact the economics of shale gas development in Mexico

- Mexico currently imports about 1.4 Bcf/day from United States by pipeline, the majority coming from Texas.
- Price averaged $4.18/mcf for 2011 but has dropped to less than $3.00/mcf in 2012.
- Imports of US sourced natural gas are increasing due to low cost and decreasing domestic supply.
Other Challenges that may impact the growth of the unconventional resource industry in Mexico

- Permitting and Bureaucratic Delays
- Environmental standards

**Infrastructure**

- High number of personnel and drilling rigs
- Daily fracturing services
- Intensive traffic of drilling rigs and heavy equipment
- Liquids separation plants

**Safety and Environment**

- Safe operations
- Wildlife protection and restoration of areas
- Aquifer protection, recycling water, metal containers, deep latrine wells

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Increased expectations for environmental standards has increased the cost of shale gas exploration and development.

Industry is expected to adopt much more rigorous operational and environmental standards than have been the norm in the past all of which add to the F & D cost of any project.
State of the art drilling and completion equipment will be necessary to effectively explore and develop the unconventional resource potential. This technology and expertise in most cases, will need to be sourced from outside Mexico.
Sourcing hydraulic fracturing fluids will be a challenge if using water is the fluid of choice.

The northeast part of Mexico is very arid and should shale gas development grow at rates necessary to provide the natural gas needed by the country, accessing water for drilling and fracturing operations may be an issue.

Concerns by local residents in the northern region have already been expressed about water usage and groundwater protection.

Even though the area is relatively remote, social media attention surrounding hydraulic fracturing will potentially be an issue.
Topics to be Discussed

Foundation of Unconventional Reservoirs

Exploration Strategies – A critical aspect for success

Reservoir Properties
  Hydrocarbon Generation and Storage
  Permeability Pathways and Fracability

Accessing the Reservoir
  Drilling Technologies
  Hydraulic Fracture Stimulations
  Microseismic Tools and Observations

Opportunities for Unconventional Resources in Mexico

Role of Government
  Lease Tenure and Royalties
  Stakeholder Issues
  Pace of Development
Determination of reservoir properties along with stimulation and production optimization requires a number of years of testing and pilot projects.

Pace of development is largely dependent on technical success, economics and market conditions and availability of equipment and materials.

**Stage 1:** Identification of UCG Resource
- Preliminary geological assessment to determine potential for hydrocarbons
- Vertical drilling to obtain core samples for reservoir properties along with estimation of resource potential and geographic limits of potential field
- Exploration Tasks

**Stage 2:** Early Evaluation Drilling
- Early horizontal drilling to evaluate well performance with varying hydraulic fracturing technologies along with continued reservoir testing to determine engineering properties

**Stage 3:** Pilot Project Drilling
- Advanced hydraulic fracturing testing and improvements of productivity with reduced expenditure

**Stage 4:** Pilot Production Testing
- Determination of reservoir properties along with stimulation and production optimization requires a number of years of testing and pilot projects

**Stage 5:** Commercial Development
- Project Reclamation

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Development of Canada’s unconventional resources has embraced technology and innovation as well as addressing market challenges and environmental considerations.

- **2004-2006**: Reservoir Characterization
  
  “Science of the reservoir”

- **2006-2008**: Technological Application
  
  “How do we produce the resource”

- **2009-2010**: Technological Evolution
  
  “How do we produce the resource at economic rates given the North American market issues”

- **2011-2012**: Technological Innovation
  
  “How do we produce the resource in a responsible manner that respects industry commitment to society and the environment”

- **2013 - ?**: Technological Transfer
  
  “How can we transfer our knowledge to new plays in different geological settings as well as geographic environments”

Technological progression in resource development is based upon continuous improvement to achieve greater economic returns but influenced by outside forces such as market, environment and opportunity.
The Role of Government in Unconventional Resource Development

Government is Supporting Responsible Resource Development

Government works with industry to develop mutual understanding of technical, business and social considerations

- Leads to improved policy and regulations......delivering “win – win” results
- Government policy and regulations honour:
  - Safe, environmentally responsible, efficient development
  - Consideration for stakeholder positions

Regulatory reform is achieved through consistency and prioritization, supported by solid analysis

- Regulations should:
  - Create a streamlined and efficient system
  - Be designed to fit the unconventional resource
- Examples include:
  - Royalties tailored to attract investment in shale gas
  - Shale gas water regulations / disclosure
  - Streamlined application and approval processes for multi-well development programs
Government now is required to be more aware of the impact of unconventional resource play development

What is different today in unconventional resource play development compared to what has been conventional oil and gas exploration?

- Surface footprint has changed due to move towards horizontal wells
  - less wells but the surface footprint of a single multi-well pad will be larger and used for a much longer period of time creating other issues that regulatory agencies must address
  - vehicle traffic will not only be greater but also will be for an extended period of time (as much as 12 to 18 months or perhaps even being semi-permanent)

- Multi-stage fracture stimulations commonly are of a larger scale requiring more materials and equipment
  - water and fluid requirements for operations need to be balanced with regional availability

- Greater stakeholder concern about hydraulic fracturing and shale gas development
Operator Stewardship and Integrity

- Alberta, British Columbia and Saskatchewan have a long history of oil and gas exploration and development including hydraulic fracturing.

- The provinces have well established regulations to guide how a wellbore is drilled and completed, what testing is done, and what data is reported. In Alberta there are also specific regulations addressing shallow hydraulic fracturing.

- Industry must comply with these regulations and if complications do arise that may compromise the integrity of the wellbore before or after the fracture stimulation, regulations are in place to ensure that corrective measures are completed.

- Proper wellbore construction is critical to protection of groundwater.
  - Surface casing is set and cemented in place to below base of groundwater protection.
  - Intermediate casing is used to isolate hydrocarbon zones between the reservoir and surface casing.
  - Wells are tested to validate cement integrity.
Operator Stewardship and Integrity

Proper well construction and groundwater protection is critical for oil and gas development.

Schematic of a horizontal well relative to groundwater.

Source: Canadian Natural Gas
Employing and investing in technology to create long term sustainability

Installing an ESP

Debolt Source Well

Water Treatment Plant

Horn River 63-K Pad

Debolt Disposal Well

Water Storage

100,000 m³
Governments have provided incentives
to enable unconventional resource development

**B.C.’s Energy Plan Commitment**

- “Pursue regulatory and fiscal competitiveness in support of being among the most competitive oil and gas jurisdictions in North America”

- Net Profit Royalty Program (NPRP) – Horn River Shale gas
  - 3 tier system: initial stage low royalty rates in exchange for later stage higher rates
  - 2% gross revenue royalty until capital invested plus return allowance is recovered

**In Alberta, the province introduced the Emerging Resources and Technology Initiative**

- Intent of the program is to “accelerate new technologies to encourage development of the province’s unconventional and deep resource pools”

- **Shale Gas New Well Royalty Rate**
  - Applies to wells exclusively producing shale formations
  - Maximum royalty rate of 5% for 36 producing months
Governments are committed to:

- Effective and *efficient* regulatory framework for unconventional gas and oil that mitigates risk to conservation, public safety and the environment, and ensures orderly development while using the least intrusive regulatory tools

- For example the ERCB Unconventional Resource Regulatory Framework addresses challenges & short term actions through
  
  - Water management and protection
  - Fracture fluid disclosure (D59)
  - Notification of HF operations
  - Containment
    - Inter-wellbore communication
  - Development planning (incl water planning)
  - Communication

* Picture source: ERCB
All wells require setbacks from water sources

Fracture operation prohibited at depths less than 600 m below ground level unless stipulated in well permit

Required to measure and report water production from all wells

Produced water and fracture return water are not allowed to be introduced into surface waters of near surface aquifers used for potable water supply
Industry has adopted improved operating standards and a higher degree of transparency

- Guiding Principles:
  - Protection of quality and quantity of fresh groundwater

- Hydraulic Fracturing:
  - Fracturing fluid additive disclosure
  - Fracture fluid risk assessment
  - Baseline groundwater testing
  - Wellbore integrity and quality assurance
  - Water sourcing and reuse

- BC and AB have committed to mandatory online reporting
  - Industry is using FracFocus as a means for public disclosure of fracture fluid additives
Collaborative industry/ government approach to address societal concerns

Industry developed Hydraulic Fracturing Practices to ensure responsible resource development and strengthen stakeholder confidence

Referenced in International Energy Agency’s Golden Rules Report
The Final Word

- Development of shale gas or tight gas resources requires:
  - Capital (return on initial capital is over a longer period of time)
  - Sufficient land tenure to be able to manage the drilling treadmill of continuous development
  - Time and recognition that the development of the resource will require a number of years of “science and learning” prior to commercial development
  - A strong commodity price to enable double digit returns on investment

- Mexico has a number of basins that are prospective for unconventional resource development

- A strong and disciplined company exploration strategy is critical for cost effective exploration and possible success

- Application of technology in terms of drilling, stimulation and microseismic monitoring form the foundation for successful development

- Attraction of capital and foreign investment will be one of the greatest challenges under the current regulatory and lease ownership framework

- Continued imports of low cost natural gas from United States inhibits the attractiveness of investing in unconventional resource play opportunities in Mexico

- Government both central and local has an important role to play in resource play development particularly in the early years of higher risk exploration
Unconventional Resource Development

Understanding the Reservoir and Applying Technological Innovation to Create Opportunities

Thank You for your Attention

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November 2013