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The Global Energy Challenge:
Reviewing the Strategies
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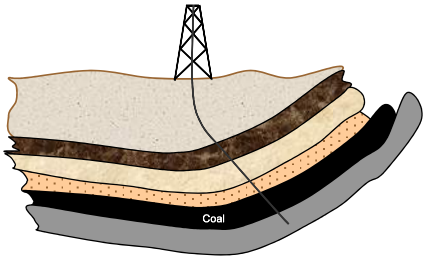
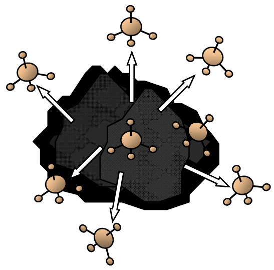
THIRTY YEARS OF LESSONS LEARNED

TIPS AND TRICKS FOR FINDING, DEVELOPING AND OPERATING A COALBED METHANE FIELD





Philip Loftin

BP America

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Lesson #1

Coal is different than conventional reservoir rock

It has unique reservoir properties

These properties will impact all aspects of a CBM project

...from exploration

...to production operations

Today's Presentation

- Introduce some CBM fundamentals
- Describe impact of coal's unique properties on
  - Exploration and appraisal
  - Development and operations
- Discuss the economic considerations of CBM
- Wrap it up

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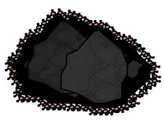
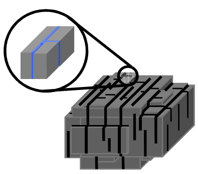
Coal has a number of unique properties

The two most impactful are:

- Gas storage mechanism
  (adsorption)



- Water-filled natural fractures
  (cleats)



These properties drive the fundamental aspects of CBM

But first, where does the gas come from?

It is generated from the organic matter within the coal itself, either through the action of

- temperature and pressure (thermogenic gas)
- microscopic organisms (biogenic gas)

Both mechanisms can provide gas to a coal, although not at the same time.

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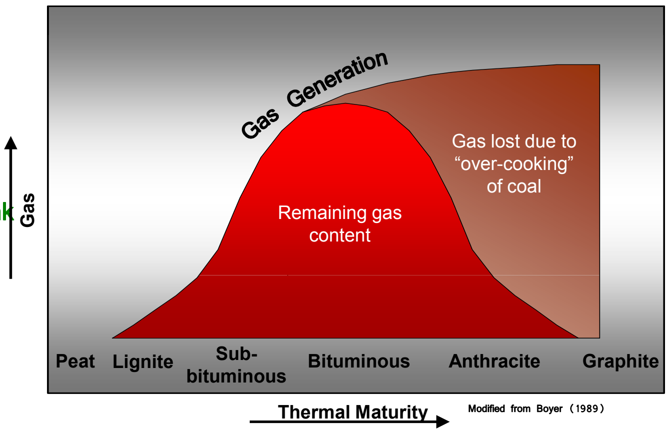
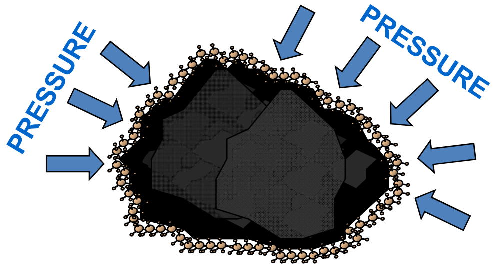
Thermogenic gas content can be strongly correlated to the thermal rank of a coal

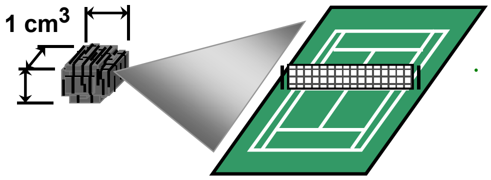


THIRTY YEARS OF LESSONS LEARNED... CBM Fundamentals

Adsorption

- Gas stored in a mono-molecular layer on the surface of coal particles at near-liquid densities
- This gas is held in place by pressure





- Coal has an extremely large amount of surface area available for methane storage
- Consequently, the storage mechanism is many times more efficient than that of conventional reservoirs

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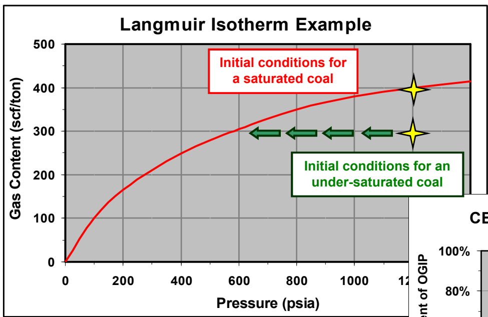
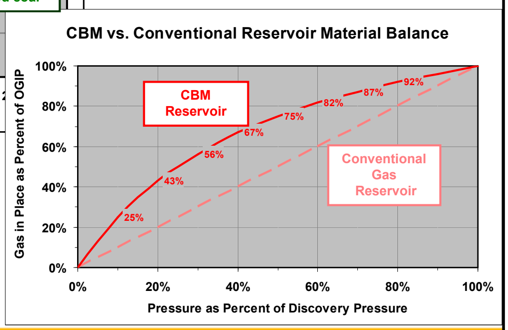


Adsorption

- Gas storage capacity is a function of pressure
- Relationship is described by Langmuir isotherm



- Decline in pressure allows desorption of gas
- More gas held at lower pressure compared to conventional reservoirs

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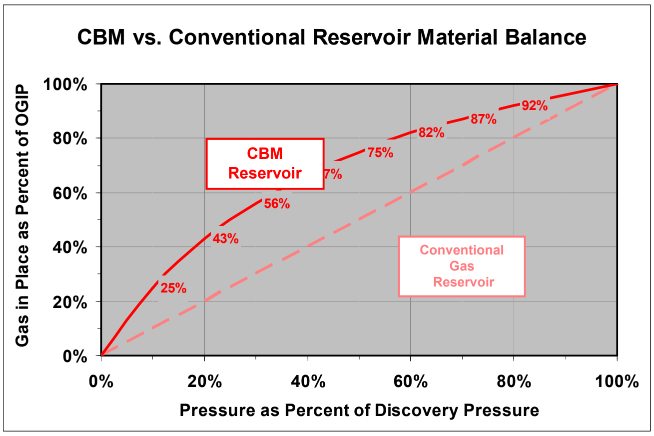

Lesson #2

Minimizing abandonment pressure is absolutely critical to achieving desirable recoveries in CBM !

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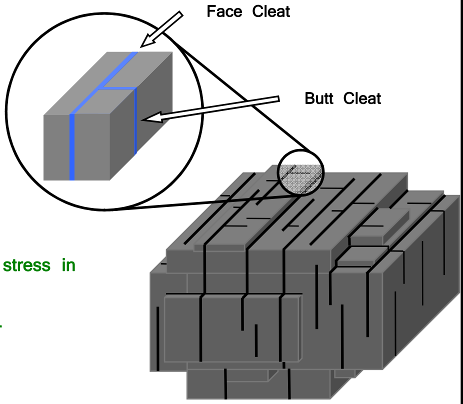
Water-filled Cleat System

- Natural fractures formed during coalification process
- Two orthogonal sets – primary, more through-going "face" cleats and secondary, less continuous "butt" cleats
- Face cleats form parallel to plane of principle stress in place at time of coalification
- Cleats are typically filled with fairly fresh water



- Cleats must be "de-watered" to drop pressure in reservoir and start de-sorption process

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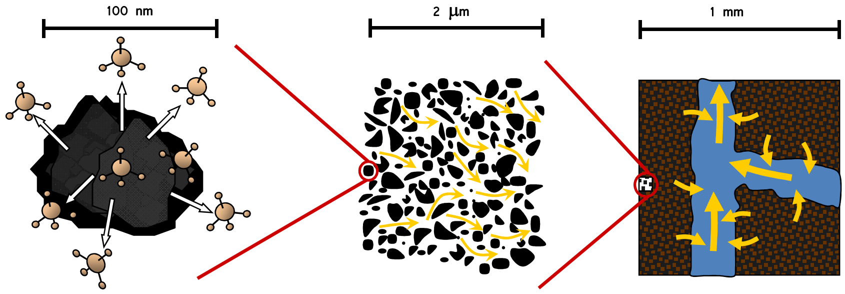
Flow Mechanism of Gas in Coal

Modified from Kuuskraa and Brandenburg (1989)



De-sorption of methane from coal surface as pressure decreases

Diffusion of methane through micro-porosity of coal matrix

Two-phase Darcy flow in cleat system

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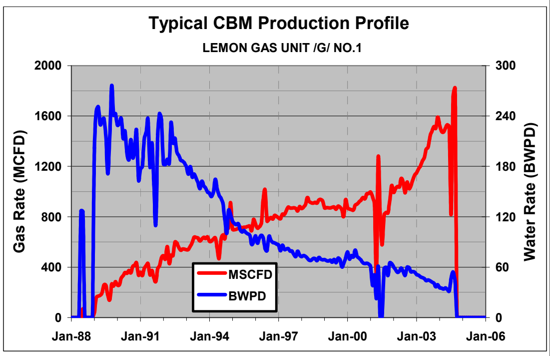
Typical Production Profile for CBM Well

- De-watering of cleat system must precede de-sorption of gas
  → Water production occurs first
- De-sorption accelerates as more water is produced
  → Gas production begins to incline



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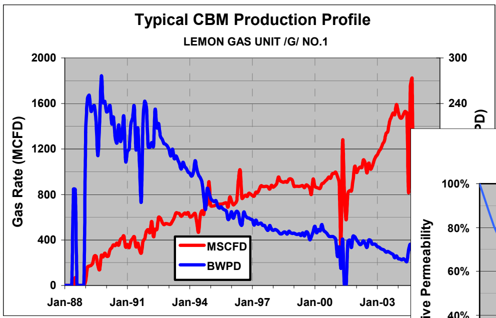

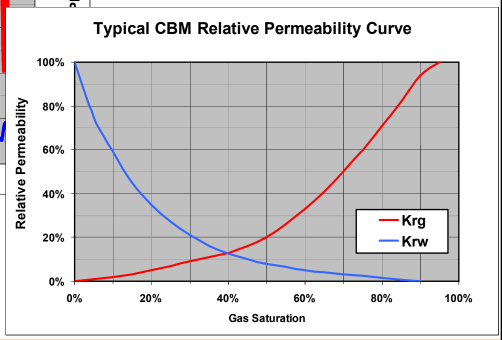

- Production profile mimics gas–water relative permeability curve

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Implications on Exploration

- Trapping mechanisms
- Screening methodologies
- Exploration drilling & testing
- Appraisal

Implications on Field Development and Operations

- System pressure losses
- Well Spacing
- Stimulation
- Artificial lift
- Gas gathering & compression
- Water gathering & handling

Economic Considerations

- Infrastructure
- Scale
- Project Metrics

THIRTY YEARS OF LESSONS LEARNED… Implications

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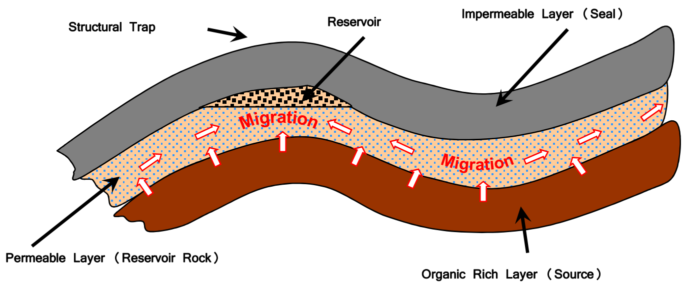
Components of a Conventional Trap

A conventional reservoir needs all of the following:

- A hydrocarbon source
- A migration path
- Reservoir quality rock
- A seal and trap
- Proper timing



THIRTY YEARS OF LESSONS LEARNED... Conventional Exploration

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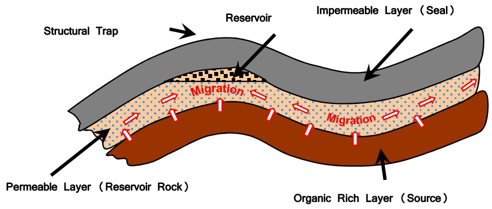
Conventional Exploration Screening Methodologies



- Petroleum system study → Hydrocarbon source, migration path, timing
- Seismic / offset well logs → Trap and seal
- Offset well logs / seismic → Reservoir rock

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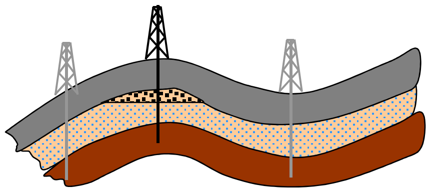
Conventional Exploration

Testing and Appraisal



- Can often confirm or condemn with one well
- Open-hole well logs are critical (and often the sole test)
- Permeability testing can be conducted via wireline tools
- None to several appraisal wells to delineate

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CBM Exploration

Given the concepts already discussed about CBM

- Gas is generated from within the coal itself
- Gas is stored on coal particle surfaces via adsorption
- Gas is held in place via pressure, usually hydrostatic pressure from the water-filled cleat system

we can conclude *Lessons #3 and #4*

Coal is self-sourcing

Coal serves as its own trap

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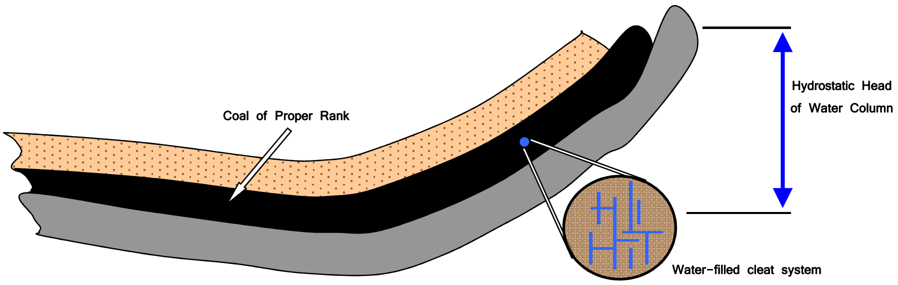
Components of a CBM Reservoir

Therefore, a CBM reservoir needs only:

- A coal of proper rank
- A water-filled cleat system
- Hydrostatic head from a column of water



If a coal is "dry" (no water in the cleat system), a structural or stratigraphic trap is needed (just as in conventional reservoirs)

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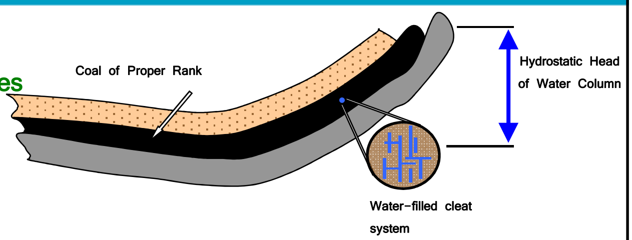
CBM Exploration Screening Methodologies



Consequently, CBM exploration screening focuses on different geologic elements:

- Gas content → Cores, drill cuttings, mines
- Coal extent → Outcrop, well logs, seismic, mines
- Saturation → Cores, mines

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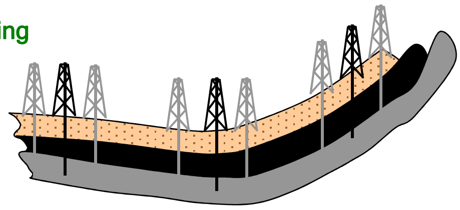
CBM Exploration Testing and Appraisal



- Usually requires multiple wells (and possibly a multi-well pilot) to confirm or condemn
- Open-hole well logs are less useful. Cores are critical.
- Permeability testing conducted via flow tests, often requiring stimulation and artificial lift
- Appraisal consists of several multi-well production pilots. Significant time needed to de-water pilots.

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Economic Considerations

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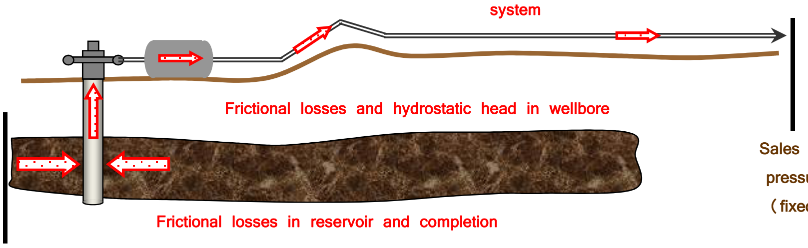
- Project Metrics

THIRTY YEARS OF LESSONS LEARNED… Implications

System Pressure Losses

Lesson #5 Because gas recovery is highly dependent on minimizing reservoir pressure, eliminating system pressure losses is key to effective field development



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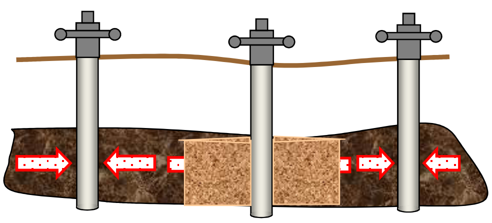
Well Spacing

- Dictated by permeability and economics
- Will control per-well recovery
- Will vary throughout field
- Identify early (if possible) to avoid future redevelopment



Stimulation

- Cleats are subject to damage from drilling and cementing
- Hydraulic fracture stimulation is common but can be tricky due to cleat system, especially in deviated wellbores
- Horizontal completions are not universally applicable, especially with multiple seams

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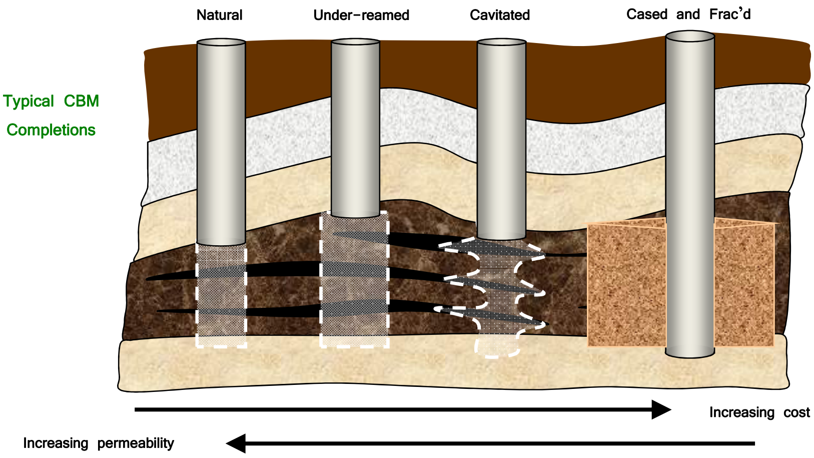
Stimulation

Typical CBM Completions



THIRTY YEARS OF LESSONS LEARNED… CBM Field Development

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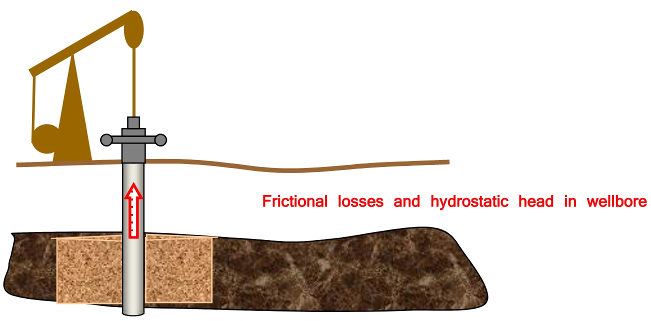
Artificial Lift

- Usually required for de-watering phase
- Helps eliminate hydrostatic head (one of largest pressure losses)
- Sensitive to solids production (frac sand and coal fines)
- Management of fluid level while controlling drawdown is critical to minimize back-pressure and limiting solids production



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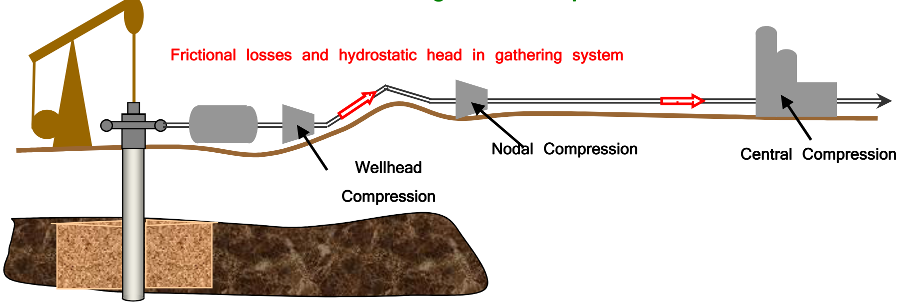
Gas Gathering and Compression



Goal is to minimize wellhead pressure

- Large diameter pipe to minimize friction
- Combination of centralized, nodal and wellhead compression
- Keep system single-phase (and provide for removal of water)

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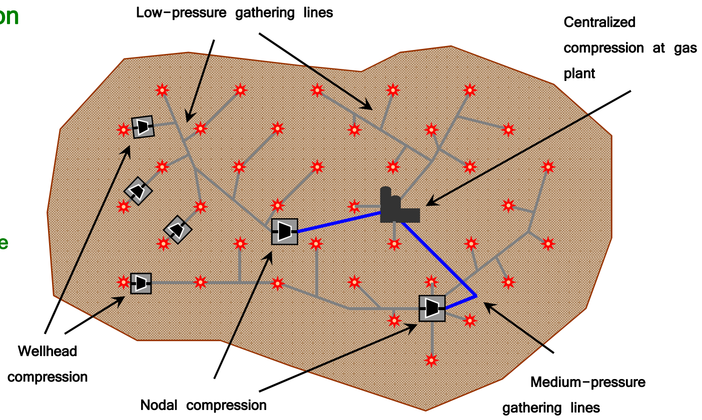
Gas Gathering and Compression

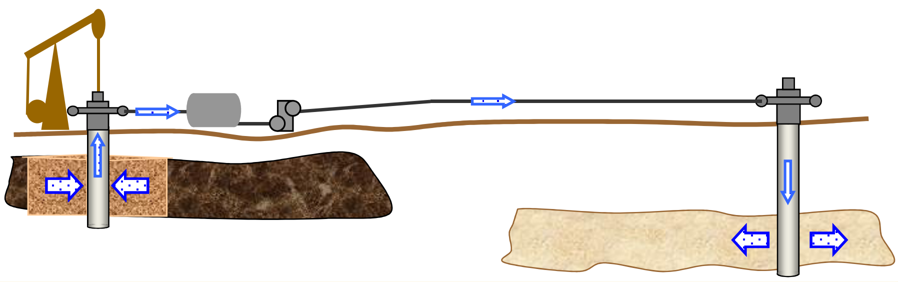
Typical CBM gas gathering and compression scheme



THIRTY YEARS OF LESSONS LEARNED... CBM Field Development

Water Gathering and Handling

- Acts as additional source of process back-pressure (a portion of reservoir energy is used to drive the system)
- Beneficial use is desirable but may be impractical
- Surface discharge is inexpensive but may be prohibited
- Subsurface injection is expensive but may be most effective



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- Water gathering & handling

Economic Considerations

- Infrastructure
- Scale
- Project Economics

CBM Field Infrastructure

- Many conventional fields require artificial lift, water handling, low-pressure gathering or compression
- However, few conventional fields require all four, and usually not in the early life of the field, as does CBM

Need for Scale in CBM Projects

- The resulting significant investment, early in the life of a CBM project, drives a need for CBM projects to possess considerable scale
- This need for scale in turn drives exploration screening criteria and project economics

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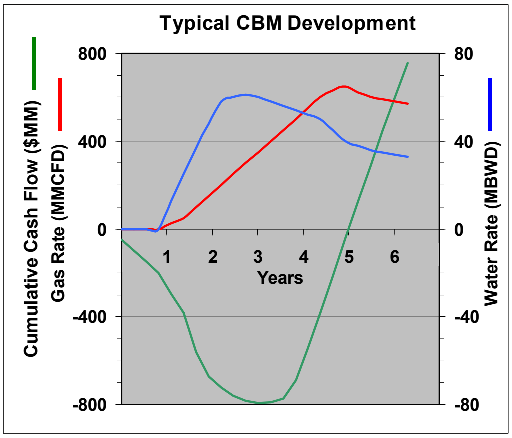
Project Economics

- Early-life infrastructure requirements represent huge up-front capital investment
- High early-life water rates generate high operating costs
- Low early-life gas rates yield little revenue



The result is a highly and persistently negative cumulative cash flow curve

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Wrapping It All Up

- Coal is different than conventional reservoir rock
- It has unique properties that shape all aspects of CBM exploration and development
- Coal's most impactful properties are the storage mechanism (adsorption) and the water-filled cleats
- The resulting production profile, along with the significant and early capital requirements, introduce challenging economics
- Which leads to perhaps the biggest lesson learned...

Lesson #6

Patience is indeed a virtue in CBM development

THIRTY YEARS OF LESSONS LEARNED... Economic Considerations