Gas Well Fracturing (Fracking) and Treatment of Frack Flow Back

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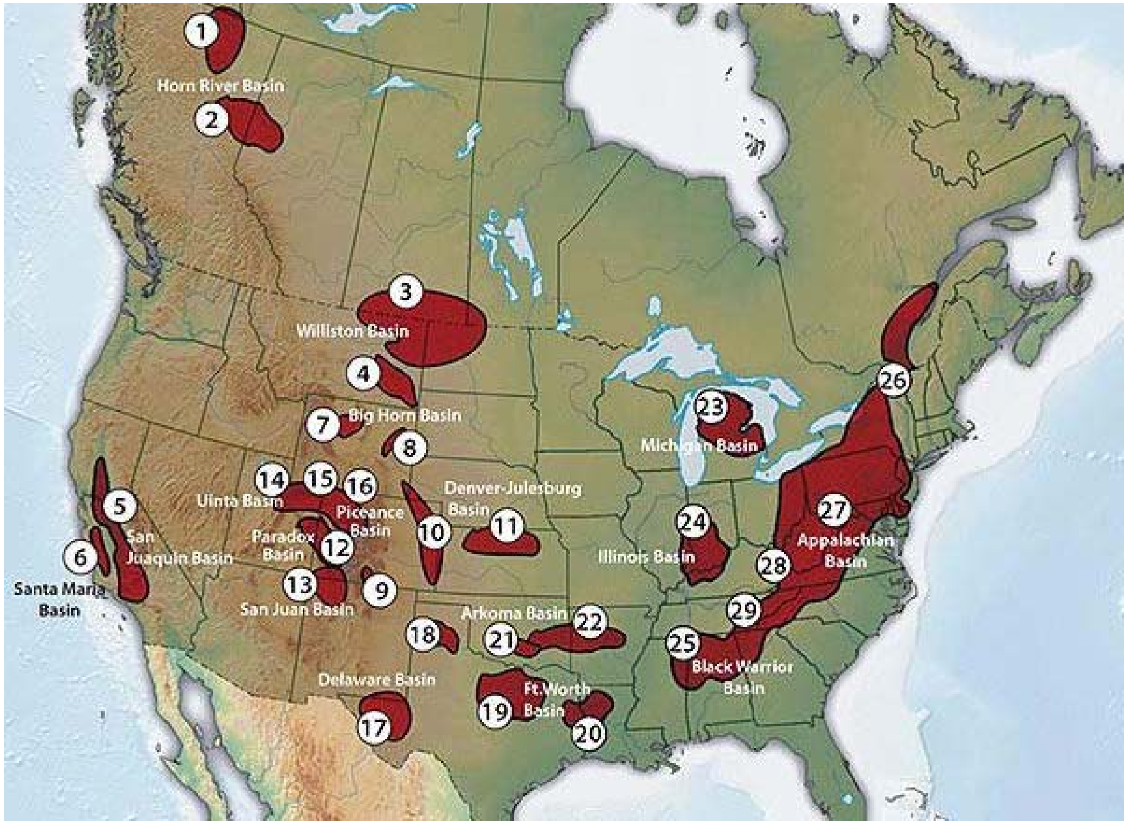
Shale - Gas
Development in North America



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Life Cycle of A Gas Well

Mineral Leasing

Companies negotiate a private contract or lease that allows mineral development and compensates the mineral owners. Lease terms vary and can contain stipulations or mitigation measures pertinent to protect various resources. (Several weeks to years)

Permits

The operator must obtain a permit authorizing the drilling of a new well. Surveys, drilling plans, and other technical information are frequently required for a permit application. The approved permit may require site specific environmental protection measures. Other permits such as water withdrawal or injection permits may also be required. (Several weeks to months)

Road and Pad Construction

Once permits are received, roads are constructed to access the wellsite. Well pads are constructed to safely locate the drilling rig and associated equipment during the drilling process. Pits may be excavated to contain drilling fluids. (Several days to weeks)

Drilling and Completion

A drilling rig drills the well and multiple layers of steel pipe (called casing) are put into the hole and cemented in place to protect fresh water formations. (Weeks or months)

Hydraulic Fracturing

A specially designed fracturing fluid is pumped under high pressure into the shale formation. The fluid consists primarily of water along with a proppant (usually sand) and about 2% or less of chemical additives. This process creates fractures in rock deep underground that are "propped" open by the sand, which allows the natural gas to flow into the well. (Days)

Production

Once the well is placed on production, parts of the wellpad that are no longer needed for future operations are reclaimed. The gas is brought up the well, treated to a useable condition, and sent to market. (Interim Reclamation: days; Production: years)

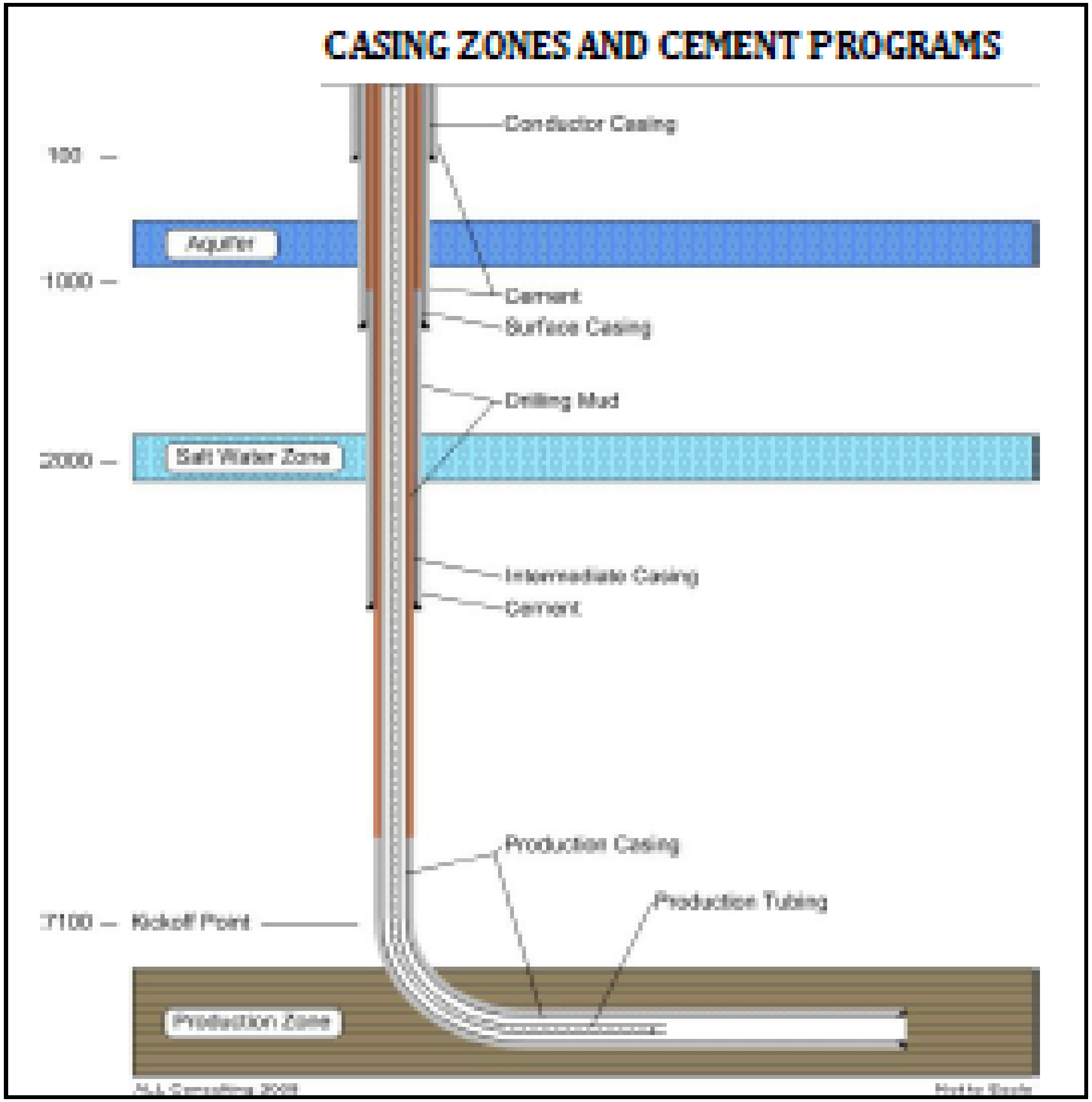
Workovers

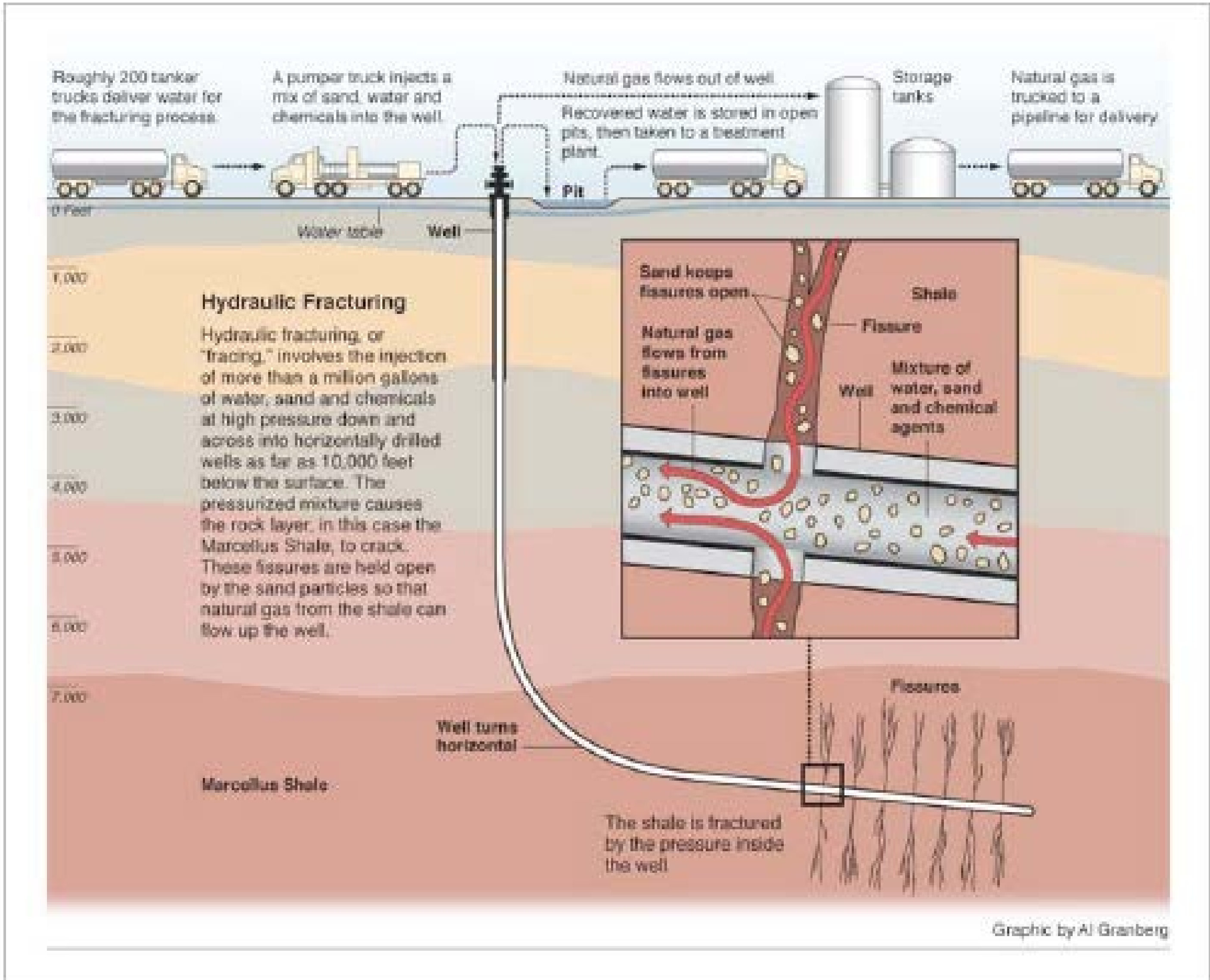
Gas production usually declines over the years. Operators may perform a workover which is an operation to clean, repair and maintain the well for the purposes of increasing or restoring production. Multiple workovers may be performed over the life of a well. (Several days to weeks)

Plugging and Abandonment/Reclamation

Once a well reaches its economic limit, it is plugged and abandoned according to State standards. The disturbed areas, including well pads and access roads, are reclaimed back to the native vegetation and contours or to conditions requested by the surface owner. (Reclamation Activity: Days; Full Restoration: Years)

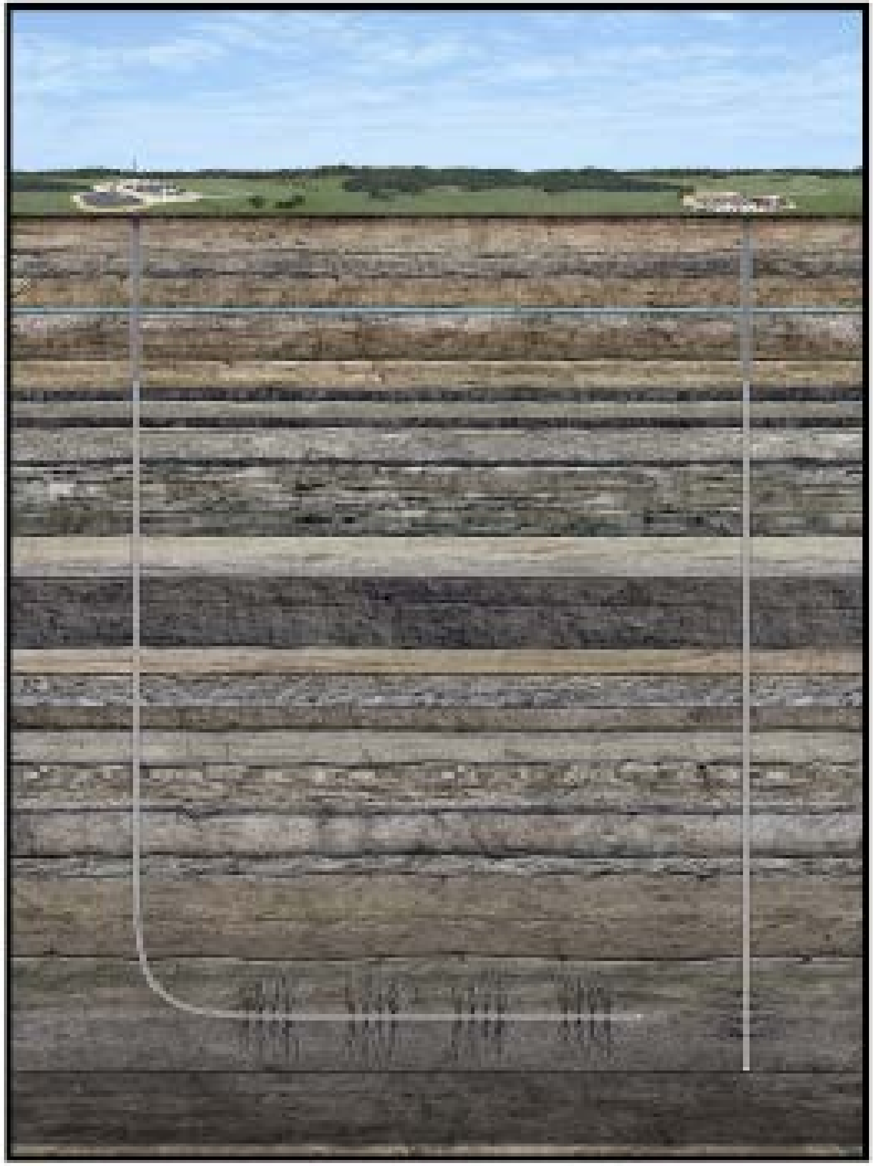

Drilling in Progress

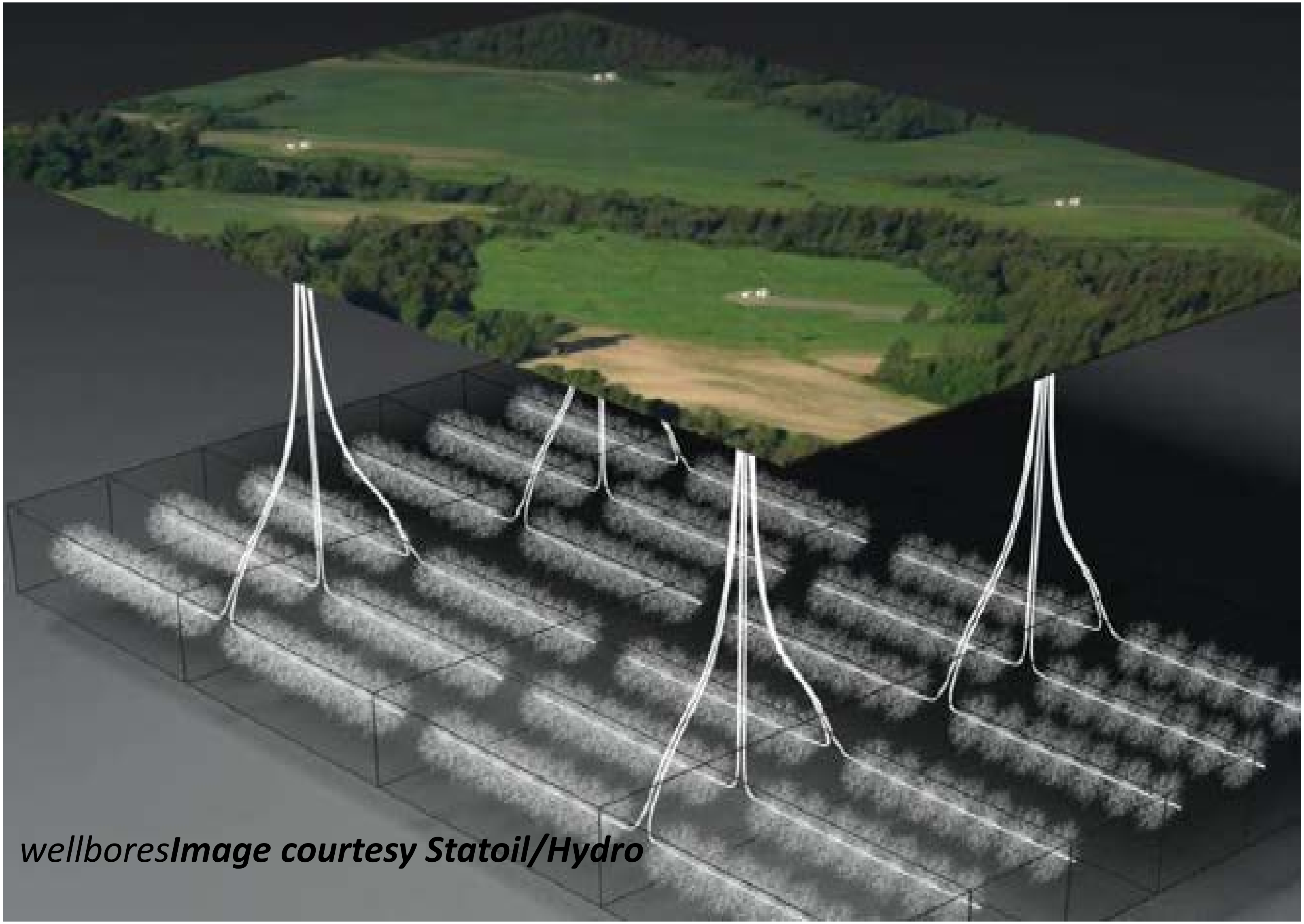

CASING ZONES AND CEMENT PROGRAMS
Conductor Casing
100
Aquifer
1000
Cement
Surface Casing
Drilling Mud
Salt Water Zone
2000
Intermediate Casing
Cement
Production Casing
Production Tubing
7100
Kickoff Point
Production Zone



Source: Natural Gas in the Marcellus Shale Formation: New York City and Upper Delaware River Watersheds, Southern Tier of New York State. Available at: http://www.catskillmountainkeeper.org/node/290

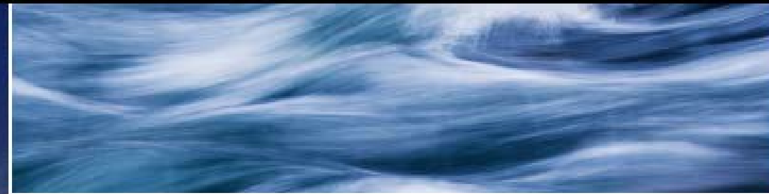
Horizontal and Vertical Gas Wells and Associated Fracking.





wellbores ***Image courtesy Statoil/Hydro***


Horizontal VS Vertical – Ten times more land is disturbed
with individual verticals than one
multi-well pad.



GUIDING PRINCIPLES FOR HYDRAULIC FRACTURING

Canada's shale gas and tight gas industry supports a responsible approach to water management and is committed to continuous performance improvement. Protecting water resources during sourcing, use and handling is a key priority for our industry. We support and abide by all regulations governing hydraulic fracturing operations, water use and water protection. In addition, we commit to following these guiding principles:

1. We will safeguard the quality and quantity of regional surface and groundwater resources, through sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse as much as practical.
2. We will measure and disclose our water use with the goal of continuing to reduce our effect on the environment.
3. We will support the development of fracturing fluid additives with the least environmental risks.
4. We will support the disclosure of fracturing fluid additives.
5. We will continue to advance, collaborate on and communicate technologies and best practices that reduce the potential environmental risks of hydraulic fracturing.

Shale gas and tight gas, for the purpose of these principles, refers to unconventional gas resources from low permeability reservoirs being developed using horizontal wells with multi-stage hydraulic fracturing.

CAPP
CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS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Source: Chesapeake Energy Corporation, 2008

Hydraulic Fracturing of a Marcellus Shale Well, West Virginia

Source: ALL Consulting, 2008

Lined Fresh Water Supply Pit from the Marcellus Shale Development in Pennsylvania

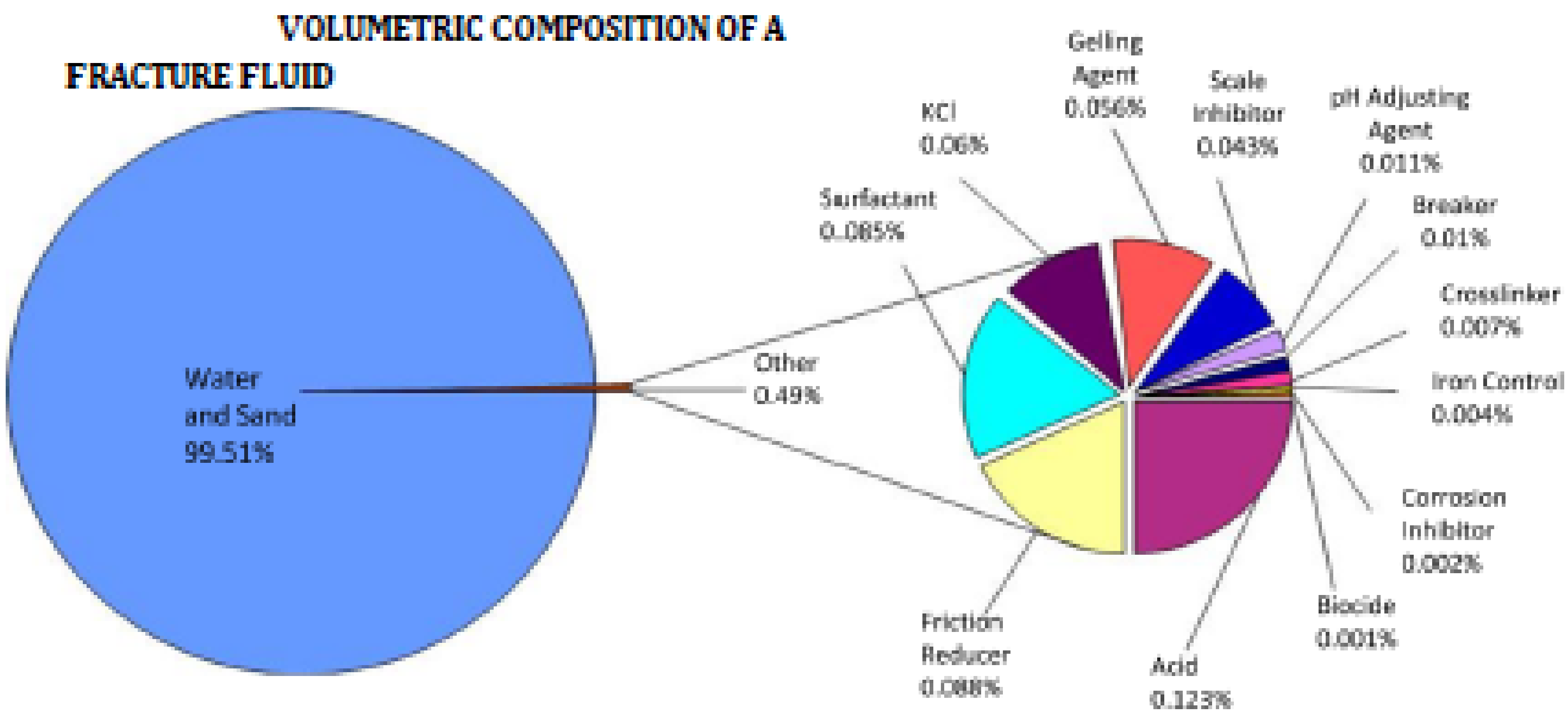
Basic Hydraulic Fracturing (Fracking) Process

- **Frack fluids are injected into producing formation under high pressure to fracture the reservoir matrix and in so doing increase porosity. Fractures are kept open by simultaneously injecting proppant (frac sand) into fractures to prevent their closure when pressure is reduced.**
- **For shallow gas wells the volumes vary from hundreds to over 100,000 gallons.**
- **Volume of water used in single frack of a shale gas well may vary from 1,000,000 gallons or 3,800,000 L to 10,000,000 gallons or 38,000,000 L (100 times or more water than for shallow gas fracturing).**
- **Frack fluid additives that are used may vary widely depending on characteristics of formation, company, method of fracturing and quality of water used for fracturing operation.**
- **Ideally water used for fracturing should be very high quality, free of chemicals that might interfere with those used during fracturing process or that might damage the formation being exploited and thoroughly disinfected.**

Note:
It is very difficult to ‘simulate’ the fracking process, not only with respect to how well it will achieve the principle objective of stimulating well production; but also, how the fracking process will effect the adjacent geology.
A great deal of ‘knowledge’ is gained by actually performing a fracking operation and carefully monitoring (routine) the process and its effects.

Common Types of Water Based Fracturing Operations

1. **Gel based systems**
    a. Require the liquid (water) be made very viscous to allow transportation and positioning of the proppant into rock fissures.
    b. Gel ultimately destroyed to allow excess water to be expelled – using gel breakers.
    c. Numerous other chemicals used to perform other functions.
    d. Difficult to treat to recyclable condition.
2. **Slickwater or slick water fracturing (energized variations)**
    a. Chemicals known as friction reducers are added to allow very high velocity of water carrying proppant (keep in suspension during transport).
    b. Numerous other chemicals used to perform other functions.
    c. Much easier to treat to a recyclable condition than gel based systems.
3. **Hybrid systems**
    a. Combination of gel based and slickwater fracturing to overcome danger of proppant being improperly located.
    b. Treatment to recyclable condition may be difficult.


VOLUMETRIC COMPOSITION OF A FRACTURE FLUID
Water and Sand 99.51%
Other 0.49%
Surfactant 0.085%
KCl 0.06%
Gelling Agent 0.056%
Scale Inhibitor 0.043%
pH Adjusting Agent 0.011%
Breaker 0.01%
Crosslinker 0.007%
Iron Control 0.004%
Corrosion Inhibitor 0.002%
Biocide 0.001%
Acid 0.123%
Friction Reducer 0.088%

The exact ‘mix’ of chemicals used will depend on the formation, nature of the frac being undertaken and the company performing the frack.

The mix of chemicals will vary widely.

While every service company that provides fracturing services will have their ‘preferred’ quality of water that is used in their operations - they are capable of using water with a very wide range of quality.

Substances added to water during fracturing process.

- Proppant (frack sand).
- Friction reducers.
- Foaming agents and antifoaming agents.
- Emulsifiers and de-emulsifiers.
- Gellants and gel breakers.
- Biocides.
- Corrosion inhibitors.
- Oxygen scavengers.
- Scale inhibitors.
- pH adjustment agents.
- Surfactants.
- Viscosifiers.
- Cross linkers.
- Stabilizers.
- Iron control.
- Breakers.

FRACTURING FLUID ADDITIVES, MAIN COMPOUNDS, AND COMMON USES.

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.

Water Sources

- Traditional
  - Surface water
  - Ground water

- Non-traditional
  - Brackish water
  - Effluent (waste water treatment plants)
  - Recycled water

Surface Water Supplies

- Regulation
  - National
  - County
- Much of the water available is already allocated
  - Not all is used
  - Contract is needed between existing owner or a permit is required from existing regulatory authority
- Supply subject to extreme seasonal or long term fluctuations
- Other considerations
  - Interbasin transfer
  - Public safety
  - Environmental flow provisions
  - Storage and dam safety

Surface Water
Flood Water vs. Routine Withdrawal

- Flood water (high stream flows) may or may not be available
  - Solutions:
    - Storage (in-stream or off-stream)
    - Ensure that alternate supplies are available (not predictable)
    - Timing of activity to allow for water availability
- Routine surface water withdrawal
  - Better control of quality (sedimentation)
  - Less engineering effort
  - Storage can be off-stream
  - May be able to pump water directly to fracking site without need for trucking.

Get it to the Lease (Site)

- Temporary pipelines to on-site storage (excavated or temporary)
- Arrangements with public and private organizations to provide water on-site (on-site storage and trucking)
- Use existing stream channels (some losses might occur) which will require regulatory approval and is not usually practical

Ground Water

- Controlled by regulatory authority
- Often flow is limited (renewable) and local storage will be required (acquisition can occur over extended periods of time)
- May be expensive to acquire (energy)
- May already be allocated (can't assume that it is available)
- Quality is highly variable (target lower quality water which is not in high demand)

Brackish Water

- Less salty (lower TDS) than sea water but too salty for potable use (natural water with TDS> 1000 mg/L and less than 10,000 mg/L.
- Brackish water is typically avoided by individuals and municipalities because of cost of treatment required to bring it to a quality acceptable for human consumption.
- Less information on availability than high quality water.
- Advantages:
  - Little or no competition for this water source.
  - Potentially, less regulation on pumping rates.
- Disadvantages:
  - Often at greater depth than freshwater.
  - May require some treatment, or more expensive additive packages, depending on frack chemistry.
  - Disposal or reuse may be more difficult.

Brackish Water Transport Issues

- Transport issues:
  - Regulation of transport via pipeline.
  - What to do in the event of a spill.
- Brackish surface water:
  - May occur in bays and estuaries.
  - Organisms (in water) can be very sensitive to changes in salinity.
  - Possibly less desirable from a regulatory perspective.

Water Management

- Distributed approach (site by site):
  - More favorable for groundwater and localized blending or recycling.
- Centralized approach (multiple sites in region):
  - Good for large surface water sources.
- Hub and spoke
  - Works well for surface and groundwater.
  - Achieves much of the treatment efficiency of large centralized facilities.

Frack Flowback

- Fluids recovered from water fracks, when the fluid pressure is relieved, is known as frack flowback. It contains all of the chemicals used in the fracturing process, formation water and some of the proppant and other solids (including drilling muds) that have been flushed from the formation.
- Volume of flowback varies from approximately 20 to 80 per cent of volume of water injected into formation (40 to 60 per cent is common).
- Quality of the frack flowback water varies widely with well condition and location and company performing the fracturing operation (companies use different mixtures of chemicals).
- Flowback water is typically very toxic. Historically flowback water is typically separated from the solid fraction and sent to disposal wells. Solids (slurry) are stabilized (e. g. addition of lime) and sent to appropriate land fill.

Frack flowback

- Volume is predictable (steadily decreases at any particular site).
- Water is already ‘owned’ by operator.
- Transportation may be a problem. How can it be transported? How far to where it might be used? What about spills?
- Further treatment or additives may be required for use in fracking.

- **Ultimate fate of frack flowback water today:**
  - **Deep well disposal.**
  - **Storage – waiting for treatment (risk of environmental problems).**
  - **Treatment for disposal into environment or reuse/recycle (Costs to treat and additional cost for reuse).**
    - **Direct reuse.**
    - **Water blending.**
    - **Complete treatment**
  - **Is the water taken elsewhere for treatment or is the treatment taken to the water supply?**
  - **How is the frack water transported?**
  - **What is the cost of treatment?**
  - **Alternate sources will be required since volume of frack flowback will decrease with time.**

CURRENT PRODUCED WATER MANAGEMENT BY SHALE GAS BASIN.

Shale Gas Basin	Water Management Technology	Availability	Comments
Barnett Shale	Class II injection wells[303]	Commercial and non-commercial	Disposal into the Barnett and underlying Ellenberger Group[304]
	Recycling[305]	On-site treatment and recycling	For reuse in subsequent fracturing jobs [306]
Fayetteville Shale	Class II injection wells[307]	Non-commercial	Water is transported to two injection wells owned and operated by a single producing company [308]
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[309]
Haynesville Shale	Class II injection wells	Commercial and non-commercial	
Marcellus Shale	Class II injection wells	Commercial and non-commercial	Limited use of Class II injection wells[310,311]
	Treatment and discharge	Municipal waste water treatment facilities, commercial facilities reportedly contemplated[312]	Primarily in Pennsylvania
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[313]
Woodford Shale	Class II injection wells	Commercial	Disposal into multiple confining formations[314]
	Land Application		Permit required through the Oklahoma Corporation Commission[315]
	Recycling	Non-commercial	Water recycling and storage facilities at a central location[316]
Antrim Shale	Class II injection wells	Commercial and non-commercial	
New Albany Shale	Class II injection wells	Commercial and non-commercial	

• **Basins such as the Eagle Ford Basin in Texas use gel-based fracks and recycling is very important because of the lack of availability of water.**

• **Basins in Northeast British Columbia, Canada have very limited opportunities for disposal but most of the fracking is performed without use of gels. Frack flow back is stored in very large covered ponds, which is considered a short term solution.**

Deep well disposal

Advantages:
- Safe disposal of hazardous waste.
- Well understood.
- Costs known and managed within project.

Disadvantages:
- Can be expensive – trucking and disposal costs.
- Roads are required for hauling flowback to disposal wells.
- Difficulties associated with defining solid fraction and liquid fraction. Solid fraction is an order of magnitude more expensive to dispose of than liquid fraction.
- Loss of water resource.

Storage

Advantages:

- **Short term solution allowing fracking activity to continue while waiting for long term solution.**
- **Can be constructed in close proximity to fracking operations.**

Disadvantages:

- **Construction of secure storage sites.**
- **Temporary solution – ultimately flowback must be either be disposed of , treated such that it can be reused or treated such that it can be disposed of in the environment.**
- **Environmental hazard and potential liability.**
- **Loss of water resource.**

Treatment for Disposal into Environment

Advantages:

- **Long term solution for disposal of wastewater with no immediate use.**
- **No long term storage.**

Disadvantages:

- **Treatment must be sufficient to allow disposal into environment – which might not be allowed under any circumstances or be very expensive to perform.**
- **Liability risk.**
- **Loss of water resource.**

Treatment for Reuse/Recycle

Advantages:

- Minimal disposal issues (only solid fraction).
- Reduce consumption of fresh water supplies by 30% to 50%.
- Minimal environmental impact.
- Maximum beneficial use of water resource.
- Avoid regulatory issues.

Disadvantages:

- Treatment must be sufficient to allow reuse/ recycle for subsequent fracking purposes.
- Treatment may be difficult, expensive or not practical.
- Treated water must be stored until it can be reused.
- Fracking companies must be able to adjust their process to use treated water which may be expensive and incur operational risks.

Frack Flowback Treatment Options

1. **Clarification – simple settling in storage facility.**
2. **Clarification – chemically enhanced (can vary from simple additions of basic coagulants to use of variety of polymers).**
3. **Clarification followed by filtration.**
4. **Clarification followed by centrifuge technology.**
5. **Direct filtration with or without use of coagulants or polymers using Oasis MPSF technology for example.**
6. **Solids removal using centrifuge technology.**
7. **Physical/chemical treatment that includes chemical addition followed by clarification processes.**
8. **Distillation and evaporator technologies.**
9. **Membrane technologies.**

Several of the *treatment technologies may be used in series* to treat difficult flowback water to a quality suitable for reuse or to produce very pure water using technologies that require careful conditioning before final treatment technology can be used (e. g. membrane systems).

Treatment using <u>municipal wastewater treatment facilities</u> is not appropriate because:

- **Not designed for treatment of frack flowback and may inhibit use of facility for treatment of municipal wastewater.**
- **Typically, only capable of removal of suspended sediments.**
- **May not remove all toxic chemicals limiting disposal opportunities available when only municipal wastewater is treated.**

- **Clarification, centrifuge and direct filtration technologies** are capable of removing most of the suspended sediment, are scalable, and typically least expensive; but, they may not have a significant impact on dissolved substances that might interfere with reuse.

- **Distillation and evaporator technologies** can provide very high quality treated water but is limited in application without pre-treatment, can be expensive to operate (though systems often use energy available at well site resulting in zero energy costs), complex and challenging to scale up to treat large quantities.

- **Membrane technologies** of varying types can be used for basic clarification to removal of all dissolved substances. Very high quality water can be produced. Typically, these will require pre-treatment. These systems can be expensive to operate and face similar challenges to distillation and evaporator technologies.

Physical/chemical technologies can be used to treat most frack flowback (gel or slickwater) to a recyclable condition depending on the concentration and type of dissolved solids. These systems are very flexible in application, use little energy, use inexpensive readily available chemicals, produce a waste that is readily disposed of, simple to operate, acceptable capital cost and scalable.

Treatment of Flow Back from Gel-based Fracks

Bench Scale Testing of Frack Flow Back Water Treatment Procedure

Before Treatment

After Treatment

Setting Up the Batch Treatment Equipment for the Four Cubic Meter Samples at Smithbrook Operation Near Brooks, AB.

Two products from treatment:

- Reusable water.
- Disposable filter cake.

Note separation of sludge and water.

Amount of sludge will depend on sample.

Summary comments related to frack flowback reuse:

1. **Treatment technology is available to treat ALL frack flowback water to a condition where it can be reused for subsequent fracking operations. Treatment technologies can be selected based on treatment needs (quality of flowback, treatment objectives, volume of water to be treated, local water management issues, remoteness of location, presence of disposal wells, solids disposal opportunities, availability of fresh water, costs, etc.).**

2. **Owner/operators must be interested in maximizing the use of water diverted for fracturing operations and instructing service companies providing fracturing on their wells to use recycled water.**

3. **Water management strategies associated with development of gas fields (regulatory role here) must include and integrate frack flowback treatment options.**

Thank You

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