HYDRAULIC FRACTURING

“FRACKING” OR “FRACING”

Getting a bad rap or well-based concerns & fears

(Beware – Now Entering the Dark Side)
Mitchell: “I had the privilege to know Buckminster Fuller in the 1960’s, and he is the one that led me to believe that Planet Earth will be overcrowded and I have been working on that for 35 years. **Sustainability** is very important to consider. *If you can’t make things work now in the world with six billion people, what are you going to do in 2020, when you have 9 billion people?”*

**RE: HF - Most responsible companies will tell you what [chemicals] they use, and they should.”**

“**Fracking** is extremely controversial and many believe chemicals used in the process are polluting sources of water.” “**If they [Gas Companies] do a proper job, there is no risk of contamination.”**


Mitchell Energy and Development Corp. – The Woodlands Texas (first “Green” Planned Community” - 1970)
Valid Mental Image ....or Not?

SCALE?
WHY NOW & WHAT’S CHANGED?

• Technology
  • Horizontal Drilling
  • Hydraulic Fracturing (applied to shale)

• Product Prices
  1. Oil – yes (± $100/bbl.)
  2. Natural Gas – now not so much (was $12/MCF, now ≤ $3 MCF) w/o liquids (dry gas)
     - Industry making shift toward liquids-rich plays
The “Old” Petroleum System

- **Entrapment**
- **Migration**
- **Generation**
- **Gas Cap**
- **Oil**
- **Water**
- **Seal Rock**
- **Reservoir Rock**
- **O & G Window**
The New Petroleum System

- **Source Rock** (shale)
- Migration
- Reservoir Rock
- Geologic Trap & Seal

Paradigm Shift - Game Changer - Transformative
HISTORIC VS. THE “NEW” HYDROCARBON RESOURCE DEVELOPMENT

1. **Conventional** Oil & Gas Resources (pre-1990)
   - Development of *isolated pools* (structural/stratigraphic traps)

2. **Unconventional** Oil and Gas Resources (post-1990)
   - Development of *Laterally Continuous Basin Wide “Resource Plays”*

**Types**
1. Coal Bed Methane
2. Shale Gas
3. Shale Oil
4. Oil Shale (in situ thermal generation or retort process)
5. Tar Sands (bitumen surface mining)
NIMBY'S UNITE!
Shale gas offsets declines in other U.S. supply to meet consumption growth and lower import needs

Marcellus shale recoverable reserves (USGS)
2 TCF in 2002 upped to 84 TCF in 2011

Source: EIA, Annual Energy Outlook 2011
1950’s DOE Nuclear Frack Test Site or Natural Example of HF? (Colorado)
So.....What Is HF? (a few details)

Hydraulic Fracturing

Hydraulic fracturing, or "fracturing," involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.

1. Perforation
2. Cluster
3. Stage (15)
4. Frac Job
Visual representation of how fracks increase the surface area of well bore to allow increased gas flow from shale rock

[ Based on Production Decline Analysis and Numerical Flow Simulation (model) ]

EXAMPLE:

- Lateral BH Length = 4700’ (Side area of that 8” dia. cylinder; $A = 2\pi rh$ or $9800$ sq. ft.)
- Surface area increase w/Fracks = 66 (70-ft. spacing of each 200’ x 400’ panel below)
- Each frack has two sides (think 66 pairs of football fields w/flow occurring across both faces)
- Doing math - effective “fracked” Surface Area > 10 x 10*6 sq. ft. or > 10,000,000 sq. ft.

From EPA HF F&T Wkshop; March 2011
“Listening to Rock Music” at work!

Or MicroSeismic Imaging (Barnett Shale)
What Are They Pumping?

• Water (80%)
• Proppant (19%) (sand or ceramic beads)
• Chemicals (<1%) (1/2 Acid + 4 – 8 other additives)
  (gels, cross-linkers, breakers, friction reducers, biocides, corrosion inhibitors etc.)

Where Does It Go???
Con’t. where frack fluids go:

Injected Frack Fluids & Chemicals - Estimates of Where they go (varies with shale play):

1. Flow back (10 - 30%) - Returns to surface first few hours to a few days after fracking stops.
2. Leak off (± 50 %) - “Imbibed” fluids penetrate fracture face & into rock matrix (pore space) during “fracturing process” then becomes locked in matrix forever as “irreducible water saturation” by capillary pressure forces and adsorption
3. Trapped in disconnected fractures (± 10%) - not all fractures stay open and in communication with well bore)
4. Longer Term Flow Back (< 10%) - Flows back over time with produced water in subsequent gas production phase
Factors that limit or control fracture propagation or growth (upward) – fracture height*

1. In Situ Stress (varies across rock type – Ss., Ls., Sh.)
   - Fractures tend to terminate when going from low stress/low modulus (sh) to high stress/high modulus Ls/Ss rock type
2. Higher Permeability Zone (e.g. porous sandstone will dissipate frack energy quickly & kill frack w/pressure drop)
3. Layering (present interfaces/boundary conditions – inhomogeneity)
4. Other discontinuities & angle of approach, material properties
5. Frack fluid density

* This information based on rock mechanic theory, models, lab tests, mineback field observations, microseismic, tiltmeter studies and analysis of frack job results
Typical Well (Marcellus)

- 4,500’ ± Lateral length (well bore)
- 15 ± frac stages with 3 – 4 frac clusters/stage
- 5 ± 2 million lbs. of proppant (sand/ceramic)
- 1 – 5 million gallons of water

Typical Shale Gas Reservoir:

- $\Phi_{\text{eff}} = 3 – 10\%$ (porosity tends to be assoc. w/ Org. Matter)
- $Sw = 10 – 50\%$ (low for shales pos. related to Thermal Mat.)
- $b = 50’ – 400’$ (shale thickness or target zone)
- $k = .01$ to $.00001$ md (permeability)*
Marcellus Shale - Example Well Design

3-Casing String Well Design w/ Open Annular Interval

Local Geology Characterized by Pervasive Shallow Fracture & Joint System in Bedrock to ±1500’

Intermediate Depth (1500’ to 5500’)
Joints and/or fractures are absent or closed, multiple units of very low permeability act as seals/barriers to vertical gas migration.

Sealing Beds (Shale)

Non-Target Gas Bearing Zones (Show Interals) Bleed off to Open Annuli

T.O.C > 500’ above TVD or 200’ above Top of Target Gas Fm

Multiple V. Low Permeability Strata & Physics of Fluid Flow in Target Shale along w/ Several other Factors Largely Preclude Escape of Free Fluids to Surface/DWS

Residual Fract fluids Bound w/in Shale Pores

Top of Gas (Target Prod. Zone) 5-1/2” Production Casing to 6500’ TVD

4500’ Perforated Lateral Section
9 Frac Stages
3 Clusters/stage
Why risks to Aquifers & DWS are so low from the Deep Underground HF Process Chemicals:

- **Frac fluids** - fairly dilute from start (compared to other chemical release situations/threats; CERCLA, RCRA, LUST – rel. risk in perspective)

- **Main component** (acid, HCl) is neutralized in subsurface by carbonate minerals in rock of target zone, casing cement, adjacent beds

- **Many physical constraints** on actual fracture propagation (upward) beyond target formation (depth, layering, porosity zones, differential pore pressure/in situ stress at layer boundaries)

- **Frack chemicals lack of persistence** - do not pose a significant risk of migration in subsurface (i.e. quickly degrade)
Why risks of frack chemical migration are so low con’t.

• During well productive life (20 – 30 years), well bore acts as pressure sink so fluid flow can only occur toward well bore - flow is impossible against a pressure gradient (depleted reservoir post-prod. sink)

• Frack fluids (and proppant) may never extend beyond the first 40 - 60% of the microseismic cloud or distance that fracturing is occurring (Effective fractured rock volume < Total fractured rock volume). The outer 40% of induced fractures are often not connected with the inner 60% & borehole so frack fluid is less likely to penetrate more distal areas of target formation.

• Industry moving toward full disclosure (e.g. fracfocus.org, new regs.) and away from the use of toxic chemicals altogether
con’t.
**Why risks of subsurface frack chemical migration are so low:**

• 50% or more of frack fluids migrate across fracture face into shale matrix and are trapped by capillary pressure effects and adsorption

Water Saturation Deficit  ➔  Imbibition ➔  Irreducible Water Saturation
(gas shales are super dry)  (they suck)  (fluids are stuck – for geologic time)

• No viable pathway – well design, casing, cement preclude chem. migration

**So what are the real subsurface risks??**
Marcellus Shale Example Well w/3-Casing String Design

**3-Casing String Well Design w/ Open Annular Interval**

- **Local Geology Characterized by Pervasive Shallow Fracture & Joint System in Bedrock to ±1500’**

- **Intermediate Depth (1500’ to 5500’)**
  Joints and/or fractures are absent or closed, multiple units of very low permeability act as seals/barriers to vertical gas migration.

- **T.O.C > 500’ above TVD or 200’ above Top of Target Gas Fm**

- **Multiple V. Low Permeability Strata & Physics of Fluid Flow in Target Shale along w/ Several other Factors Largely Preclude Escape of Free Fluids to Surface/DWS**

- **Top of Gas (Target Prod. Zone) 5-1/2” Production Casing to 6500’ TVD**

- **Residual Frack Fluids Bound w/in Shale Pores**

- **Tully Ls**

- **Onondaga Ls**

- **4500’ Perforated Lateral Section**
  - 9 Frac Stages
  - 3 Clusters/stage
The Real Risk: (that remains)

**Stray Gas Migration!**
- unrelated to the HF process itself
- sourced from non-target formation
- can impact aquifer/DWS with methane gas

Example: NE PA Marcellus Well Design
- Cemented surface & intermediate casing
- Cemented production casing
- Open annular interval w/ non-targeted formation gas flows (shows)

Why methane gas readily migrates (upward):
- high concentration (potential)
- buoyancy (as free gas phase)
- viable pathway (well annulus)
- overpressure potential (gas kick)
- shallow fractured bedrock (open fractures)
SEISMIC SECTION - NE PA

Zone of deep-seated vertical faults and fracture swarms related to transpressive faulting. These large scale fault systems occur throughout the Appalachian region and can serve as naturally-occurring vertical conduits for gas migration from deep-seated gas source rocks (Ordovician and Devonian shales) up to the near-surface gas sands in the Upper Devonian Lock Haven and Catskills Formations. Fresh groundwater aquifers also are formed in heavily fractured areas of these same Upper Devonian rocks and in near-surface glacial alluvium.

~800 to 1000' bgs
FRESHWATER
AQUIFERS
LCS
TOC
Stray Gas (non-target Fm)
Target Fm
Marcellus Sh

Upper Devonian section containing freshwater aquifers above sandstone gas reservoirs.
So what are the principal risks from deep underground HF “process”??

- **Frac Chemical Migration Risks** are few and **very remote** – very limited pathways or mechanisms for chem. migration w/o violating several laws of physics of fluid flow

- **Methane Gas Migration** from non-targeted formations:
  - abundant/concentrated, pathway exists (annular space - subject to well design), buoyancy drive of free gas
  - may be overpressured relative to hydrostatic conditions at surface/intermediate casing seat
  - local fractured shallow geology would facilitate migration across fractured bore hole wall, into country rock and around surface or intermediate casing of good integrity to reach aquifer/DWS
  - must manage bradenhead pressure (vent GHG, capture for sale, remediate well)
HF UNDER THE MICROSCOPE

- EPA HF Study, Air and Water Reg. Rule Adequacy Reviews
- DOE study/field tests and SEAB Reports (90 & 180 – day)
- USGS Cumulative Impact Studies (baseline GW monitoring w/NPS)
- River Basin Commissions (DRBC, SRBC) revised rules
- Reports to State Governors on HF (PA., Corbett)
- Industry Studies to improve efficiencies & advance BMPs
- EPA Air Regs – NSPS (phased in through 2015)
MAIN ISSUES ARE WITH UNCONVENTIONAL GAS DEVELOPMENT ITSELF, NOT THE HF PROCESS

- The **Footprint** (infrastructure density - well pads, roads, pipelines, compressor stations, cumulative impacts)
- The **Industrial Activities** of Assembly Line Development
- **Water Demands** – 10 - 50x that of conventional resource dev.
- **Waste Management** (Drill mud & cuttings, flow back and produced water, NORM)
- **Poorly Constructed or Maintained Wellbores** – Drilling Fluid contamination of aquifers / Drinking Water Supplies
- **Surface Spills / Releases / Air Emissions**
- Are these all manageable under current/enhanced regulatory structure?
THE HUMOR: “FRACKING NEWS” HEADLINES

Under the Category of:

• Disturbing the Dead: “Gas Drilling Opponents Raise Concern Over Fracking Near Cemeteries” (R.I.P.)

• Justification for CEO pay(?): “Halliburton CEO Drinks Fracking Fluid At Industry Conference”

• Politicians Straddling the Fence (even when it doesn’t matter): Gov. Christie (NJ) Recommends One Year Moratorium On Fracking.....But Vetoes Perm. Ban Sent by Legislature......
  (Context: NJ has no Nat. Gas prod. & none is anticipated!)
Dueling Government Estimates: USGS Increases Marcellus Shale Recoverable Reserve “Estimate” 44 Fold (from 2 to 88 TCF)….. Which Slashes Recent DOE Estimate by 80% (down from 410 TCF)

Green Party Spokesman: “fracking is essentially mountaintop removal….underground” (huh??…please include a picture, diagram or something)


Blogosphere Weighs in: “fracking to blame for 5.8 magnitude earthquake in Virginia” (no drilling within 100 miles of earthquake epicenter – ……granted …a minor point in blogosphere land)
CONCLUSIONS

1. The real, long term risk to potable aquifers/DWS is from stray gas migration and cumulative methane build-up, not frack fluid chemical migration from the HF process. (borne out by empirical data, NE PA, SW CO)

2. Methane impacts can be exacerbated by the geographic extent of unconventional resource plays when large numbers of wells have open annulars coupled with a shallow fractured bedrock situation.

3. Few viable options currently exist to address pressure build-up in the well annulus from stray gas migration given the GWP of methane (e.g. venting unacceptable, well remediation/CFS costly) (trade-offs w/devil in the details).

4. The focus should be directed to ensuring proper well design (zonal isolation and migration pathway elimination), wherever a fractured shallow geology can facilitate methane migration past surface casing.
SO........What's Your Focus???

“Thank You”
TAKE AWAYS (A FEW)

- Risk to DWS from HF deep underground “process” is remote w/few exceptions (e.g. frack intersects poorly abandoned old borehole)
- HF coupled with Horiz. Drilling will significantly increase worldwide fossil fuel reserves w/carbon footprint½ (?) that of coal (maybe)
- Water demands for shale gas are significant but temporary and small relative to other industries (Elec. Pwr.; Ag.) & Municipal but recycling is gaining (however, frack use is largely consumptive)
- **Real Issues** that should be the focus in unconventional gas (and oil) development are:
  - DWS impacts from **stray gas (methane) migration** is related to poor well design/casing & cement jobs… and not the HF “process” itself – Their needs to be a refocus/more emphasis on well design to protect DWS.
  - **Air pollution** (NSPS 2015); **Landscape Fragmentation & Well Siting** (roads, pipelines, well pads, compressor stations, proximity to Nat. Resources)
  - **Vehicle Traffic** (locals sharing roads w/ 1000 trucks/well)
THE HYDRAULIC FRACTURING PROCESS (HF): REAL CONCERN or MISDIRECTED FOCUS CONCERNING THREATS TO DRINKING WATER SUPPLIES (DWS)

Introduction

This study’s main objective is to conduct a literature review of hydraulic fracturing (HF) processes, impacts, and associated risks to drinking water supplies. The research focuses on the hydraulic fracturing process and its potential impacts on groundwater quality and quantity. The study aims to address concerns regarding the hydraulic fracturing process and to evaluate the evidence and scientific understanding of these concerns.

Thermal stimulation has a pathway for hydraulic fracturing that does not exist anywhere else, and it can cause significant risks to drinking water supplies. In the real world, hydraulic fracturing processes involve the injection of fluids into the formation to fracture the rock matrix, leading to the propagation of fractures and the mobilization of groundwater. This process involves the injection of large volumes of water and chemicals into the formation, which can result in the contamination of groundwater supplies.

Key Questions

1. How accurate are the subsurface representations of brine gas migration, relative to real fluid flow, and what are the reasonable pathways (shown or not shown)?
2. When an aquifer becomes overpressured, can significant amounts of methane gas (enough to impact DWS) penetrate the borehole wall in the dissolved phase or only in the free gas phase? (i.e., this requires some understanding for determining what is the ‘water level’ in the annulus below the intermediate casing, or further downstream in the case shown, so that free gas is opposite the borehole wall?
3. Is venting the preferred management solution to prevent brine gas or methane release from overpressurized fractures? What is the role of methane in being released to the atmosphere by this standard practice?
4. Given that there is a large amount of gas that is known and documented in impact DWS (new pathways exist), why are methane releases from hydraulic fracturing not being addressed in several cases (due to a documented drive mechanism and a pathway, where are limited resources better spent?).

Conclusions

The research presented in this study demonstrates the potential impacts of hydraulic fracturing on drinking water supplies. The study highlights the need for further research to better understand the mechanisms and pathways of brine gas and methane migration and to develop effective management strategies to mitigate these risks. The study also emphasizes the importance of monitoring and regulating hydraulic fracturing activities to protect drinking water resources.
Thoughts/Expressions to Consider:

"This session is titled incorrectly and headlines that the biggest issue is hydraulic fracturing...I want to talk to you about the real issues that unconventional resource development of oil and gas bearing shales present." While many concerns are very real and justified, the threat to drinking water supplies from the deep underground HF process are probably not.

The term “Hydraulic Fracturing” means many things to many different people. The more narrow definition is the that of a “well stimulation process” applied to enhance HC flow to the well bore to make oil/gas wells more economic. The most broad use of the term is all the cradle-to-grave operations associated with the unconventional resource development that hydraulic fracturing particularly when coupled with horizontal drilling has made possible. In this talk my focus will largely be on the narrow definition of the term and what the real threats are from the deep underground HF process and risk of chemical migration to Drinking Water Supplies/potable aquifers. My insights result from the last two or more years looking into this issue on behalf of many of our National Parks that now have or will have this activity encroaching upon them.

Keeping relative risks in “PERSPECTIVE” (chemical exposure via drinking water aquifers impacts under RCRA, CERCLA, State LUST programs (10,000 or more releases - often free product) impacting near surface aquifers at concentrations up to levels of product solubility way above regulatory levels – (contrast to highly dilute Frack Fluid chemicals used in fracking at depth when one has to reach to point to 1 clear impact to a DWS after over 1 million frack jobs.)
Frequent Mitchell Quote:

Efforts to solve environmental issues are very important…..Yet it’s not enough. Sustainability is a much bigger issue. Environmentalists should think one notch higher than what they are doing….They need to convert the environmental interest into a sustainability interest”

Greenwire:
Critics, often environmentalists, apply the "fracking" moniker to all aspects of shale drilling -- from the first truck that shows up at the well pad all the way through to waste disposal and plugging. Because of this divide, the drilling industry's critics and boosters argue a lot, but they often refuse to talk about the same thing.
Man-Induced HF in Oil & Gas Development

Potable Aquifer down to 800 to 1000 feet bgs

2000 to 9000 feet TVD

Surface Casing Depth ~ 1000 feet

main risk w/o cemented casing string, non-Target (stray) gas can migrate up borehole

Well is turned horizontal

(Up to 1 Mile Lateral)

Marcellus Shale (Target Fm)

Hydrofrac Zone (fractures every 500 feet)