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 Buckminister 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."

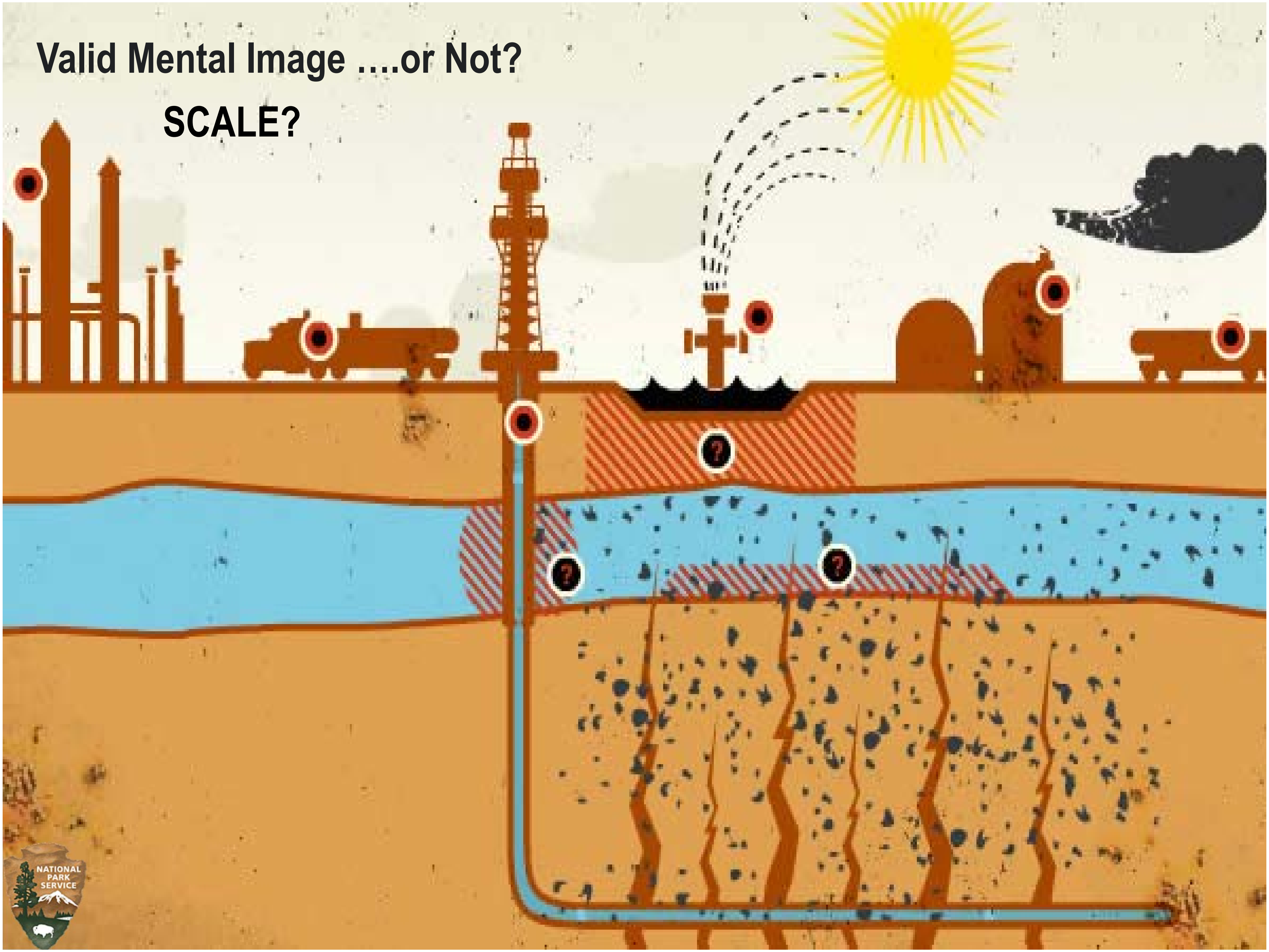
"**Fracking** is extremely controversial and many believe chemicals used in the process are polluting sources of water." **"If they [Gas Companies] do a proper job, there is no risk of contamination.**"

George Mitchell, (Pet. Engr./Geol.) - Developer of Hydraulic Fracturing Technology in Shale Rock – Energy – Real Estate – Philanthropy - Sustainability Advocate – Club of Rome Honoree

Mitchell Energy and Development Corp. – The Woodlands Texas (first "Green" Planned Community" - 1970)

Valid Mental Image ….or Not?

SCALE?



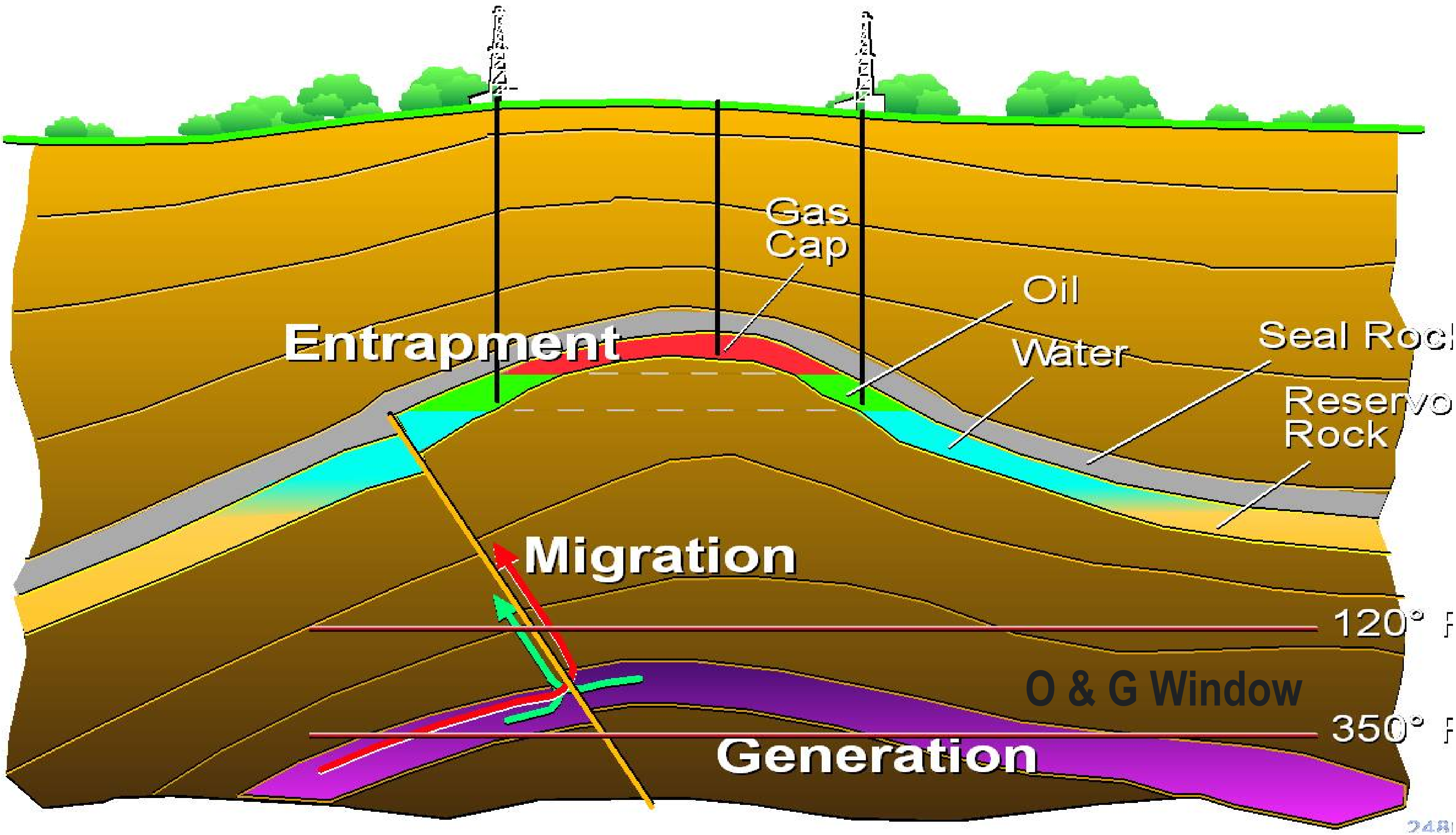
WHY NOW & WHAT'S CHANGED?

- 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



The New Petroleum System

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

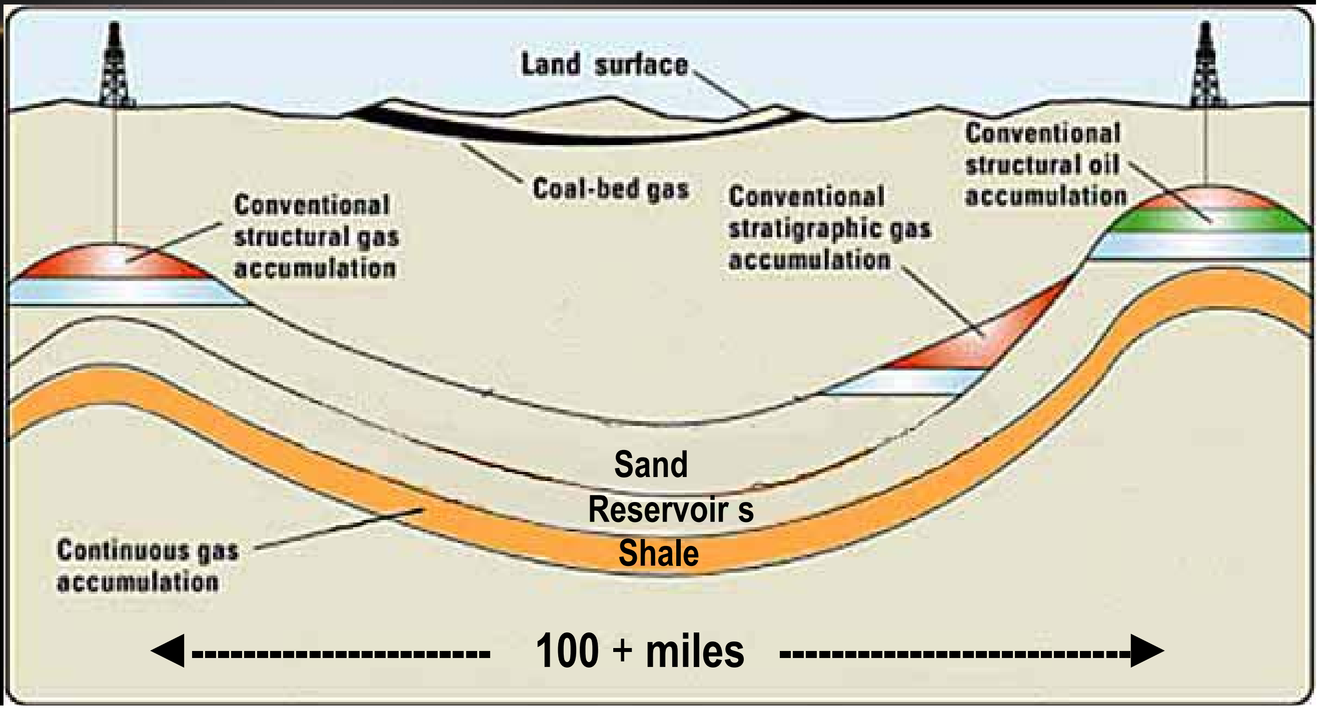
Paradigm Shift - Game Changer - Transformative

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)



Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011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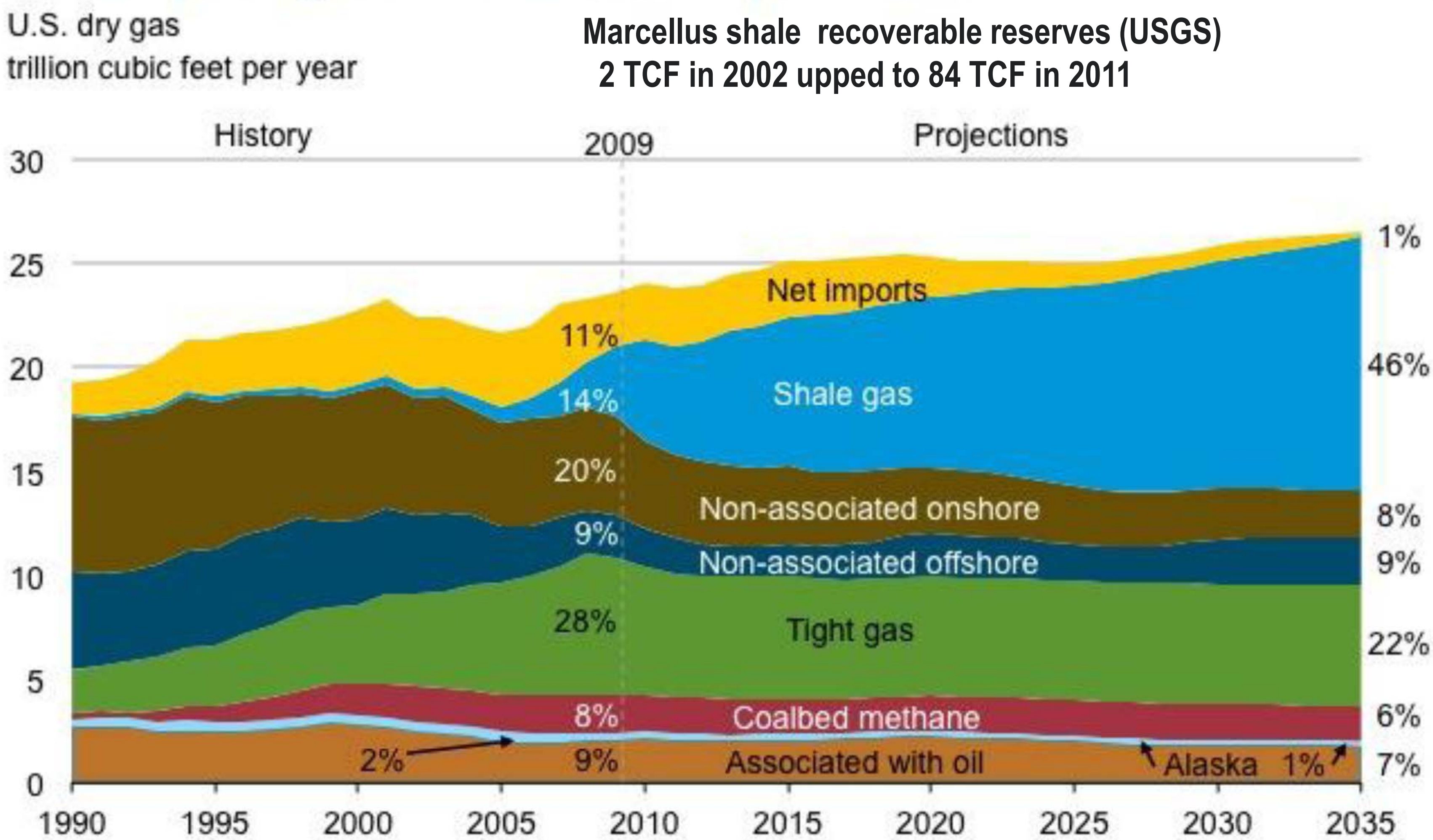
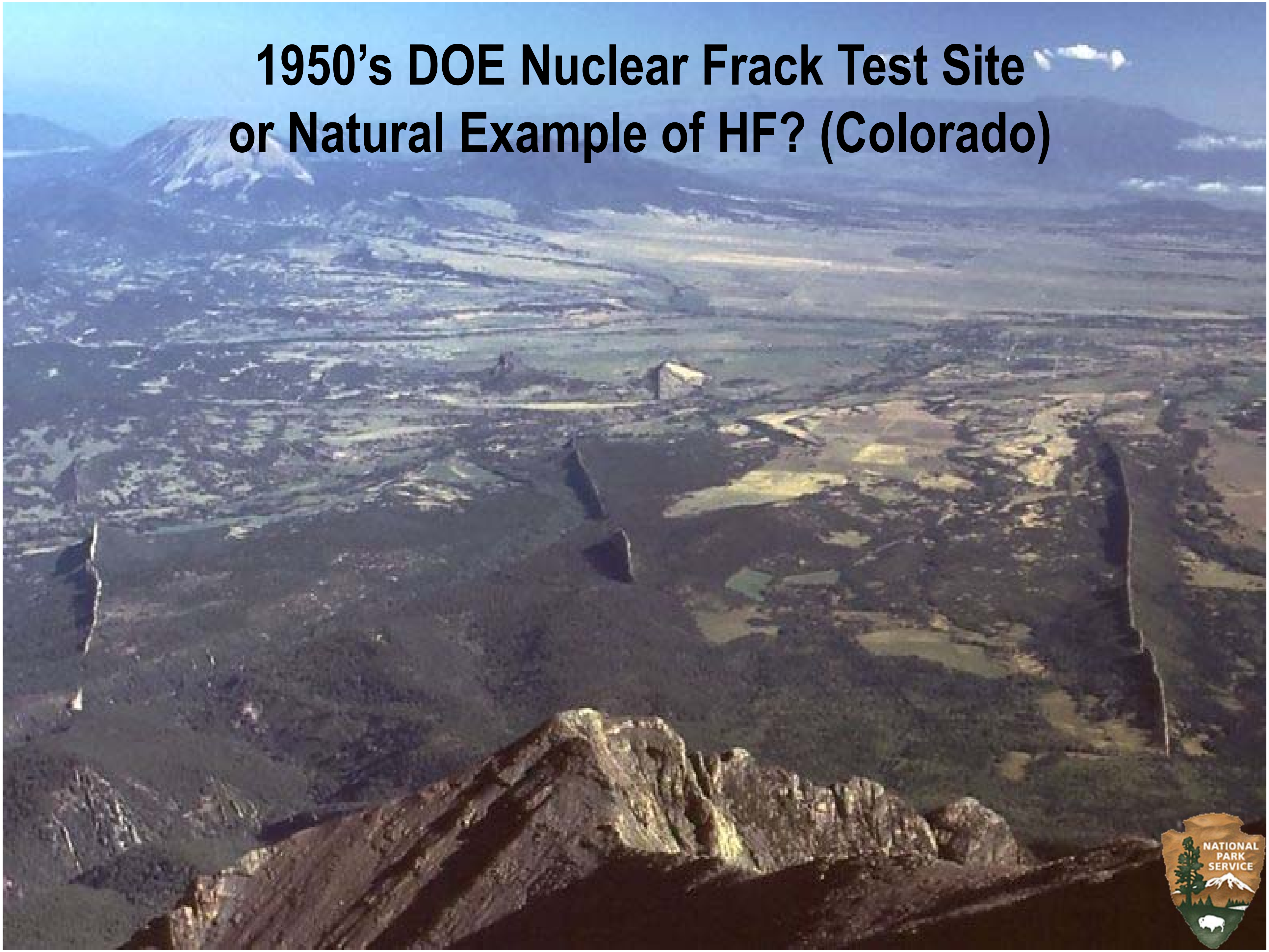
Shale gas offsets declines in other U.S. supply to meet consumption growth and lower import needs

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

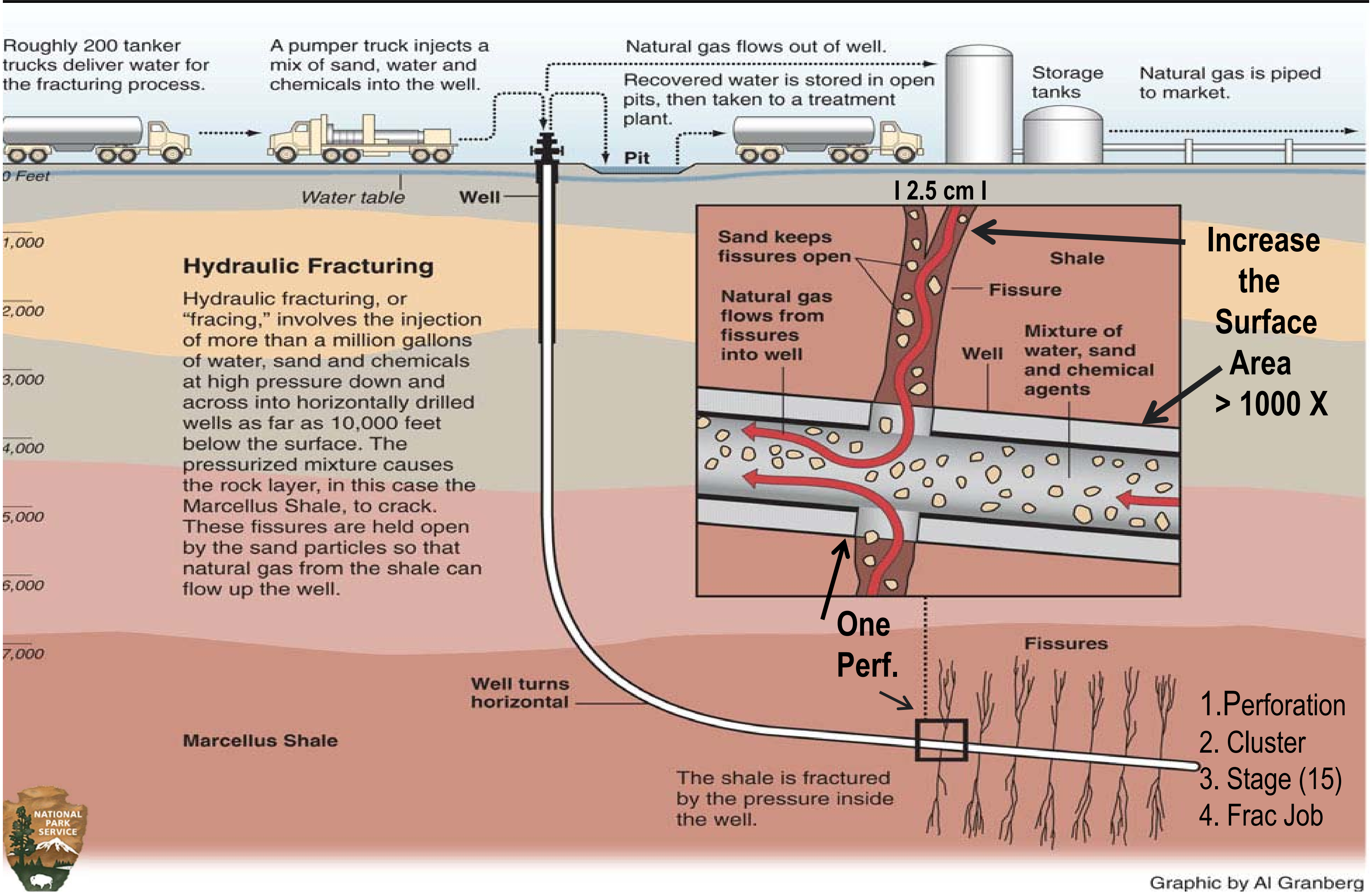


Source: *EIA, Annual Energy Outlook 2011*

1950's DOE Nuclear Frack Test Site or Natural Example of HF? (Colorado)



So.....What Is HF? (a few details)

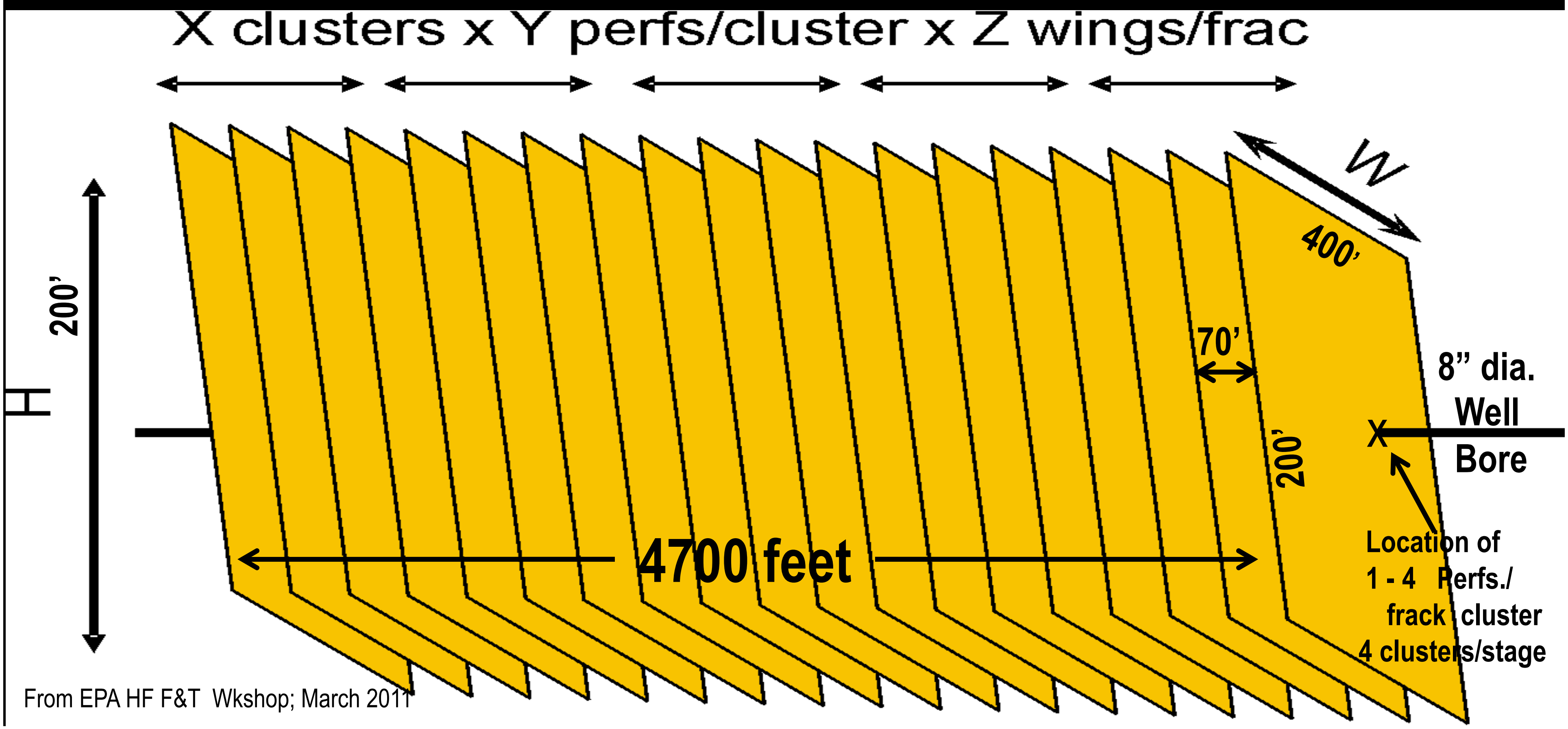


Visual representation of how fracks increase the surface area of well bore to allow increased gas flow from shale rock

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

EXAMPLE:

- Lateral BH Length = 4700' (Side area of that 8" dia. cylinder; A = 2πrh 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

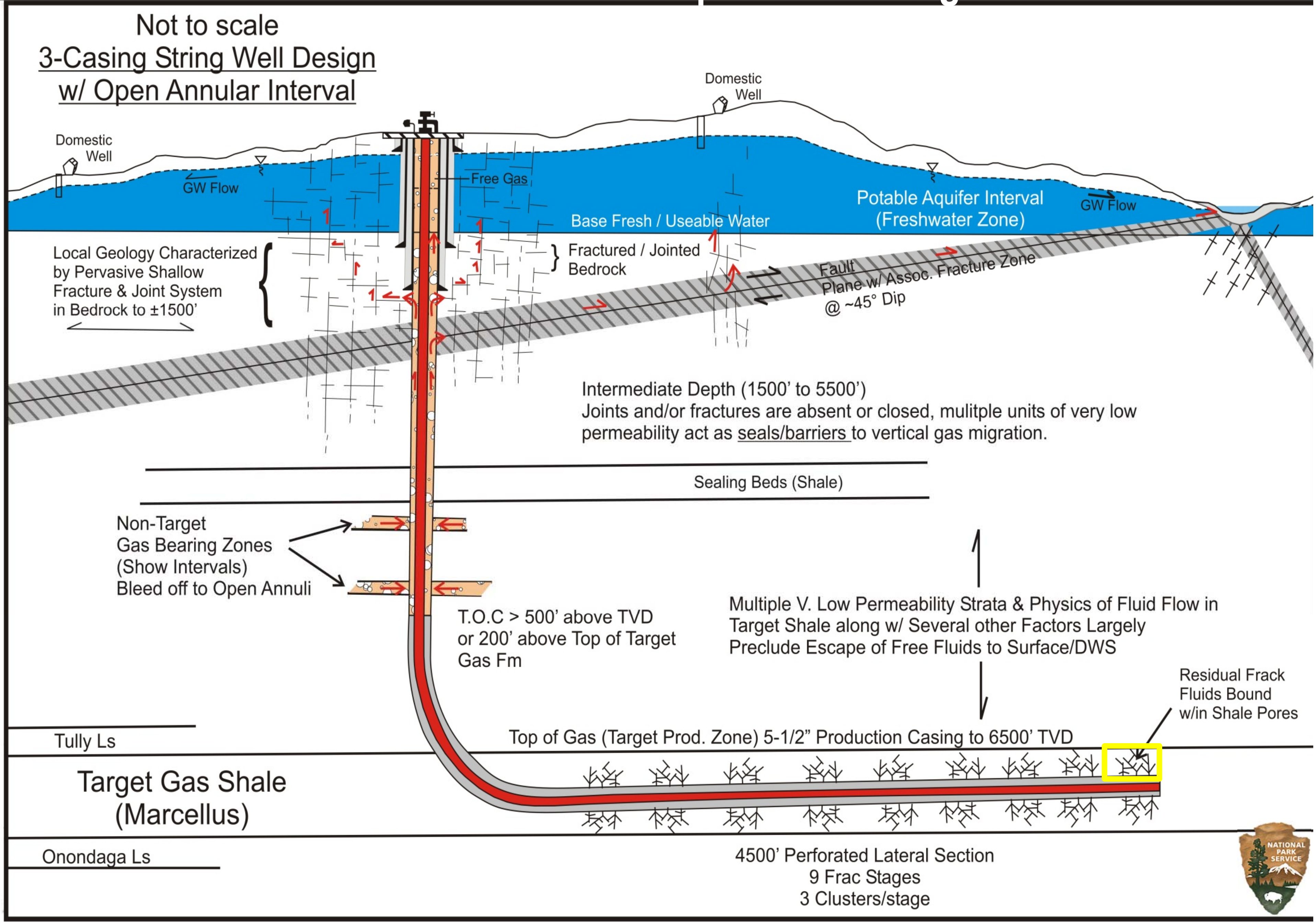
Typical Well (Marcellus)

- 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:

- Φ_{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



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??

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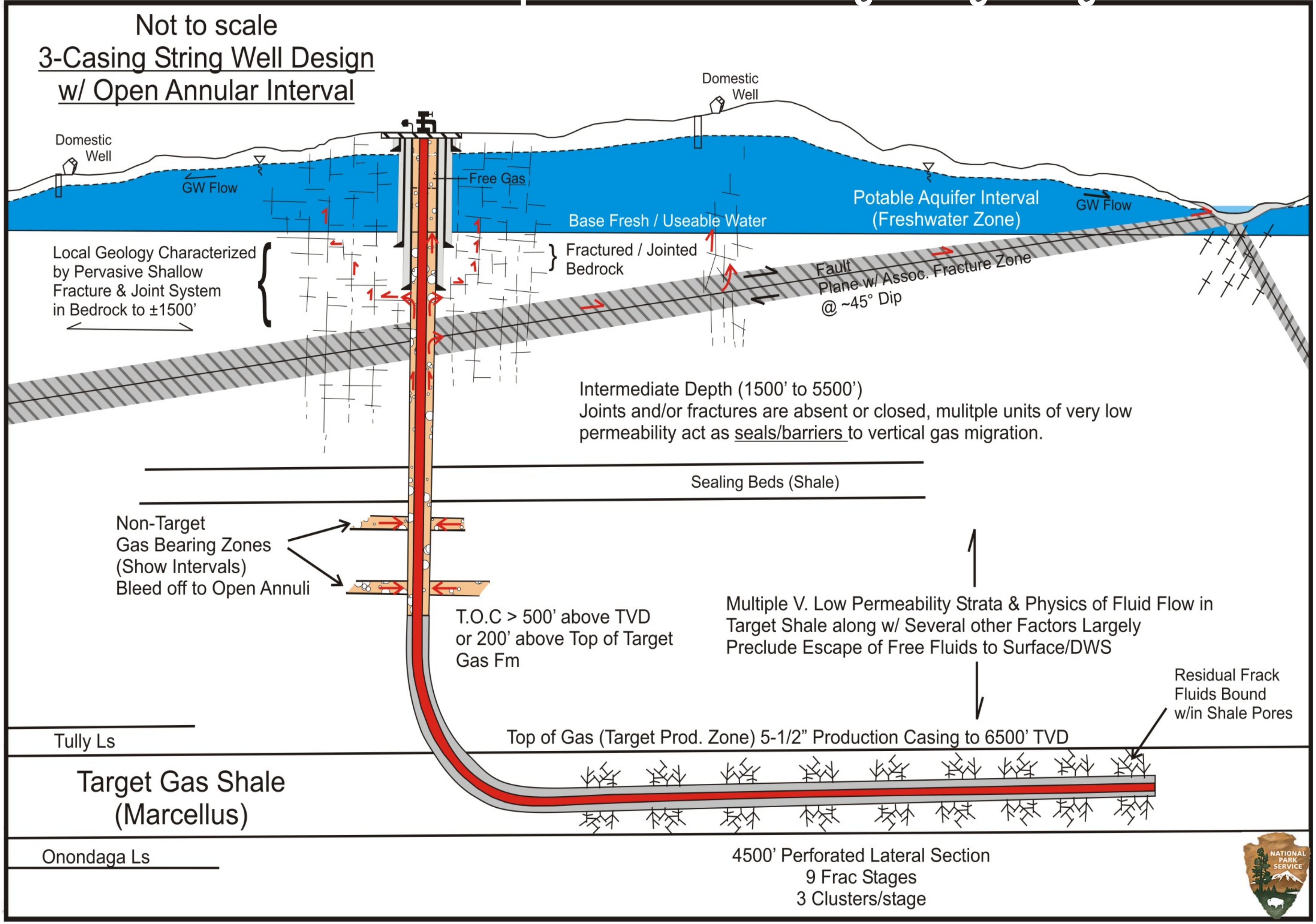
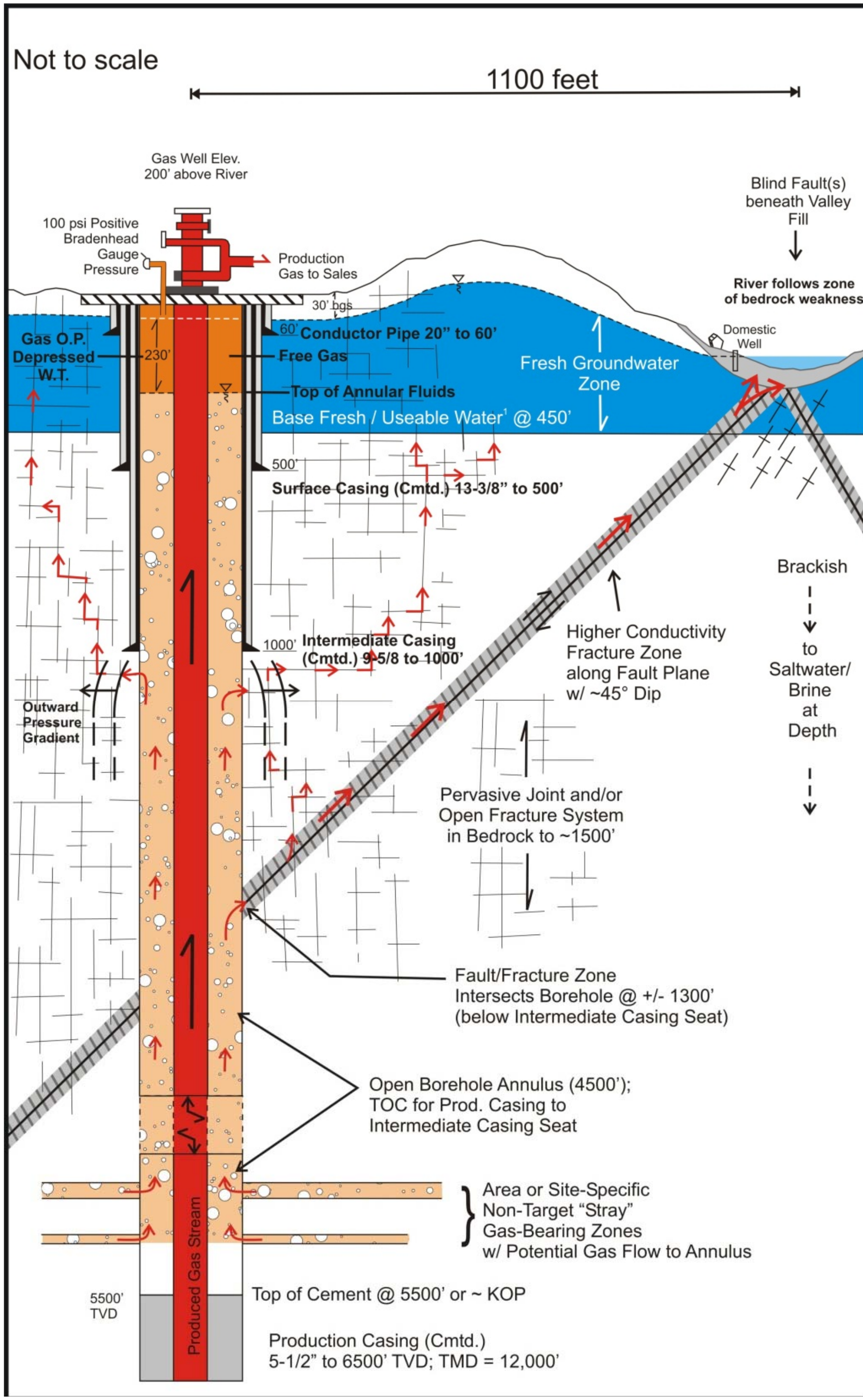
Marcellus Shale Example Well w/3-Casing String Design





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

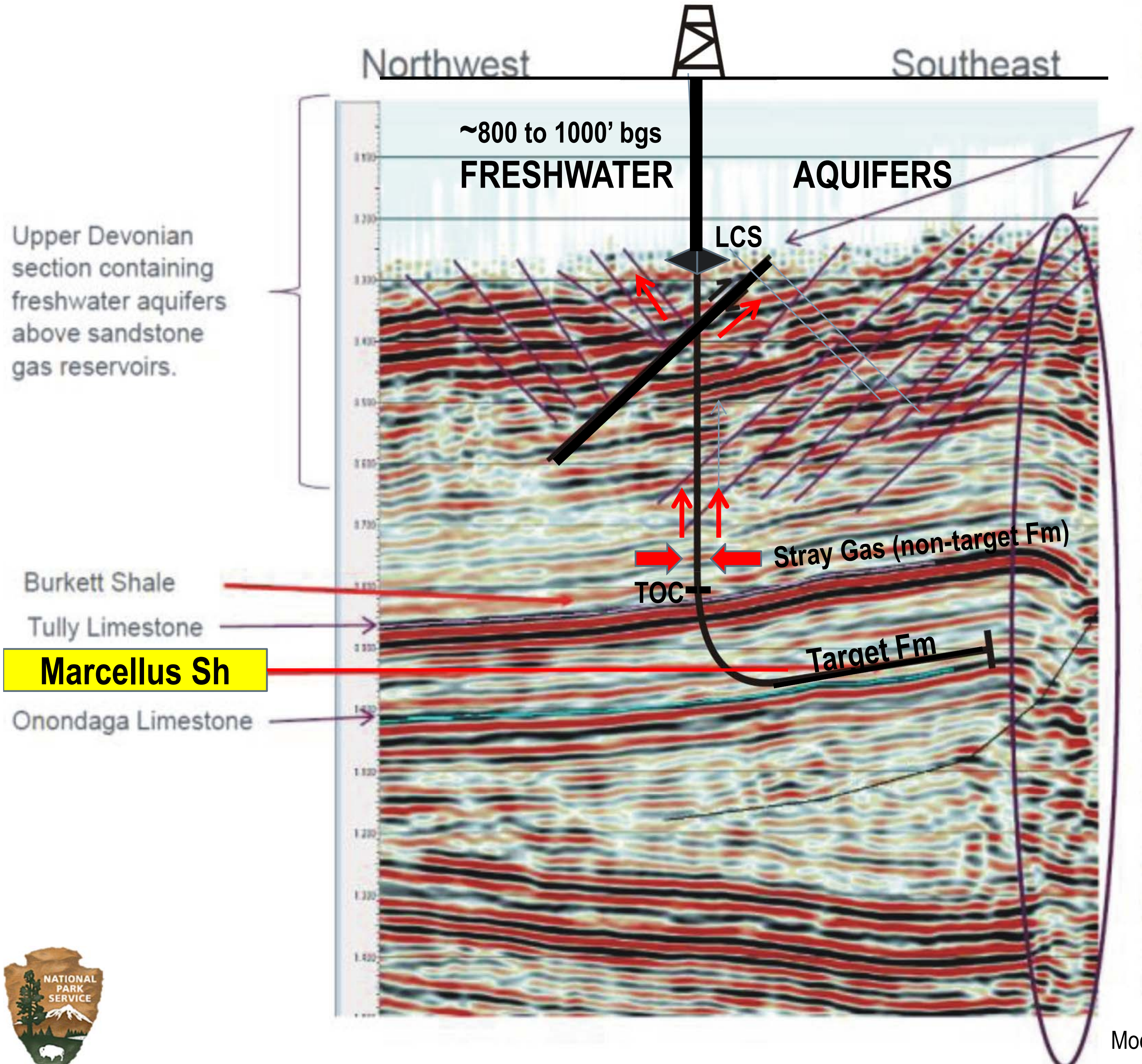
Example: NE PA Marcellus Well Design

- **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.

Modified From PA DEP website & Shell

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

- New State Rules and Regulations (CO., WY., PA., NY., et al.)
- 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)

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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!)

HUMOROUS FRACKING NEWS CONT.

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)**

Politicians Best Example of Direct Cause and Effect: "Hydraulic Fracturing Correlated with Spread of STDs Amongst Womenfolk" State Rep. Michael Sturla, Lancaster Co. PA.

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???

EXTRA SLIDES

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 footprint ½ (?) 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)

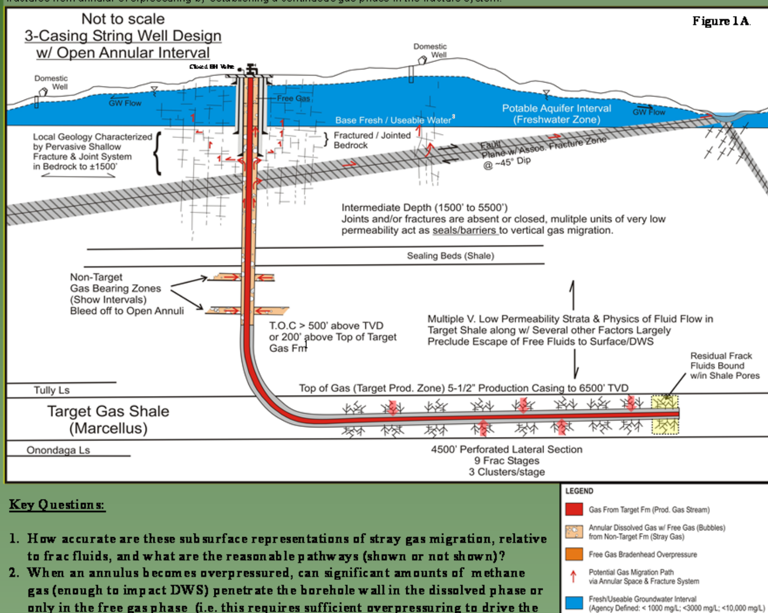
THE HYDRAULIC FRACTURING PROCESS (HF): REAL CONCERN or MISDIRECTED FOCUS CONCERNING THREATS TO DRINKING WATER SUPPLIES (DWS)

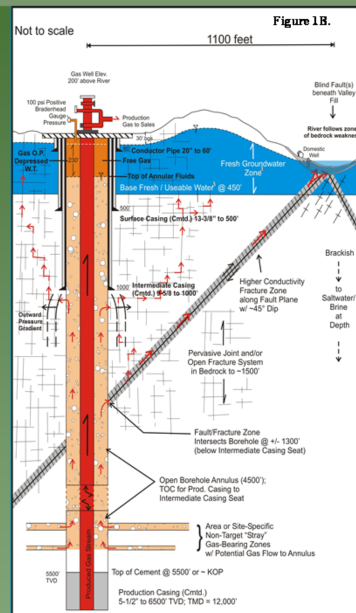
NRSS Directorate
National Park Service
U.S. Department of the Interior

Introduction

This author's literature review, attendance at various hydraulic fracturing (HF) symposiums, forums, conferences, an EPA sponsored HF workshop on Fate & Transport and discussions with oil and gas regulatory agencies and industry representatives suggest there is a growing, if not already strong consensus among those who have performed objective analyses of the HF process, that the risk posed to potable aquifers or drinking water supplies (DWS) from the deep underground process of HF is now miniscule. Assessments of potential impacts range from "remote" (DOE 90 Day Report) to "do not present a reasonably foreseeable risk of significant adverse environmental impacts" (NYS SGEIS). Furthermore, multiple lines of evidence including theory based on the physics of fluid flow, fate and transport modeling and empirical evidence from hundreds of thousands of frac jobs performed by industry in the last 60+ years without documented impacts to DWS, indicate that further public focus on this concern is misdirected and simply unwarranted. It is often a challenge for experts to communicate complex concepts to the public to allay fears and concerns. Terms such as imbibition, irreducible water saturation, and capillary pressure effects and their underlying conceptual basis while critical to a technical understanding of why 70% to 90% of frac fluids remain unrecovered in flow back, also make it difficult to convey to the public why these residual frac fluids are highly unlikely to subsequently appear in a DWS. Residual frac chemicals are most likely locked in rock pores of the target shale with no means of escape for periods possibly on a scale approaching that of geologic time. The public rarely differentiates between direct impacts by methane gas to DWS, and their contamination with other constituents from other mechanisms or processes. Direct impacts by methane gas to DWS have occurred, and documented pathways for this type of contamination do exist related to gas well construction, when an uncemented annulus becomes over pressured. However, in most instances methane occurrence in DWS is still attributable to sources unrelated to gas development. When methane impacts from gas development do occur, they are most typically related to non-routine overpressuring "events" during drilling, cementing or casing operations unrelated to the hydraulic fracturing process itself. Some well design practices can facilitate stray gas migration when site-specific geologic conditions, as depicted here, are not fully understood. Specifically, should shallow fractured bedrock extend below surface (two-string design) or intermediate (3-string design) casing depths, higher risks for gas migration may be present.

This poster illustrates two pathways for stray gas migration that may occur independently of each other, or operate in conjunction, to facilitate gas migration to a DWS when a 3-string casing design with open annulus becomes overpressured. From a relative threat standpoint, a change in focus from potential hydraulic fracking fluid impacts to DWS, to the real threat of stray gas migration, is long overdue. While public concerns about HF fluid impacts to DWS have brought about better regulation and many operational improvements by industry, including frac chemistry disclosures (e.g. fracfocus.org), use of less/non-toxic (green) chemical substitutes and greater transparency of overall operations, few significant additional environmental gains in this area are likely to occur that further reduce risk in any appreciable manner from its already low state. Further, opponent arguments and concerns regarding impact to DWS from the hydraulic fracturing process appear increasingly without technical merit. In contrast to frac fluids largely sequestered in the target formation, methane gas from non-target gas bearing zones is abundant and concentrated, can be highly mobile and migrate as a free phase in addition to dissolved phase, has a pathway that permits several thousand feet of cross-strata migration (open annulus above production casing cement) and a drive mechanism (buoyancy). Furthermore, methane from a deeper source (normal to over pressured gas bearing geologic unit) often leads to over pressuring of casing and annular intervals at shallow depths (i.e. exceed hydrostatic conditions). Overpressuring is undesirable and mitigation/remediation can be problematic and costly or result in continuous venting of this potent GHG over a long period (e.g. life of well). Gas build up (overpressuring) of the annulus can also create the required gradient for stray gas to penetrate fractured bedrock through the open borehole wall and move upward and around surface/intermediate casing strings of good integrity to reach a DWS. Earlier overpressure events (e.g. gas kicks) during the drilling and completion phase may also facilitate subsequent movement through shallow fractures from annular overpressuring by establishing a continuous gas phase in the fracture system.

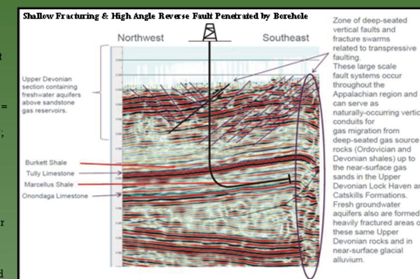


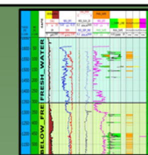


NOTES:

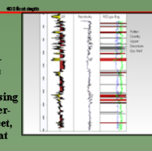
1. 200' for TOC in Figure 1A applies to minimum height above top of perforations in vertical or slant wells only (PA DEP).
2. Positive bradenhead gauge pressure <u>not to exceed</u> 80% x hydrostatic pressure at depth of surface casing shoe per PA DEP (.80 x 0.433 psi/ft. x 500 = 173 psi in this example Figure 1B.)
3. Base of fresh/useable water (1000 mg/L, NY DEC; 3000 mg/L, some other states; 10,000 mg/L some other states, EPA and BLM (Onshore Order #2)
4. Neither figure depicts slower gas migration through cement that can sometimes occur. These are referred to as mechanical discontinuities that create annular conductivity. They include micro-annular flow (between cement sheath and casing or borehole wall) or matrix permeability/channeling when a slug of gas enters the cement and migrates upward before the cement sets. This is most common in the GOM where shallow overpressured gas zones that lie opposite cemented casing strings can lead to sustained (annular) casing pressures (SCM). That stray gas may also require venting.

Below Illustrations Modified From PA DEP and Shell Oil



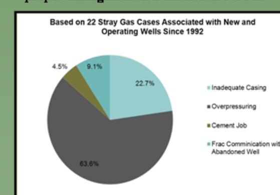


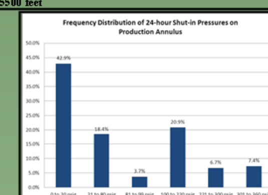
Potential For Non-Targeted Gas Sand Show Intervals in Open Annular Intervals Below Freshwater Zones and Surface and Intermediate Casing String Intervals



Marcellus Well Logs Illustrating Non-Target Shallow Gas Zones. Conditions similar to Figure on Left w/Surface Casing set to 450 feet below FW, Intermediate Casing set to 1000 feet, TOC for Production Casing at 5500 feet

Evidence that stray gas, its monitoring and its proper management is a concern in PA DEP





Key Questions:

1. How accurate are these subsurface representations of stray gas migration, relative to frac fluids, and what are the reasonable pathways (shown or not shown)?
2. When an annulus 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 sufficient overpressuring to drive the water level in the annulus below the intermediate casing seat or further downward than in the case above, so that free gas is opposite the borehole wall)?
3. If venting is the preferred management solution to prevent borehole annuli from overpressuring, what quantity of methane is being released to the atmosphere by this standard practice?
4. Given that frac fluids have not been documented to impact DWS (few pathways exist), while methane related to stray gas migration has been implicated in several cases (due to a documented drive mechanism and a pathway), where are limited resources better spent?

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Conclusions

Relative to HF fluids used in fracing target gas shales, stray gas from non-targeted (noncommercial) gas bearing zones found above targeted gas is far more abundant, concentrated and mobile with much greater upward migration potential from the deep subsurface due to the buoyancy drive mechanism within an open borehole annulus. A several thousand foot potential cross-strata migration pathway exists to DWS via the open borehole (open annular space between top of production casing cement and cemented surface or intermediate casing string/shoe) under most current well designs accepted by states and the BLM. Should an overpressured annulus develop from these gas sources and an open fractured/jointed condition characterize shallow bedrock that extends below surface or intermediate casing depths, this gas migration pathway to DWS is potentially complete. With the advent of unconventional shale resource plays, their expansive coverage, increased well densities and intermingling with rural domestic wells, greater risk over the long term exists from non-routine annular overpressuring events or when wells are not vented. Mitigation of annular space methane gas build up through venting is less of an option than in the past due to concerns for GHG emissions as this methane source is poorly quantified. The complexity of the stray gas migration issue suggests further research into its component parts is warranted for a better understanding of best management practices. These include **1) Quantification** of the nature of the problem or approximate amount of stray gas currently vented by the gas industry, possibly through a random/probabilistic sampling design **2) Source Identification & Isolation** – methods of source (strata) identification (borehole logging options), zonal isolation, conditions fostering or limiting flow/bleed-off to well bore/annulus **3) Annular Environment** – effects of fluids present (water, mud, brine, gas), gas transport phase (free phase gas vs. dissolved), slough/cave (borehole bridging effects) and their effect on gas flow from the source to the borehole and outward to country rock from overpressuring **4) Overpressure Conditions** – gas phase and entry pressure requirements for rock matrix vs. fracture (pore & aperture minimums), wetting phase of matrix/fracture faces, residual effects from non-routine overpressure "events" that would facilitate gas connectedness in fractures and subsequent stray gas migration **5) Monitoring** – casing annular pressures correlation with annular fluid levels, freshwater zone heterogeneity (stratification) and appropriate freshwater intervals or aquifer horizons for early detection of methane migration to DWS. There are many trade-offs in selecting management strategies and well designs to minimize stray gas. Further analysis of the components is warranted to better assess cost-benefit relationships and to ensure that GHG emissions and potential impacts to DWS are minimized.

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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