The future (and promise) of fracking technology:

US Energy Association, Washington
Jan. 26, 2012

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Many energy & environmental challenges face the world

Increasing energy demand

Increasingly complex market

Water scarcity

Pollution reduction

Greenhouse gas emission reduction

Technology leaders are market leaders

Low Impact Fossil Energy (LIFE) is the keystone

Low-impact fossil energy must have a greatly reduced environmental footprint compared to conventional coal, oil, and gas is every way

- 50-90% reduced GHG emissions
- Reduced water consumption
- Ultra-low sulfur, mercury, and particulate emissions
- Reduced surface footprint for extraction and use

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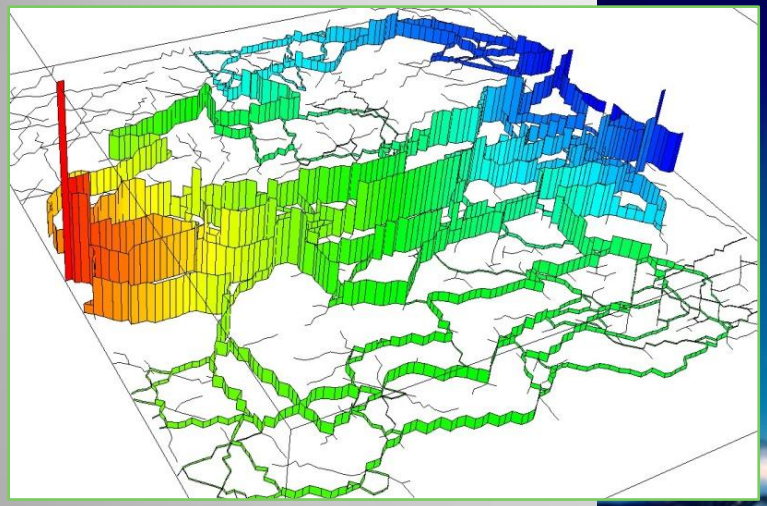
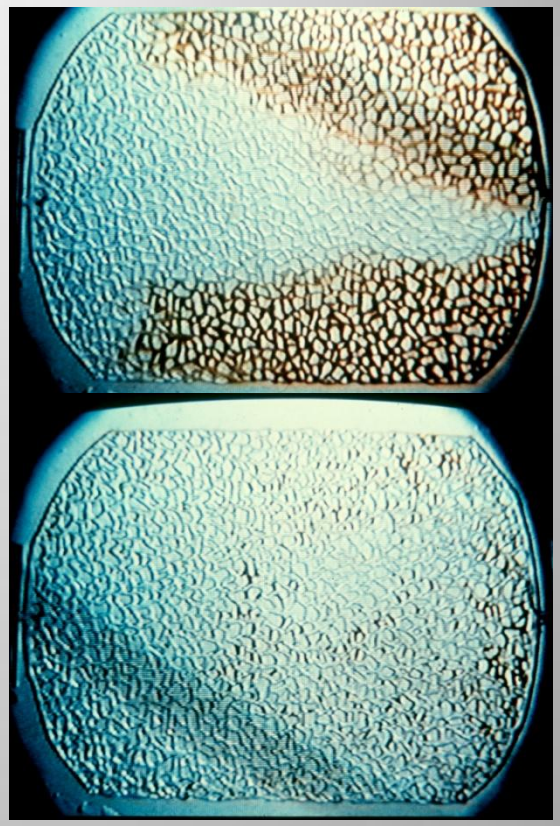
Three technologies will reinvent three LIFE markets



Shale Gas and Liquids

Underground Coal Gasification



CO_2-Residual Oil Zone production

High-performance computing (HPC) will improve all LIFE technologies

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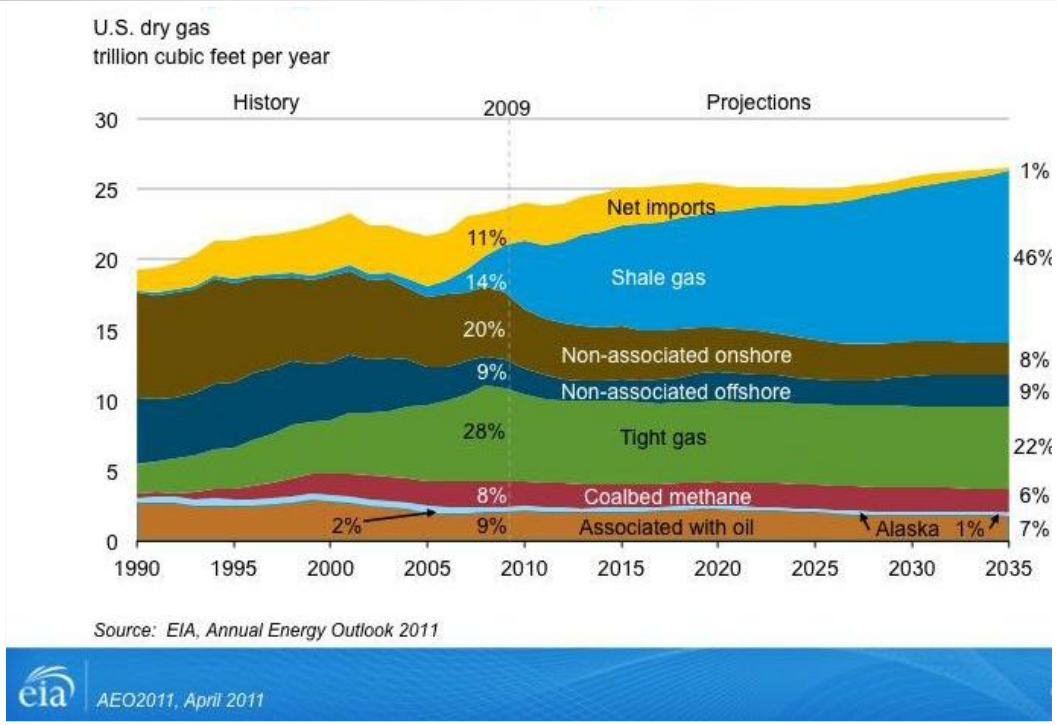
Shale gas and liquids provide many direct economic and environmental benefits (with costs) to the US



Domestic supply

- Over 20% of current US gas production
- Roughly 1M Bbls/day
- Tax revenues for states, Fed

Jobs

- Over 200,000 jobs recently
- Higher than average wages
- Foreign direct investment

Costs and issues:

- Water use
- Induced seismicity
- Flaring

The challenge: improve production and recovery; reduce negative impacts

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Comments from State of the Union, Jan. 24 2012

We have a supply of natural gas that can last America nearly 100 years… my administration will take every possible action to safely develop this energy. Experts believe this will support more than 600,000 jobs by the end of the decade. …America will develop this resource without putting the health and safety of our citizens at risk.

… And by the way, it was public research dollars, over the course of 30 years, that helped develop the technologies to extract all this natural gas out of shale rock –- reminding us that government support is critical in helping businesses get new energy ideas off the ground.

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North American market is established, not quite mature

Well understood plays

- Bakken, Barnett, Fayetteville, Marcellus…
- Many large developments
- Proven, simple technology

Issues and questions remain:

- Lifting cost
- Drilling density
- Environmental impacts
- Resource vs. reserves

Derived from CBM and tight gas drilling and production technology

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Marcellus Acreage Deals since Jan.1 2010

Mitsui/Anadarko	$1.4 Billion
Consol/Dominion	$3.5 Billion
Reliance/Atlas	$1.7 Billion
Shell/East	$4.7 Billion
Chevron/Atlas	$4.3 Billion
ExxonMobil/Phillips	$1.7 Billion

Additional deals in the Bakken, Utica, and Eagleford

Over $30B of direct investment, including >$15B foreign direct

Thanks to Mike Moore, BlueSource

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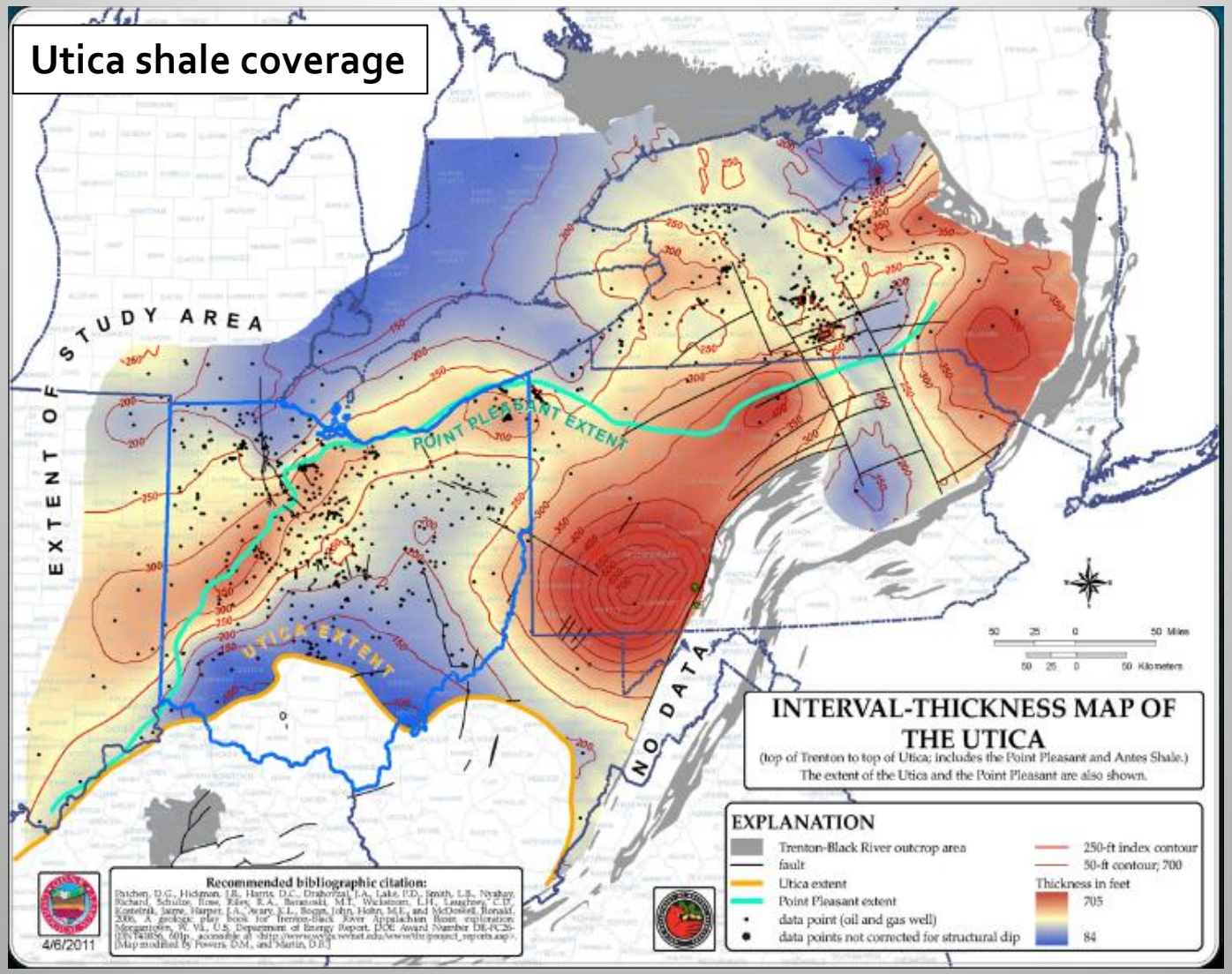
New plays are in densely populated areas



This increases benefits, visibility, and concerns

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Ohio OOGEEP Utica Projections

YEAR JOB IMPACT

- 2011 4,614
- 2012 22,297
- 2013 102,924
- 2014 178,088
- 2015 204,520

Source: *September 23 2011 Economic Impact Study - Ohio's Natural Gas and Crude Oil Industry*
www.oogeep.org

TYPE OF TAX 2011—2015

- Severance $ 50.9 million
- Commercial Activity $ 27.9 million
- Ad Valorem (Property) $125.4 million
- Income (Federal) $219.7 million
- Income (State & Local) $ 54.9 million
- **Total** **$478.8 million**

REINVESTMENT OF REVENUES

- 2011 $ 0.25 M 2012 $ 1.4 B
- 2013 $ 6.8 B 2014 $12.4 B
- 2015 $14 billion

Thanks to Mike Moore, BlueSource

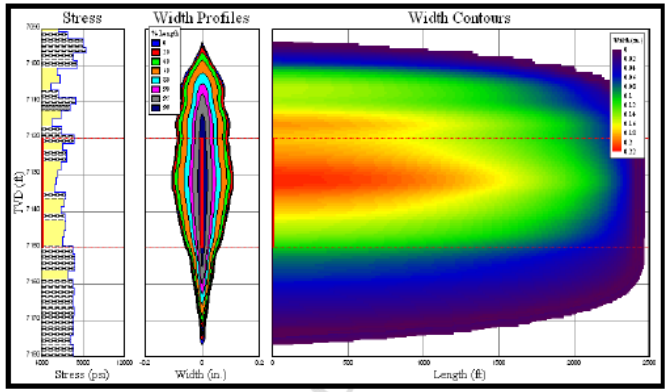
Key goals and challenges for the next decade

Many stakeholders desire the same goals:

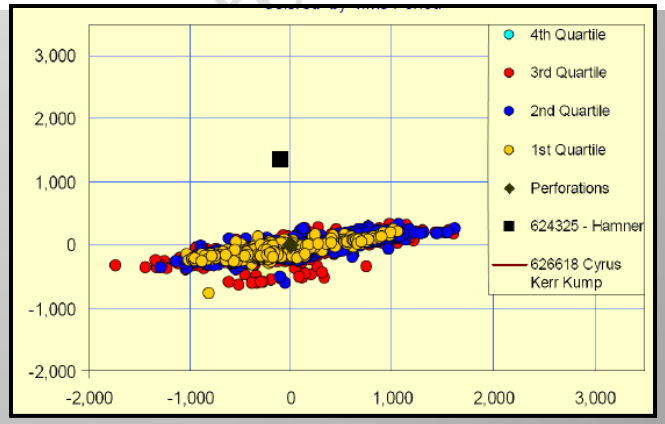
- **Increase productivity per well**
- **Reduce well count**
- **Reduce the environmental footprint**

"The public should expect significant technical advances associated with shale gas production that will significantly improve the efficiency of shale gas production and that will reduce environmental impact."

-- Sect. of Energy Advisory Board, Shale Gas Subcommittee Report



Source: Chesapeake Energy Corporation, 2008.



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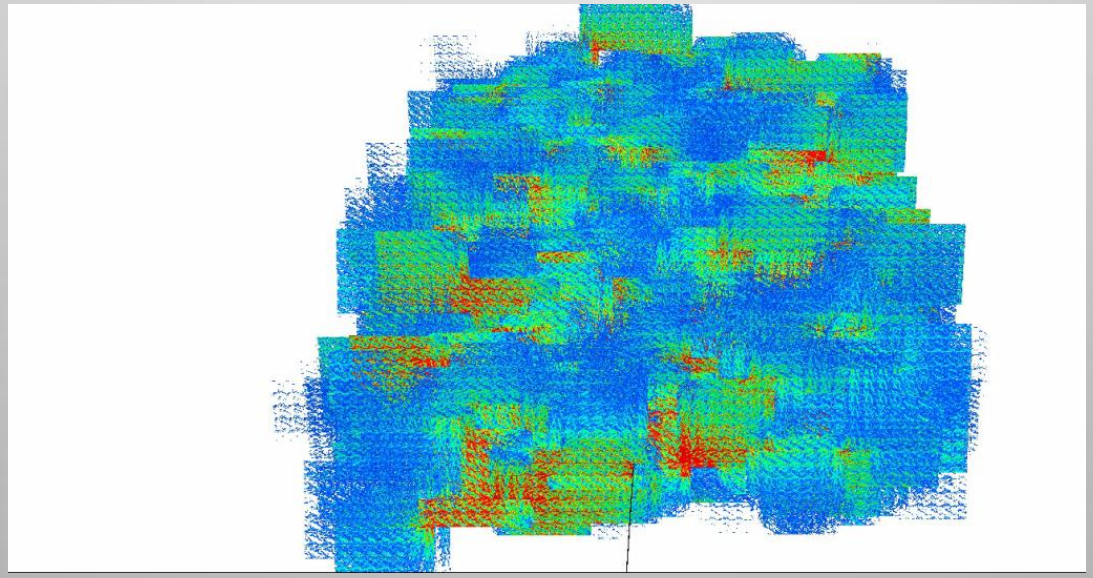
These challenges require new tools and technologies

- New simulation and modeling tools
- New stimulation and fracking tools
- New drilling and completion strategies



It's all about making and controlling fractures

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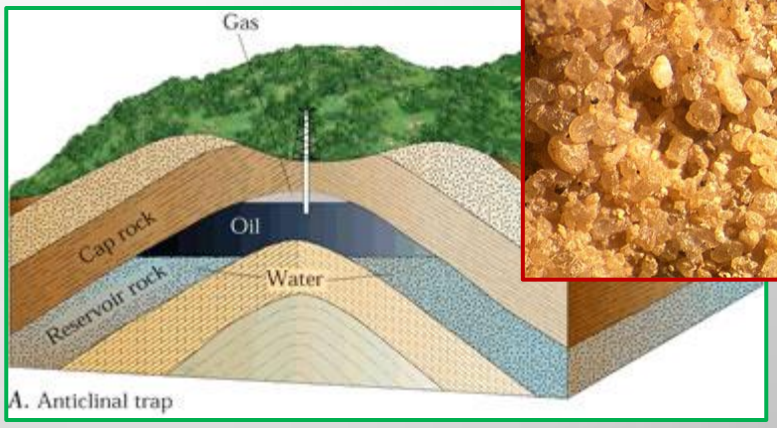
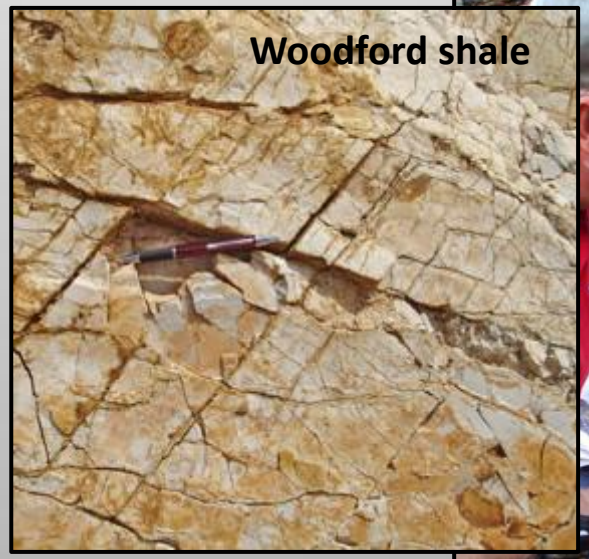
Shale gas production is VERY different from regular oil and gas production



Conventional oil and gas:

- local accumulations
- flow through porous rock
- high resource density
- costs relate to reservoir complexity
- milliDarcy-Darcy permeability reservoir



Shale gas systems:

- Wide-spread resource
- flow through fracture systems
- low resource density
- costs relate to drilling complexity and stimulation effectiveness
- microDarcy-nanoDarcy permeability reservoir

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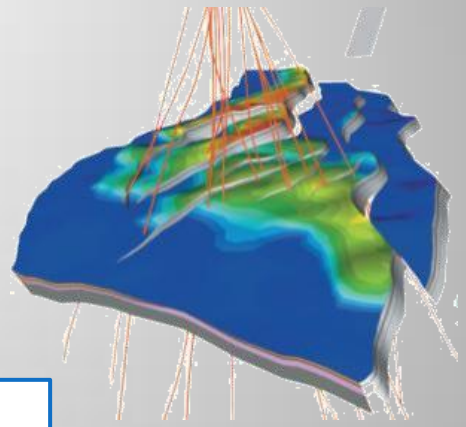
Shale gas production and exploration requires subsurface simulation tools very different from conventional models

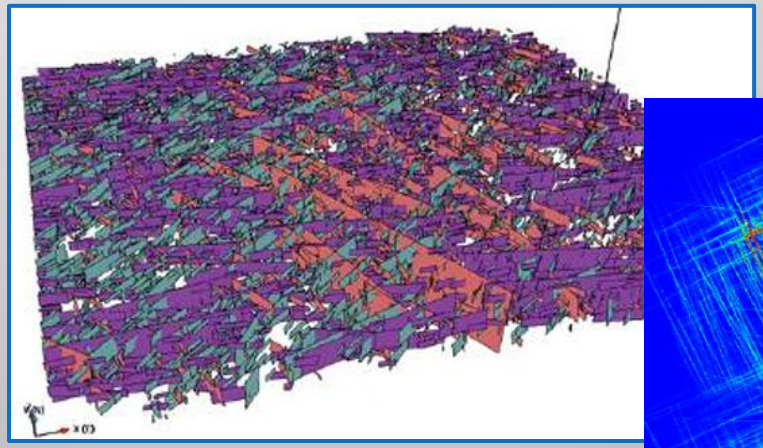
Conventional simulators:

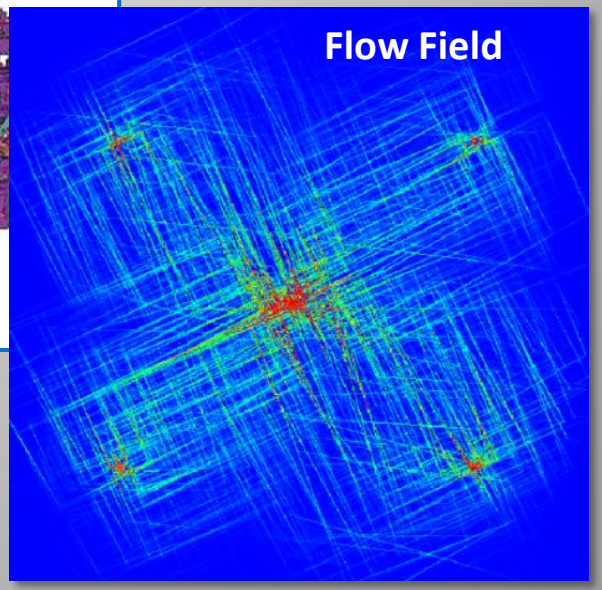
- Darcy flow approximation
- Continuum models only
- Constitutive approximations in scale-up
- Simple physics and chemistry



Shale gas systems:

- Darcy flow approximation fails: mostly fracture/ percolation flow
- Requires both continuum and discrete representations
- Complex, non-linear physics and chemistry





New simulation tools require fit-for-purpose design

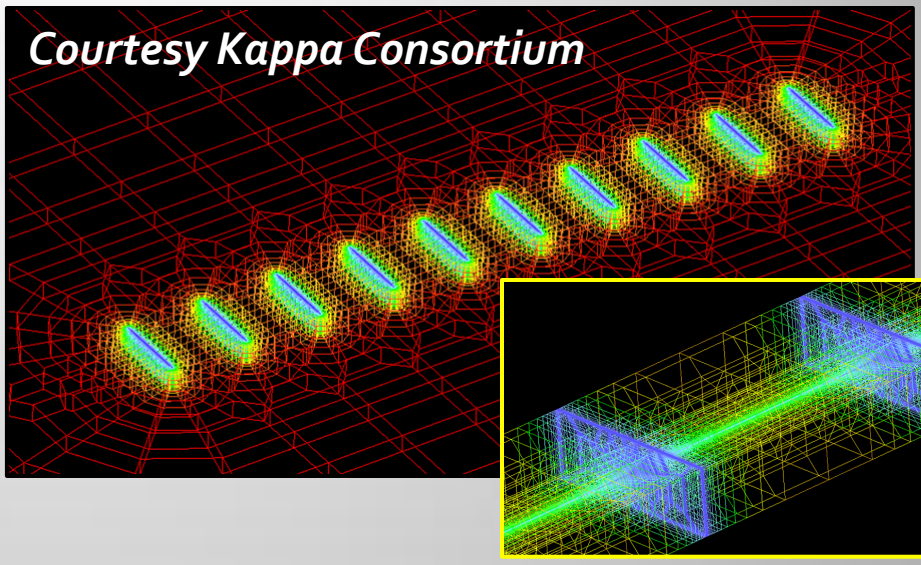
Improve continuum models

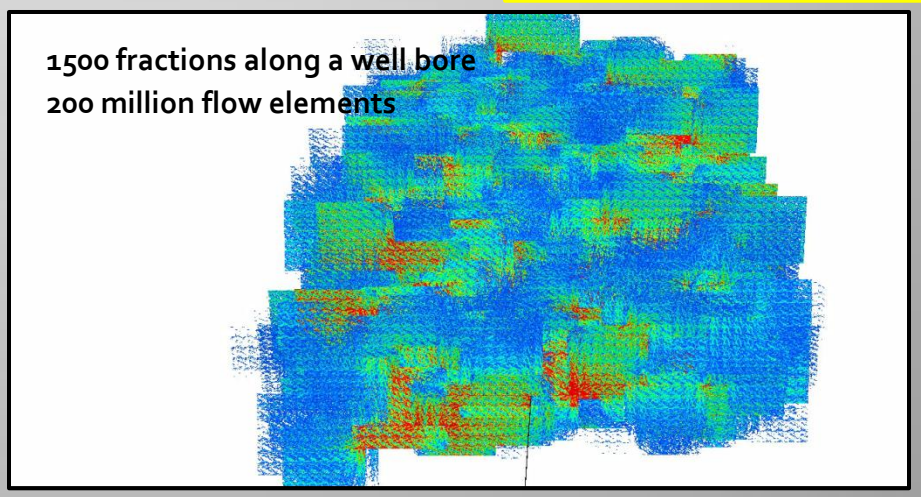
- Improved constituative models for sweep, transmissivity, etc.
- Improved gridding around wells; improved meshing technologies
- Improved linear and non-linear solvers

Alternative models

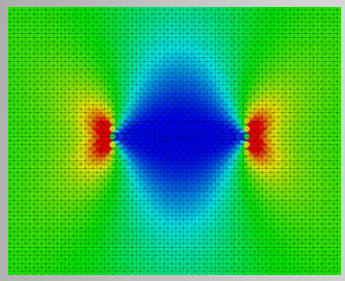
- Discrete element models; finite element models (FEM-DEM)
- Hybrid systems
- Node-splitting/fracture creation
- Better coupled process (hydrology + geomechanics)

Validation required!





New simulation tools require fit-for-purpose design



Finite element geomechanics solver

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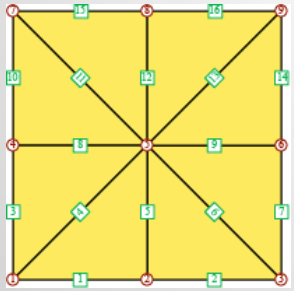

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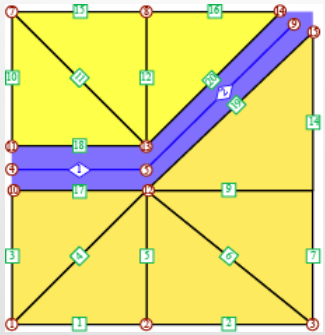

Adaptive remeshing module

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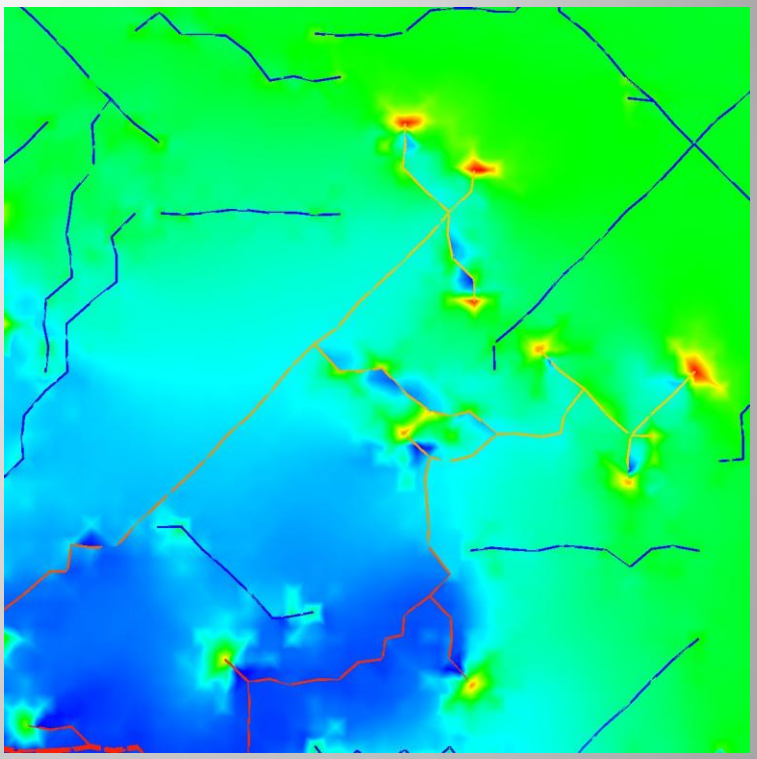
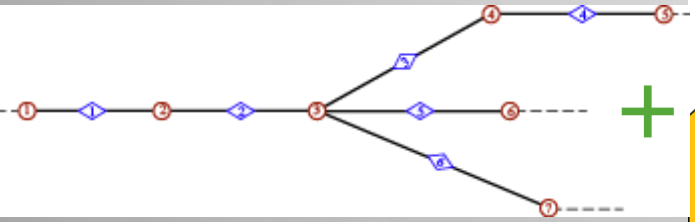


Fully coupled numerical test bed for hydraulic fracturing



Finite volume method fracture flow solver

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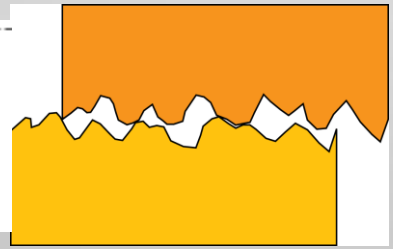


Rock joint model

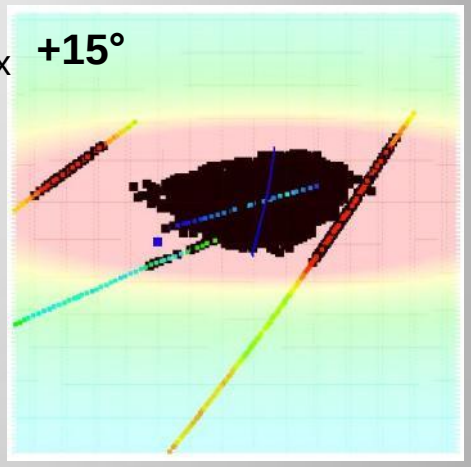
It's all about making and controlling fractures

New simulation tools require fit-for-purpose design

Coupled fracture/pressure/fluid systems:

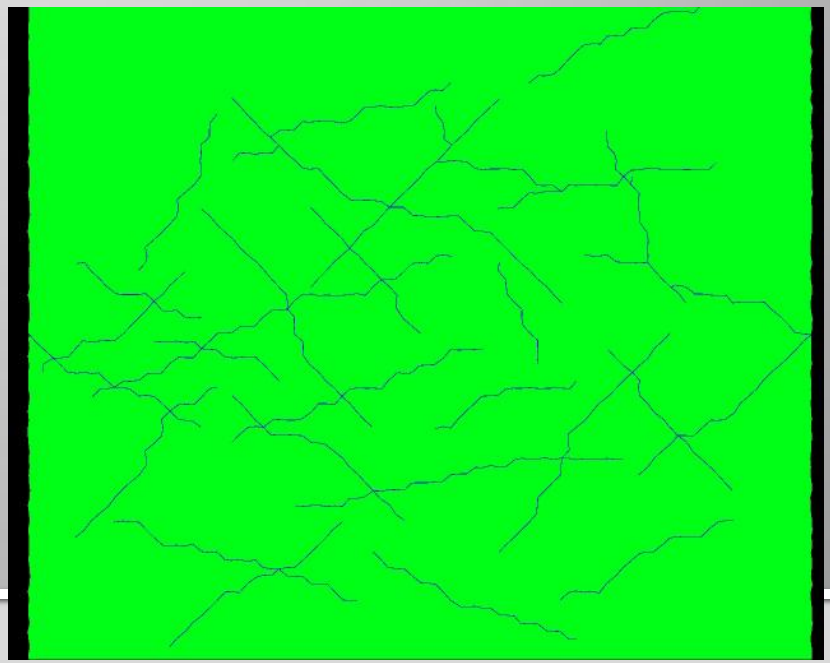
LDEC – LLNL discrete element code

- Can simulate any fracture geometry
- Born parallel – has run 10 billion cell model
- Can handle arbitrary fracturing; gas sorption/desorption
- Closely coupled geomechanics and fluid mechanics
- Generates and quantifies microseismic events



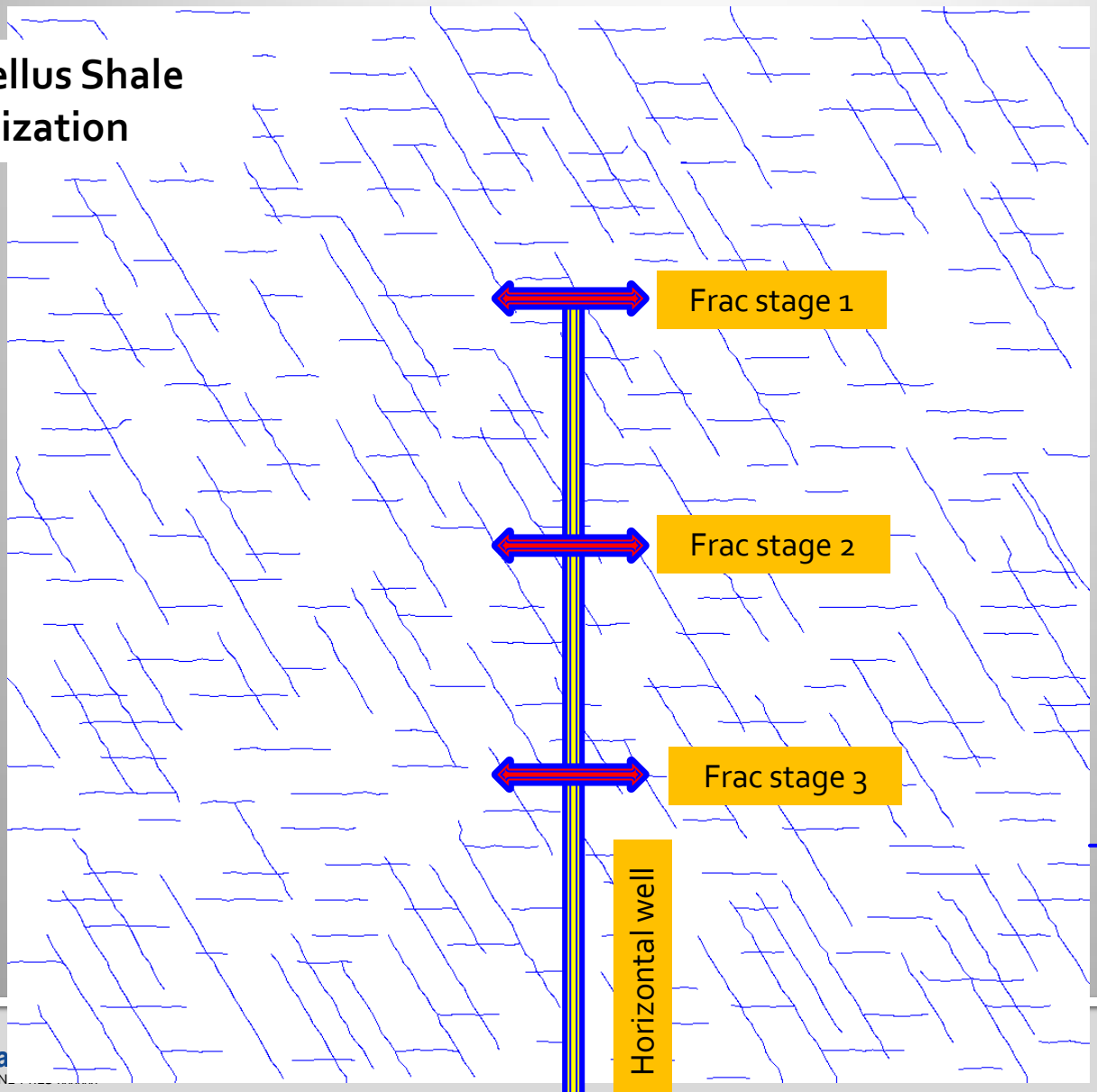
Improved well-rock interface

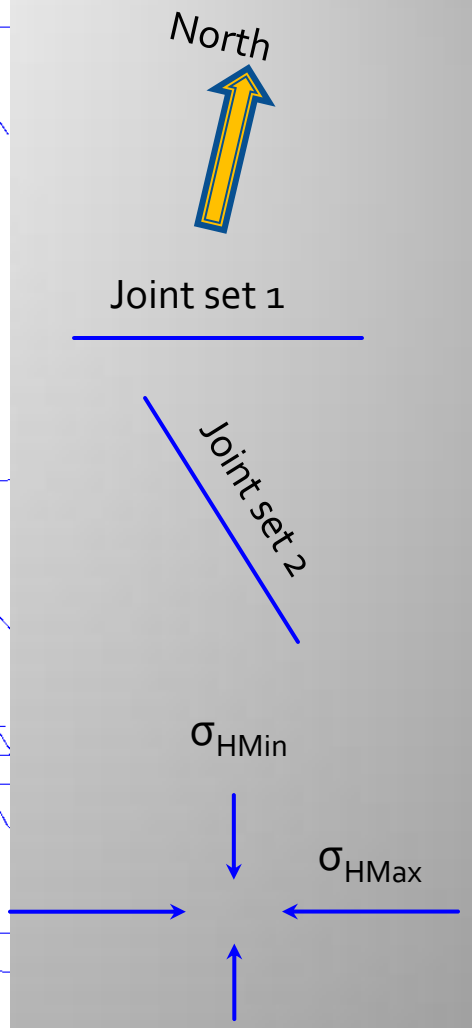
- Improved sorption/desorption models for shale gas/water systems and shale-gas/water/CO_2 systems
- Improved shrinking/swelling models
- Improved handling of propants in near-well environments
- Improved fracture generation



Explicitly coupled hydro-geomechanical simulation of fracking

Marcellus Shale Initialization





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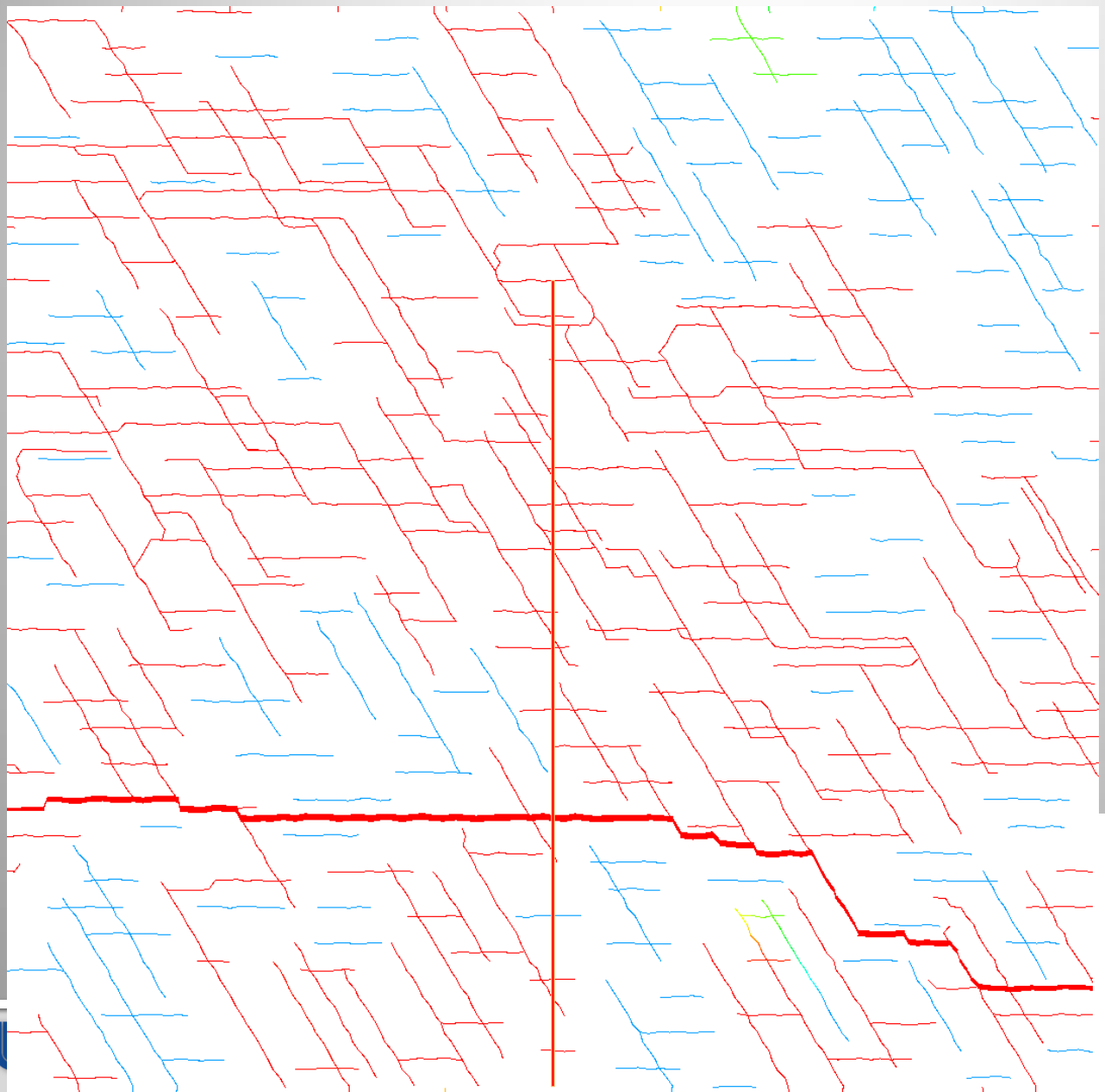
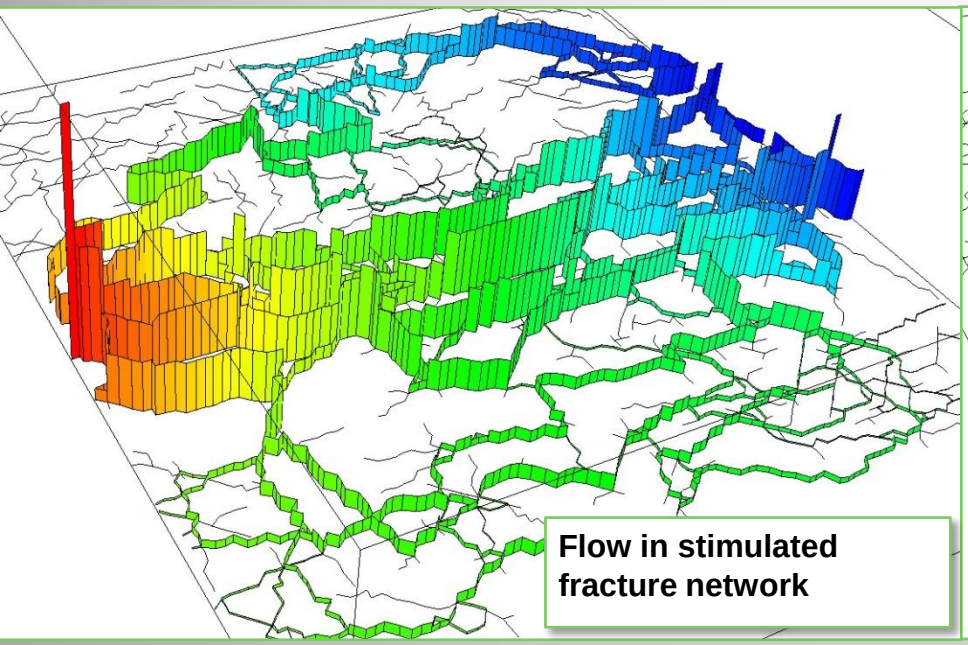
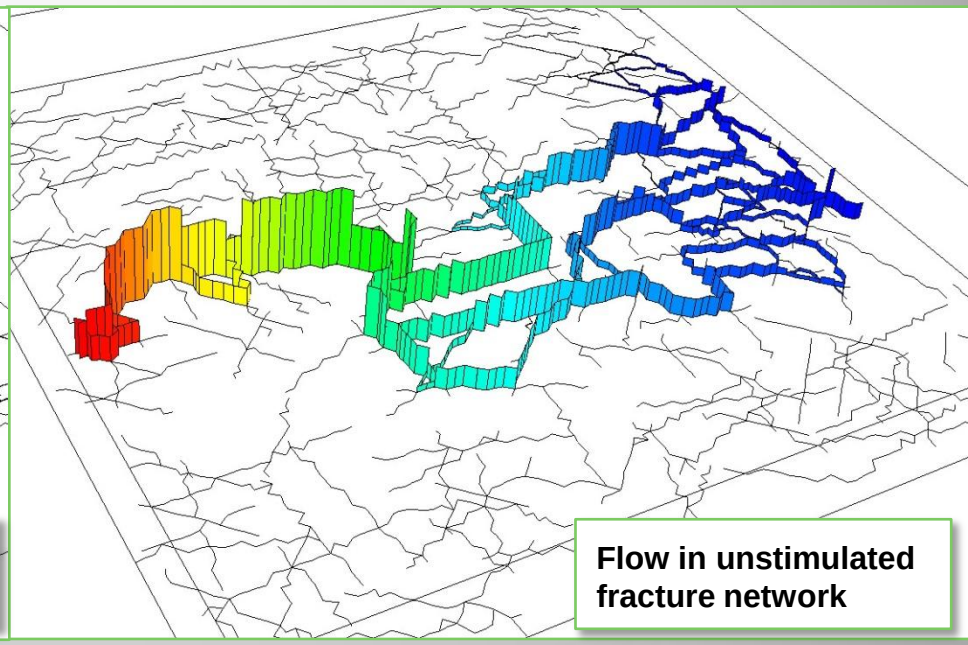


Stimulated fracture system and enhanced connectivity.

Next generation simulators provide unprecedented insight





Note: The height and color of the vertical bars indicate the flow rate and fluid pressure in the fractures.

These tools will greatly enable new drilling and completion strategies

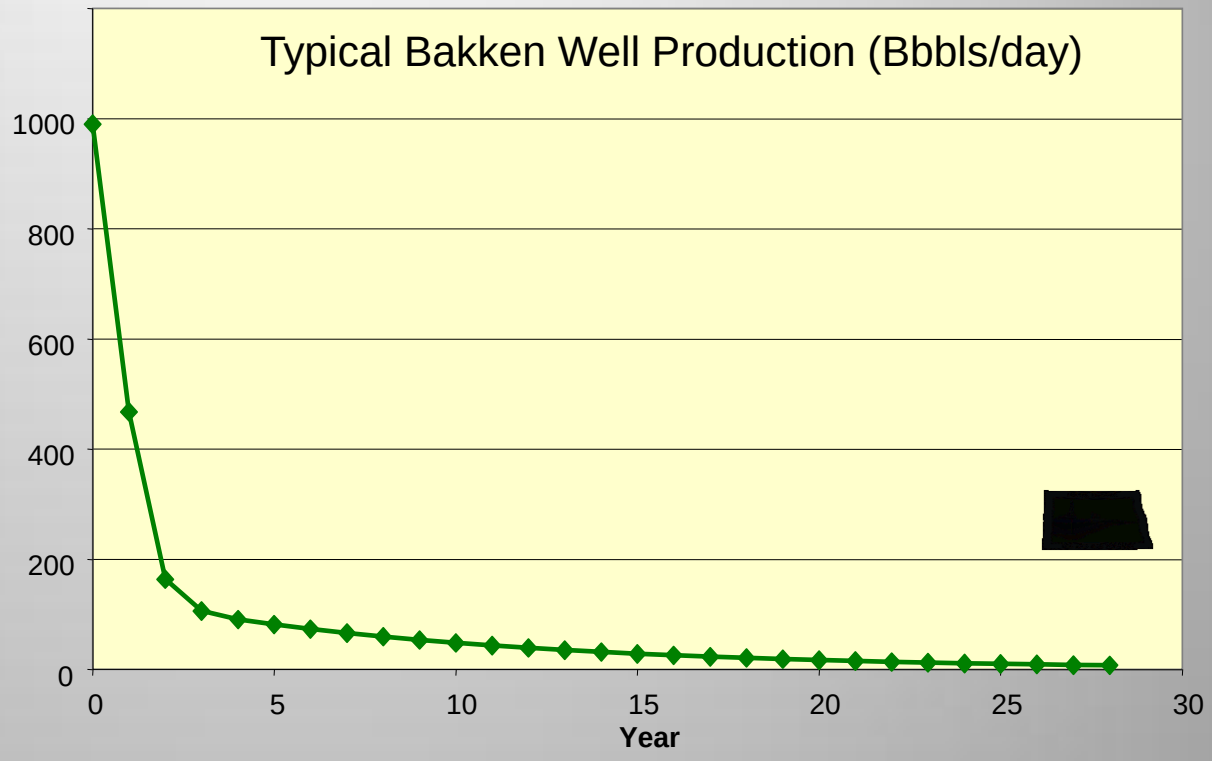
It's all about making and controlling fractures

Water use is large & brings complicating impacts

Improved recovery and restimulation require new approaches

Low recovery efficiency

- 8-13% typical
- really not well known
- incentive to recomplete or restimulate is small compared to risk



Is it possible to do stimulation or restimulation without water?

New stimulation approaches will increase fracture density, control geometry, and reduce water use

Downhole explosives remain promising

- Advanced explosives
- Multi-phase explosives (integrated explosives and propants)
- Multi-cycle explosives and shock-wave guiding

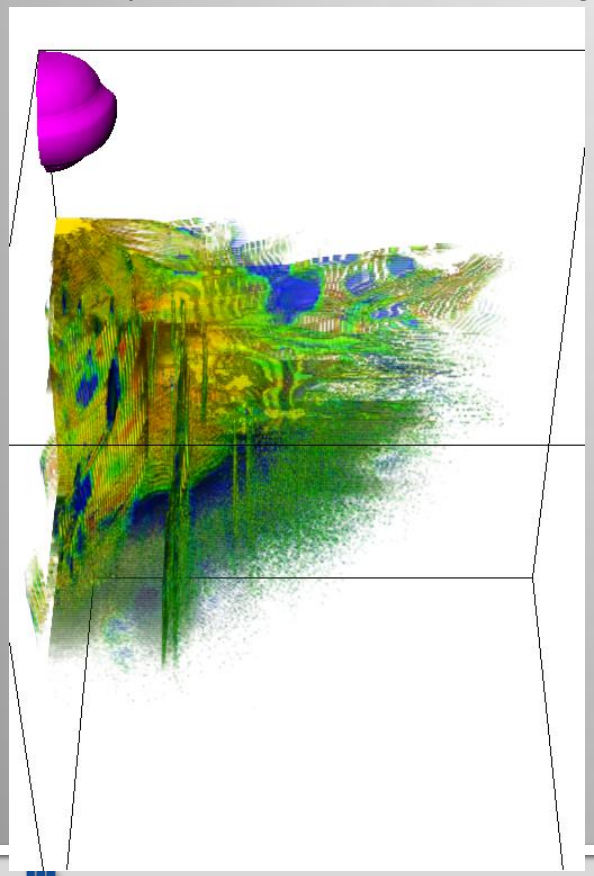
Better frac monitoring remains criti

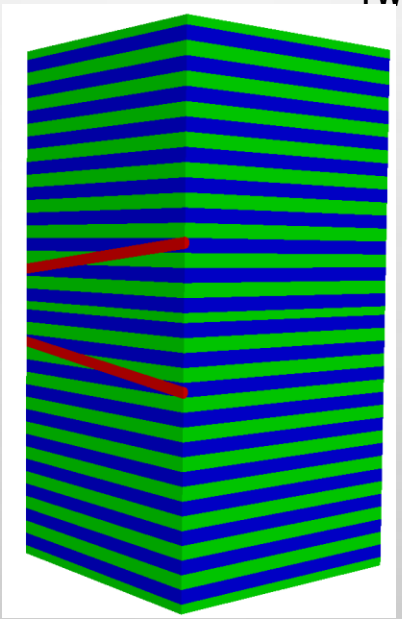
- Improved detection of events
- Improved network reconstruction
- Improved far-field interpretation

Studies should be field based integrated with mod/sim

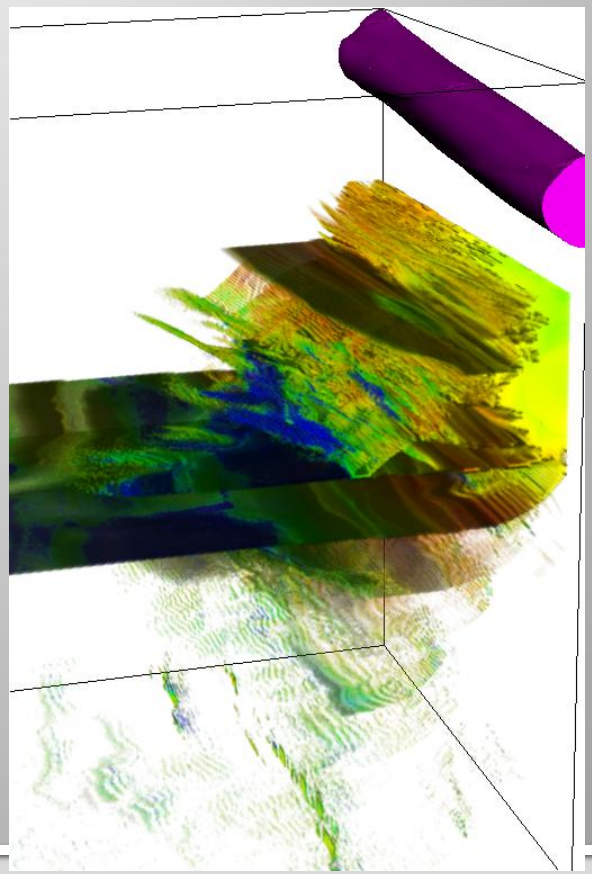
Modeling of explosive fracturing can provide valuable insight and taylor explosive-driven fracture networks for a specific application

- Two vertically arranged spherical charges, 6 kg each, fractured region is 10 cubic meters (would scale with the charge size)

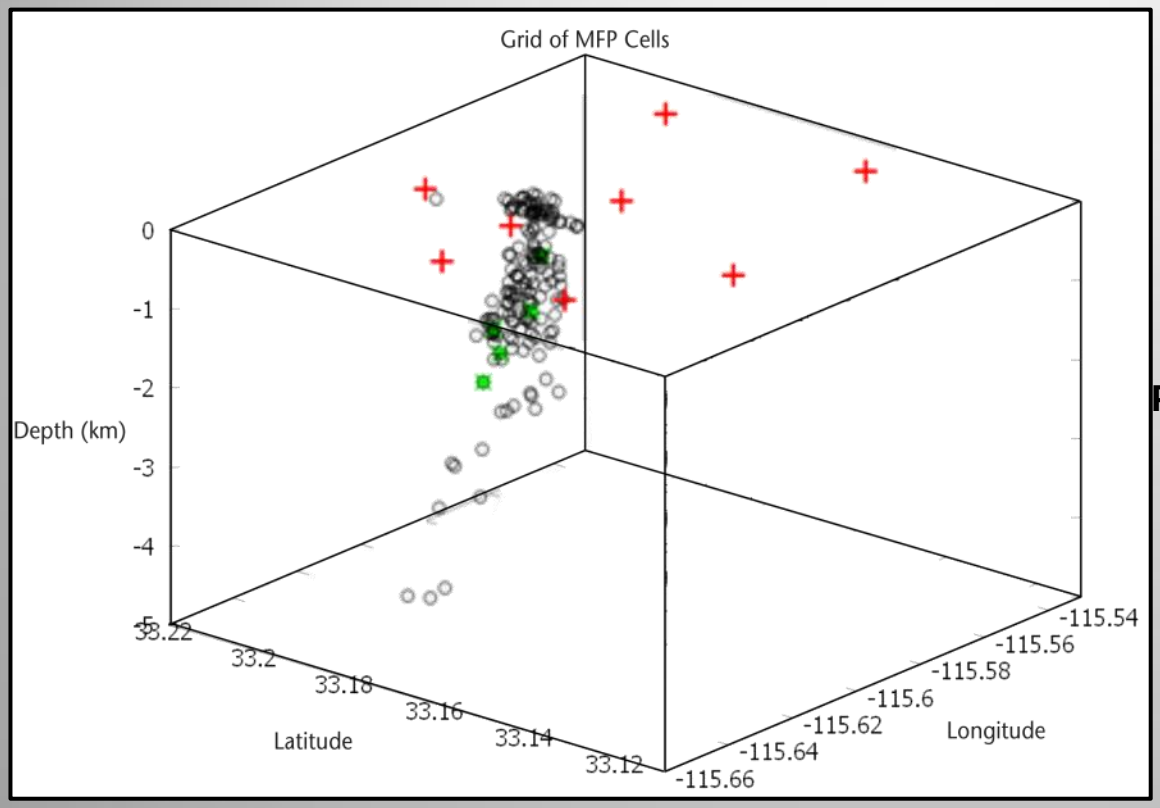




- Two line charges, 9 kg/m each



Advanced mathematical techniques can greatly enhance the fidelity and resolution of induced fracture events



Create the template/process data

Real-time waveform data

Narrowband filter

HPC synthetic data

Previous seismicity

Inner product

$\int |\cdot|^2$

Matched field statistic

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

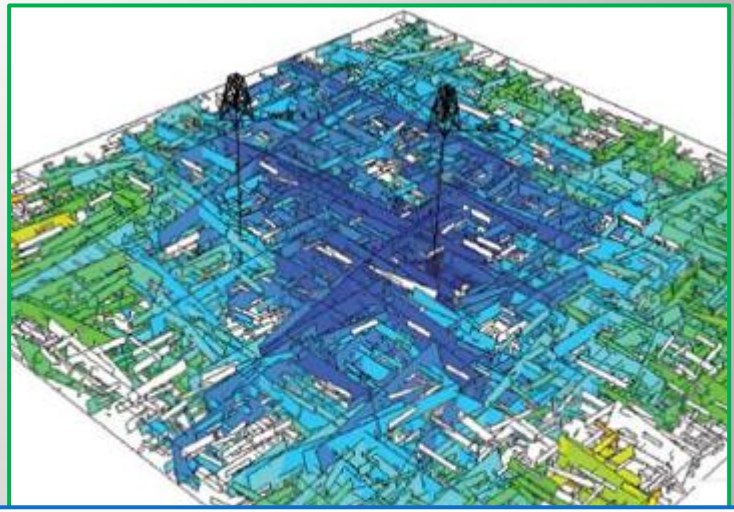
80-100% more events detected; better first motion and azimuth results

New drilling and completion designs can significantly increase sweep, production and reserves

Multilaterals

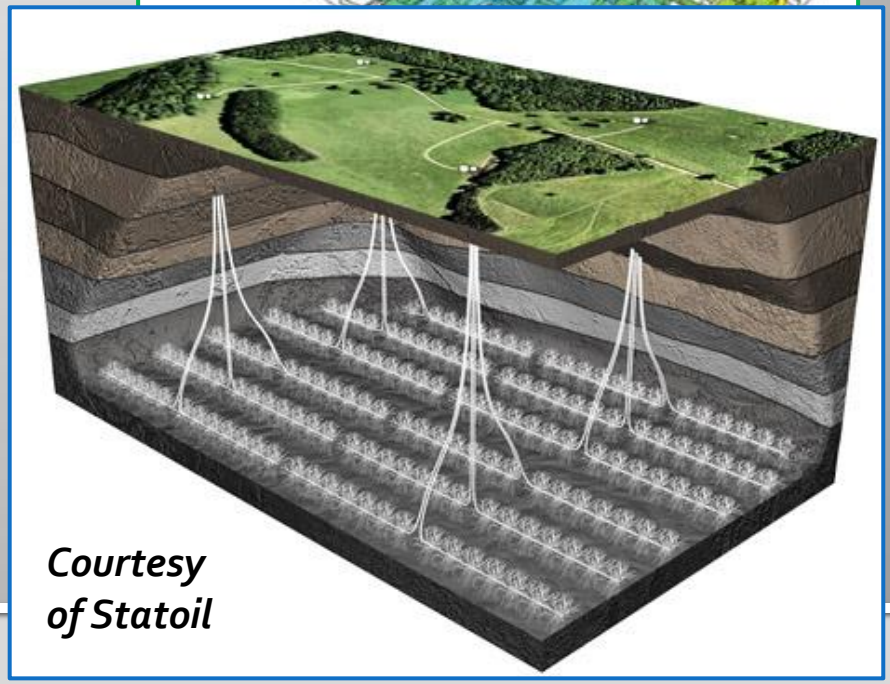
- Reduce pad number
- Cavity completions; successive packing stages
- Increased length and control

Opportunity for optimization



Novel approaches and designs

- Hybrid hydrofrac/explosive
- Successive stacked stimulation
- Stochastic design and optimization



Courtesy of Statoil

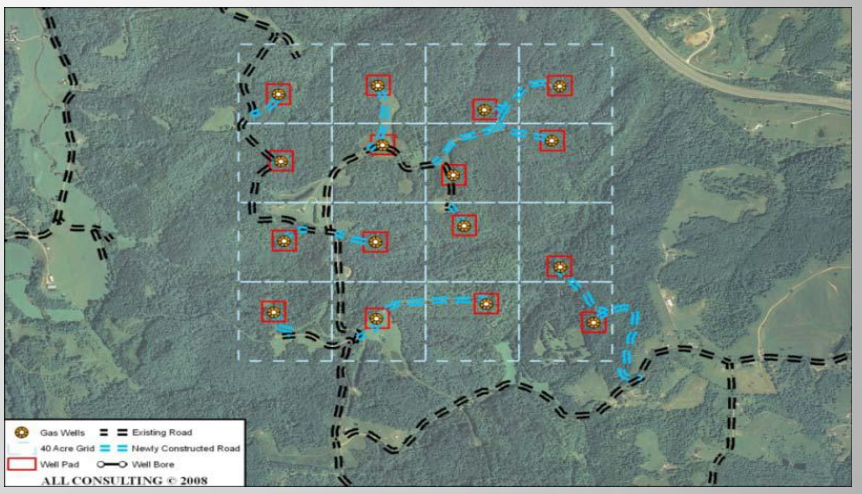
Studies should be field based integrated with mod/sim

Marcellus Drilling/Production/Processing Sites and Access Roads-Allegheny, PA

Vertical vs. Horizontal Wells

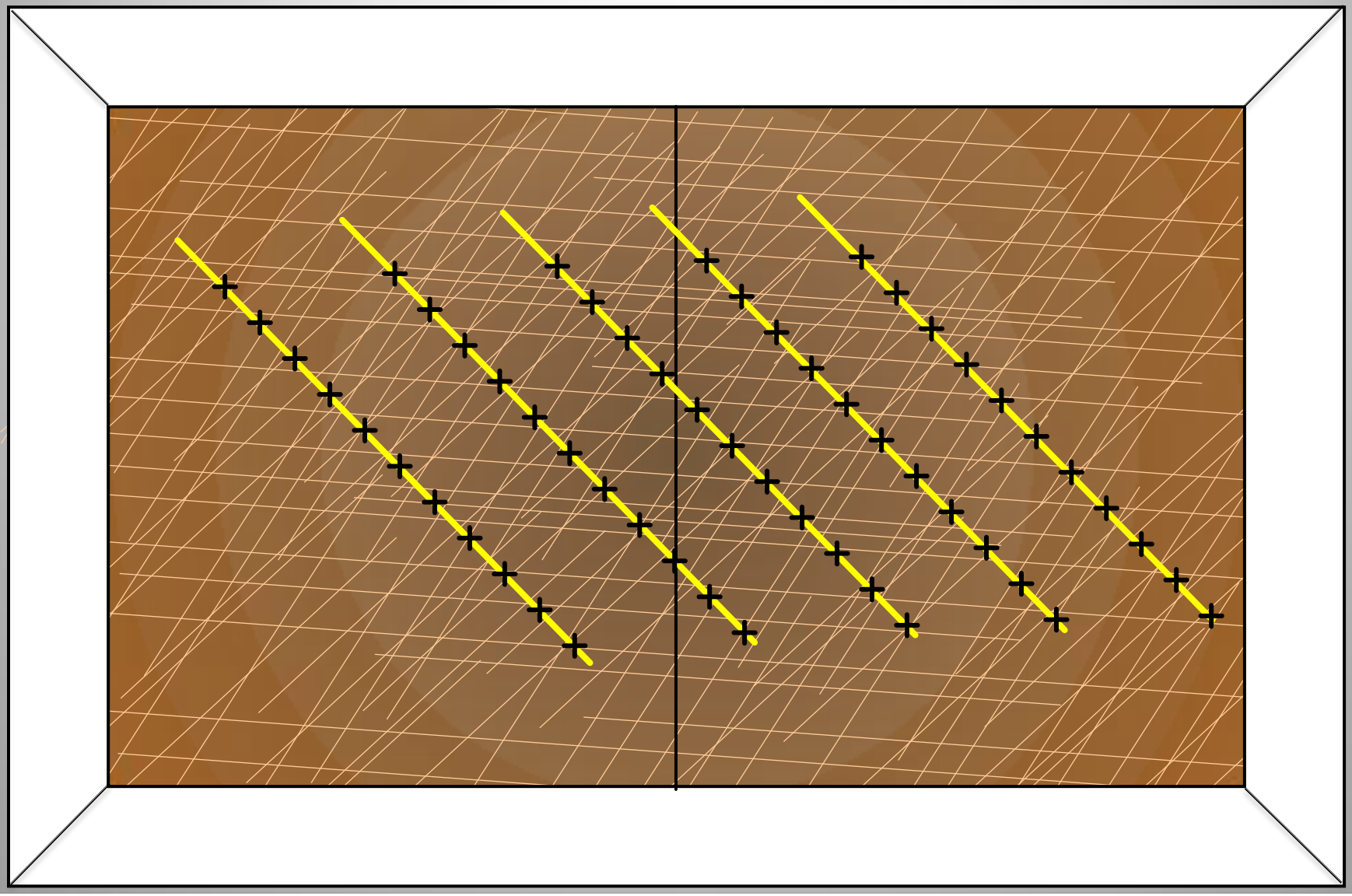
Source: http://www.all-llc.com/publicdownloads/AOGR-0810ALLConsulting.pdf

- 16 vertical wells develop 640 acres with approximately 77 ac total disturbance (including proportionate share of roads and utilities)



- 6 to 8 horizontal wells develop 640 acres with approximately 7.4 ac total disturbance –10 times less acreage disturbed

Capital vs. revenue also affects drilling strategies



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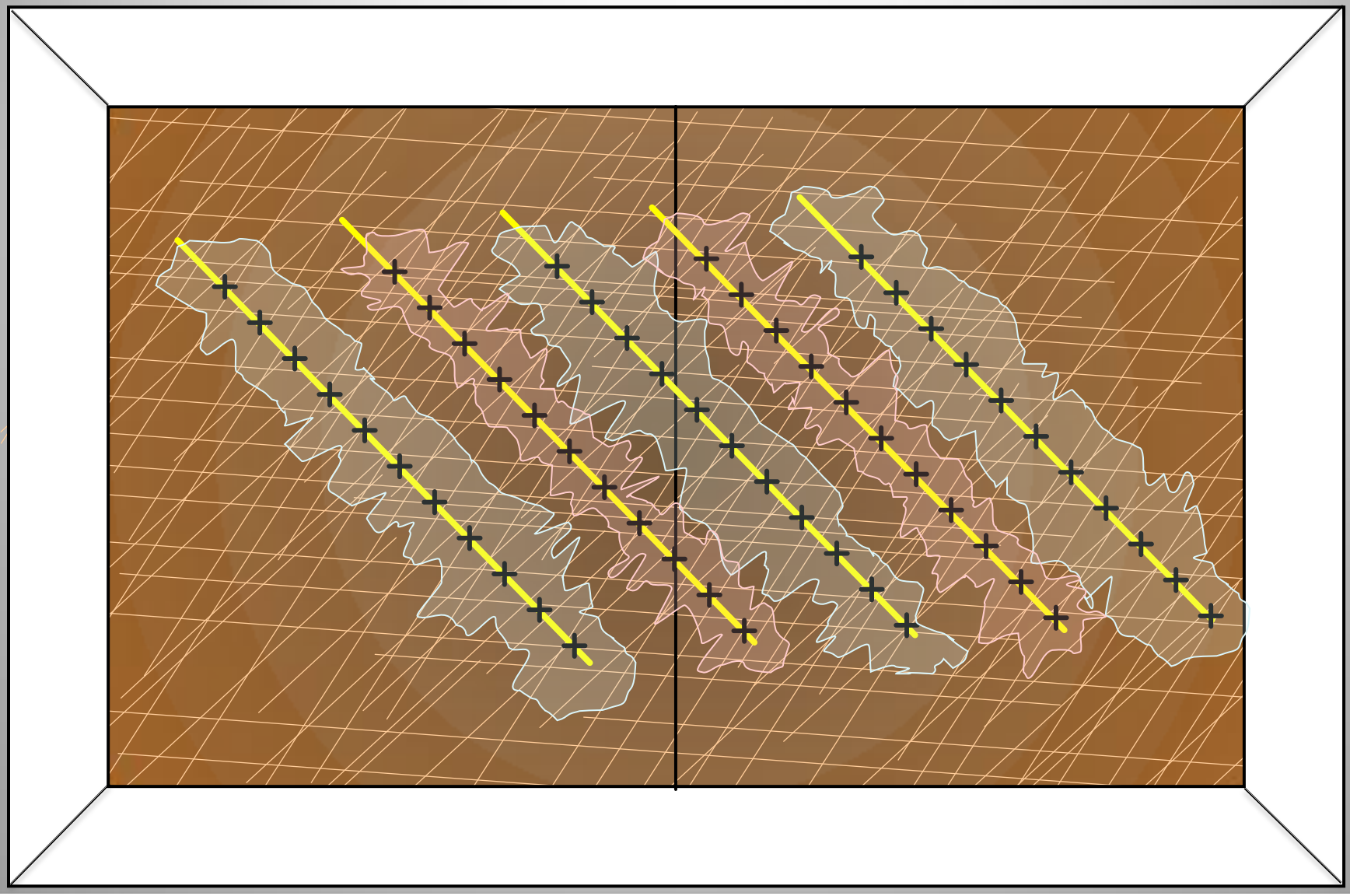

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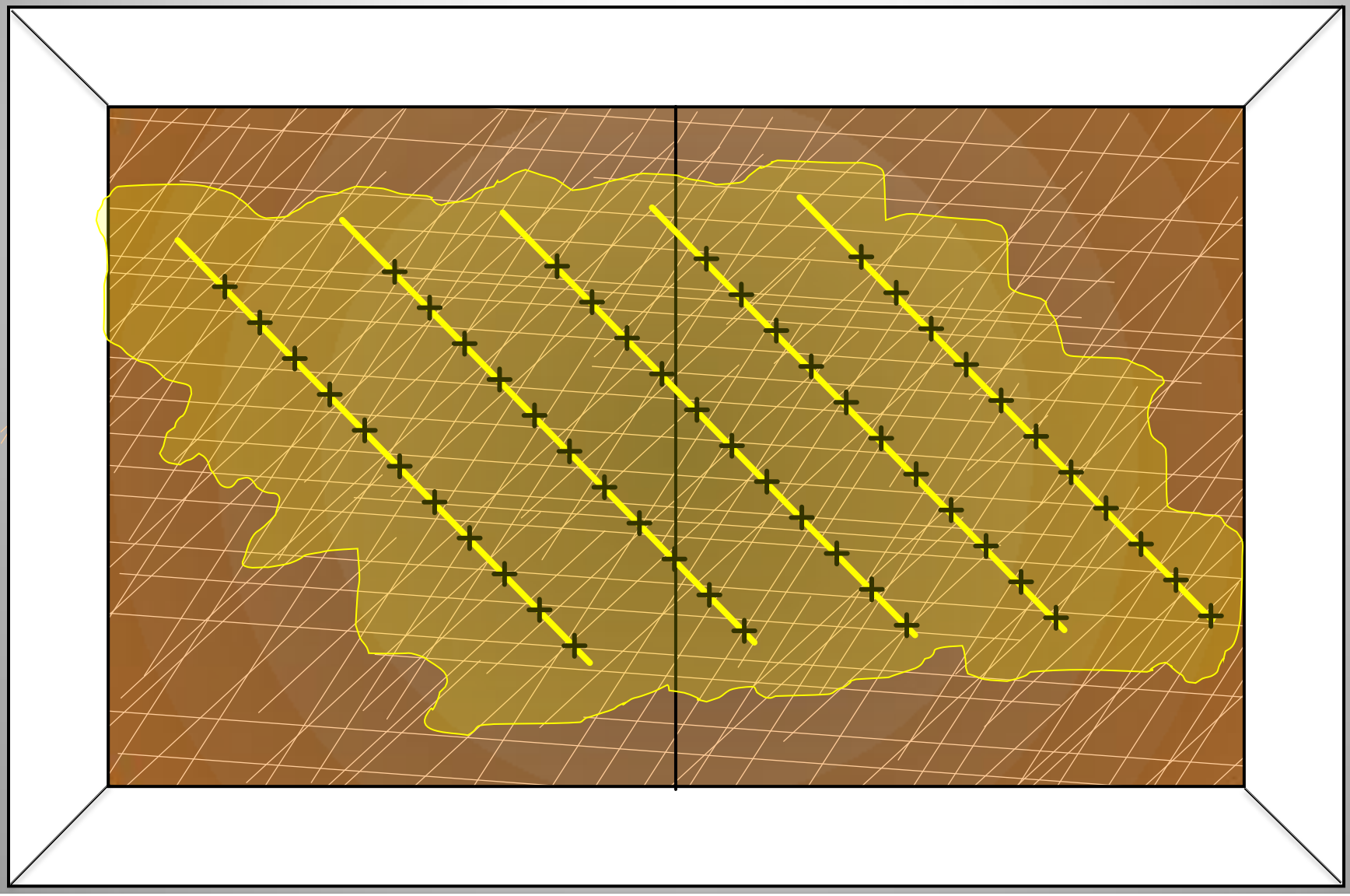
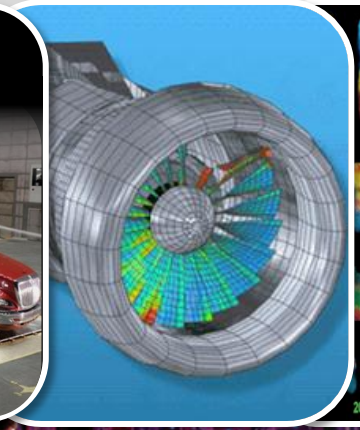
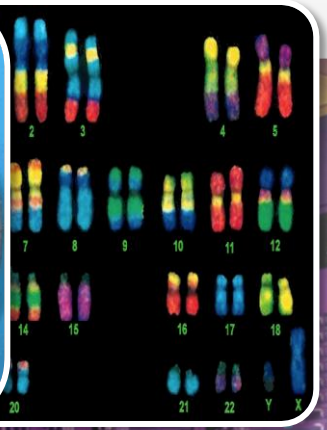


Application of high-performance computing can reduce risk and boost production





Extensive use in many industries

Increasingly powerful

Increasingly low cost

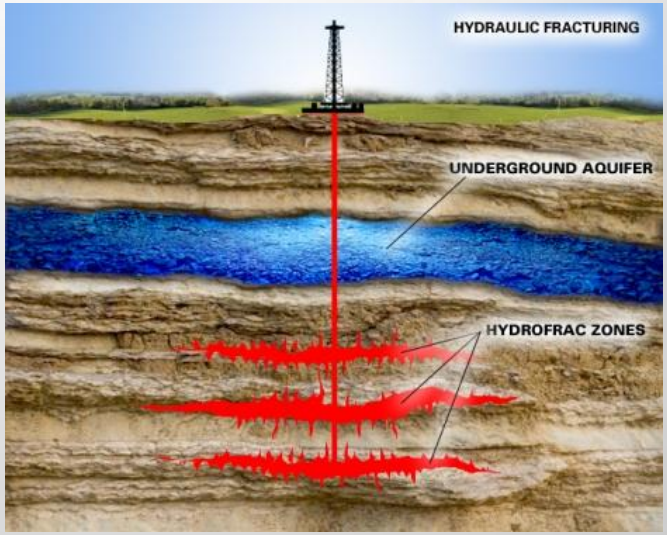
Shale gas production in the US is water intensive and has created new environmental concerns

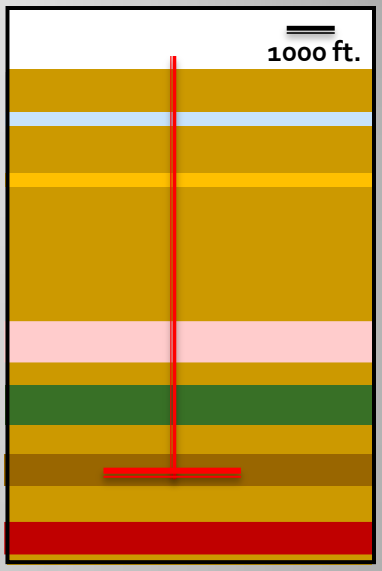
Heavy water demand

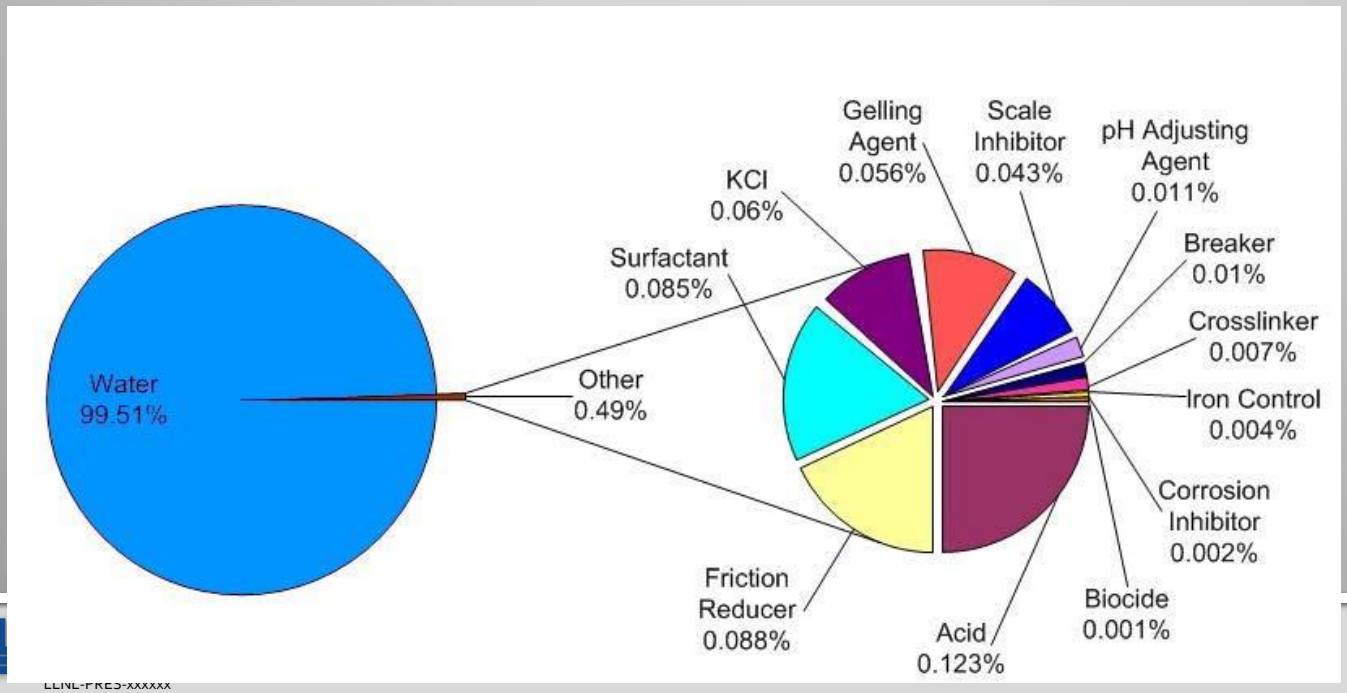
- Hydro-fracking
- Pumping for production
- Water treatment and recycling

Water environmental concerns:

- Gas leakage into groundwater
- Depletion of surface water
- Contamination of surface water







Already the future is the present: green fracking fluids and rapid processing of produced water

Electrocoagulation

Courtesy Powell Water

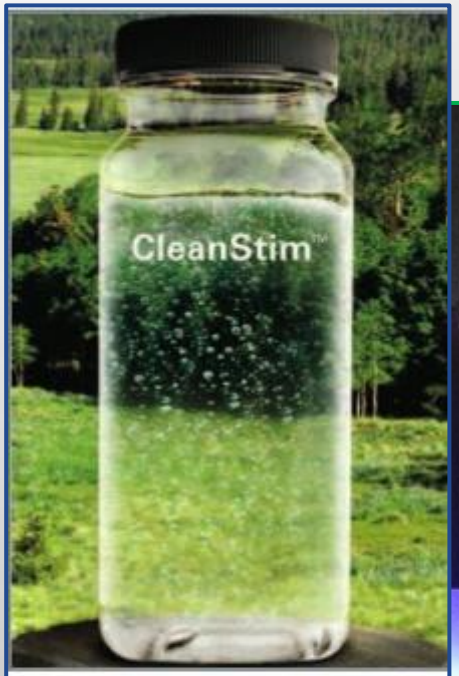


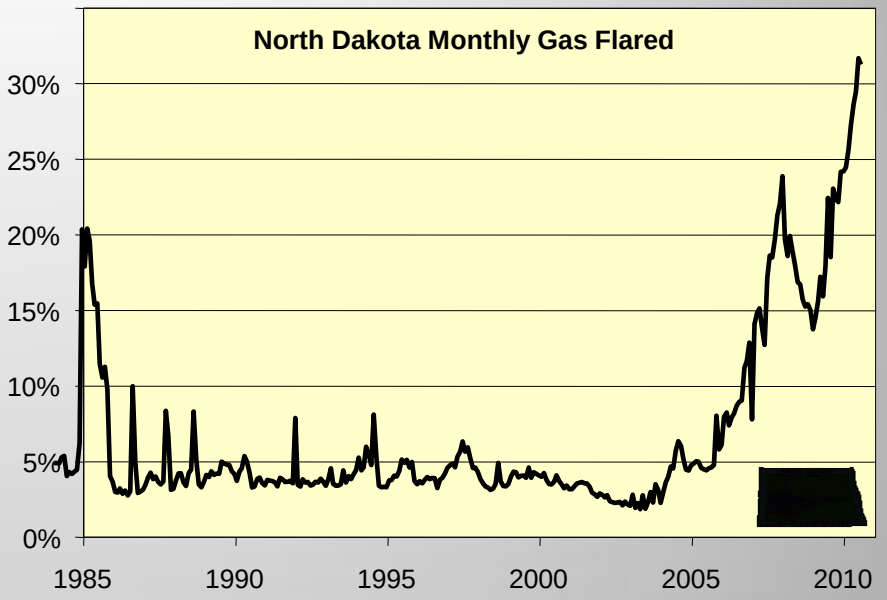
Figure 1 - The CleanStim fracturing fluid components are sourced from the food industry and can provide an extremely clean fracturing fluid with excellent proppant transport and cleanup.

Courtesy Halliburton

Flaring and flow-back leakage remain environmental concerns, but requires very little technology to fix

Flaring

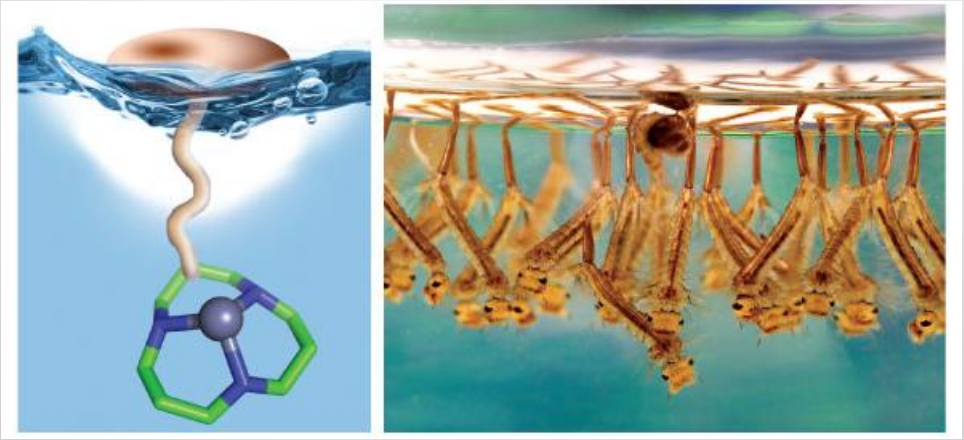
- Companies like Whiting and KinderMorgan are adding gas pipelines and processing stations
- Interconnects may stabilize or even reduce price

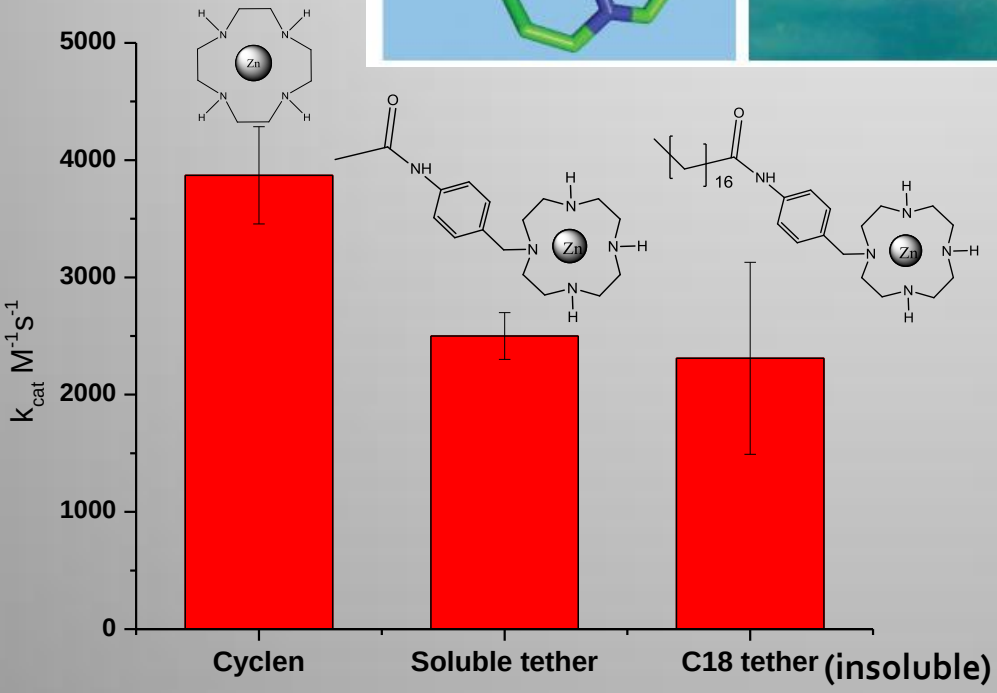


Leakage

- strong greenhouse gas CH_4 = 21x CO_2
- Cornell paper raises legitimate concerns
- Primary issue: capture of flow-back gas
- Can be managed well through conventional completion technology

Are promising technologies to harness and monetize flared, flow-back, or fugitive methane

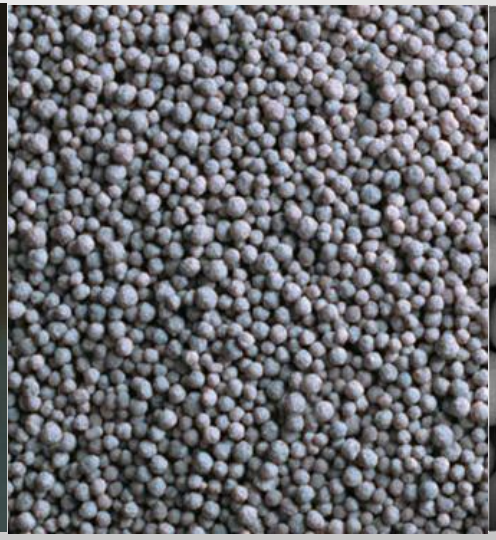


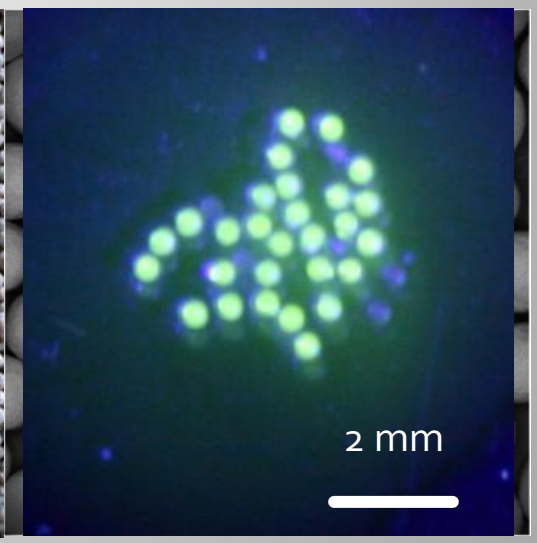


- Developed synthetic catalysts (using computational dynamics)
- Can be functionalized many ways
  - Micro-encapsulation
  - Tethering to gas-soln interface
- Developing reactor to convert fugitive or flow-back methane to methanol

Conventional proppants can also improve in cost, performance, and information return

Typically, sand is used as a proppant to hold fractures open





New ceramics and nanostructures can improve performance

"Smart" proppants can be chemically coded to provide geological, production, and environmental insights

Both fracking and waste-water disposal can lead to threatening earthquakes

- Rarely associated directly with fracking
- Usually associated with waste-water disposal from fracking
- Mostly VERY small (M_{max} < 2)

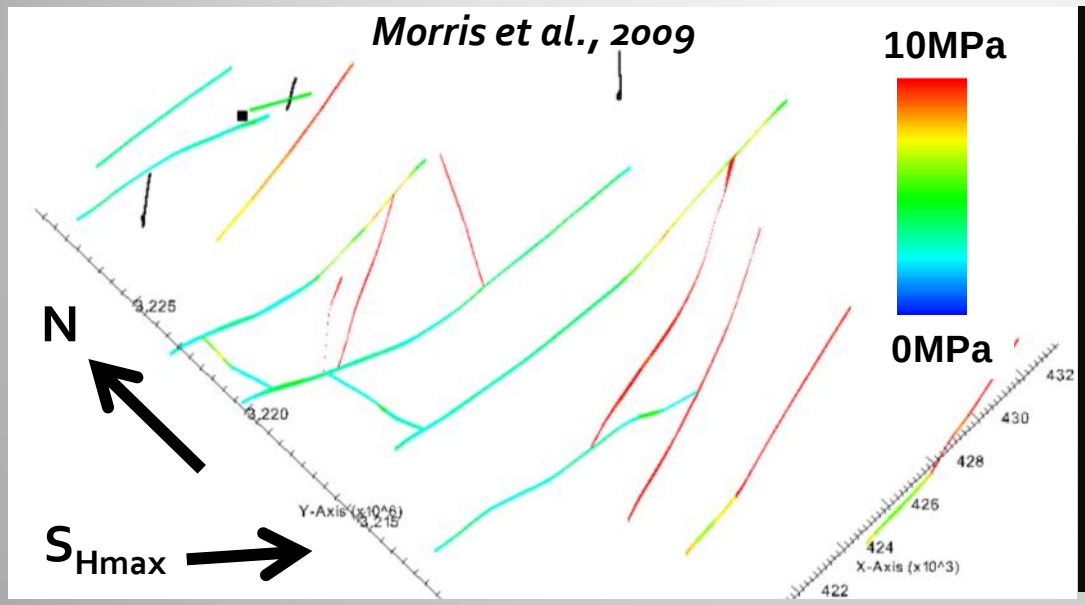
Most "outsized" events occur where fluids are injected into pre-existing low-strength zones and ancient faults

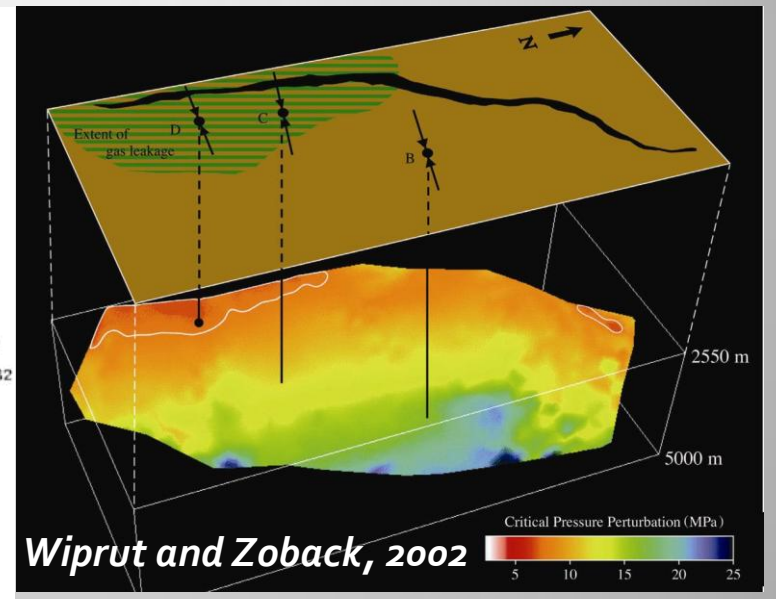
Induced earthquakes by magnitude

(blue associated with shale liquid and gas production)

Project	Date	Type	M_{max}
Lincoln Co., OK	11/5/11	Fluid disposal	5.6
Denver, CO	1967	Fluid disposal	5.5
Trinidad, CO	8/22/11	Fluid disposal	5.3
Guy, Ak	2/27/11	Fluid disposal	4.7
Lincoln Co., OK	11/5/11	Fluid disposal	4.7
Trinidad, CO	8/22/11	Fluid disposal	4.6
Paradox Valley, CO	5/27/00	Fluid disposal	4.3
Ashtabula, OH	1/26/01	Fluid disposal	4.3
Ekofisk, N. Sea	5/7/01	EOR	4.1-4.4
Youngstown, OH	12/31/11	Fluid disposal	4.0
Guy, Ak	10/11/10	Fluid disposal	4.0
Cooper Basin, Aust.	11/14/03	Enhanced geothermal	3.7

There are well established and understood tools to avoid damaging man-made earthquakes





Most states have fault maps sufficient to avoid low-strength zones and ancient faults that could lead to failure events

Other initiaves by major stakeholders

"Superfracking":

- Increased rate; surface area; fracture density; speed of completion
- Baker-Hughes: DirectConnect (larger fractures
- Baker-Hughes: dissolving well packing
- Schlumberger: HiWAY (fiber proppants)
- Halliburton: RapidFrack (sliding downhole sleeves)

Institute for Gas Drilling Excellence (IGDE)

- NGOs, R&D centers, Companies, Layers, Govt.
- Develop protocols, standards, and practices
- Provide consensus advice on environmental and regulatory concerns

Comments from State of the Union, Jan. 24 2012

We have a supply of natural gas that can last America nearly 100 years… my administration will take every possible action to safely develop this energy. Experts believe this will support more than 600,000 jobs by the end of the decade. …America will develop this resource without putting the health and safety of our citizens at risk.

… And by the way, it was public research dollars, over the course of 30 years, that helped develop the technologies to extract all this natural gas out of shale rock –- reminding us that government support is critical in helping businesses get new energy ideas off the ground.

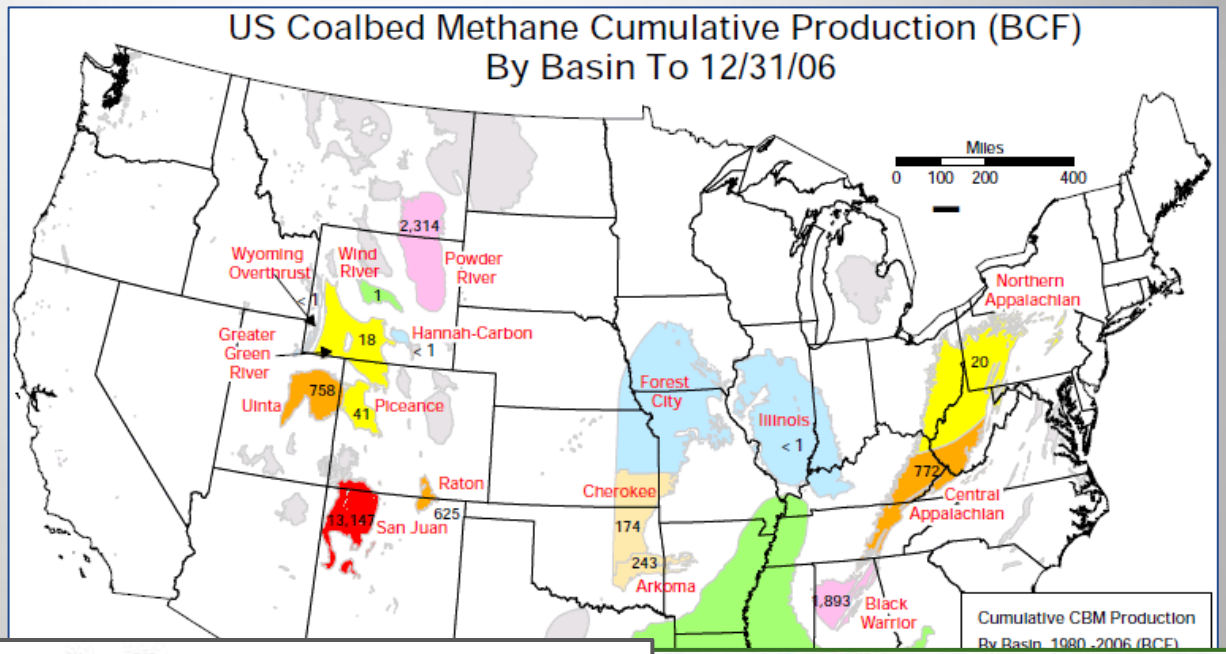
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

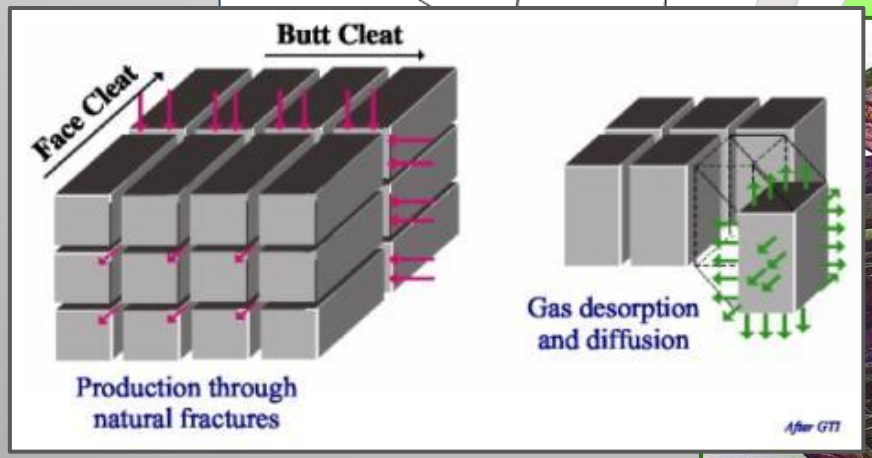
Comparison with CBM technology development

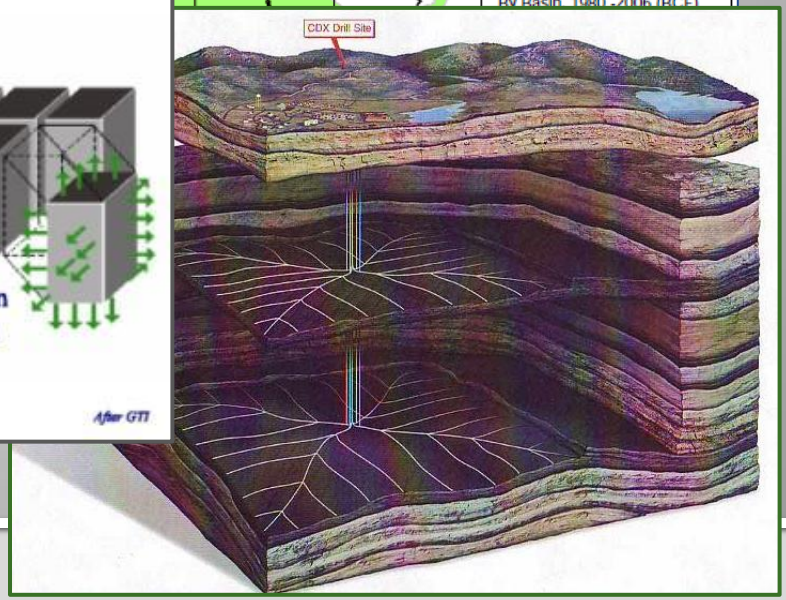
DOE-FE program (70's)

GTI program (1982)

- About $80M over 10 years (>120M today)
- Basic science
- Applied (e.g., drilling)
- Field tests
- Private-public
- Water issues







Basis for sound investment, decision-making, and regulation

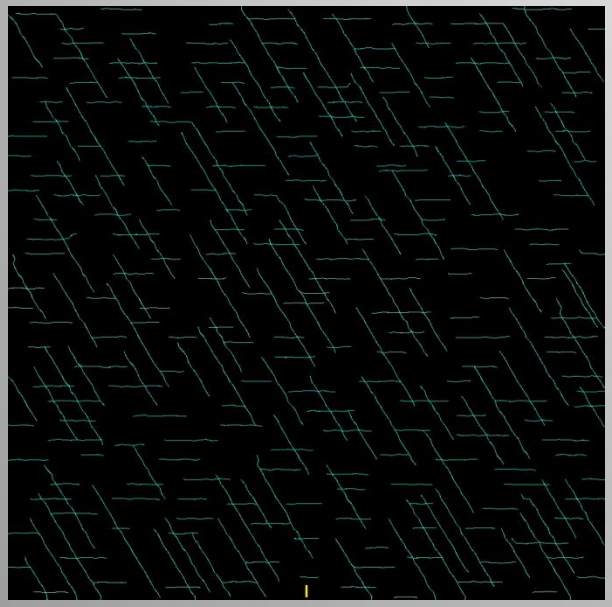
The needs are simply greater than existing R&D budgets

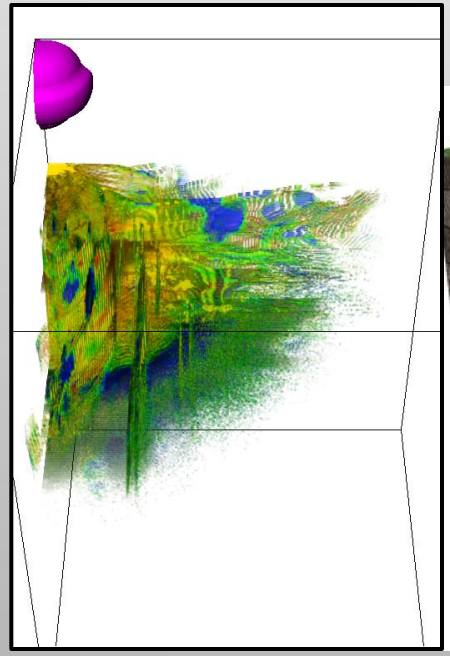
Unconventional Gas R&D Outlays for Various Federal Agencies ($ millions)					
	FY2008	FY2009	FY2010	FY2011	FY2012 request
DOE Unconventional Gas					
EPAct Section 999 Program Funds					
RPSEA Administered	$14	$14	$14	$14	0
NETL Complementary	$9	$9	$9	$4	0
Annual Appropriated Program Funds					
Environmental	$2	$4	$2	0	0
Unconventional Fossil Energy	0	0	$6	0	0
Methane Hydrate projects	$15	$15	$15	$5	$10
Total Department of Energy	$40	$42	$46	$23	$10
Environmental Protection Agency	$0	$0	$1.9	$4.3	$6.1
USGS	$4.5	$4.6	$5.9	$7.4	$7.6
Total Federal R&D	**$44.5**	**$46.6**	**$53.8**	**$34.7**	**$23.7**

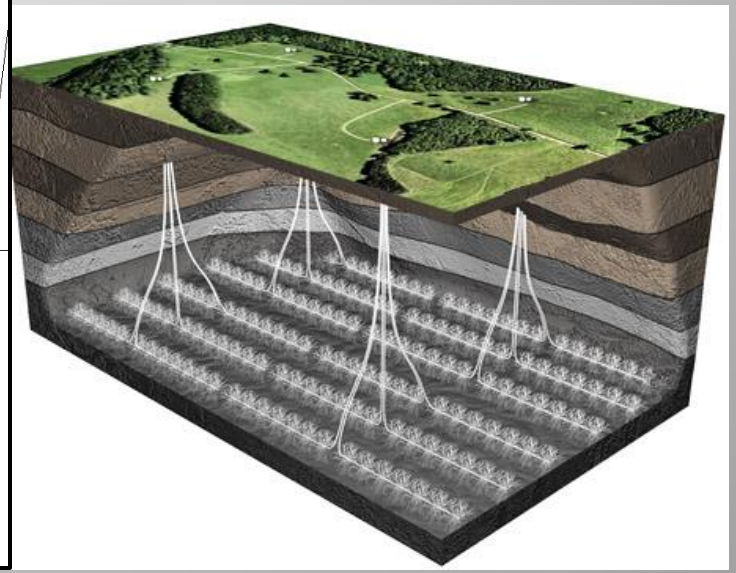
A larger, more comprehensive R&D program would benefit all

New tools and technologies can drive economic and environmental benefits

- New simulation and modeling tools
- New stimulation and fracking tools
- New drilling and completion strategies







This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344