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Continental RESOURCES

Argentine Section
Buenos Aries, Argentina
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Bridging the Gap Between Drilling and Completions

Challenges and Solutions in Horizontal Wells

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Distinguished Lecturer Program
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My Background

BS Chemical Engineering, University of Oklahoma

11 years Halliburton Research Center

12 years international

- Leiden, The Netherlands
- Cairo, Egypt
- Copenhagen, Denmark

7 years with operating companies

- Maersk Oil, Danish Operations
- Chesapeake Energy, Fracturing Services
- Continental Resources, Bakken

Presentation Format

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- Define the challenge
- Evolution of technologies
- Establish today's baseline
- What does the future hold
- Conclusions

The Challenge

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Economic development of unconventional reservoirs necessitated the development of leading edge horizontal drilling and well completion techniques.

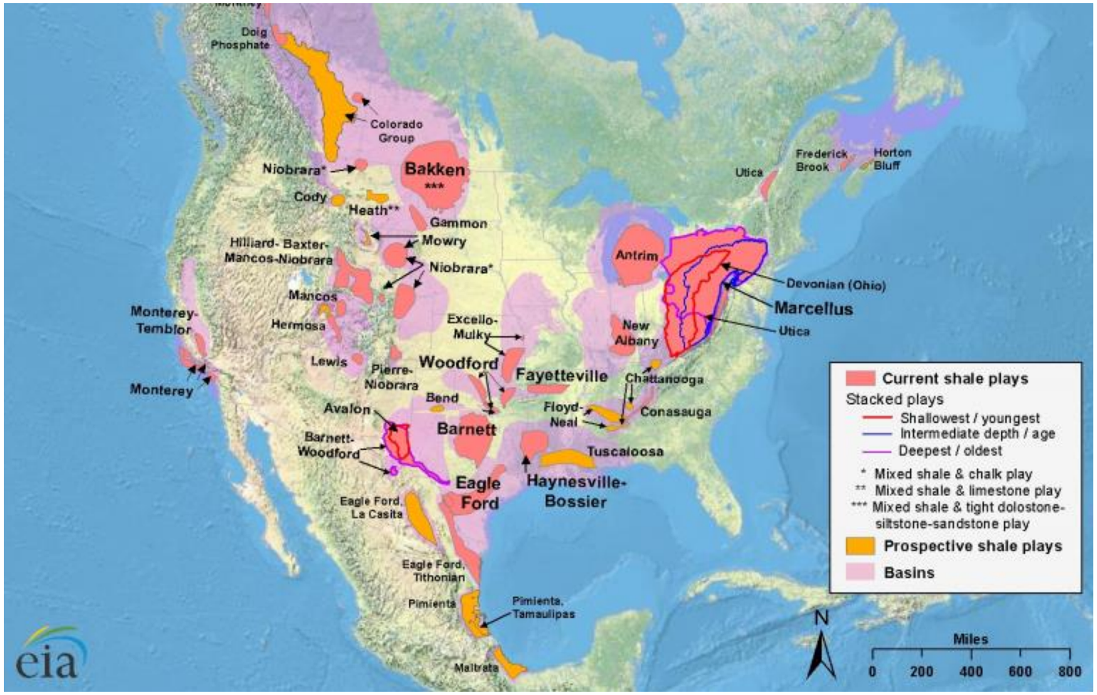

Photo courtesy of US Energy Information Association

The question for today

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Can we drill longer wells than we can effectively complete?

Photo courtesy of Continental Resources

Photo courtesy of MT ACTION Photography

Scope: Stimulated horizontal wells

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Horizontal wells…

2 miles = 3.2 km
3 miles = 4.8 km

- Are getting longer and longer
- Require more stimulation stages
- Must be optimized; not just efficient and economical
- Environmental concerns can not be ignored

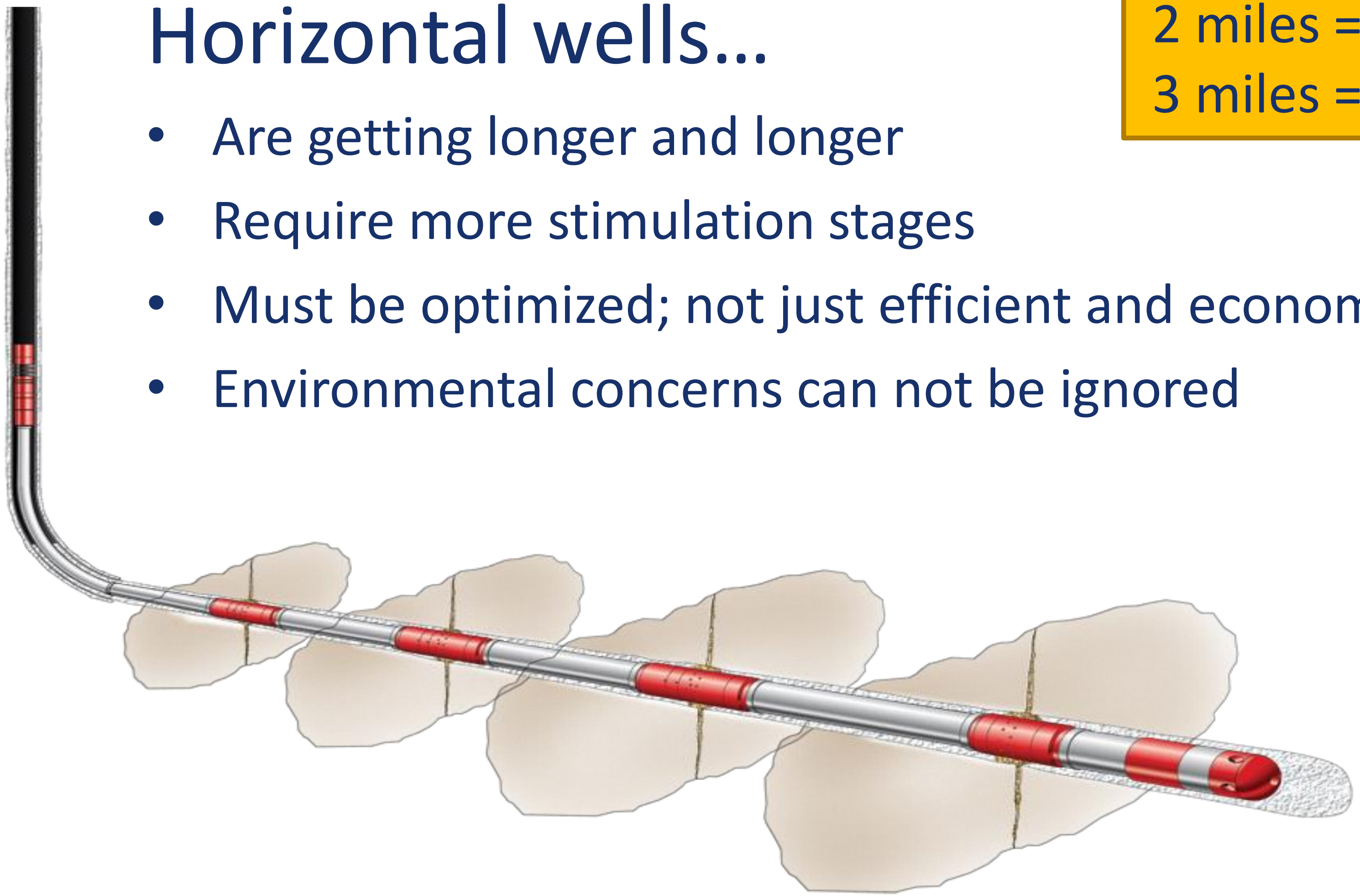

Photo courtesy of Halliburton Energy Services

When, and where, was the first horizontal well with multi-stage fracturing treatments?

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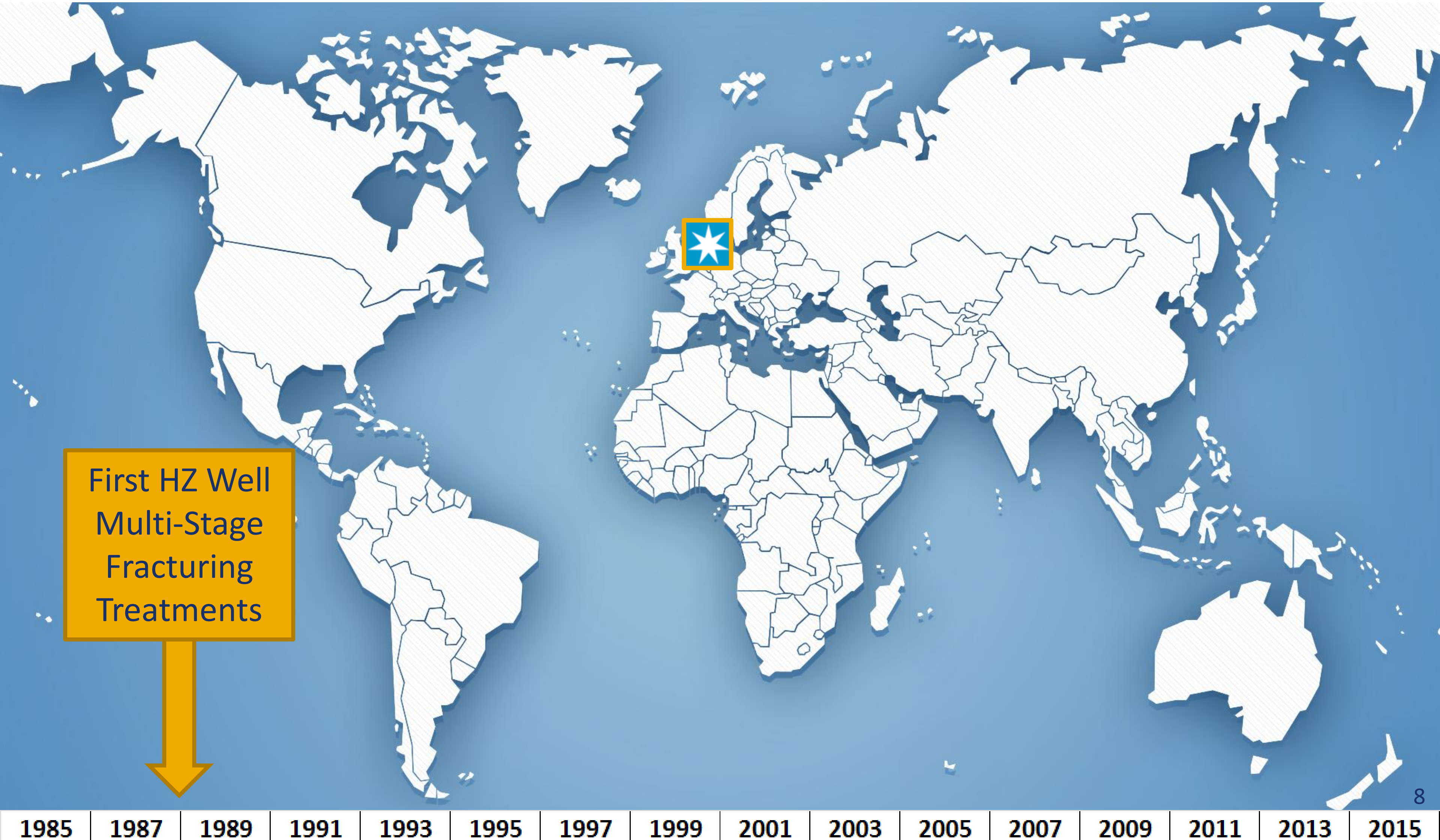

Multi-Stage PSI Completions (1988)
Perforate-Stimulate-Isolate

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Key drivers:

1) Production more important than efficiency
   - Ensure each frac as productive as possible
   - Allow selective testing of individual zones
2) 48 to 60 hours between stages

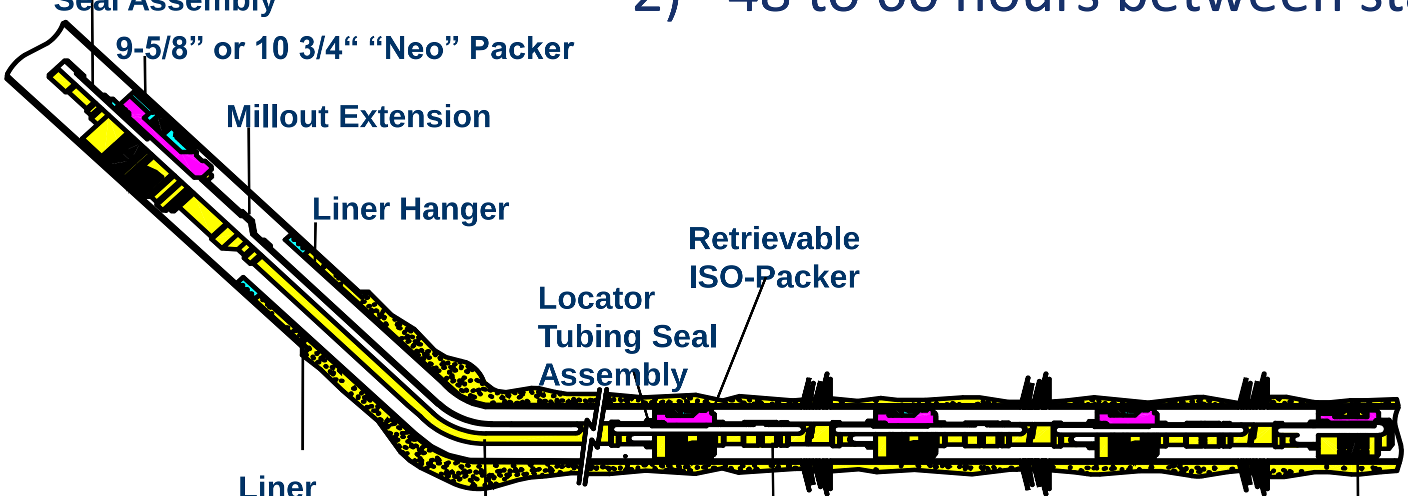
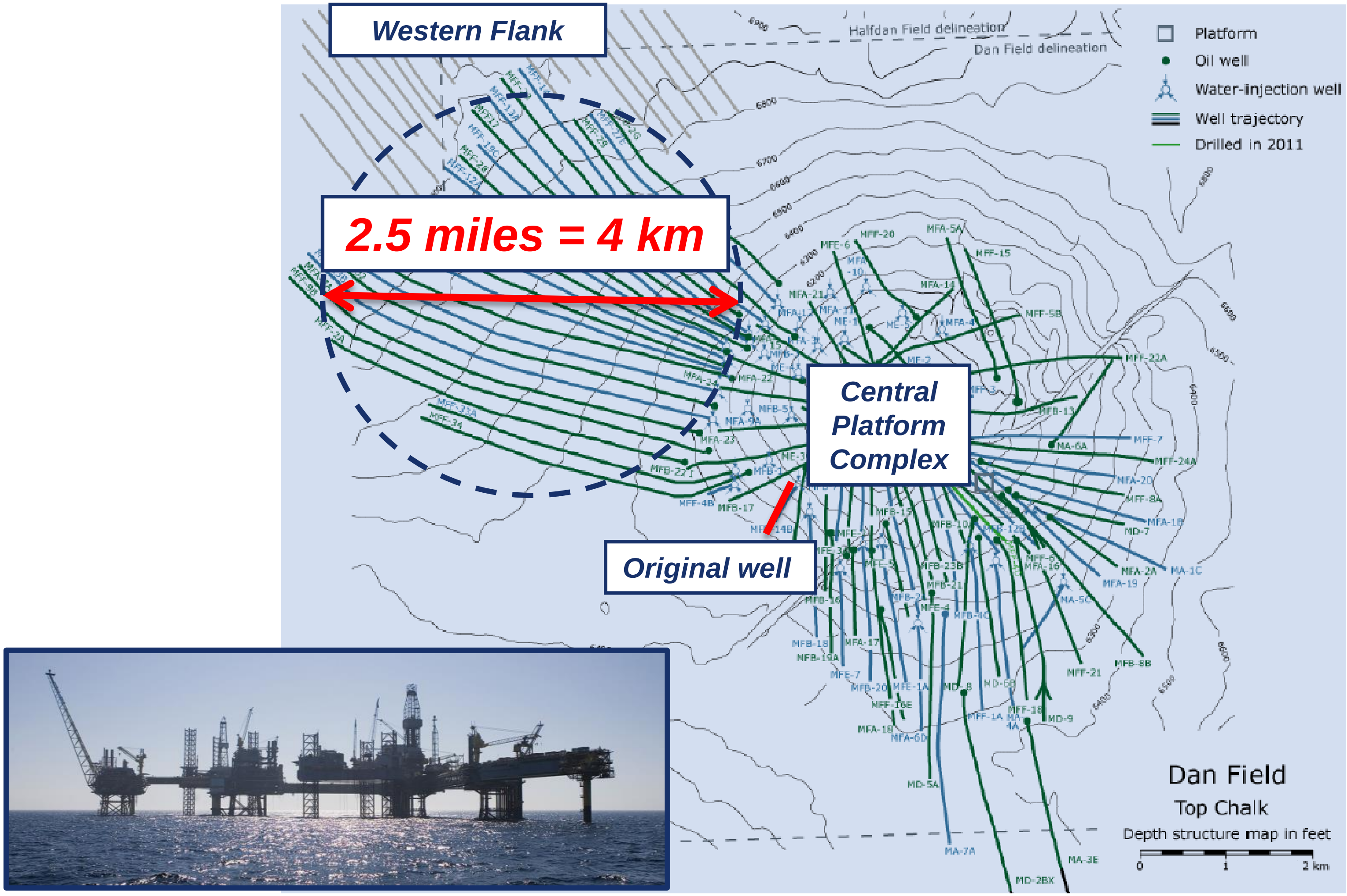


Image reference SPE 170981

The Dan Field Today



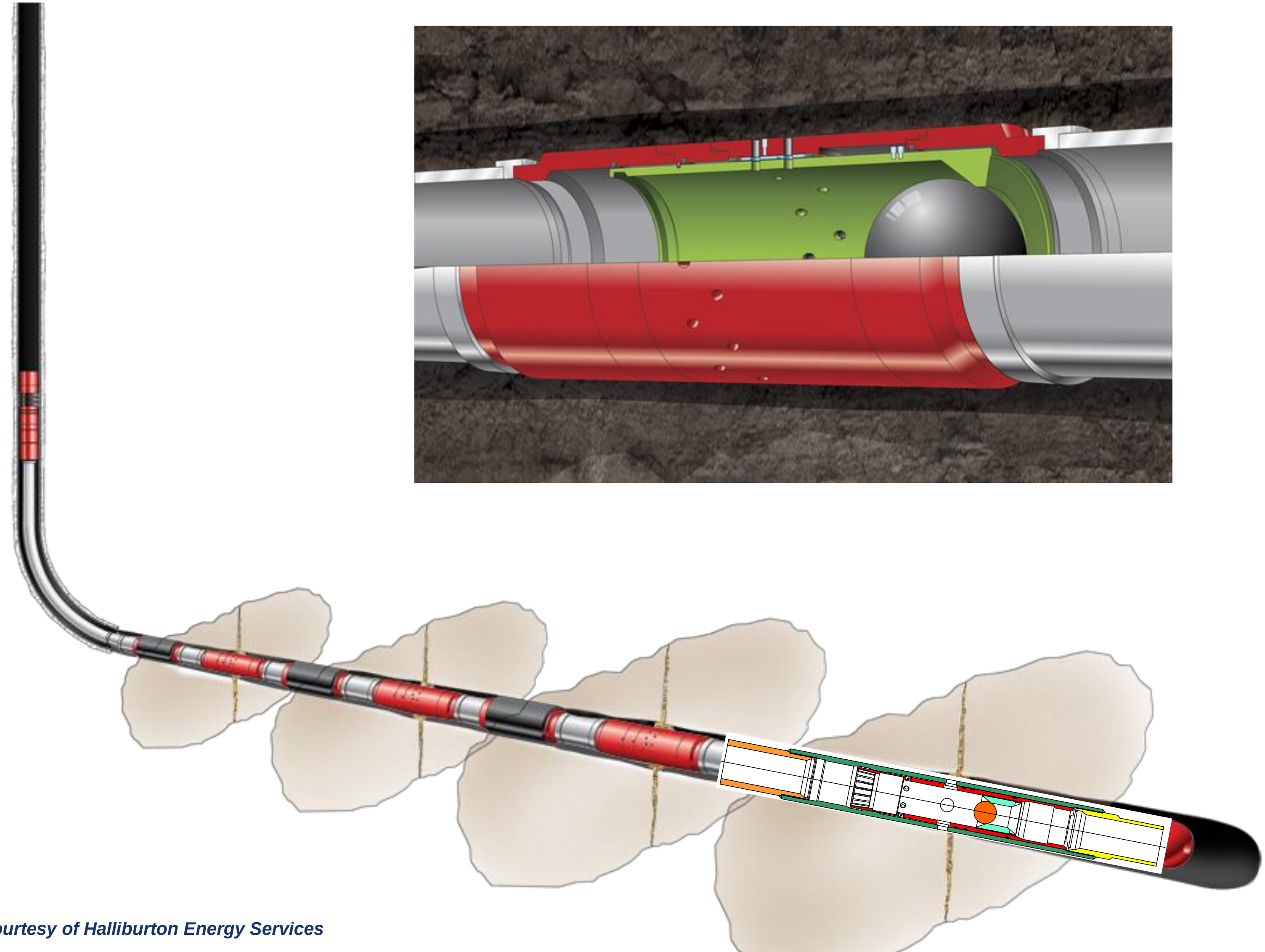
Reference: Danish Energy Agency "Oil and Gas Production in Denmark" (2013)

When, and where, was the first HZ well to use a ball shifted sleeves completion?

1985	1987	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015

Ball shifted sleeves

Open Hole Multi-Stage (OHMS)



Images courtesy of Halliburton Energy Services

Joanne Field (1994)

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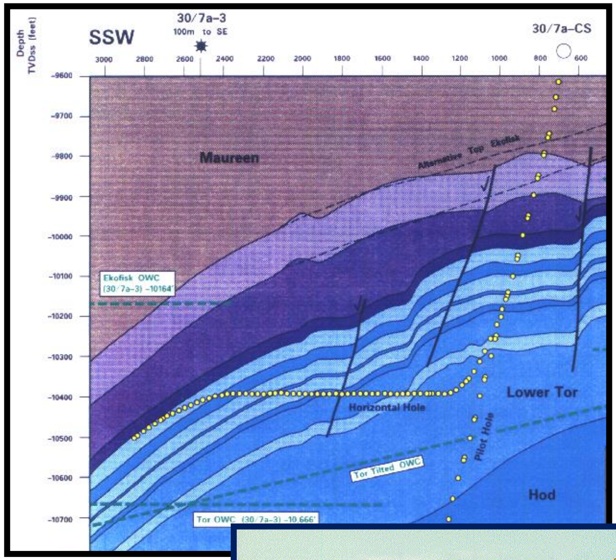
The Challenges

- Marginal development
- Variable permeability and fractures
- Supply of stimulation materials

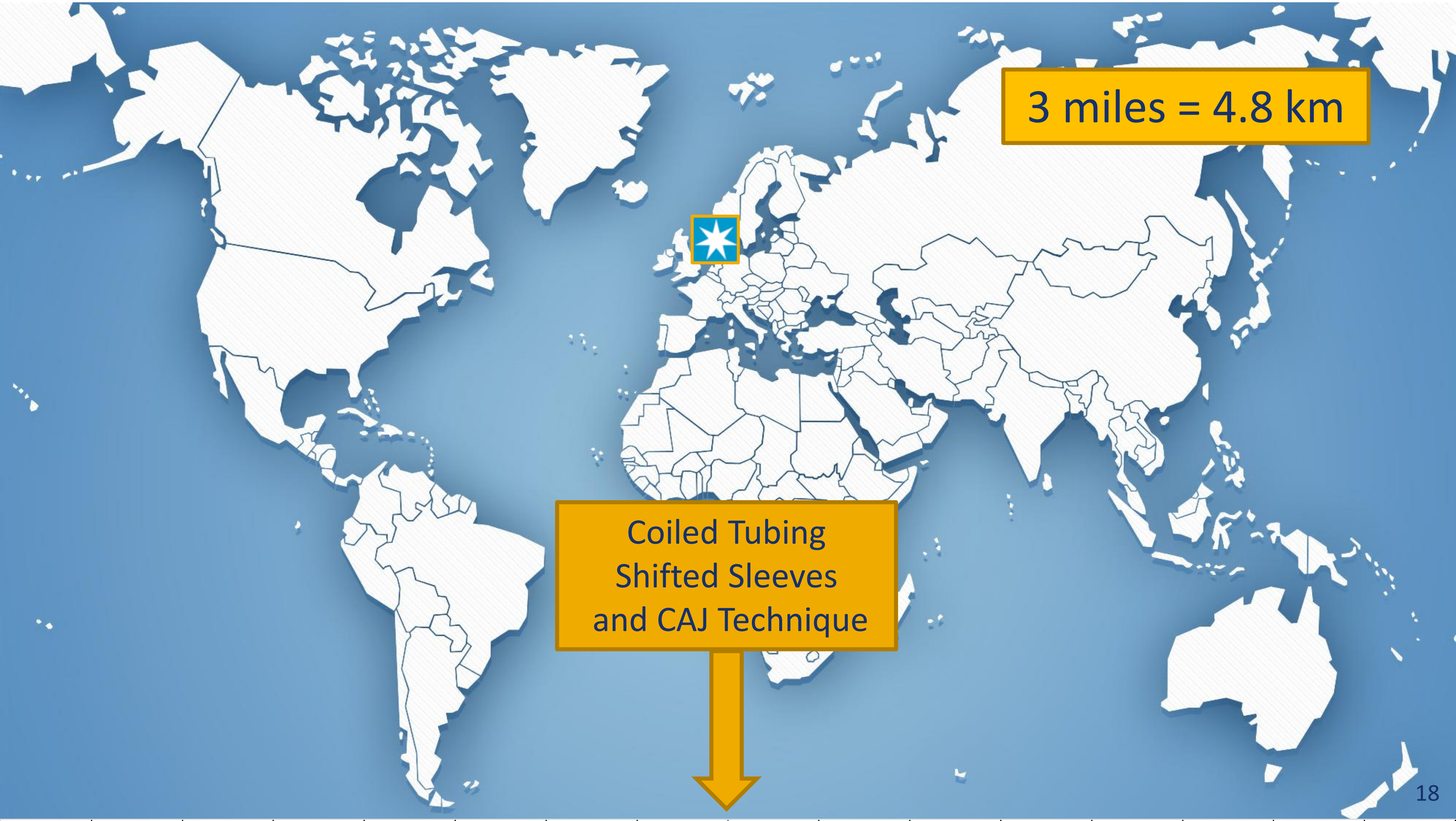
The Solutions

- 1st ball drop sleeves completion
- 4 wells, 10 stages each
- Stimulation completed in 8 to 24 hours per well
- Two stimulation vessels, simultaneous operations



Reference SPE 51177

Stimulating a "3-mile lateral"

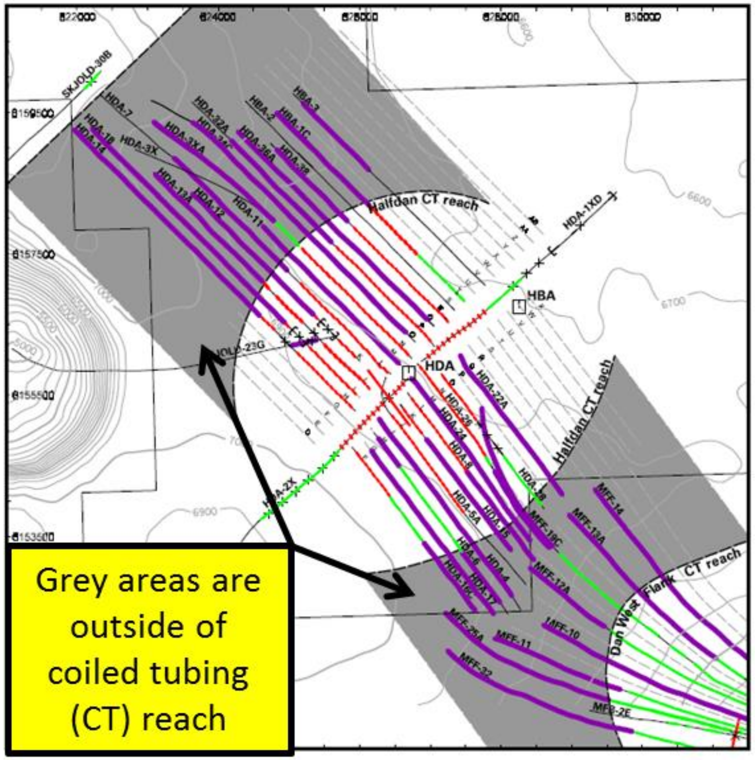


1985	1987	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015

Halfdan Field (2000)

The Challenges

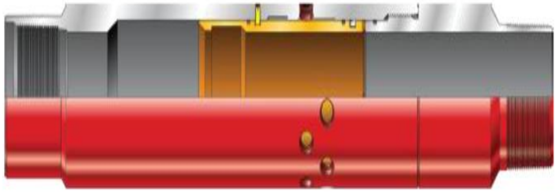
- Thin, flat reservoir requiring stimulation in order to produce at economical rates
- Lateral sections up to 6,000 m
- > 50% of laterals outside of coiled tubing reach



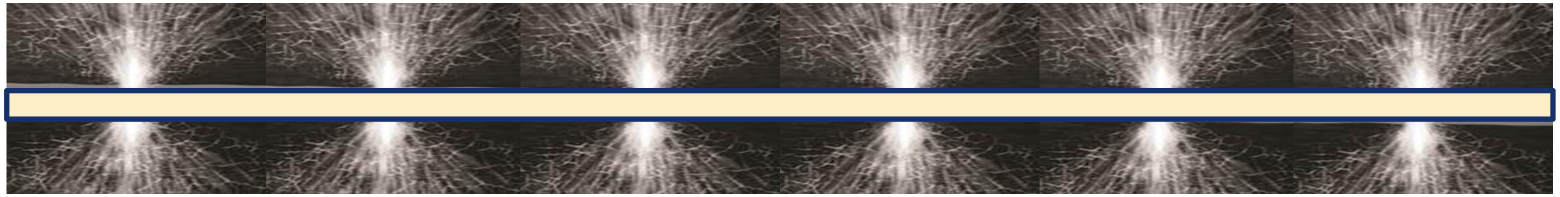
Reference SPE 71322, 78220, 78318 and SPE 108531

Halfdan "Hybrid Completion"

- Inner 2,500 m: Coiled Tubing (CT) shifted sleeves
  - Stages are fracture stimulated
  - 1 week to complete 14-16 stages

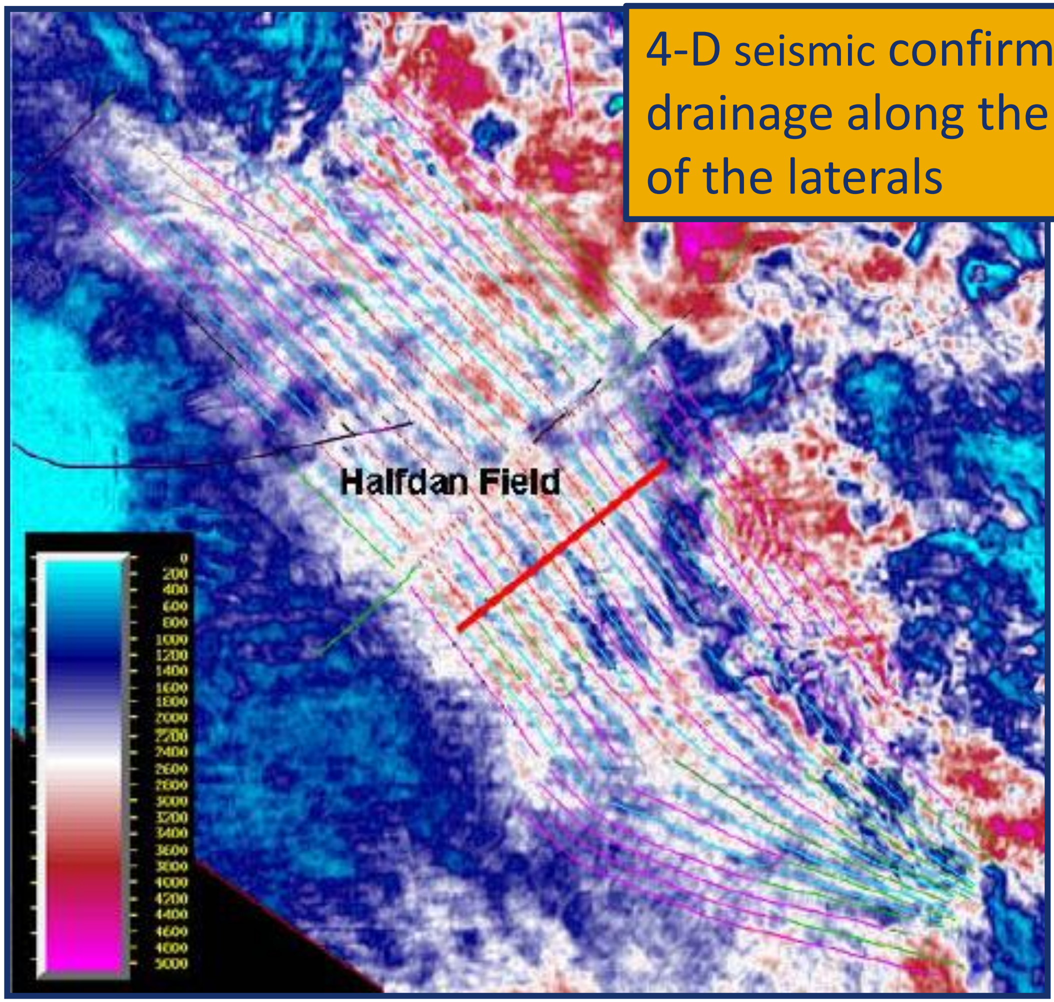


- Outer 3,500 m: Controlled Acid Jetting (CAJ)
  - Single, long interval is matrix acidized
  - 1,500 m^3 15% HCl acid
  - Typically completed in 12 hours



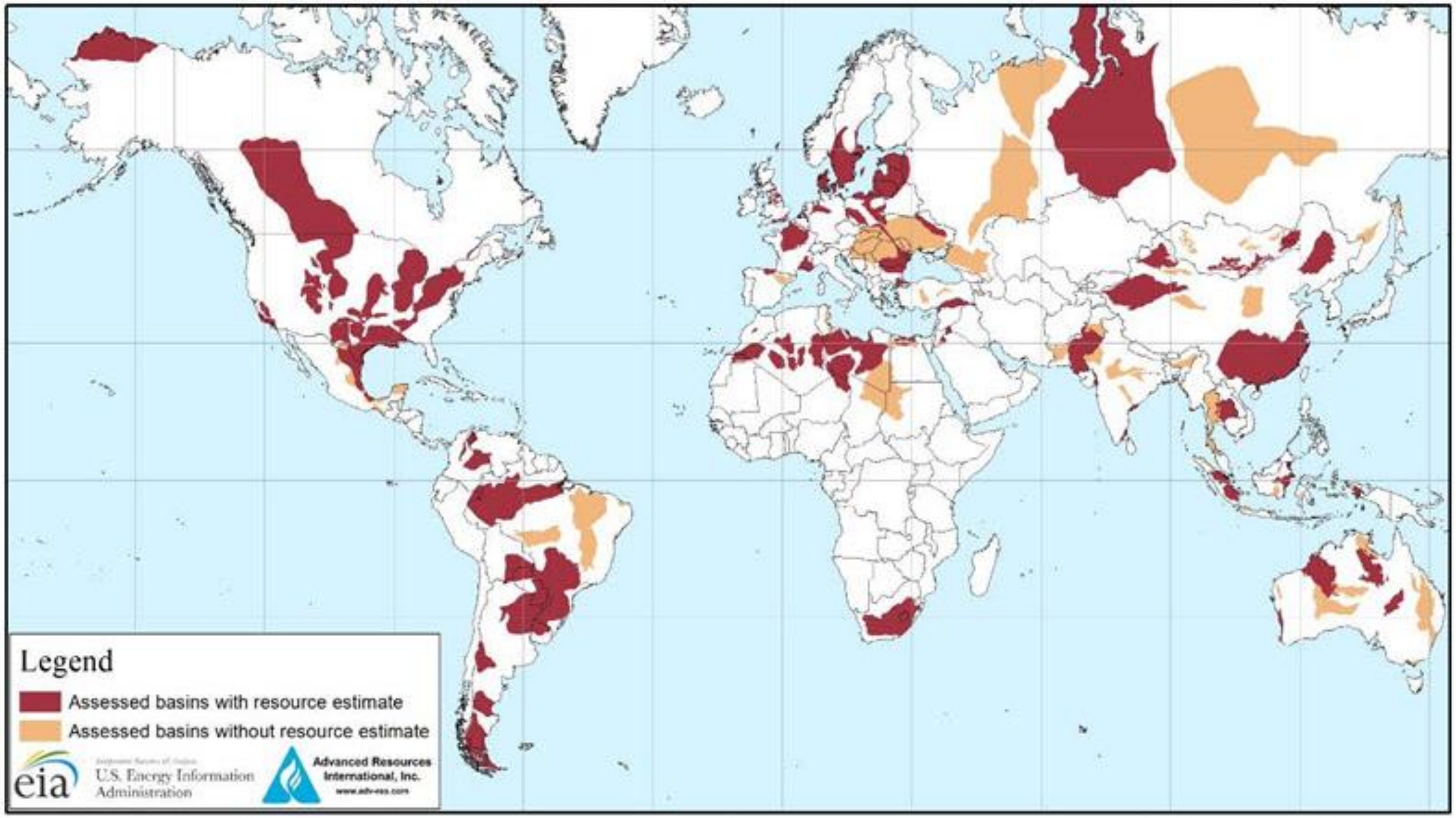
The Halfdan Field Today

4-D seismic confirms effective drainage along the full length of the laterals



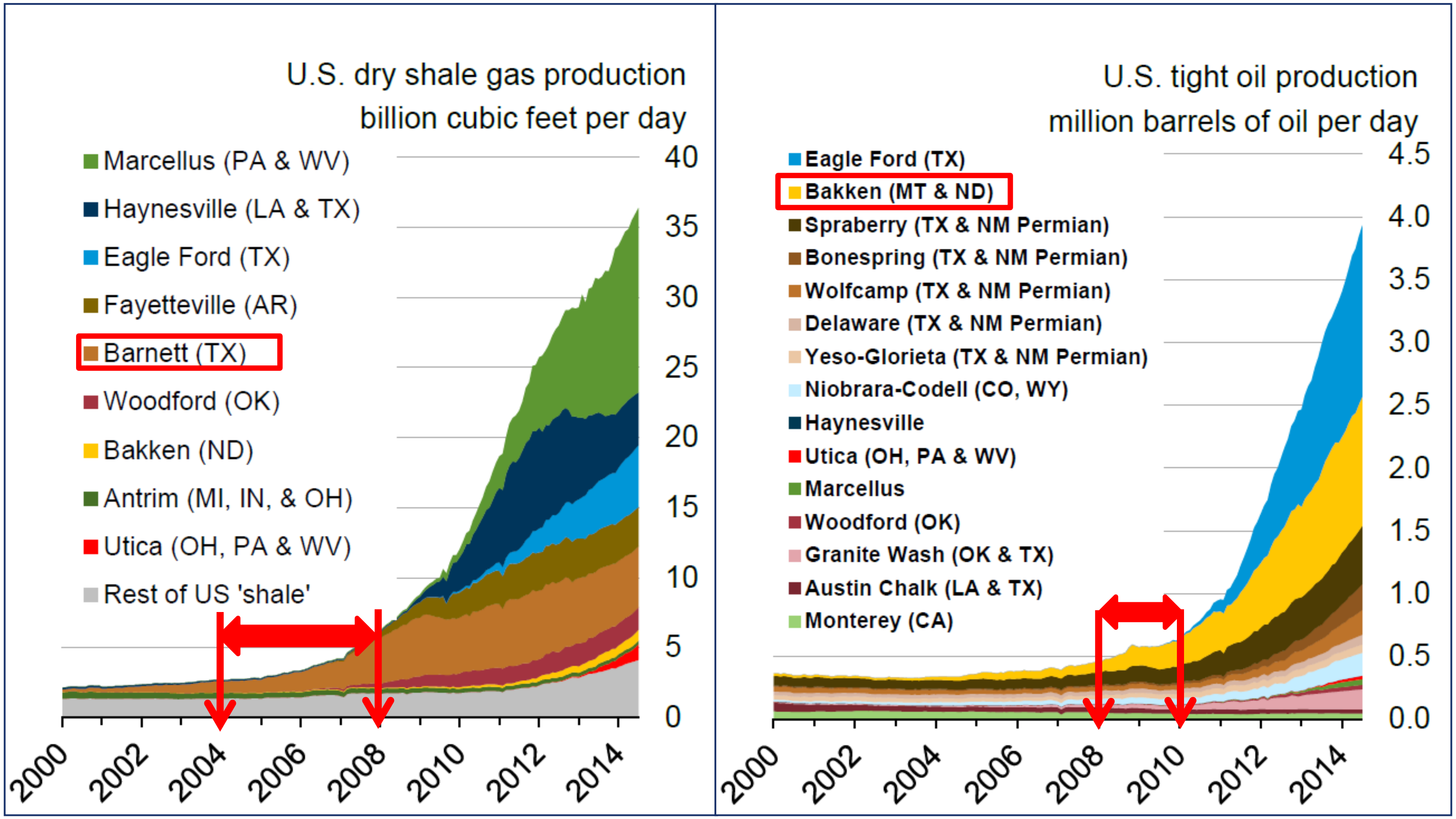
Reference SPE 71322, 78220, 78318. and SPE 108531

Unlocking reserves through horizontal drilling and completion technologies



US Energy Information Administration: "Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States" (June 13, 2013)

Accelerating the learning curve



Source: EIA Energy Infrastructure Summit, September 2014

By 2010, 90% of the wells in the Bakken were horizontal with multi-stage fracs and the operators were preparing to ramp up in the Eagle Ford

Bridging the gap between drilling and completions

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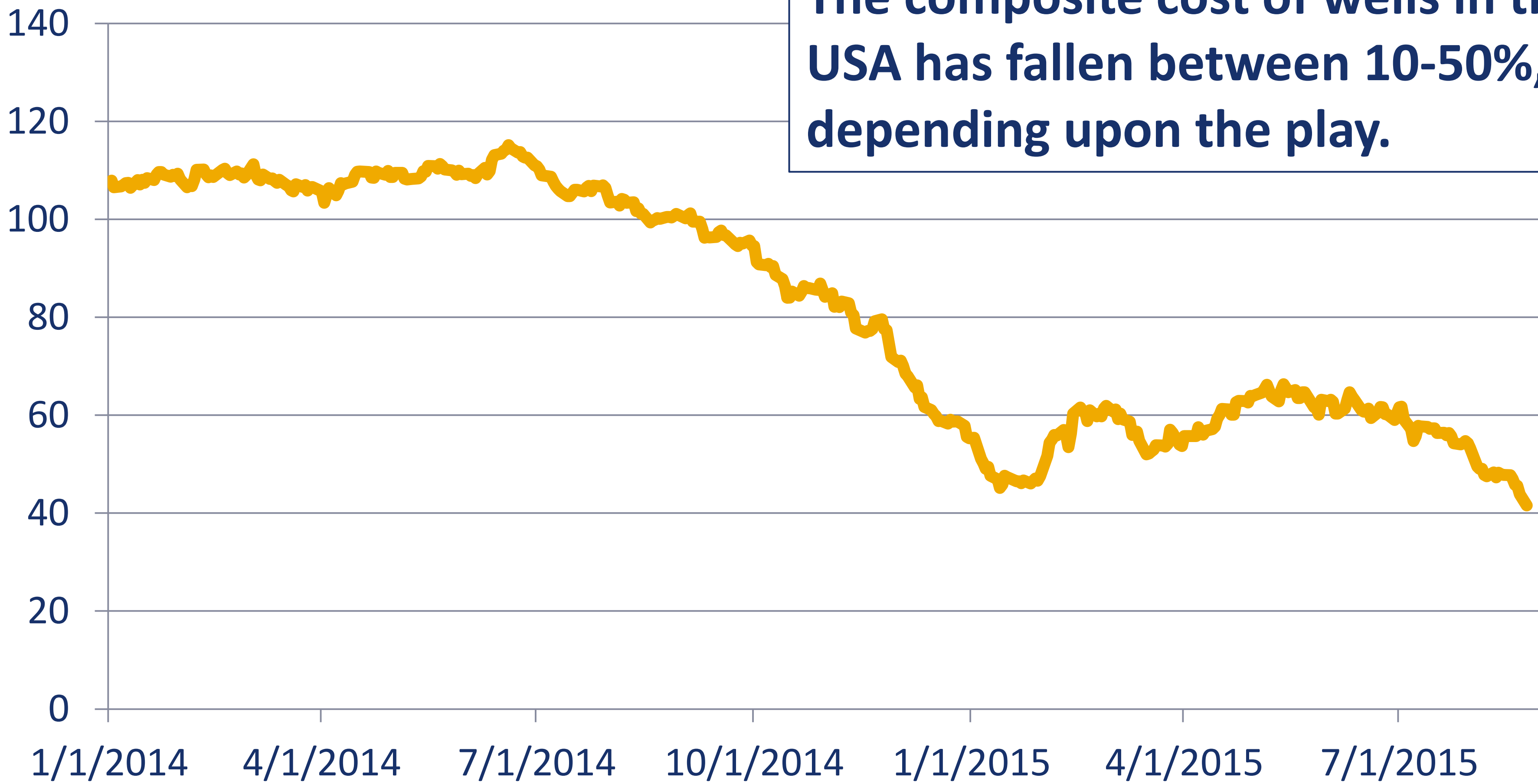
What are today's challenges?

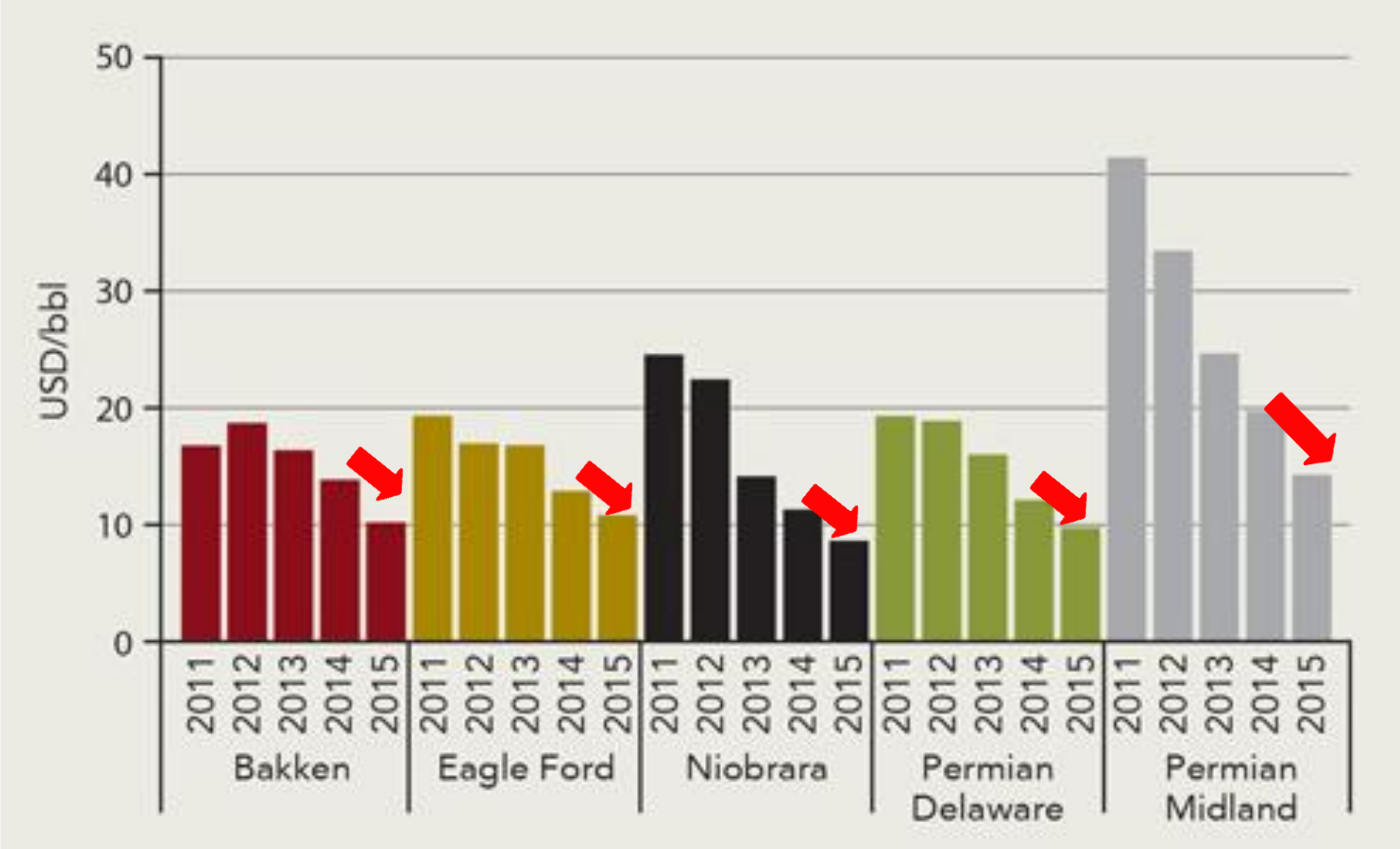
- Time and money
- Laterals are getting longer
- Availability of materials, especially water
- Public perception and environmental regulations
- Selecting the optimum completion for a given area

Brent Oil Spot Price ($/bbl)

The composite cost of wells in the USA has fallen between 10-50%, depending upon the play.

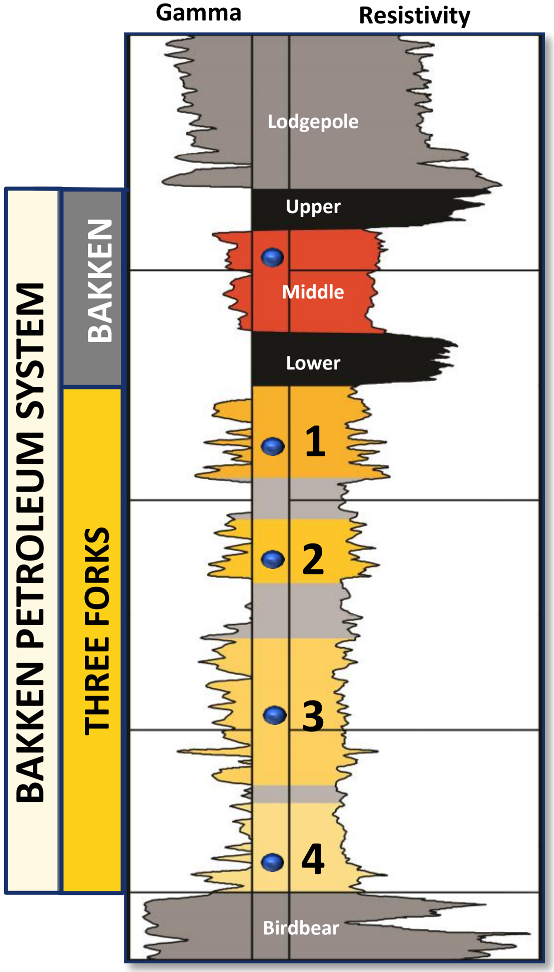


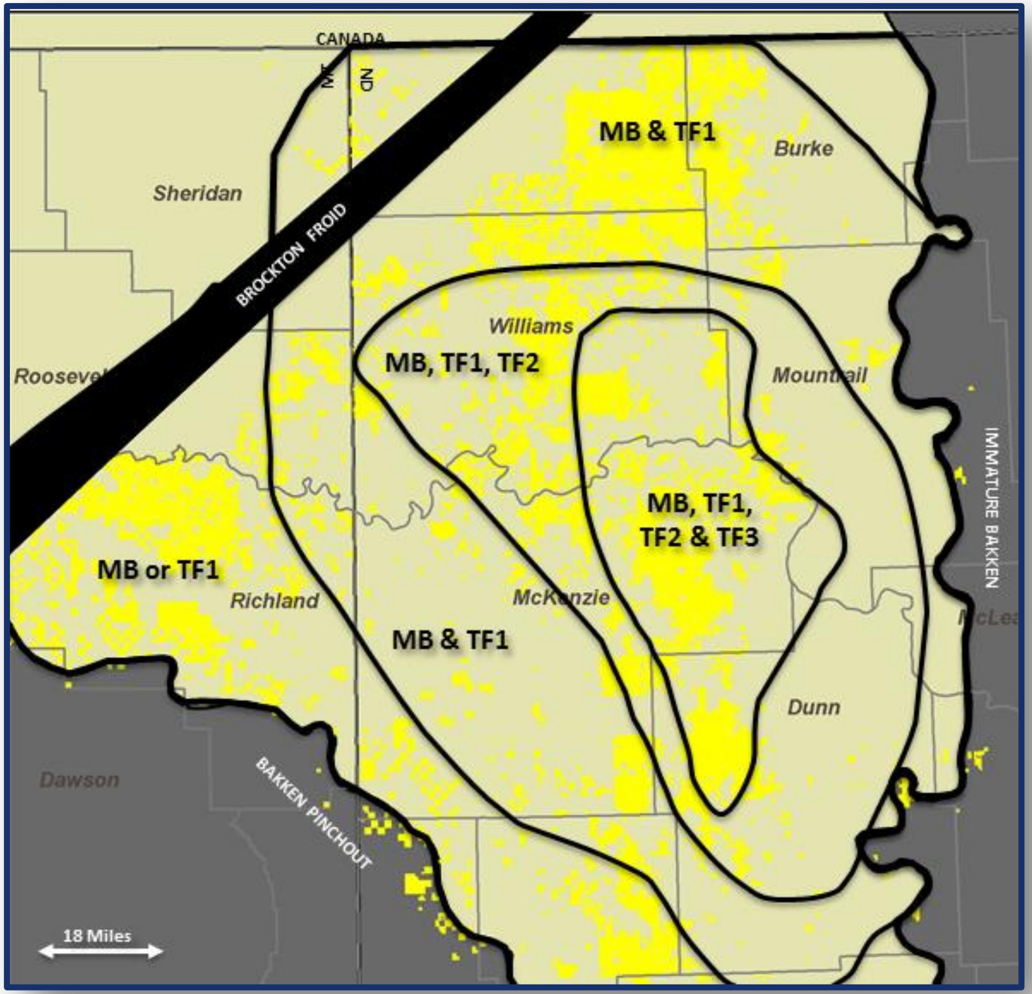
Drilling and Completion Costs
CAPEX per EUR



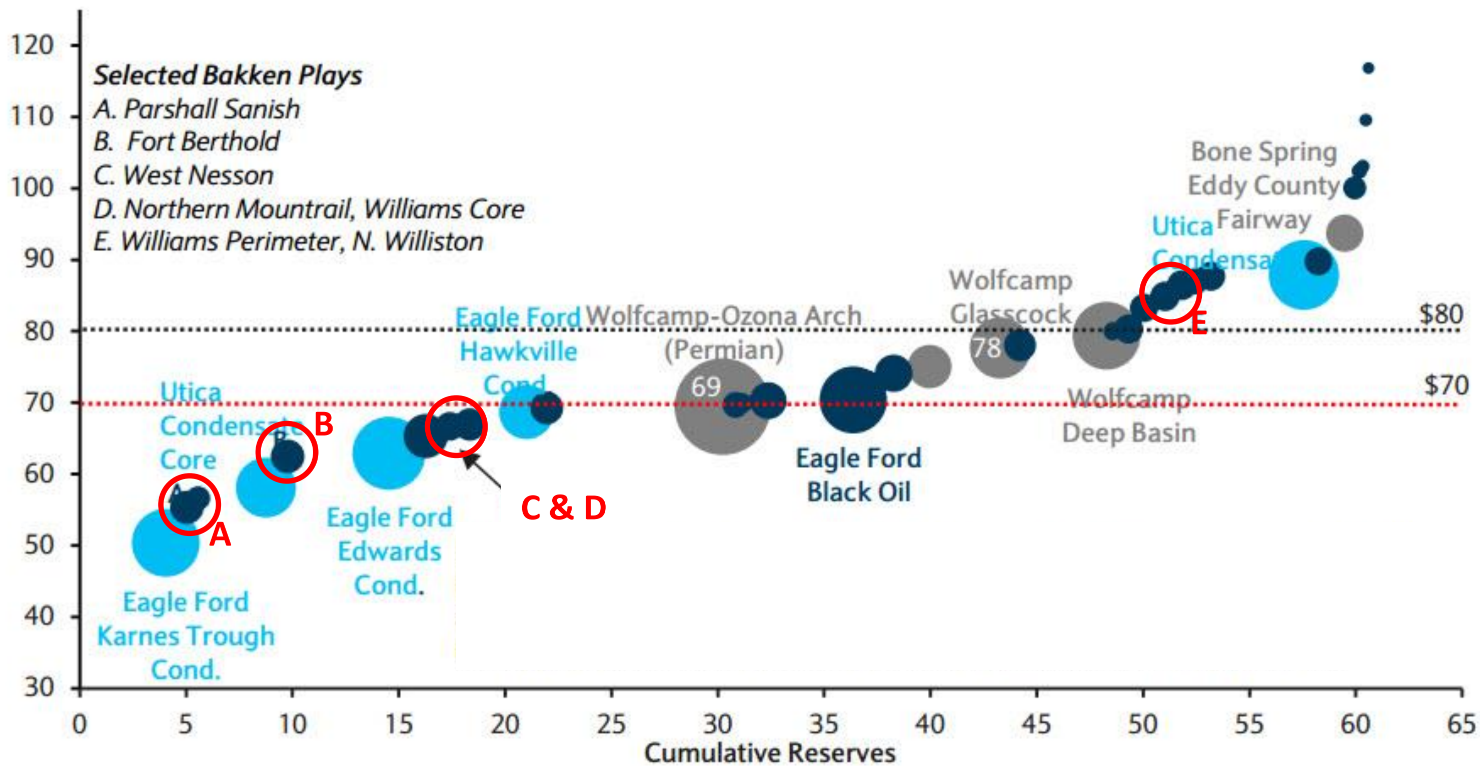
Source: Oil & Gas Financial Journal, November 2015 (Rystad Energy NAS Well Data and Analysis)

Brief Introduction to the Bakken





Tight Oil Breakeven Prices
2014 "High Grading" Example



Source: WoodMackenzie, Barclays Research (November 2014)

What will happen in 2016?

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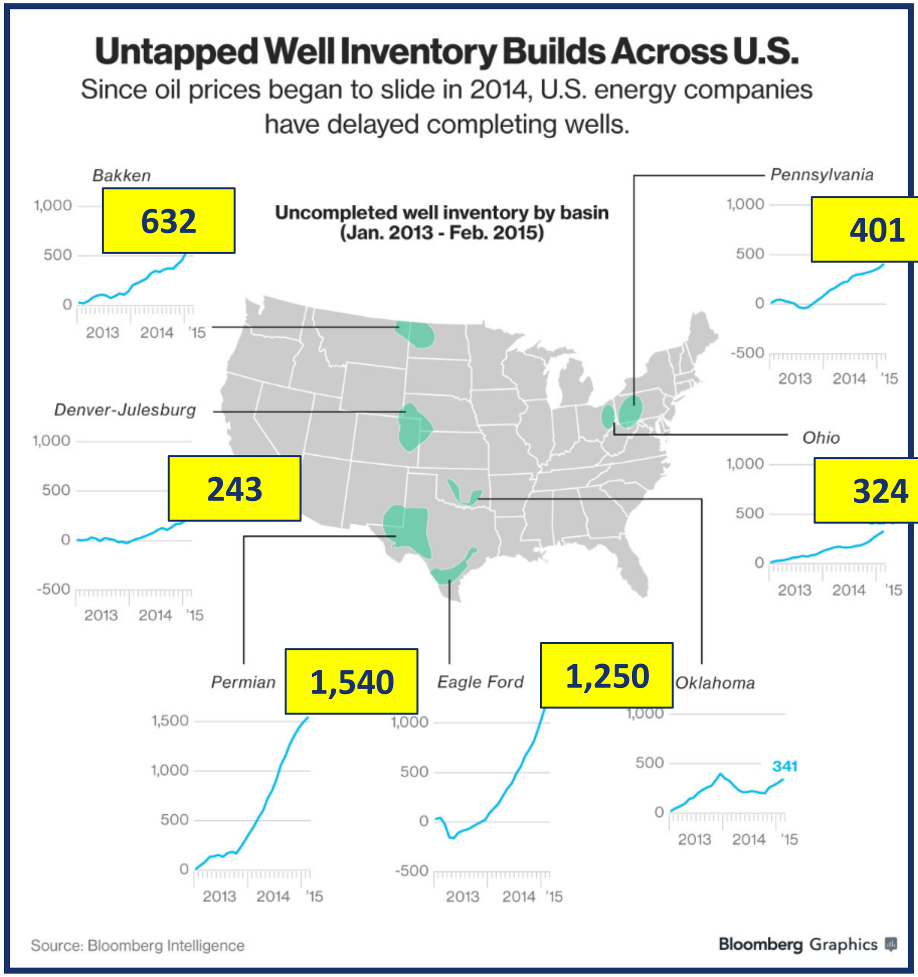
Drilled Uncompleted Wells

- 3,600 in U.S. (~ 1 mil BOPD)*
- 998 in Bakken at year end 2015

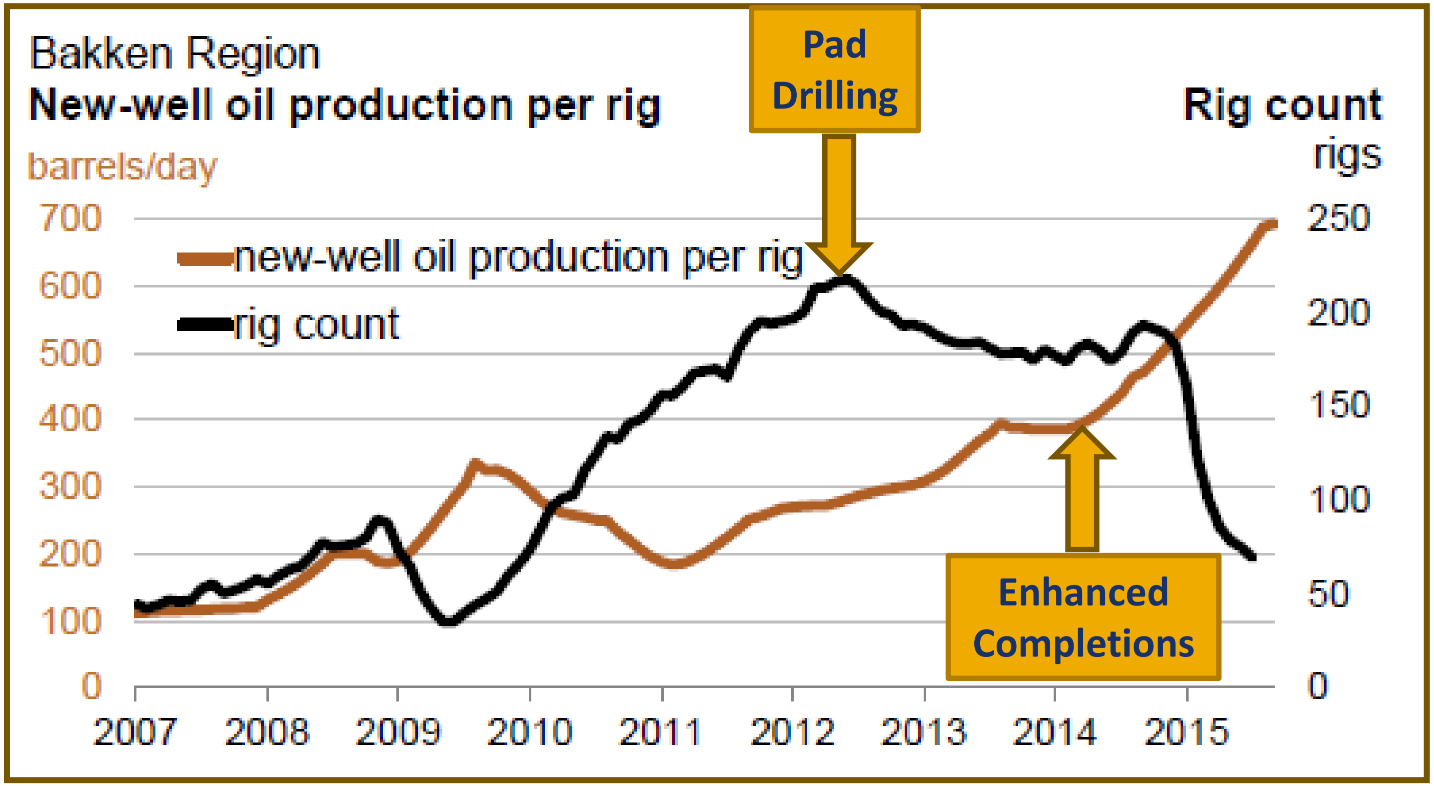
Important questions:

- Where is the opportunity in this challenge?
- How do we prepare for the recovery when it happens?



** PIRA Energy Group, Midland Reporter Telegram, January 10, 2016*

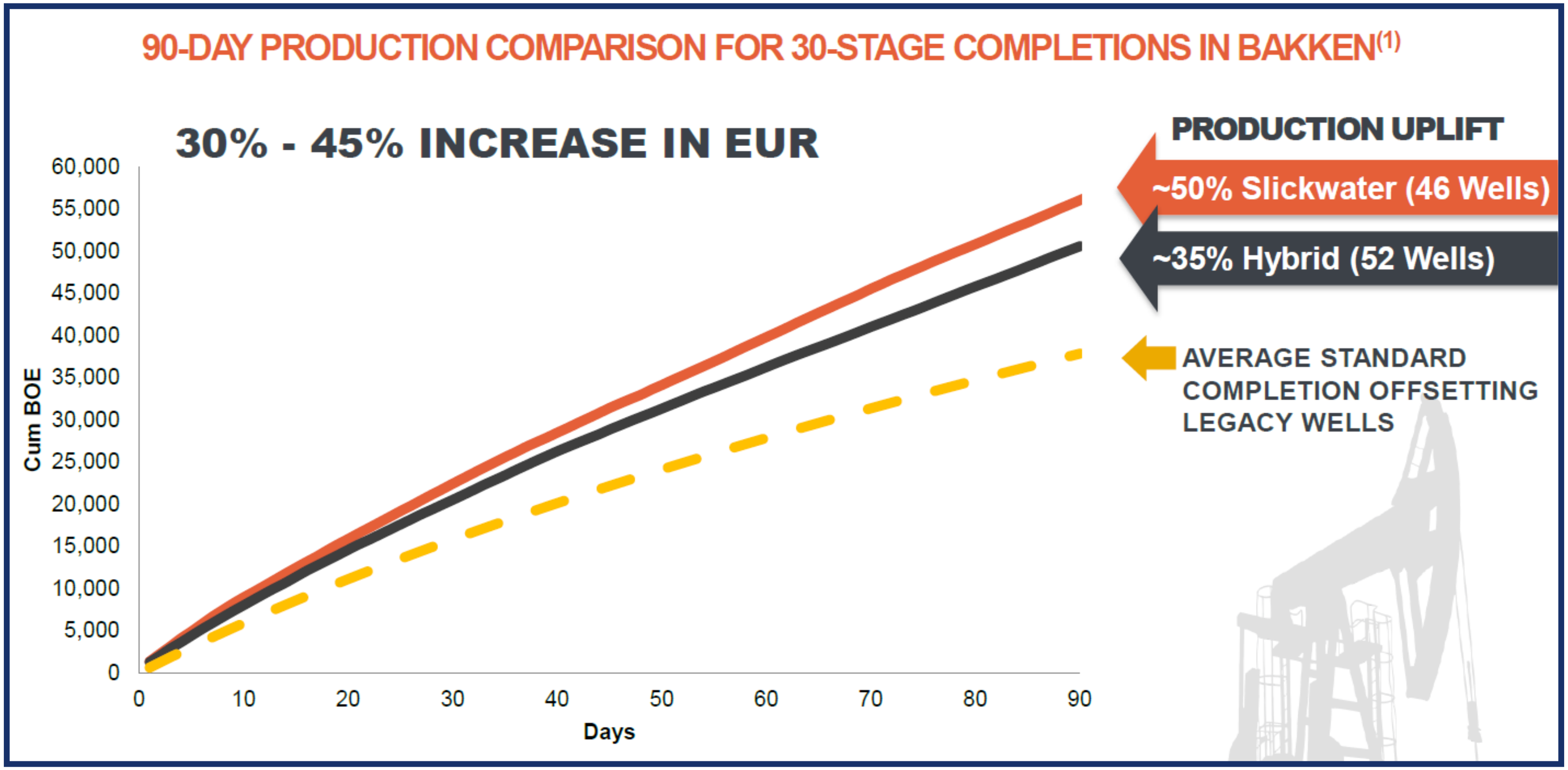
Drilling vs. Completion Efficiencies



Source: US Energy Information Administration Bakken Rig Efficiencies Report August 2015

Bakken Completion Trends

Enhanced Completions



Source: Continental Resources November 2015 Investor Presentation

Challenge: Completion ~~Efficiency~~ *Effectiveness*

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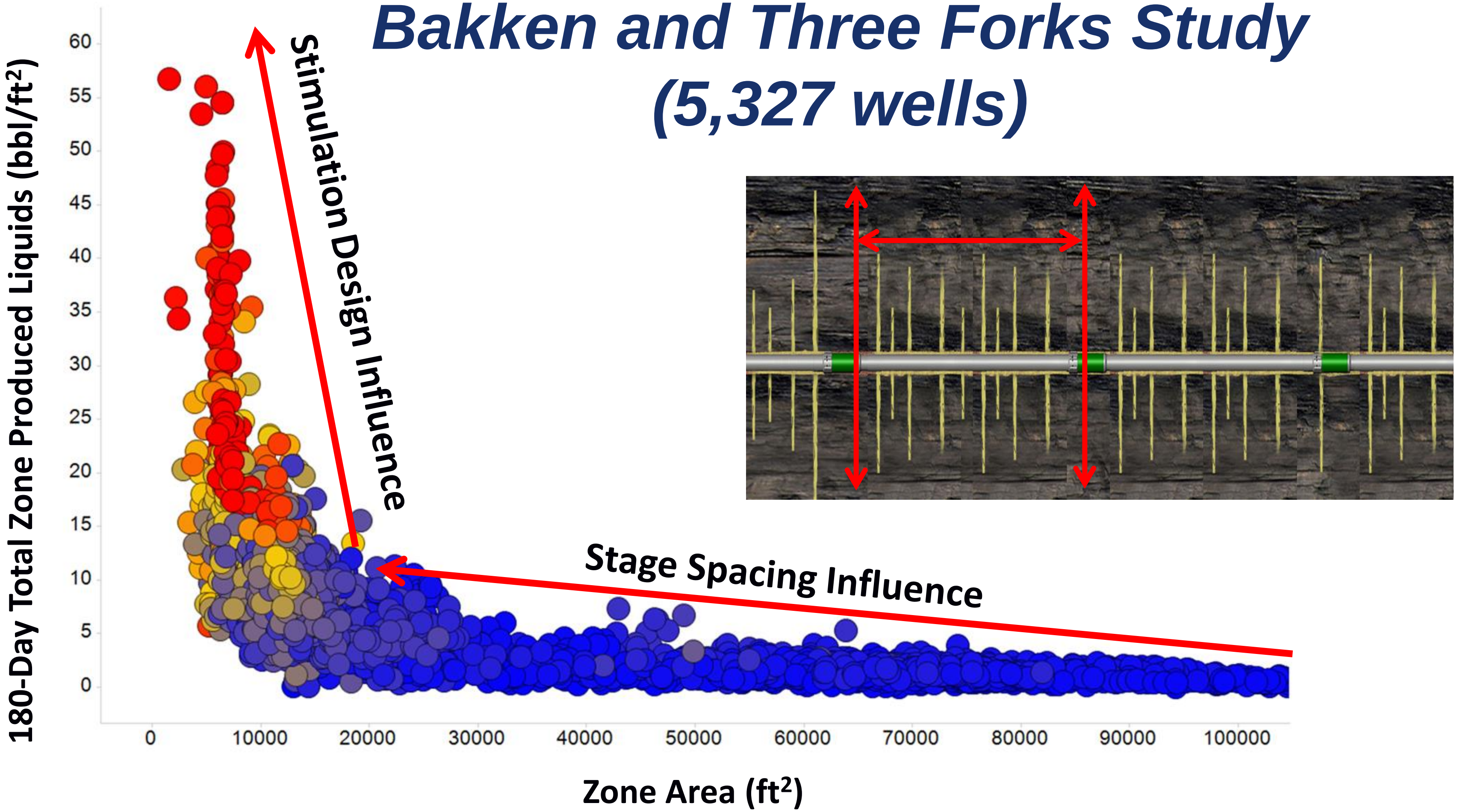
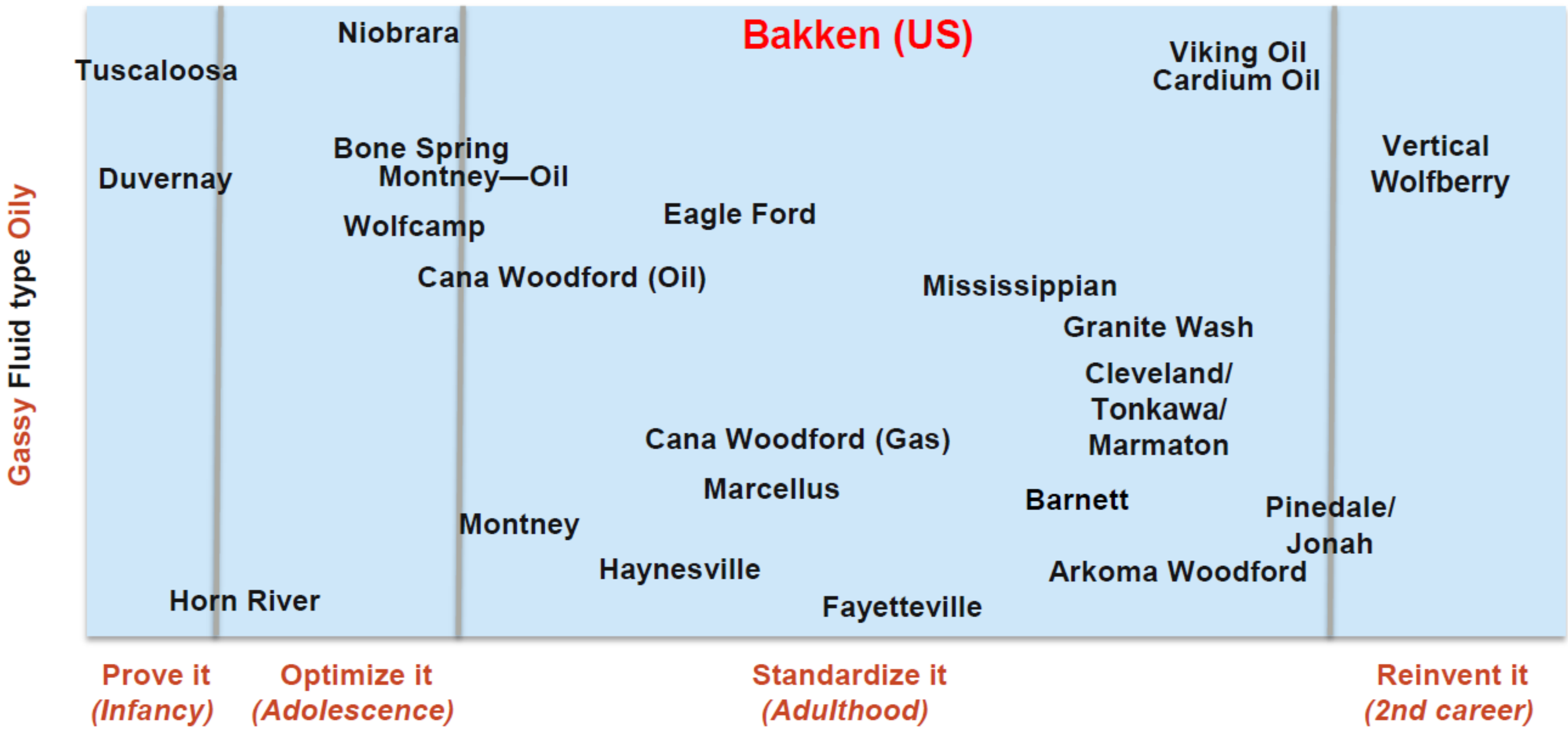
Bakken and Three Forks Study (5,327 wells)



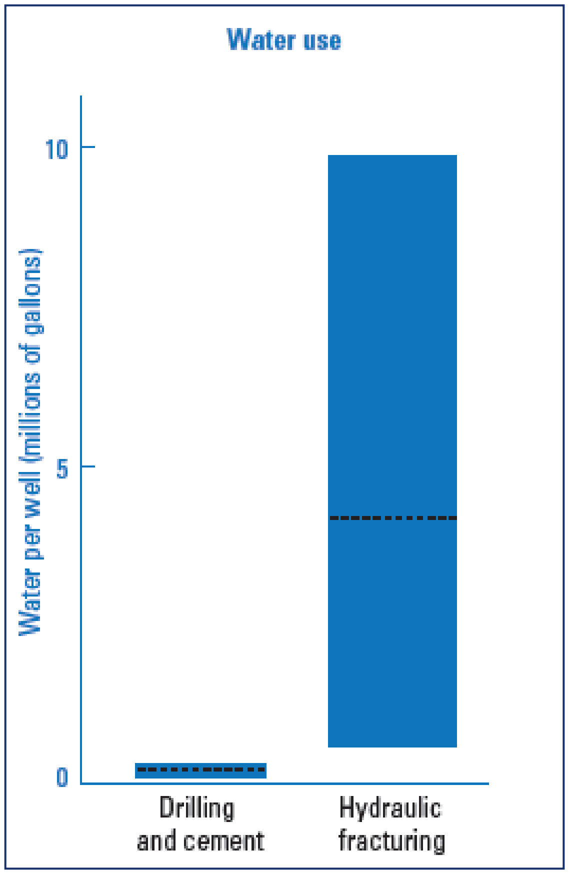
Reference SPE 169531 and SPE 171629

Life Cycle of Unconventional Plays



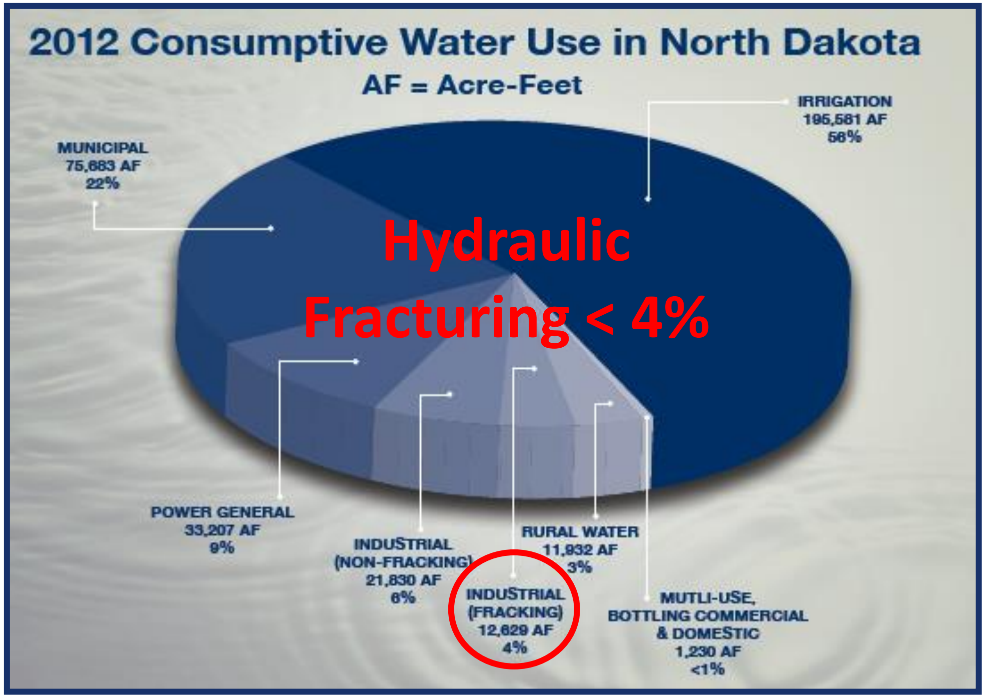
Source: HIS Bakken Playbook (May 2015)

Water Requirements – Horizontal Wells
Drilling vs. Completions



Source: US Geological Survey Fact Sheet 2014-3010 (March 2014)

- Significantly more water is used during completion compared to drilling; however,
- The amount is a small percentage of all industrial water usage



Source: North Dakota State Water Commission

Water Recycling: Why or why not?

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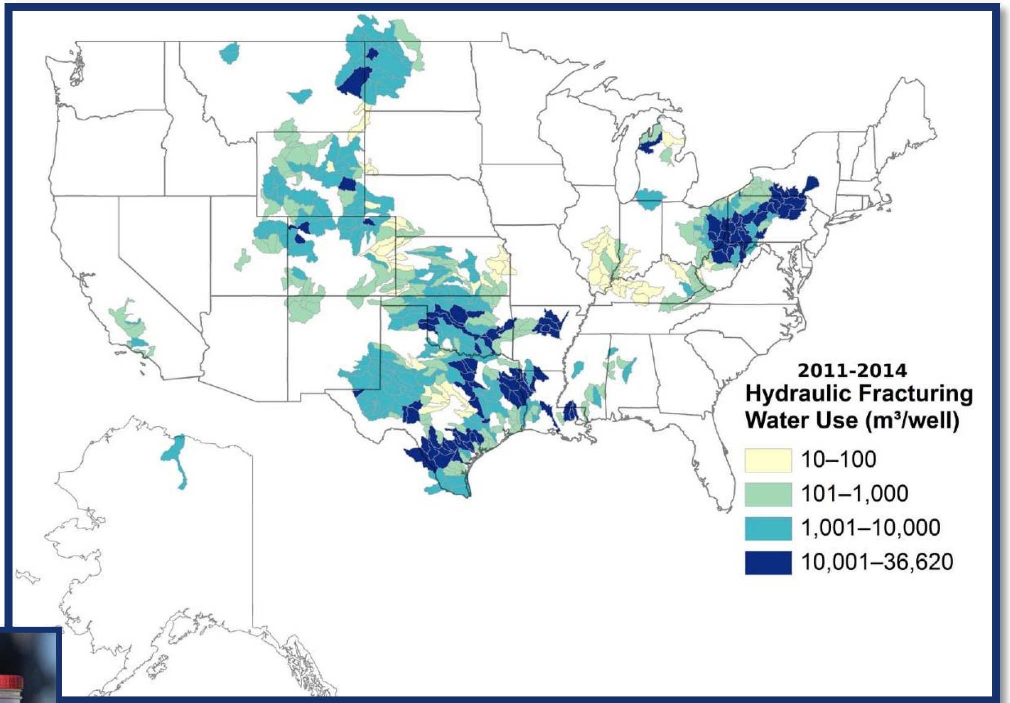
Considerations:

Feasibility
- Availability of fresh water
- Legislation

Economics
- Quality of produced water
- Water transfer options
- Central storage



Source: USGS Article 10.1002/2015, June 2015

Remediating for entrained oil and for solids

Produced Water Recycling Facility

Reference SPEPOS Panel Session on Water Management for Hydraulic Fracturing, March 2015

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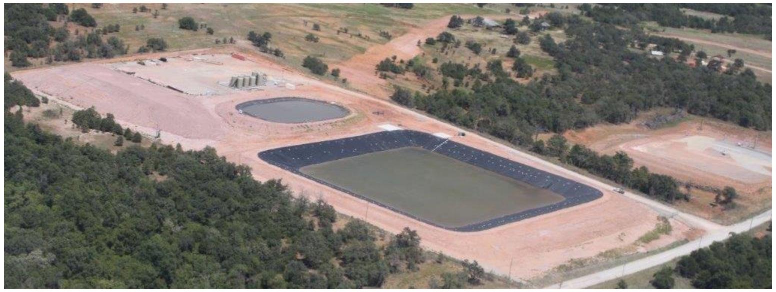
<u>Components</u>

- Produced water storage
- Flocculation to remove solids
- Treatment to remove organics
- Underground water transfer pipelines

50,000 bbl/day Recycling Capacity and 1,500,000 bbl Useable Storage

<u>Economic Benefits</u>

- Low OPEX ~ \$0.30-\$0.50/bbl
- Facilities generate revenue
- Minimizes salt water disposal
- 30% reduction in fresh water consumption



10,000 bbl/day Recycling Capacity and 500,000 bbl Useable Storage

Note: Temporary recycling facilities are available which do not require CAPEX
OPEX is \$2.50-\$3.60/bbl, depending upon produced water quality and throughput

Pushing the limits of lateral length

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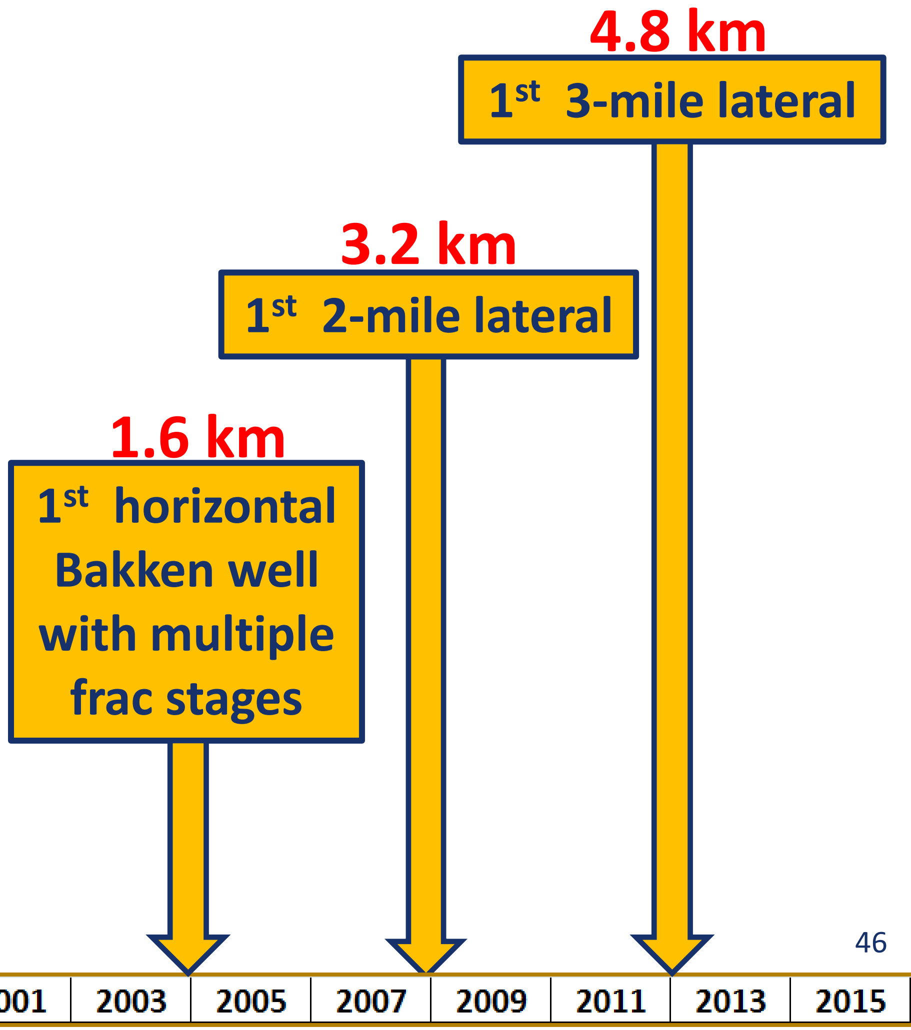

Drilling Efficiency Gains with Longer Laterals

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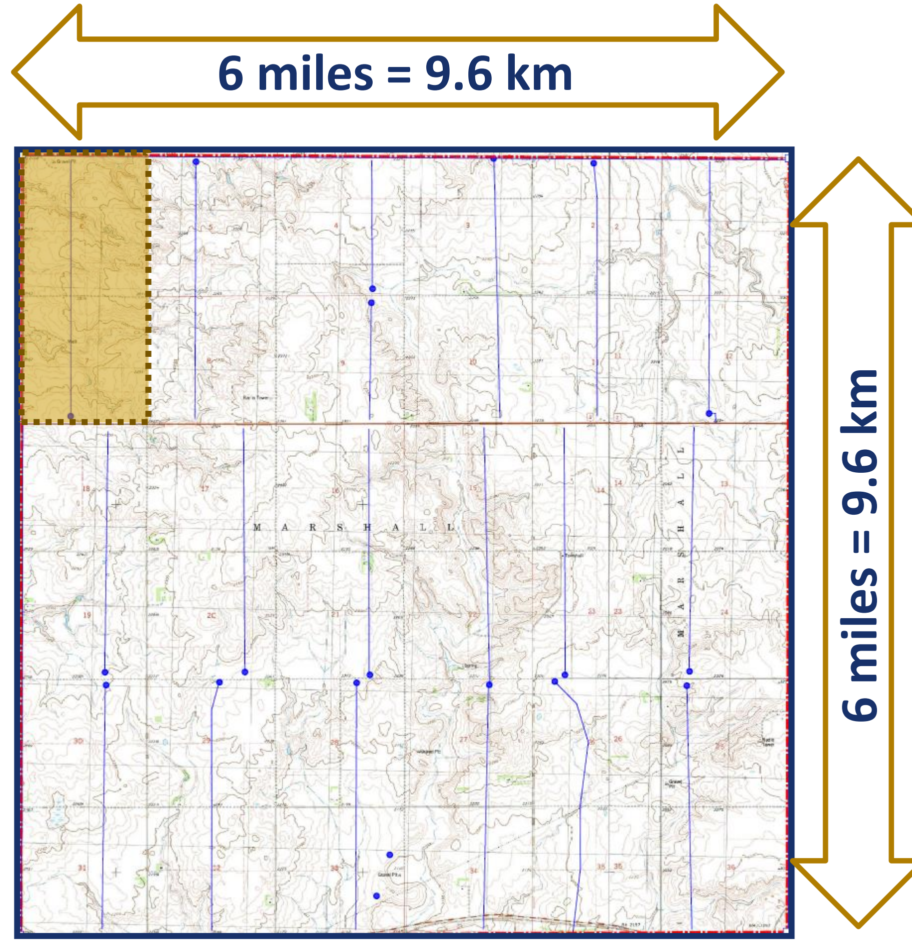
Challenge:

- Economic full field development
- Conventional development
  - Full township (6 miles x 6 miles)
  - 18 units (1 mile x 2 miles)
  - Each unit HBP (held by production)



Example data modified from American Association of Drilling Engineers (AADE) Technical Symposium held in Tulsa, OK, February 19, 2014

Drilling Efficiency Gains with Longer Laterals

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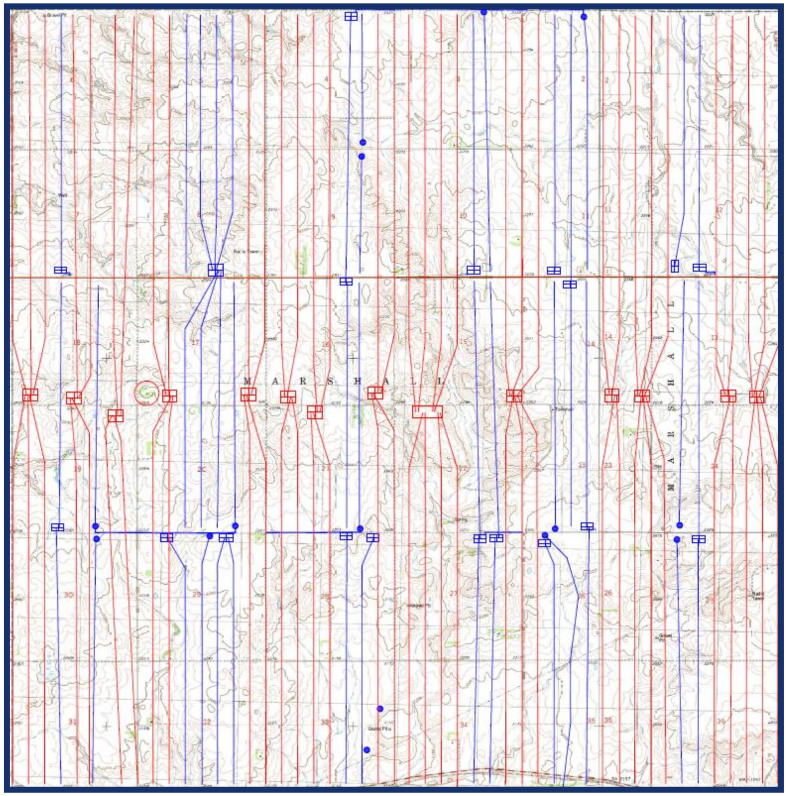
Solution:

Extended lateral development:

- Infill using 14 4-, 6- and 8-well pads
- 18 fewer pads and 32 less wells
- 36% reduction in footprint

	2-mile development	3-mile development	Potential Benefit
Lateral length	10,000 ft	15,000 ft	~ Neutral
Wells required	141	109	- 32 wells
Number of pads	64	46	- 18 pads
Total footprint	280 acres	179 acres	- 101 acres



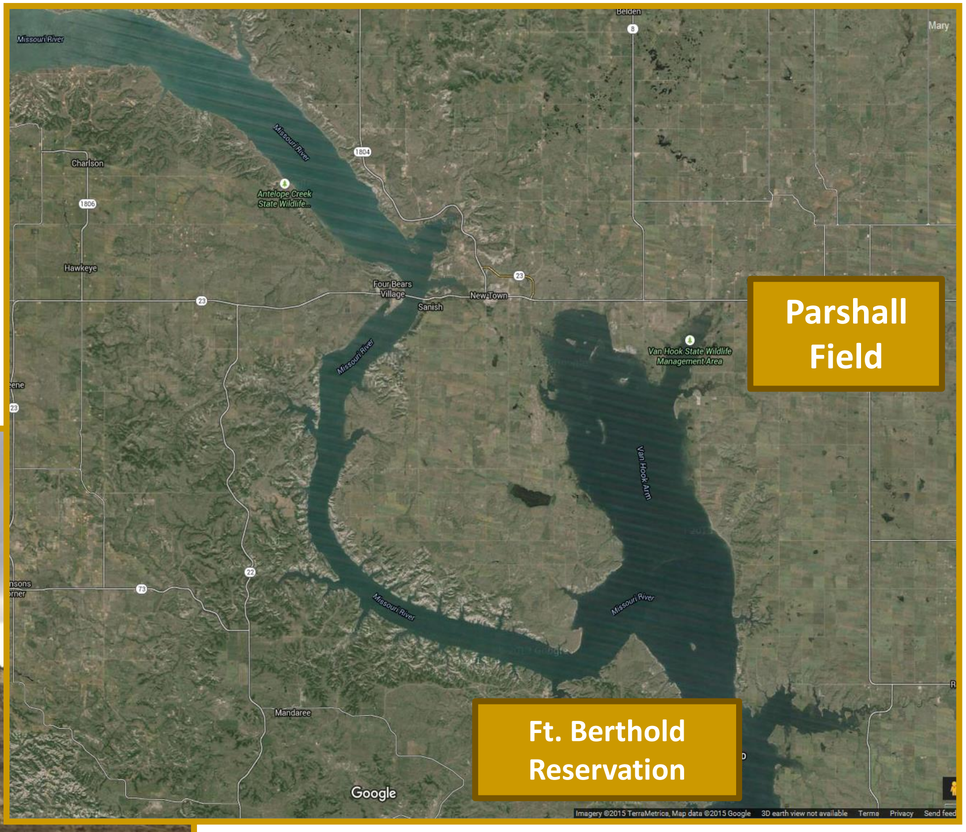
Red wells are 3-mile laterals

Example data modified from American Association of Drilling Engineers (AADE) Technical Symposium held in Tulsa, OK, February 19, 2014

Drilling Efficiency Gains with Longer Laterals

Challenge:

- Accessing “offshore reserves”
- Surface constraints



Drilling Efficiency Gains with Longer Laterals

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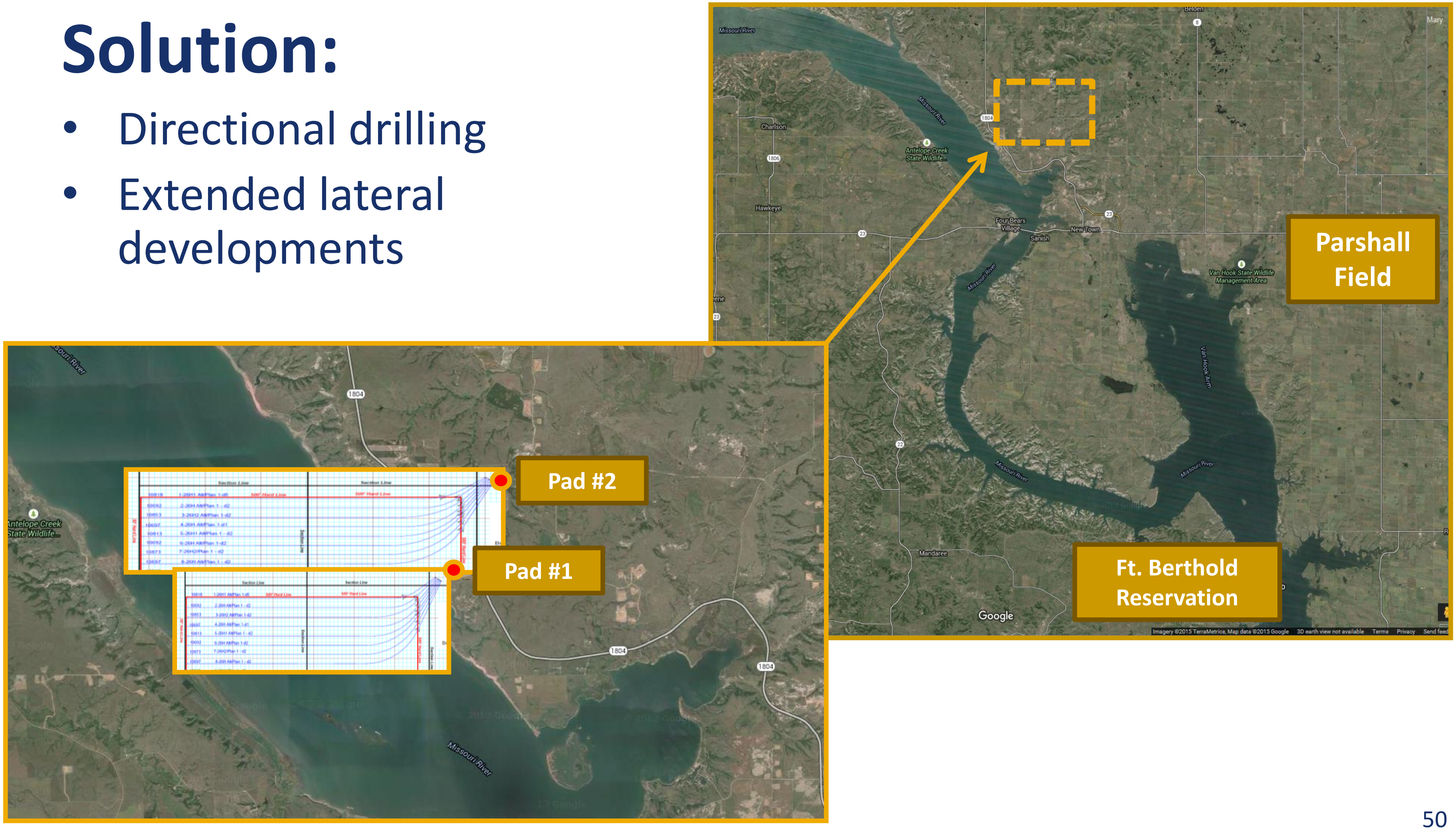
Solution:

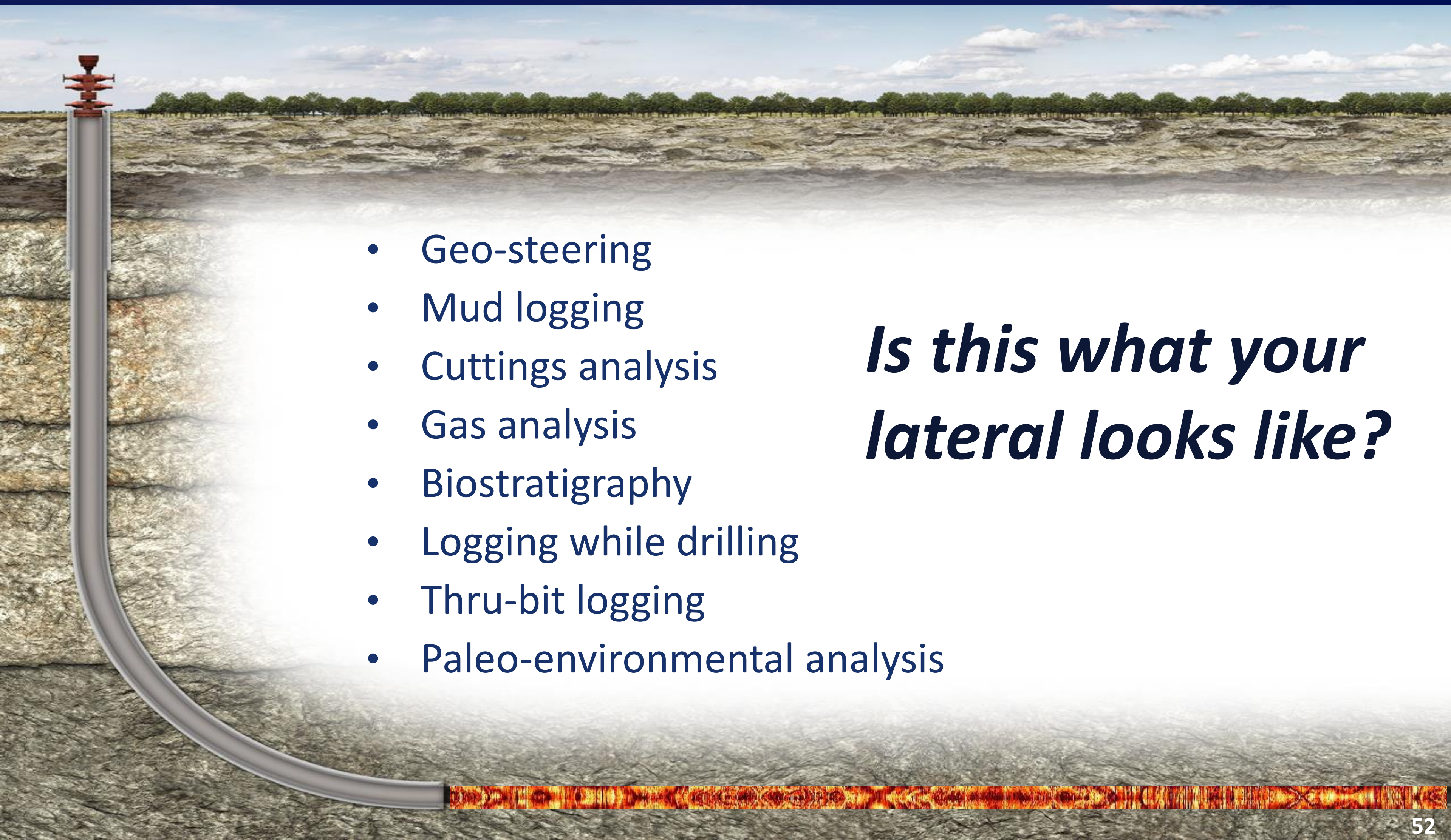
- Directional drilling
- Extended lateral developments



Chasing the drilling rig

- Steering the lateral
- Where to perforate
- Stage isolation
  - Plug and Perf
  - Ball shifted sleeves
  - CT shifted sleeves
- Post frac cleanout

Challenge: Steering the lateral



- Geo-steering
- Mud logging
- Cuttings analysis
- Gas analysis
- Biostratigraphy
- Logging while drilling
- Thru-bit logging
- Paleo-environmental analysis

Is this what your lateral looks like?

Challenge: Steering the Lateral

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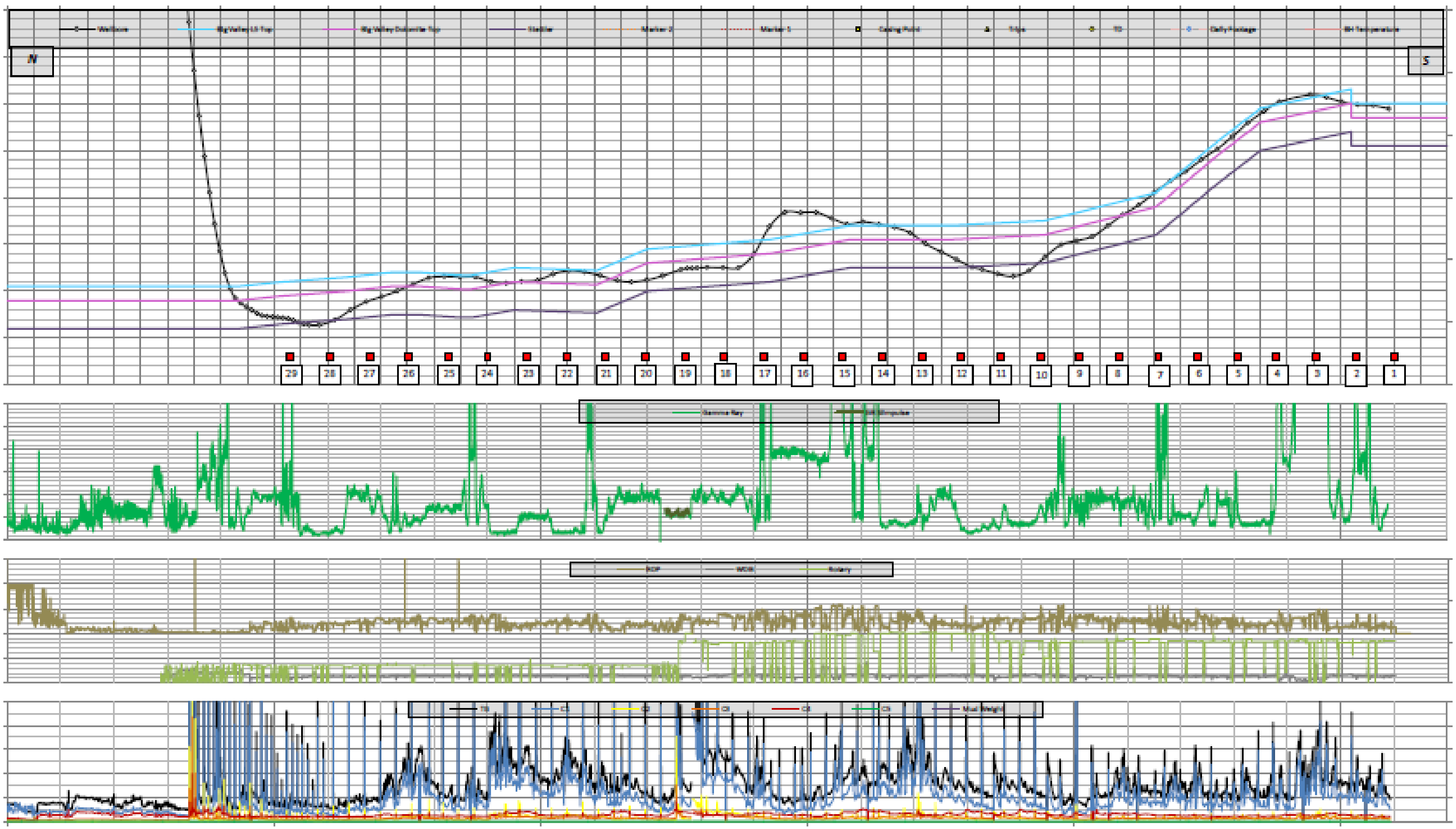

Challenge: Quantifying rock properties

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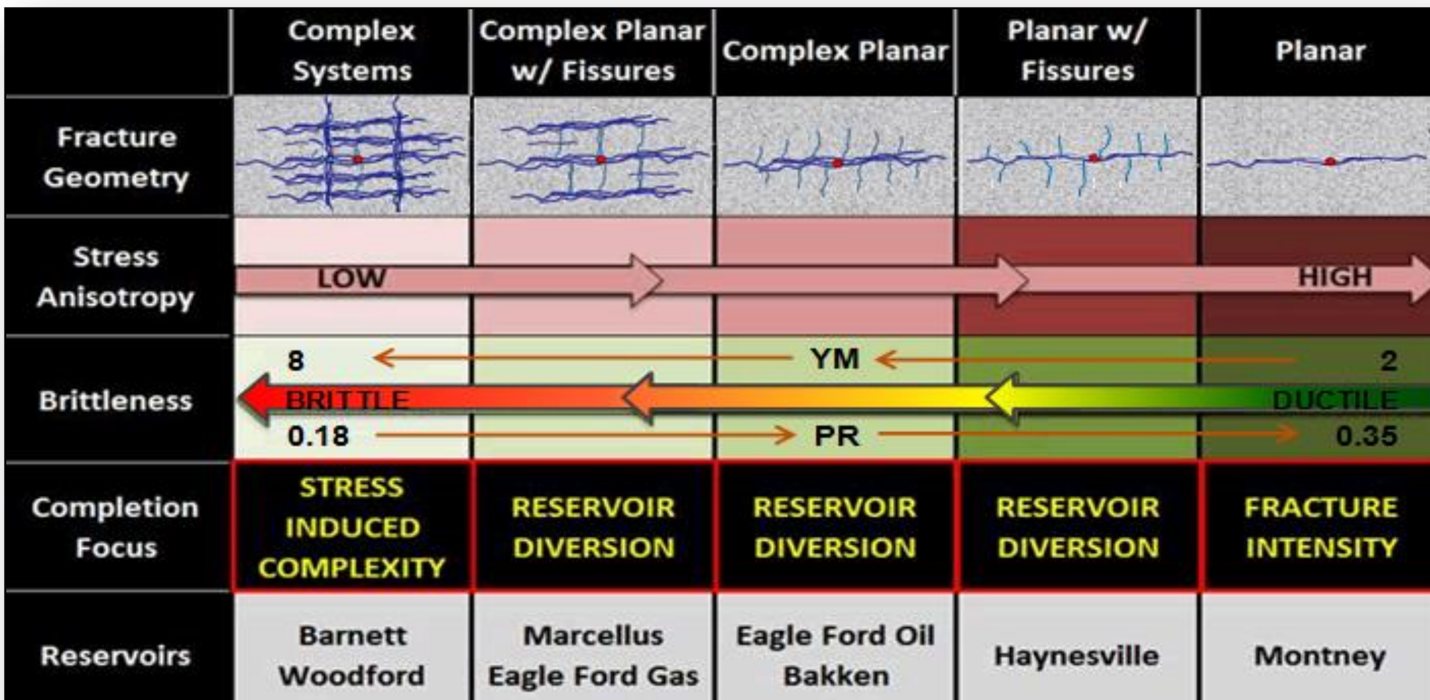
Is your rock brittle or ductile?



	Complex Systems	Complex Planar w/ Fissures	Complex Planar	Planar w/ Fissures	Planar
Fracture Geometry					
Stress Anisotropy	LOW				HIGH
Brittleness	8 BRITTLE 0.18		YM PR		2 DUCTILE 0.35
Completion Focus	STRESS INDUCED COMPLEXITY	RESERVOIR DIVERSION	RESERVOIR DIVERSION	RESERVOIR DIVERSION	FRACTURE INTENSITY
Reservoirs	Barnett Woodford	Marcellus Eagle Ford Gas	Eagle Ford Oil Bakken	Haynesville	Montney

Reference SPE 115258, 152704, 164271, 167726, 168763

Challenge: Where to perforate

Need to balance

- Reservoir quality with
- Completion quality

Various approaches

- Thru-bit quad-combo logs
- Projecting pilot hole data via resistivity or density logs
- Specific mechanical energy (SME) from drilling parameters

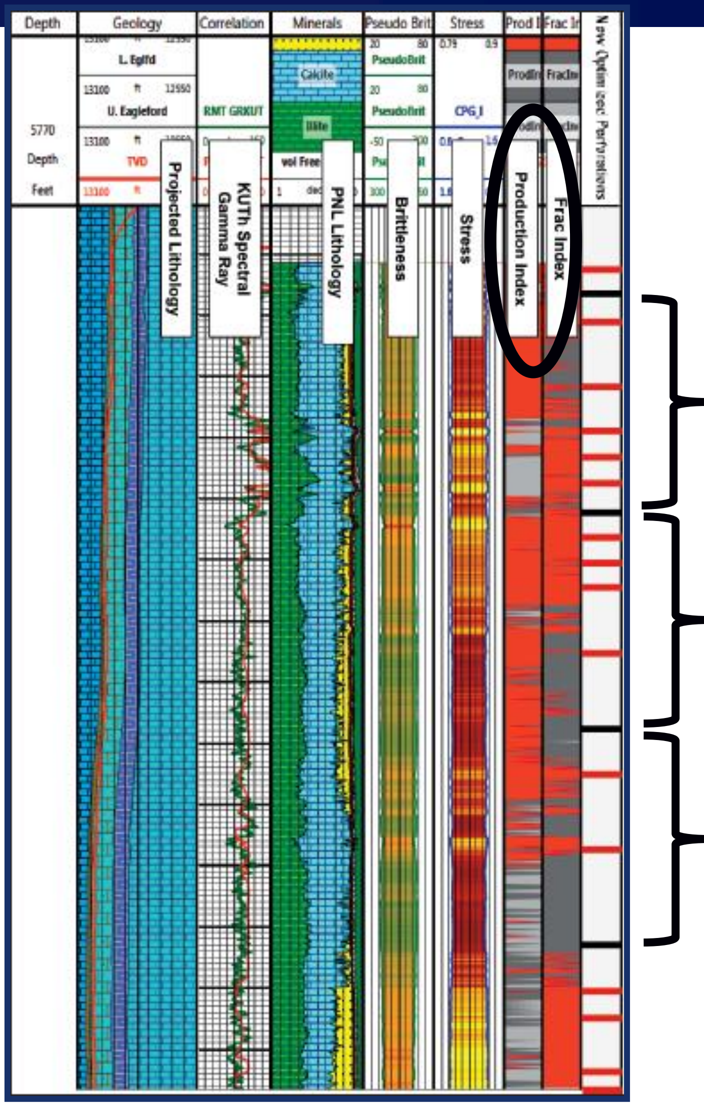
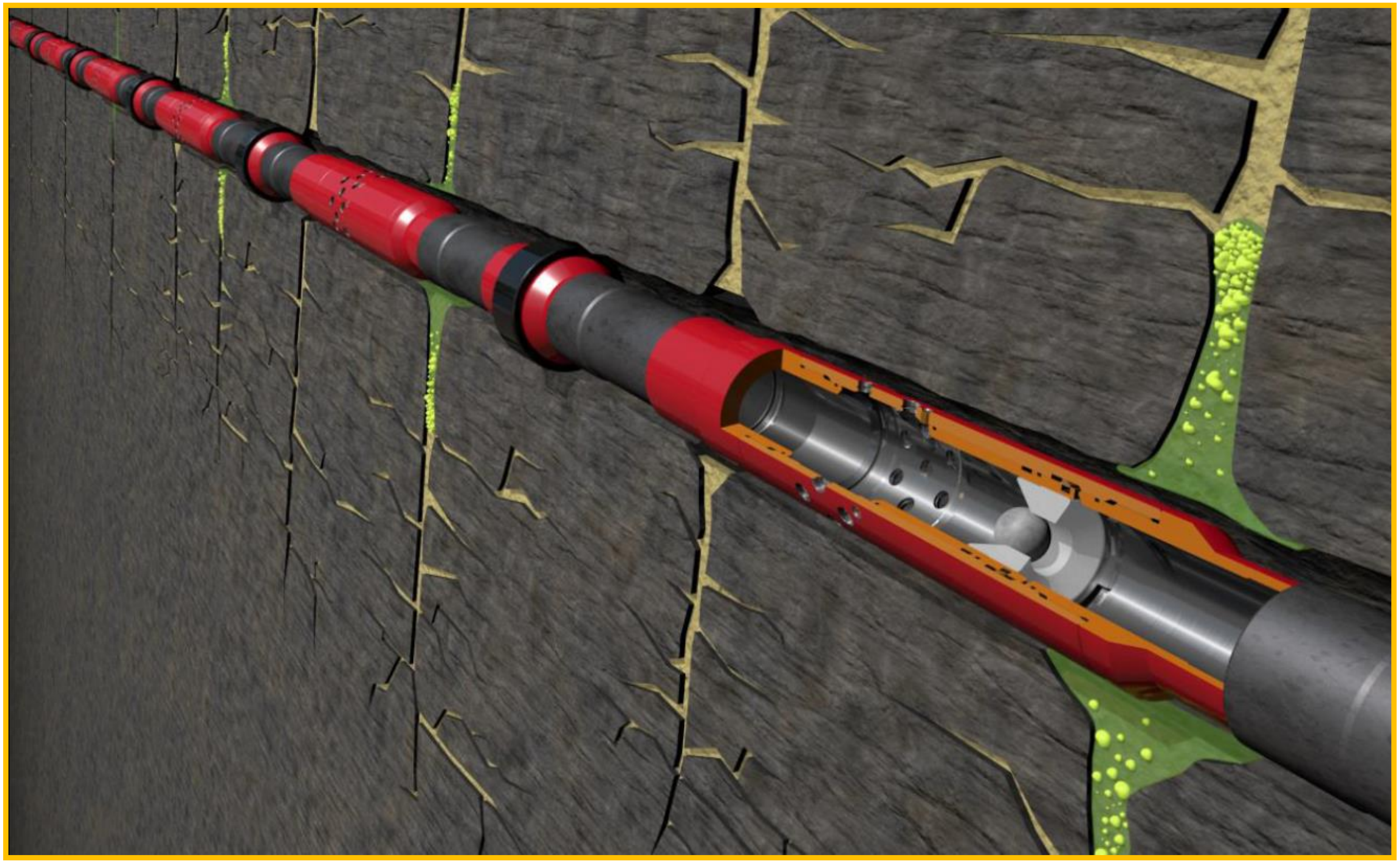


Image courtesy of Halliburton Energy Services

Challenge: Stage Isolation

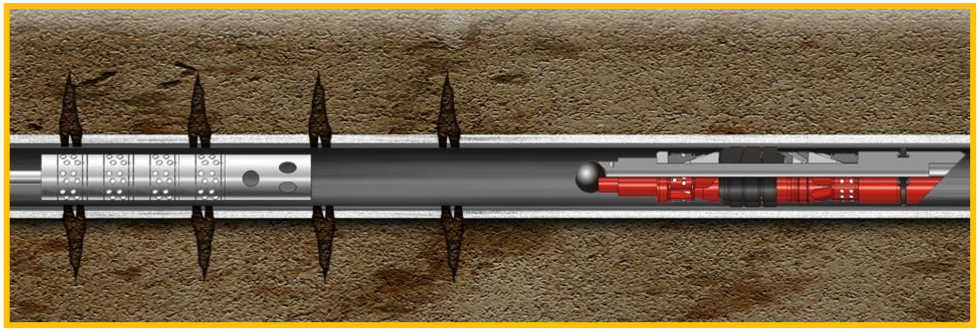


Images courtesy of Halliburton Energy Services

Challenge: Stage Isolation

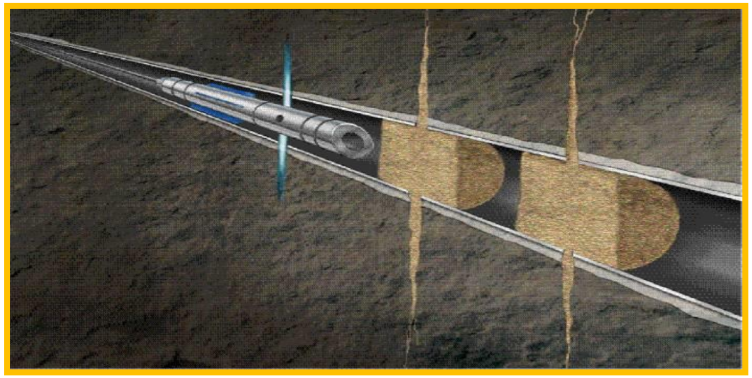
Mechanical systems

- Plug-and-perf
- Ball and sleeves
- Coiled tubing activated



Dynamic systems

- Jet assisted
- Proppant plugs



Images courtesy of Halliburton Energy Services

Plug-and-Perf Completions

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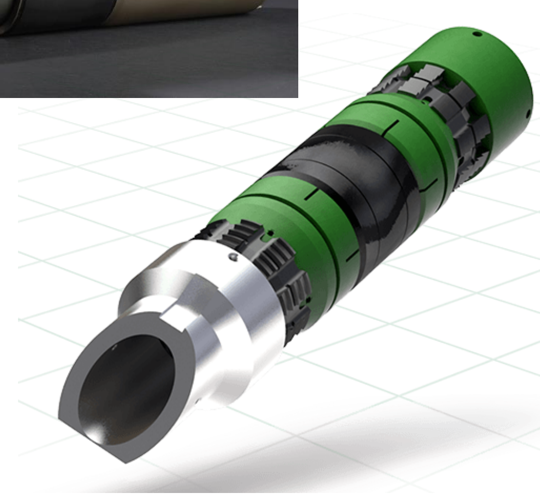
P’n’P; along with “zipper fracturing” reduced completion times significantly

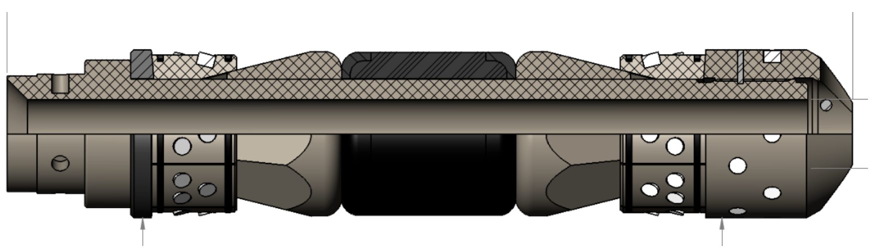
Zipper Fracturing

Challenge: Frac plug mill-out

Solutions:

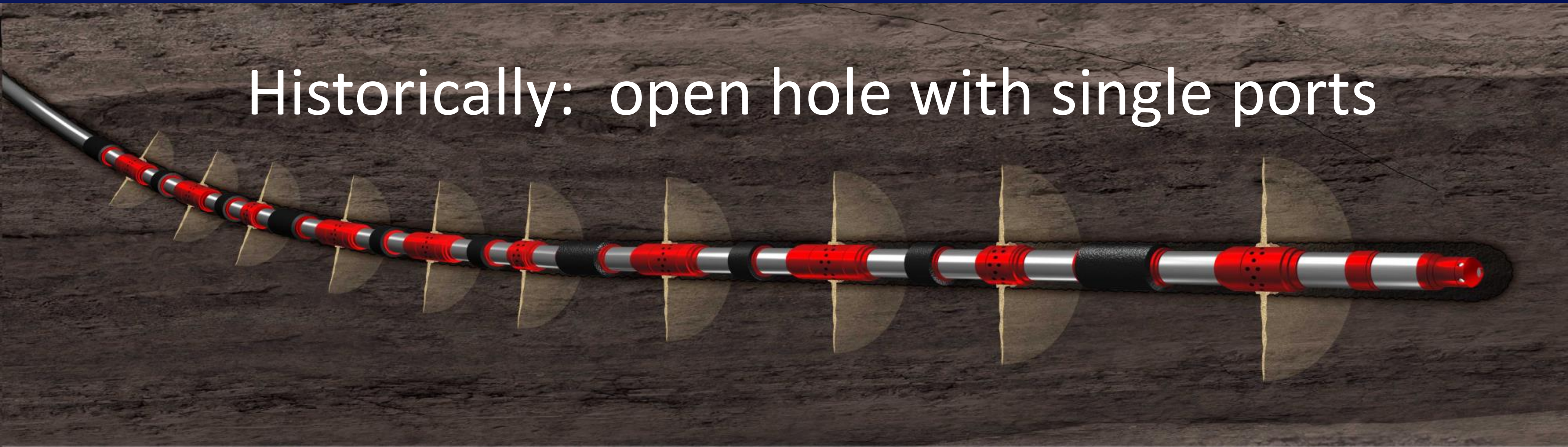
- Larger coiled tubing
- Large ID frac plugs
- Dissolvable frac plugs

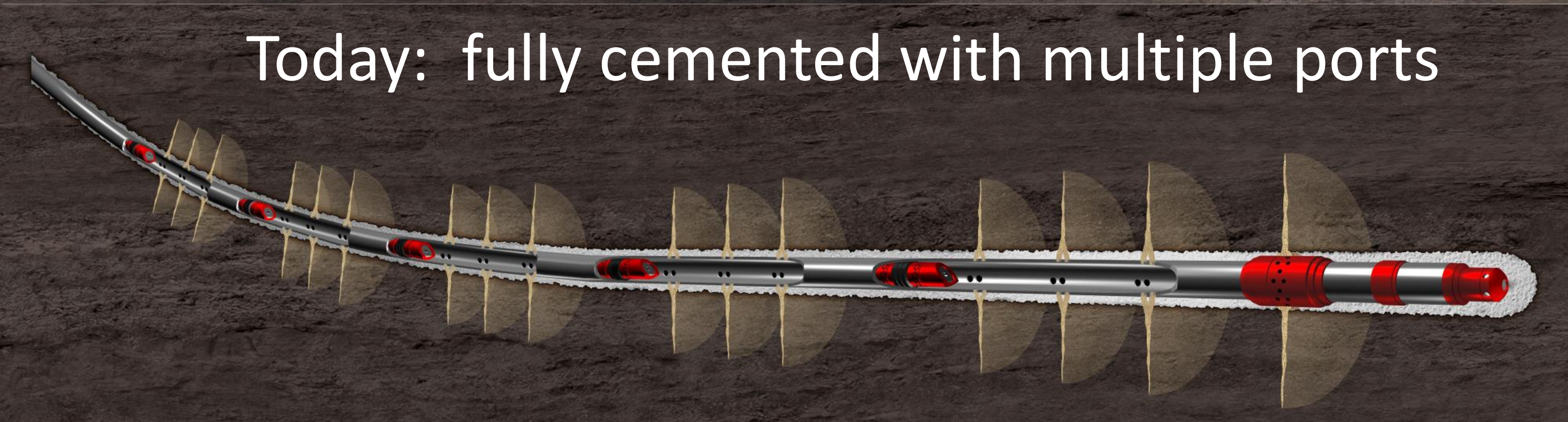




Images courtesy of Halliburton Energy Services, Baker Hughes, Magnum Tools, and Schlumberger

Ball and Sleeves Systems





Images courtesy of Halliburton Energy Services

Ball and Sleeves Systems

Maximum number of stages	Open Hole	Cemented
Single entry sleeve systems	50-55	35-40
Multi-port systems, 3-5 ports/stage	48-54	20-25

- Exact number of stages possible is dependent upon
  - Formation characteristics
  - Wellbore construction
  - Stimulation treatment parameters
- Balls are made of various materials
  - Generally in 1/8” size increments
  - Degradable balls are available

Images courtesy of Schlumberger

Coiled Tubing Fracturing

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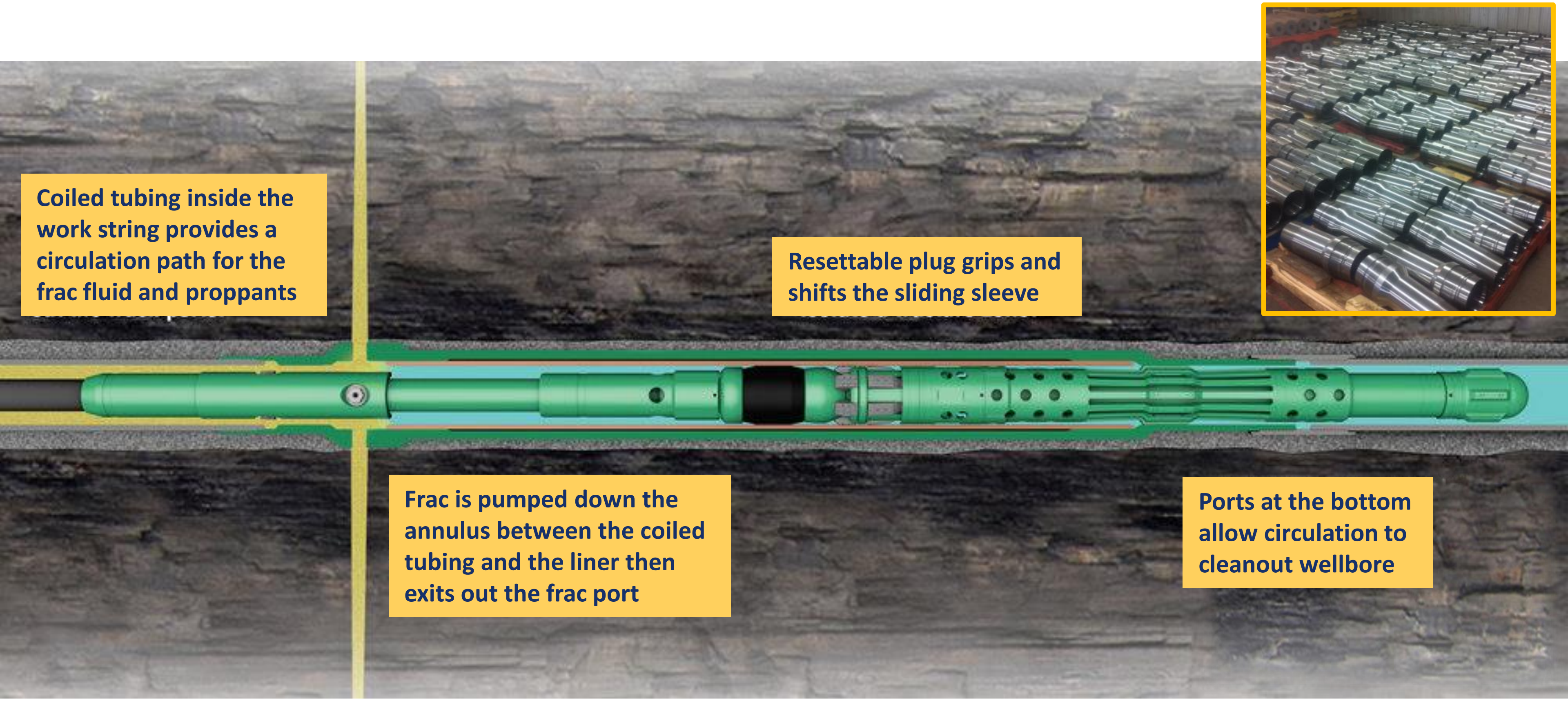
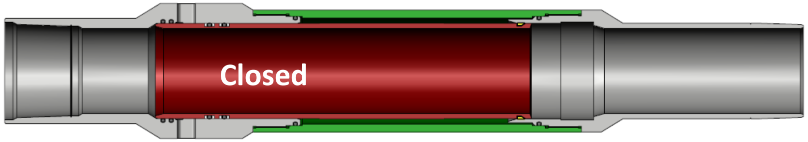
Sleeves are run in the liner, then shifted with coiled tubing during stimulation operations

Coiled Tubing Fracturing



Images courtesy of NCS Energy Services



Full circle in horizontal well completion technologies

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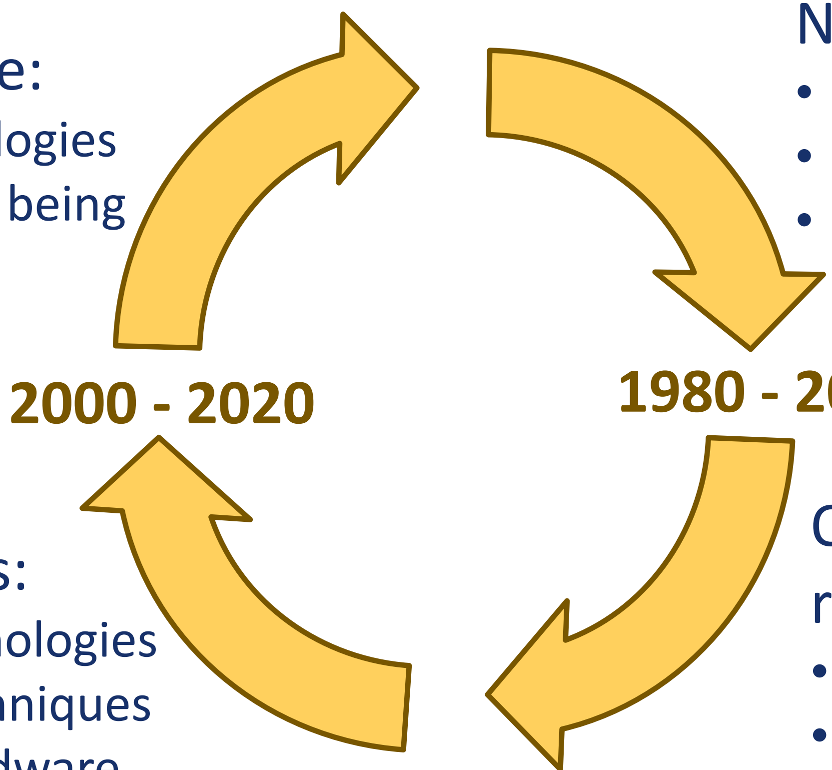
Today and Future:
Completion technologies developed onshore being applied offshore

North Sea:
- Directional drilling
- Extended reach wells
- Horizontal wells with multi-stage stimulations



Unconventionals:
- Fracturing technologies
- Completion techniques
- Completion hardware

Onshore conventional reservoirs:
- Tight gas
- Mature fields
- Horizontal wells
  - Austin Chalk, Texas
  - North Slope, Alaska

Inspiration credit: Martin Rylance, JPT, April 2015

Technology sharing

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- Collaborate
  - All disciplines: geosciences, drilling, completions, production
  - With service providers and other operators
- Accelerate learning curve
  - Learn from both successes and failures
  - Think outside the box when looking for analogs
- Be prepared
  - There will be a shortage of skilled people
  - Keep focus on being effective not just efficient

In conclusion:

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Does completion technology lag behind drilling technology?

- Drilling envelope is pushed first
- Completion technology is a fast follower

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