Shale Gas;
Wellbore Positioning Challenges

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ISCWSA, Copenhagen, 3/4/11

Shale Gas;
Wellbore Positioning Challenges

- Why is it important to us?
  - Emerging trend in drilling industry
  - Several familiar challenges in a new environment
  - Several unique challenges

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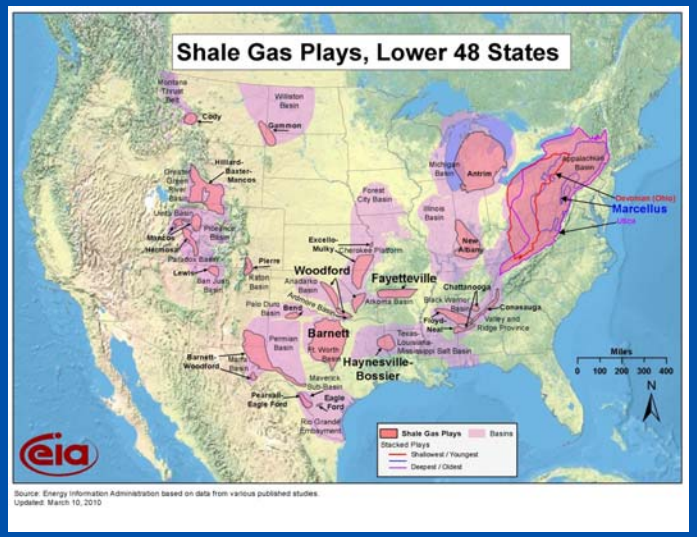
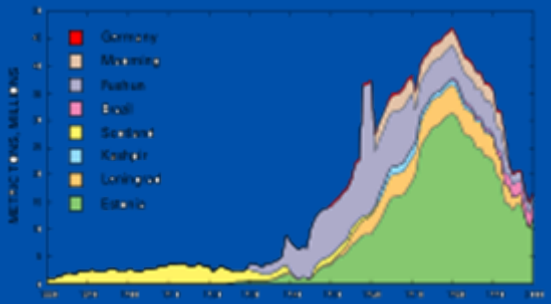
Market Place

- Shale Gas
  - 1821 shale gas well, Fredonia, NY predates Drake oil well by 38 years
  - Extensive basins US land
  - Over 100 rigs currently drilling in Marcellus shale
  - Significant drilling market share with smaller DD / MWD service providers





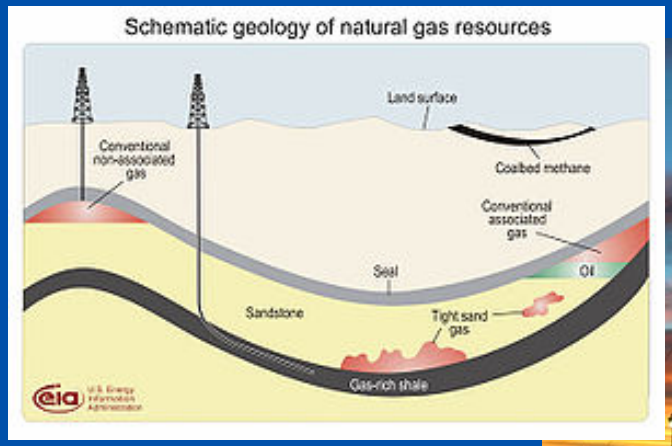
- Shale Oil
  - International
  - Considered “unconventional”
  - Emerging energy source

Market

- Shale Gas (USA)
  - 1996, 1.6% of US gas production
  - 2006, 5.9% of US gas production
  - 2007, 4185 shale gas wells drilled
  - Trends continuing upward
- Shale Gas (international)
  - November 2009 agreement between USA & China to share shale gas technology
  - November 2010 agreement between USA & India to share shale gas technology
  - Austria, Germany, Hungary, Poland assessing shale gas potential

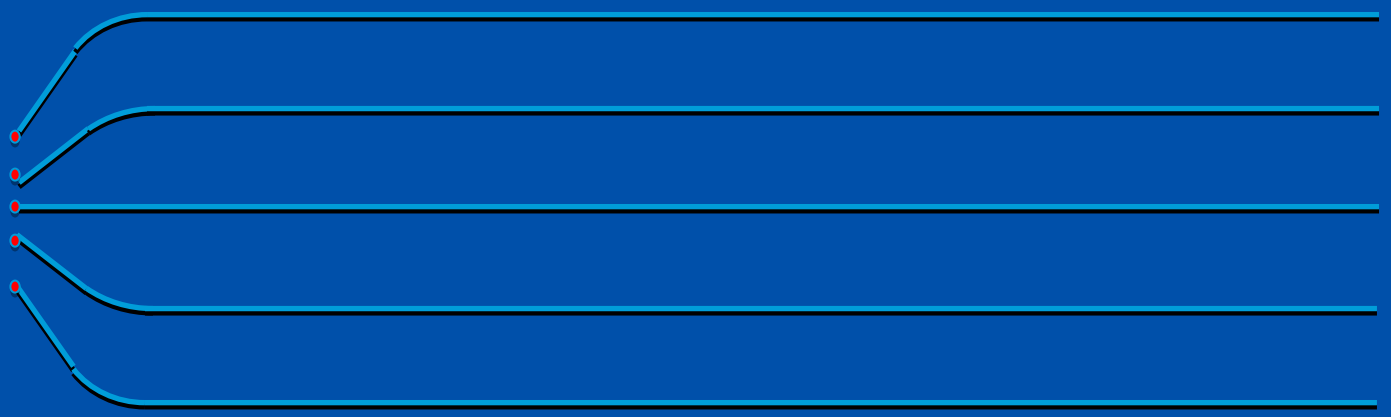
Current Well Design & Practices

- Drill vertically, build at medium radius then drill horizontal
- Hydraulically fracture rock to release gas
- Trend towards multi-well pads
- Parallel horizontal wellbores aligned with stress orientations
- Horizontal length may be determined by lease boundaries



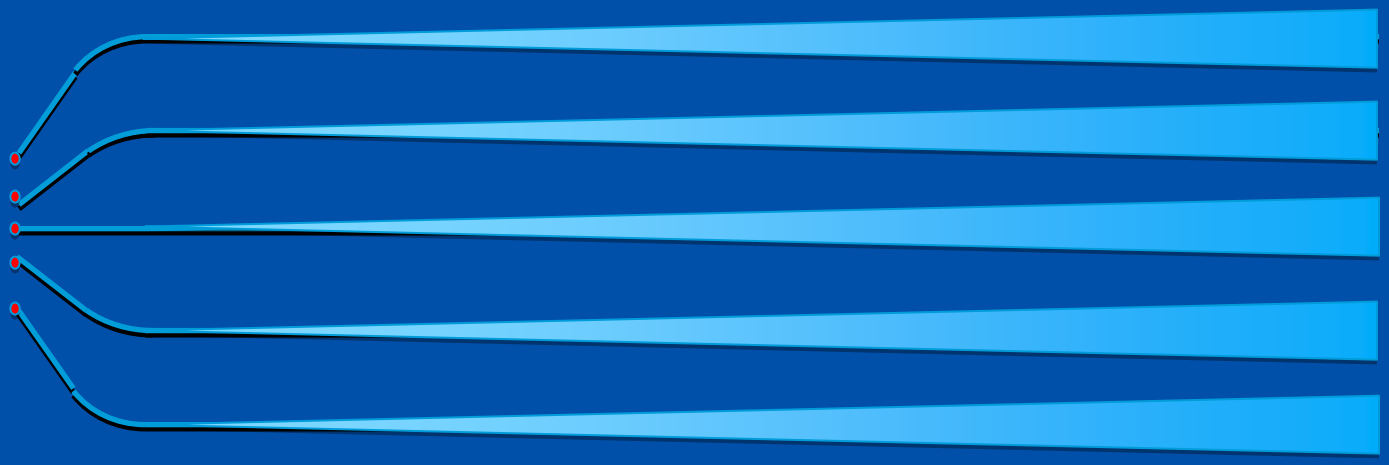
Typical shale gas well development

- Plan view



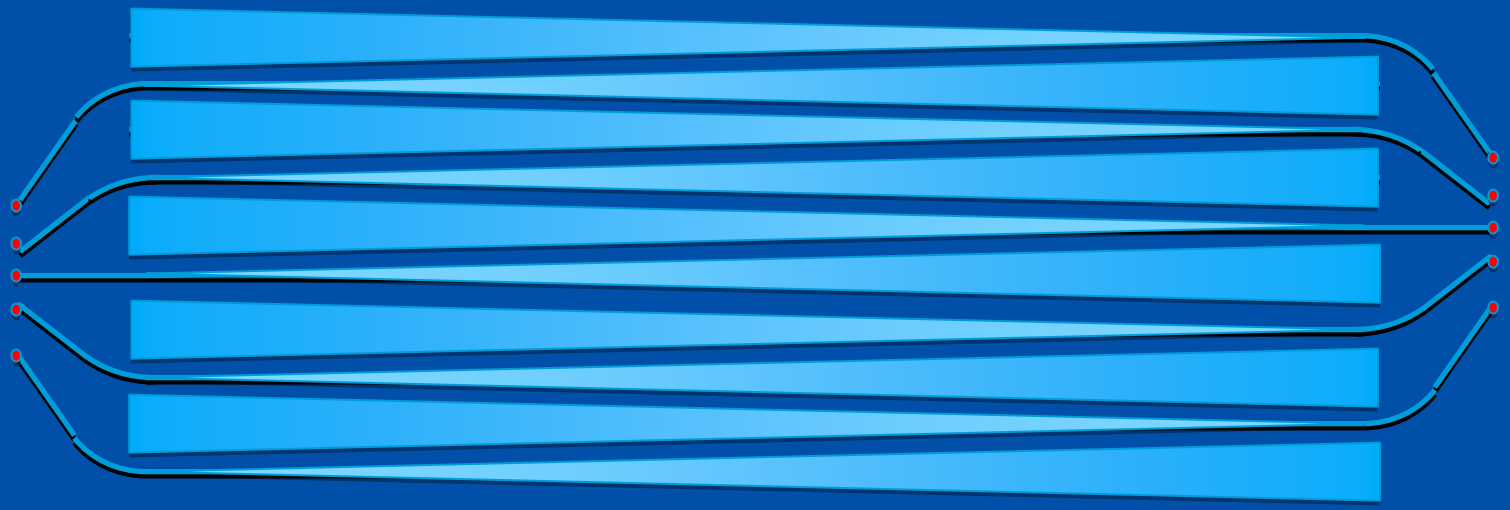
Typical shale gas well development

- Plan view showing positional uncertainty



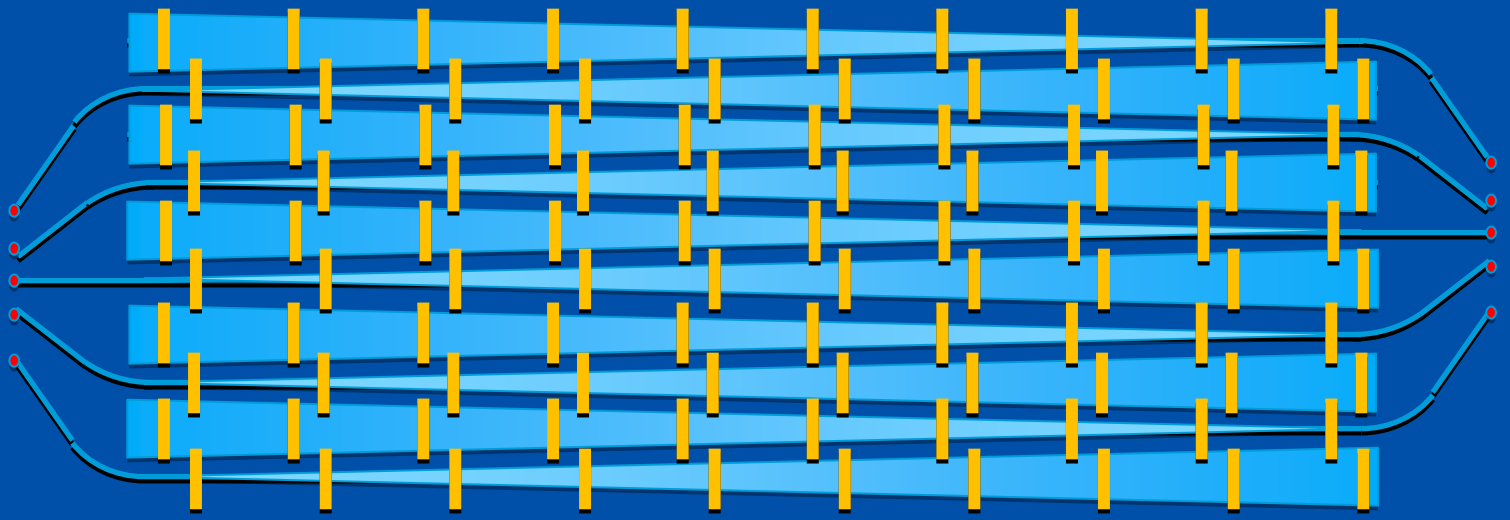
Typical shale gas well development

- Plan view showing positional uncertainty
- Horizontally opposed wells may facilitate shorter development timeline



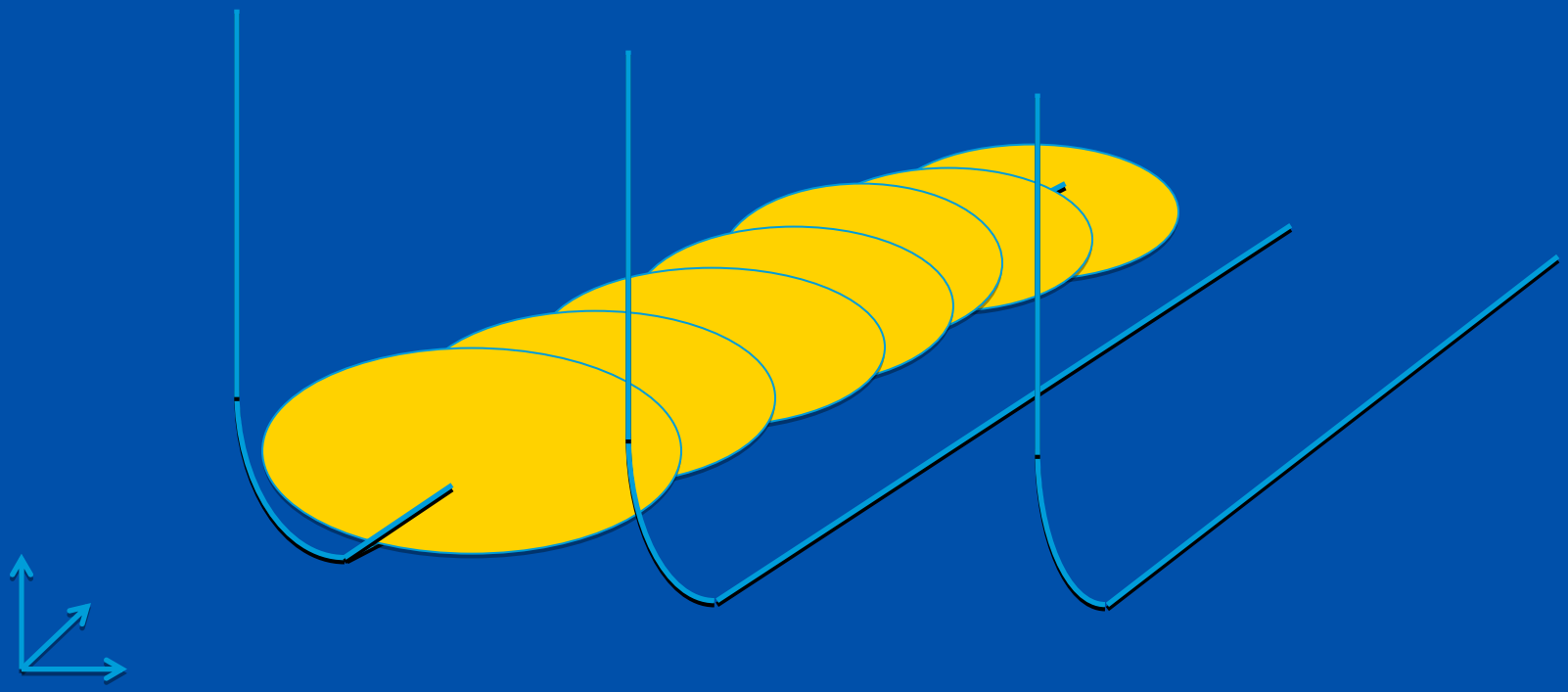
Typical shale gas well development

- Plan view showing positional uncertainty
- Horizontally opposed wells may facilitate shorter development timeline
- Frac's indicated by orange bars



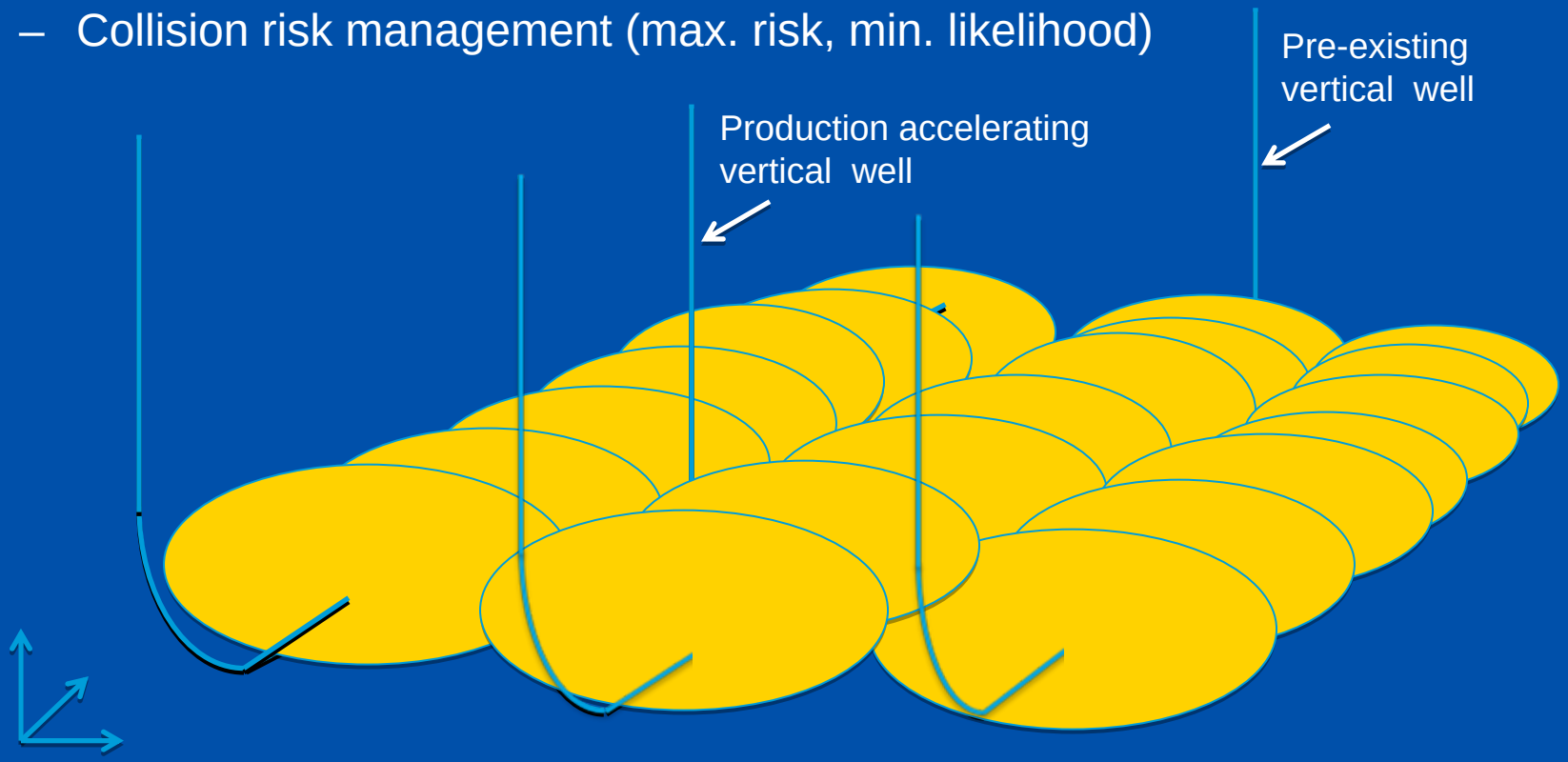
Frac

- Frac growth measured by microseismic
- Timing; investment, return on investment & scheduling



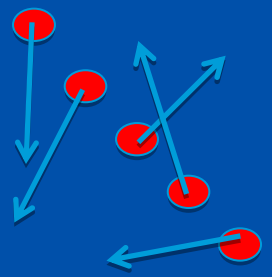
Frac

- Vertical's
  - Pre-development & frac "parasites"
  - Collision risk management (max. risk, min. likelihood)



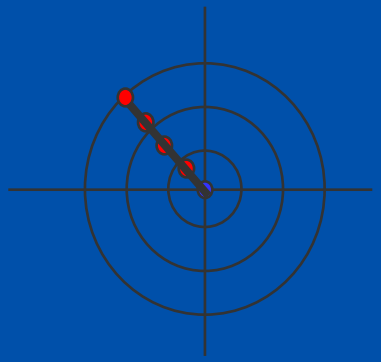
Multi-well pads

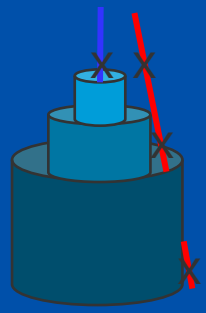
- Multi-well pads – environmental impact & cost
- Parallel wells in reservoir
  - Constant separation at optimal orientation (100's of ft based on frac propagation)
  - 3D well designs achieving separation from surface
  - Opposing pads
- "Air rig" drilling vertical portion
  - Multiple rigs on single well; depth offset
  - Generally run with inclination only surveys or single shots
- Surface positional uncertainty
  - Correct use for neighboring slots and opposing pattern
- Batch drilling
  - Potential for drilling next to live gas wells
- Best practice – manage slot to target allocation
- Best practice – implement well bore surveying & positional uncertainty standards
- Best practice – implement collision avoidance planning and monitoring standards



Collision Avoidance

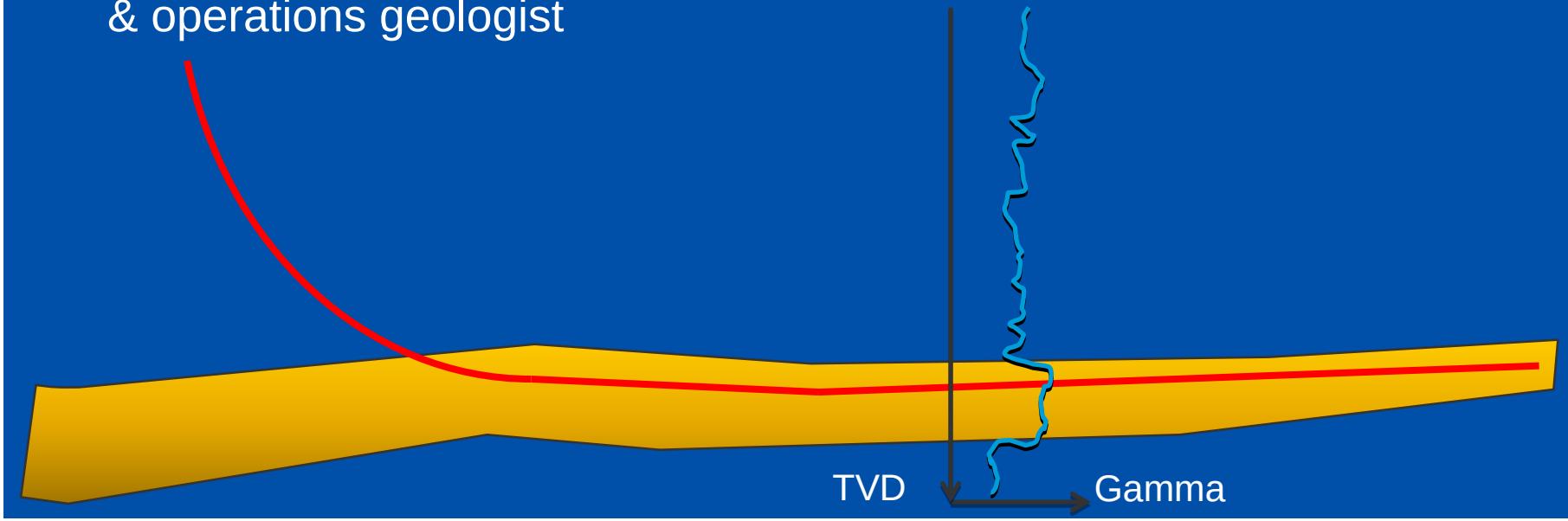
- Cultural issue
  - Shale gas drilling currently US land centric
  - US land market generalized by solo wells in relatively low pressure reservoirs
- Risk
  - Flowing gas wells accessing fractured reservoir
  - Intersection followed by lost circulation and kick
- Standards & interpretation
  - Calculation should be run consistently
  - Calculation should be easy to interpret
    - Simplified workflow for well construction production line
    - Visual rather than numerical answers
    - Real time, at site





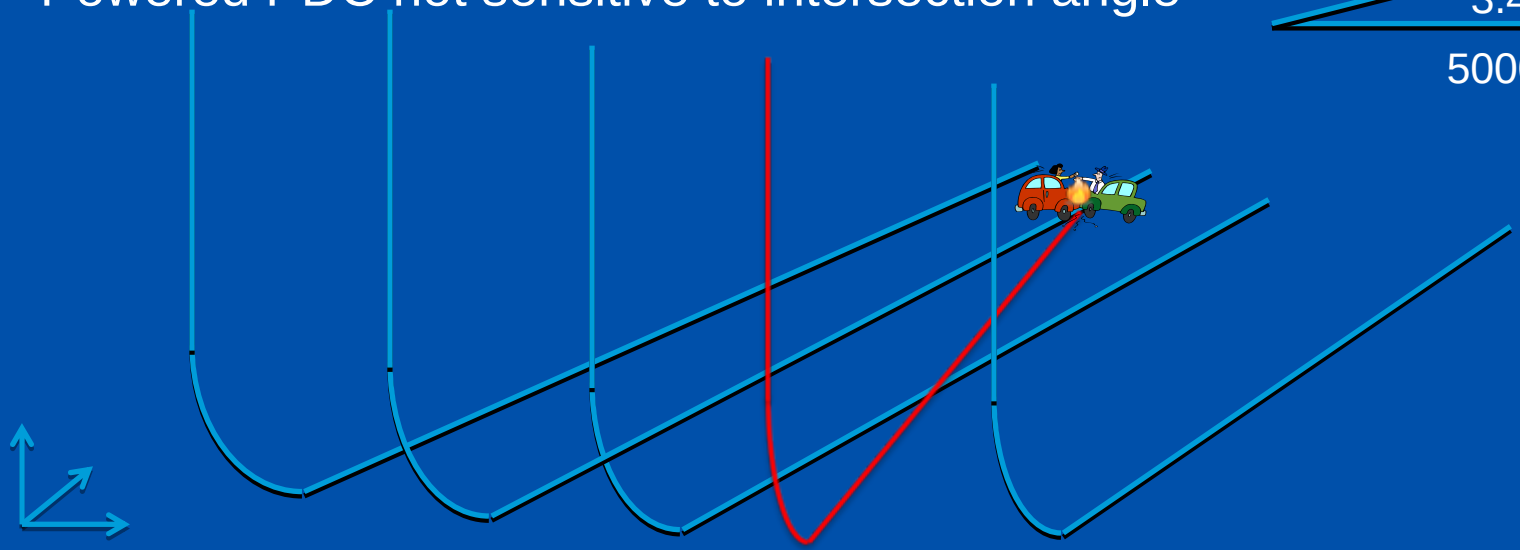
Drilling the Horizontal

- Omni-directional gamma steering / sonic for “Frac” index
- Bent motor or VGS causing “slide / rotate” patterns
  - Especially horizontal, curve tends to be high percentage steering
- Steering relative to geologic type log
- Success requires management of interface between directional driller & operations geologist



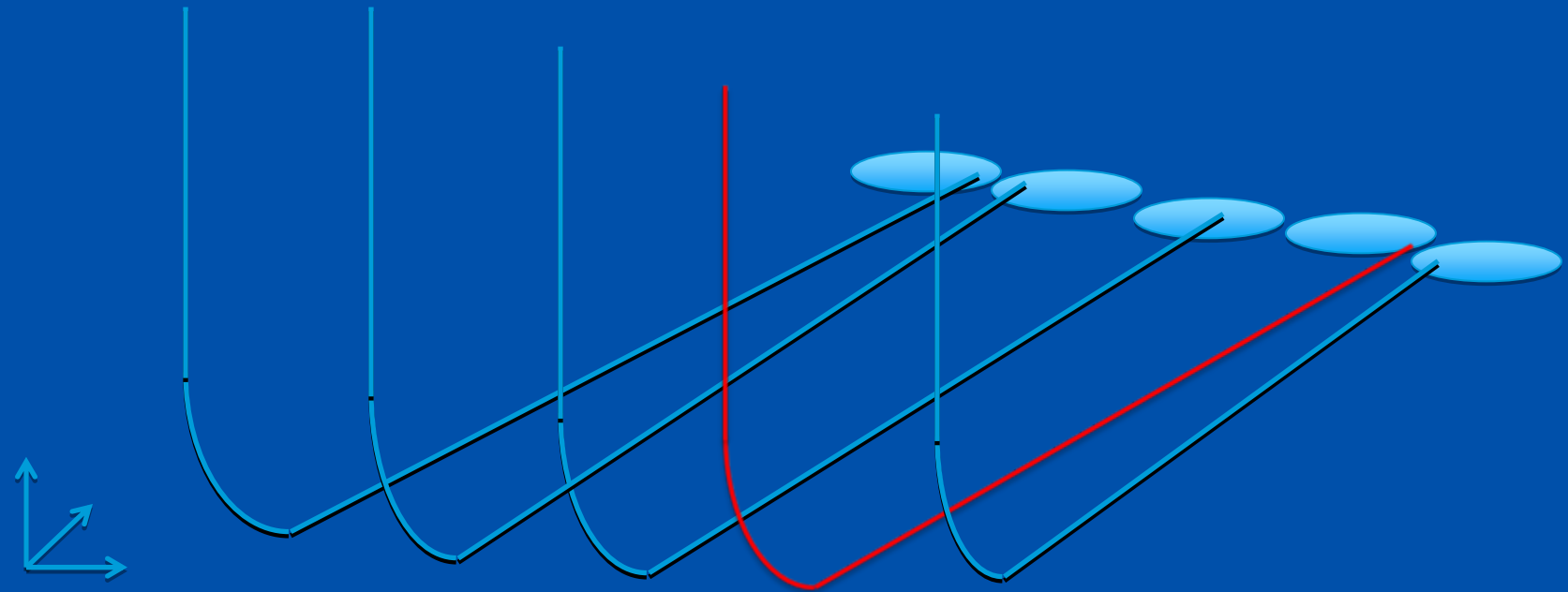
Well spacing

- Assumption; mis-application of Total Azimuth Correction (TAC) is one of the most common well-placement gross errors
- Assumption; constant separation distance and navigating for reservoir “sweet spot” (tvd)
- Risk; mis-application of TAC leading to well intersection
- Powered PDC not sensitive to intersection angle



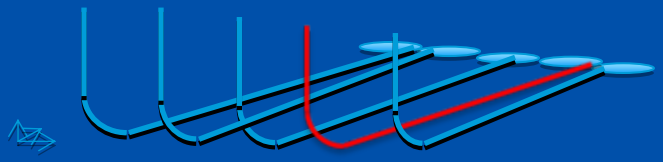
Well spacing

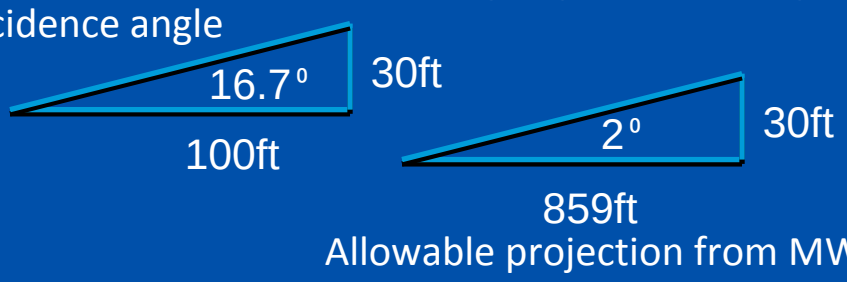
- Lateral uncertainty
  - Determinant of horizontal length
  - Determinant of frac efficiency
    - Potential to meet specification without meeting objective



Well spacing

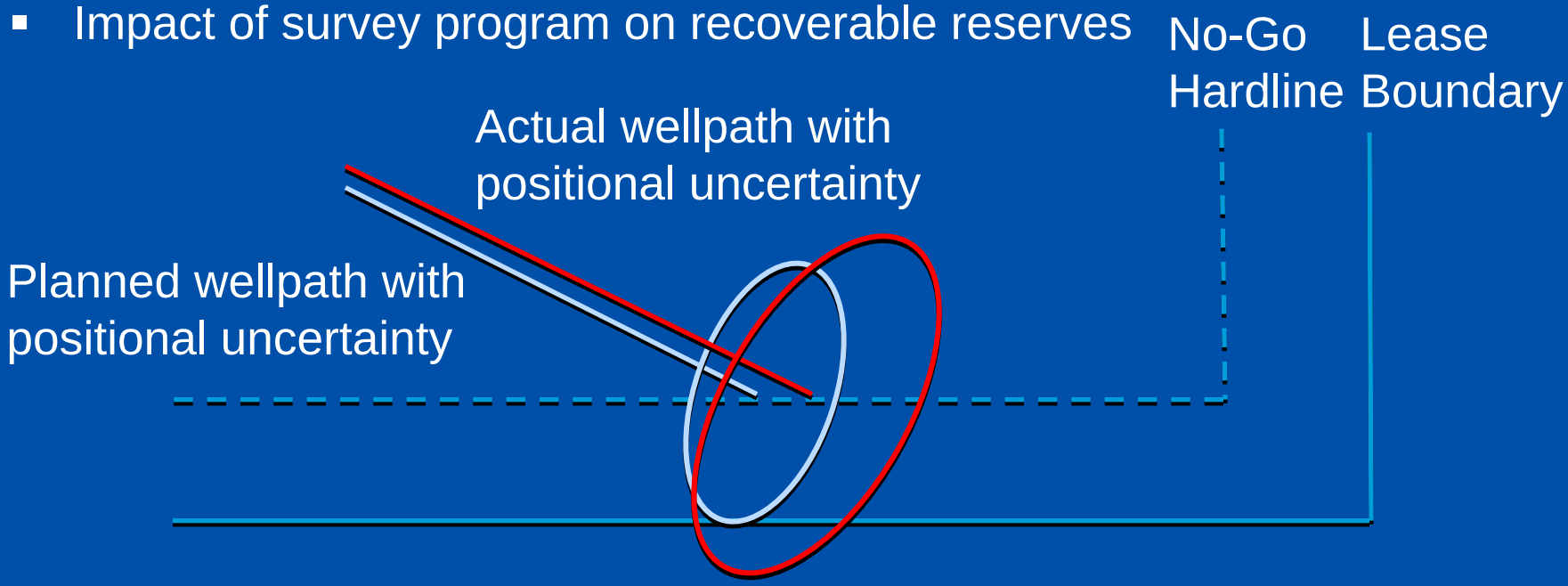
- Well design variables
  - Horizontal length, well separation, lateral uncertainty
- Well separation based on optimal placement / frac. efficiency
- Survey accuracy / lateral uncertainty likely to cause frac.-less volumes
- Systematic errors between wells should / could be excluded in calc.
- Horizontal length determinants
  - Lease boundary, drilling capability, production capacity
- Knowing wells are not ideally separated do we drill past the conventional acceptable collision risk rule while ranging to manage risk of intersection?





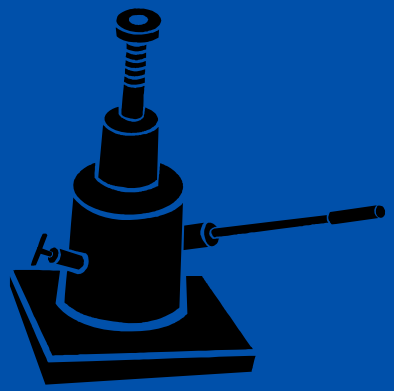
Lease Efficiency

- Hardlines and boundaries
  - Hardline may be based on nominal or planned positional uncertainty
  - Shape of lease
- Proximity to plane & plan
- Impact of survey program on recoverable reserves



Microseismic Well Spacing & Frac Monitoring

- Real time frac. monitoring
- Frac positioning modeling partly dependant on positional uncertainty of monitoring well
- Geophones on surface and / or in monitor well
  - Due to high frequency (~100-150Hz), 2000 – 2500 ft max spacing from monitor to treating well
- May need to plan monitor wells in order to optimize well spacing / frac program / horizontal length
  - Well design / development plan issue
  - Potential collision risk

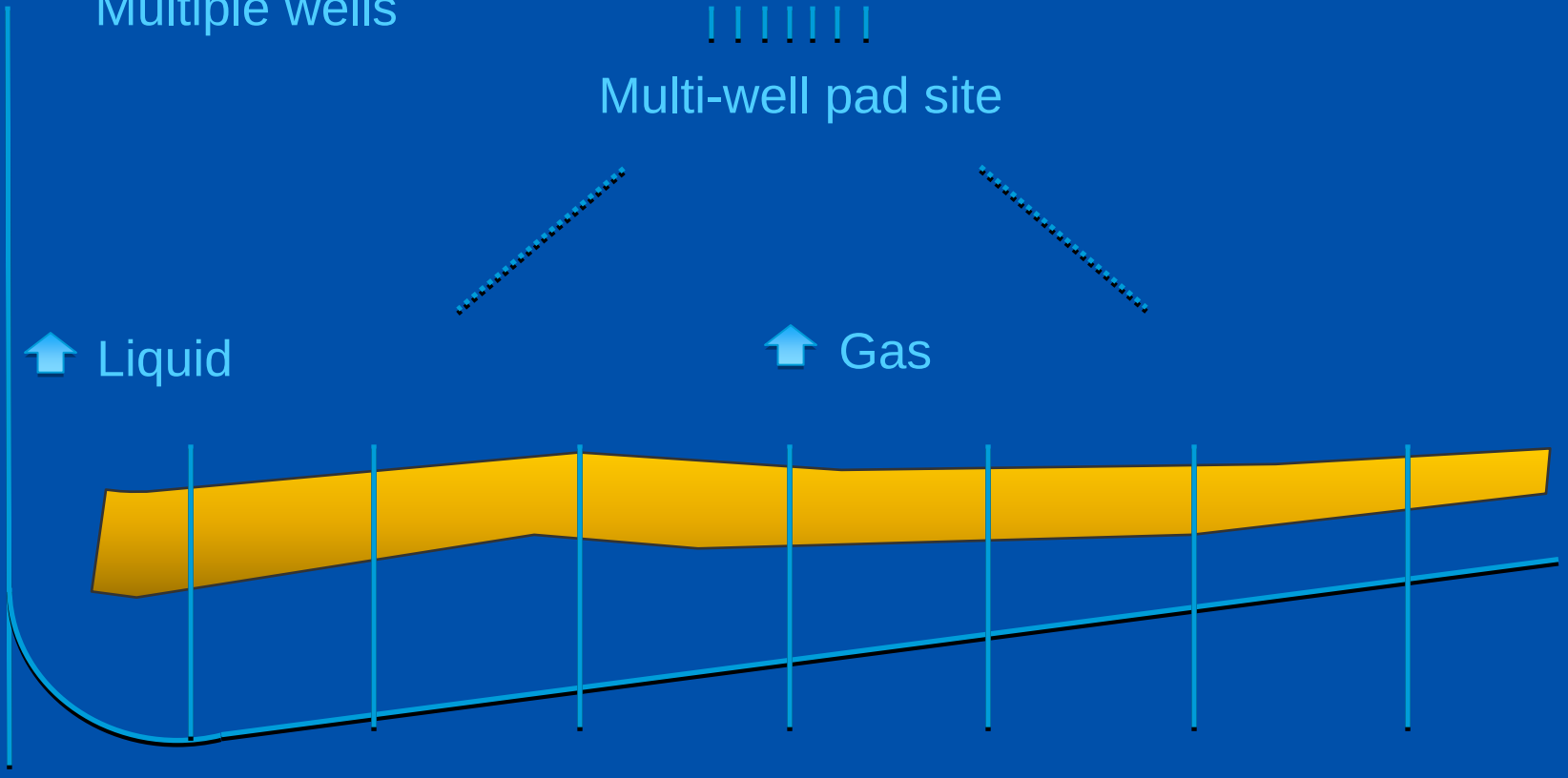


…and beyond

- Intended intersections with geometric challenges

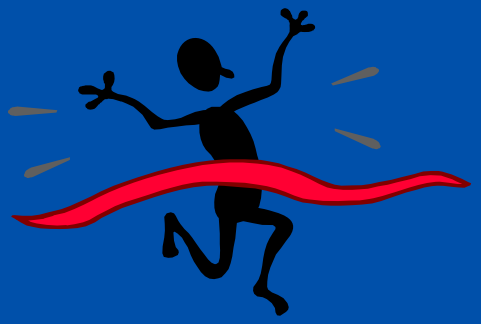
Single pump-jack
Multiple wells

Multi-well pad site



Conclusions

- Risk – collision
  - Gross error
  - System failure
  - Exempt offset & manage risk with ranging



- Positional uncertainty
  - Robust application of surface uncertainty
  - Clearance calculations should already take global systematic errors into account. Parallel wells need a similar approach to target analysis
- 3D well designs / collision avoidance in high volume environment
  - Take current best practice and refine workflow for efficiency – visual answers
  - Remote specialists aiding rigsite operations; knowledge management
  - Assess lease efficiency
- Technology & tools easy to transferred. Experience, less easy

- It's the well you don't know about that's likely to be the problem.