Frac Sand Frenzy

Focus on supply & demand for hydraulic fracturing sand

Mike O'Driscoll
Editor, Industrial Minerals

Silica Arabia 2012
Jeddah, 12-14 March 2012

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Oilfield Minerals Outlook

20-21 June 2012, Houston

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Frac sand • Barytes • Bentonite • Drilling fluids • Logistics • Processing

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FRAC SAND FORUM

Day 1

Oil & gas drilling outlook
Drilling minerals outlook
Drilling fluids demand
API specs reviewed
Barytes
Bentonite
Other minerals
Logistics
Processing

Day 2

FRAC SAND

Proppants overview
Significance of shale gas
Fracking issues
Frac sand overview
Frac sand producers
Frac sand projects
Chinese ceramic proppants
Other proppants

Confirmed Speakers

AM2F Energy
AMCOL
American Gilsonite
Anglo Pacific Minerals
Baker Hughes
Heemskirk Canada
IHS
Mark Zdunczyk
McLanahan Corp.
Miles Industrial Mineral Research
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Outline

1. What is frac sand & fracking?
2. Consumption
3. Market demand & developments
4. Conclusions & Outlook

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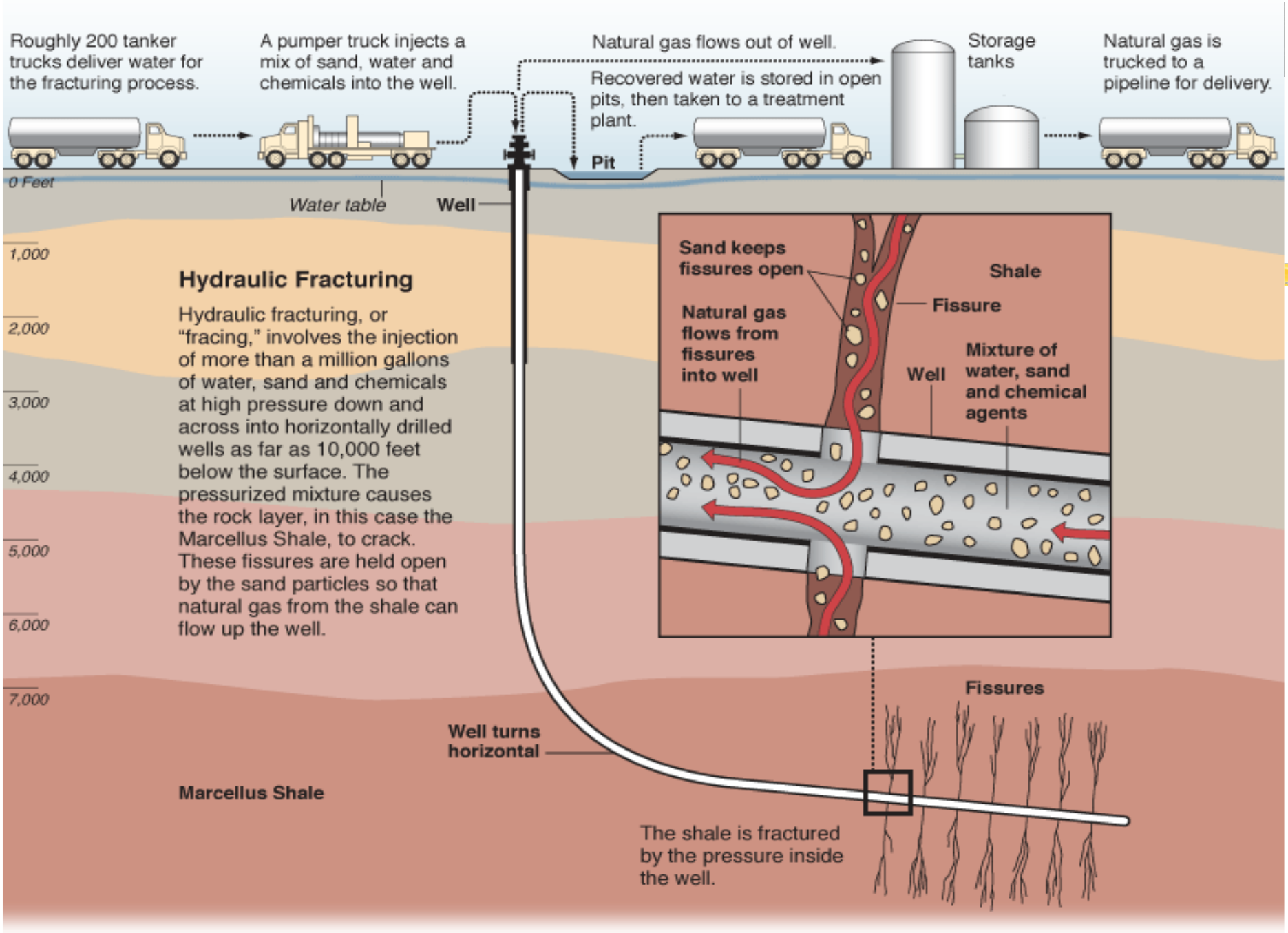
1. What is frac sand?

Hydraulic fracturing

- First used in USA in 1940s
- Fracking increases the flow of oil or gas from a well
  = well stimulation
- Fluids pumped down well under high pressure to fracture rock
- Creates network of interconnected fractures and pore spaces that enhance flow of oil and gas to well bore
- Used in approx. 90% of US wells
- Accounts for 30% of US recoverable oil and natural gas
- > 600 trillion cu ft of gas and 7bn bbl produced in US with fracking



Graphic by Al Granberg

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1. What is frac sand?

Hydraulic fracturing

- George Mitchell, "Father of shale gas" took 18 years to work through solution using fracking
- 1981: Mitchell Energy explored Barnett Shale, Texas
- Rock had pore space, but little permeability = commercially unviable
- Early 1990s used fracking (water only) to "link" pore spaces to ease flow

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1. What is frac sand?

Hydraulic fracturing

- **Problem: when pumps stopped, new pore spaces closed up**
- **Solution: add sand to fracking fluid, sand carried into fractures**
- **Water pressure drops, but sand particles prop open fractures – perfected by 1999**
- **Hence "*proppants*": small compression-resistant particles**
  - **natural: silica sand**
  - **synthetic: "ceramic" = sintered bauxite, kaolin, alumina**
  - **resin coated**

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1. What is frac sand?

Hydraulic fracturing

- **Mitchell Energy drilled <u>horizontally</u> through Barnett Shale**

- **Multiplied length of the pay zone in the well**
  eg. if unit was 100 ft thick = pay zone of 100 ft in a vertical well

If well steered horizontal and for 5,000 ft through target formation = pay zone was fifty times longer!

Fracking with proppants + horizontal drilling = successful exploitation

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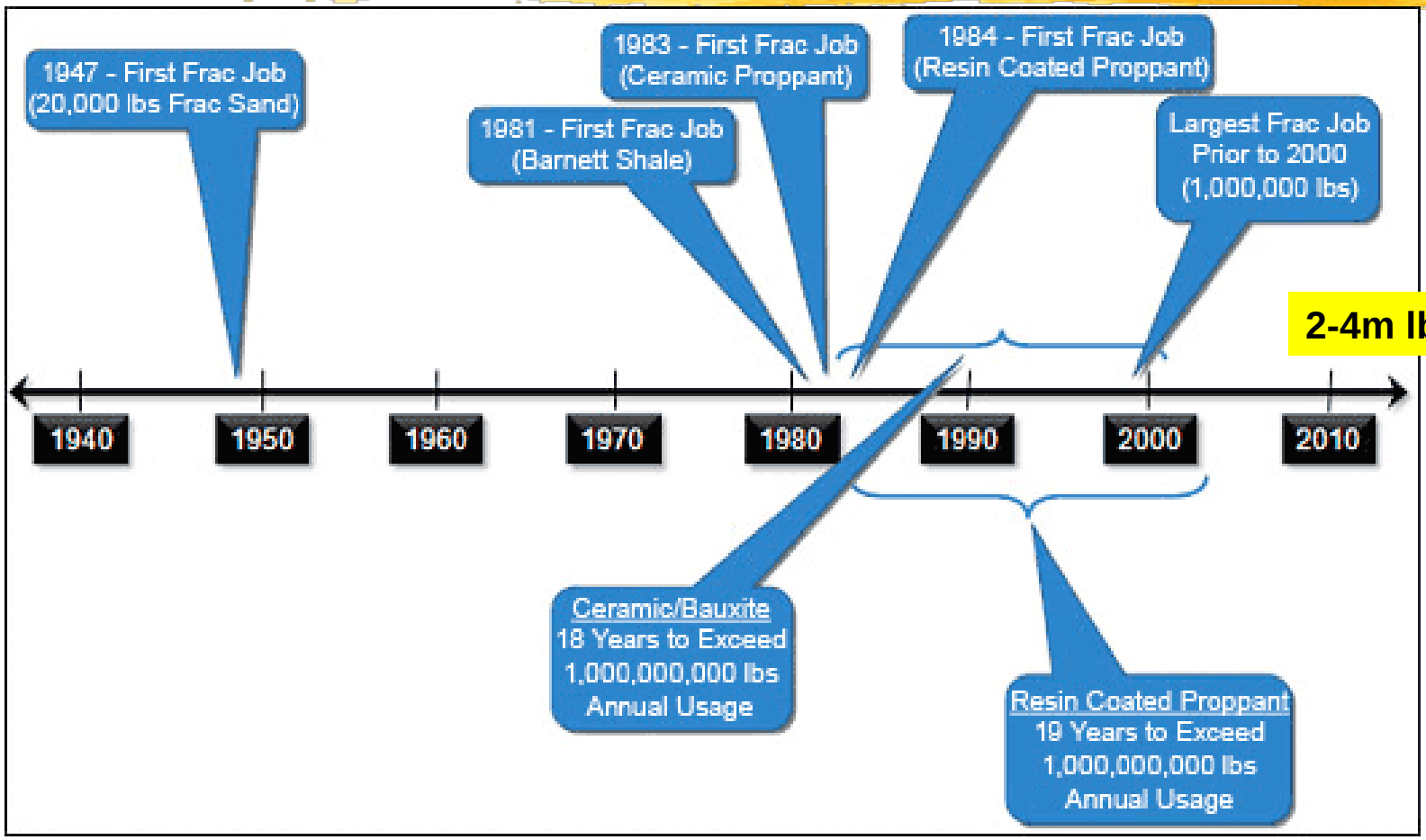
1. What is frac sand?

Proppant evolution timeline



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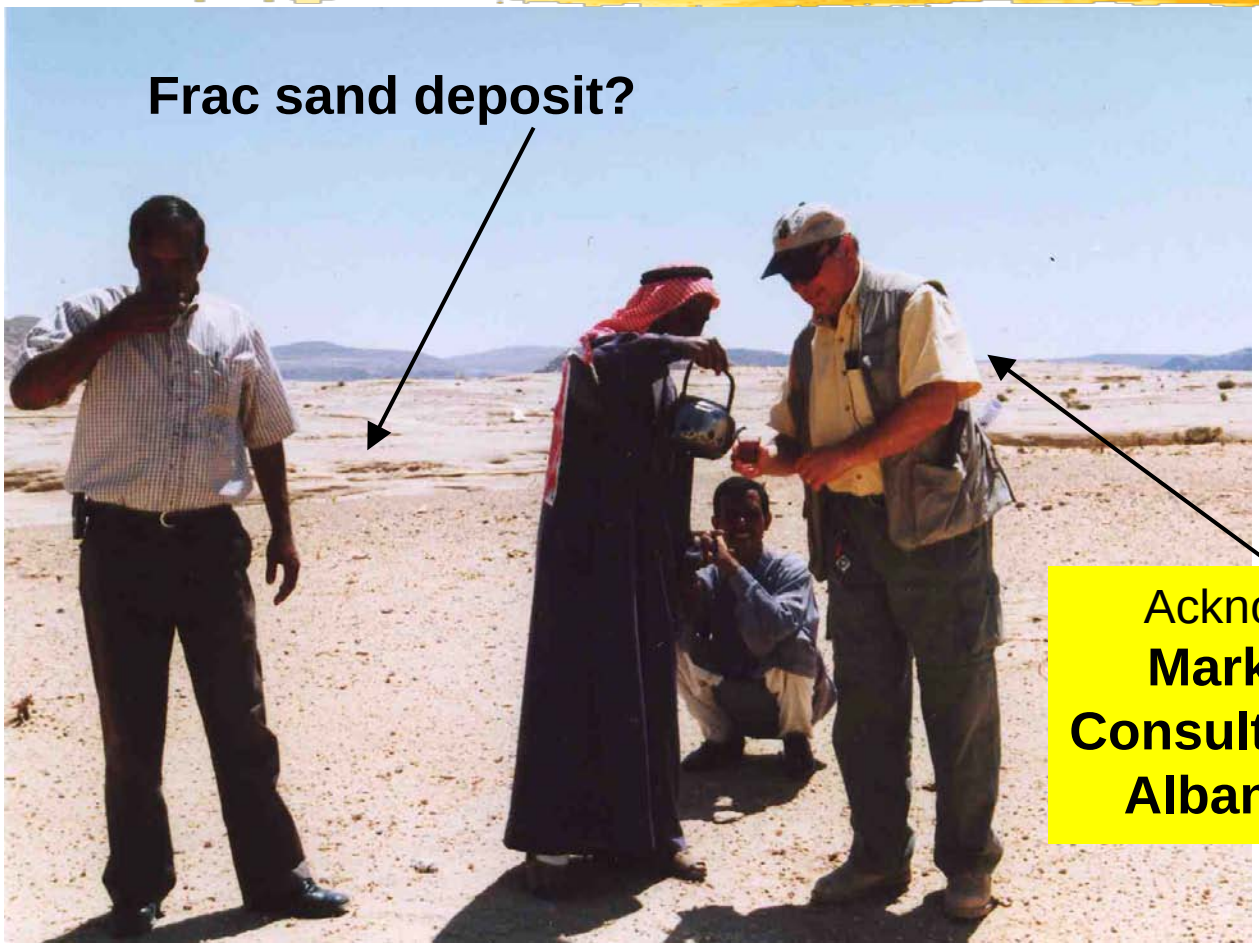
1. What is frac sand?

Frac sand properties



Acknowledgement
Mark Zdunczyk
Consulting Geologist
Albany New York

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1. What is frac sand?

Frac sand properties

- Conductivity of "proppant pack" has direct effect on deliverability of fluids to wellbore
- Good conductivity is the primary goal
- Conductivity = permeability of proppant pack x propped width
- Since conductivity is heavily influenced by propped width which can be only estimated after treatment, most engineers use actual proppant permeability to choose between proppants.

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1. What is frac sand?

Frac sand API specifications

American Petroleum Institute

API RP 56

- **Quartz (SiO_2)%**
- **Size fraction**
- **Roundness & sphericity**
- **Crush resistance**
- **Acid solubility**
- **Turbidity**

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1. What is frac sand?

Frac sand API specifications

Quartz composition
API 99+% SiO_2

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1. What is frac sand?

Frac sand API specifications

Size fractions

Sieve Opening Sizes (micrometers)	3350/ 1700	2360/ 1180	1700/ 850	1180/ 600	850/ 425	600/ 300	425/ 212	212/ 106
Frac Sand Size Designations	b 6/12	b 8/16	a 12/20	b 16/30	a 20/40	b 30/50	a 40/70	b 70/140

90% to fall within range

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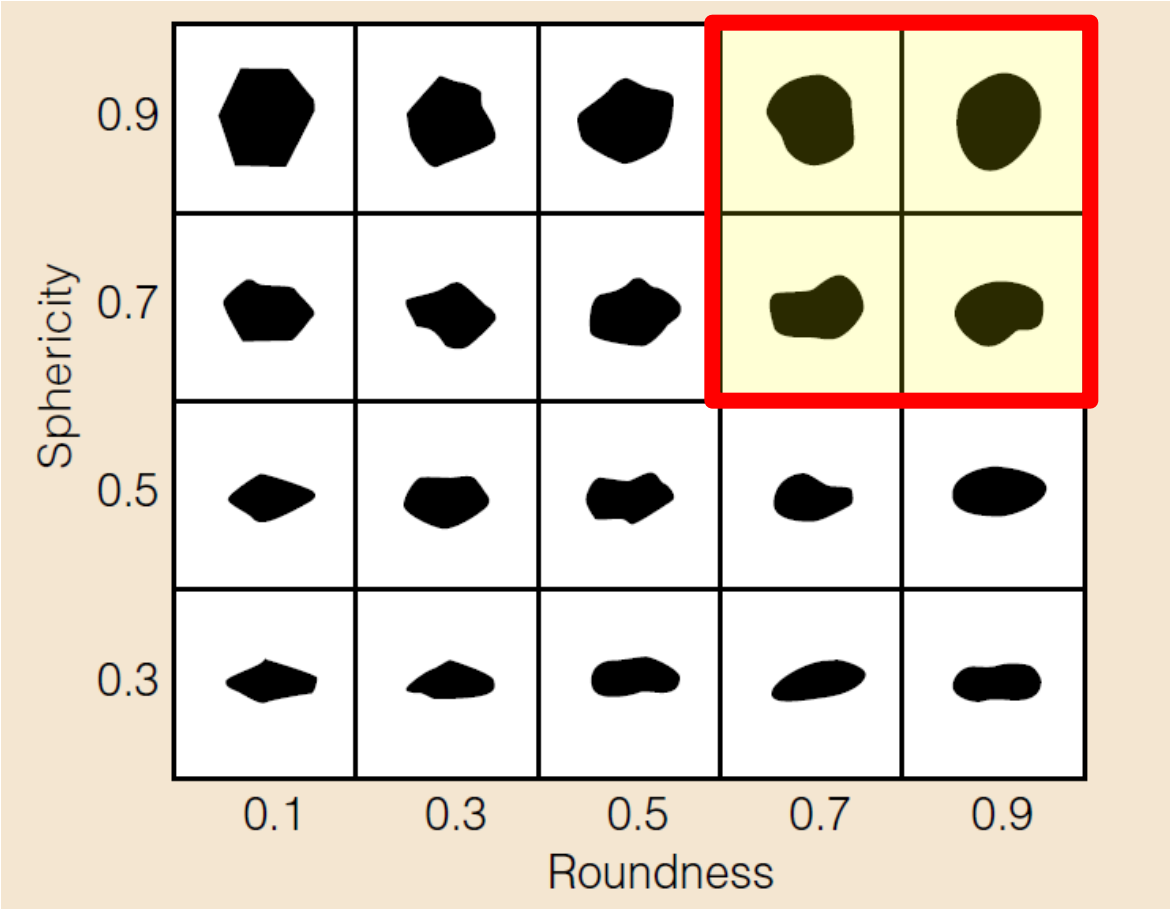
Frac sand API specifications

Roundness & Sphericity



API
≥ 0.6

Source: redrawn from
Krumbein & Sloss 1955

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1. What is frac sand?

Frac sand API specifications

- **Crush resistance - high:**
  withstand compressive stresses of 4,000-6,000 psi
  max. fines wt.%: 14% for 20-40, 16-30 mesh
  10% 30-50 mesh
  6% 70-40 mesh
  20% 6-12 mesh

- **Acid solubility - low:**
  – solubles (CO_3, fsp) usually washed out in processing
  in wt. % <2% 6-12 to 30-50 mesh
  <3% 40-70 to 70-140 mesh

- **Turbidity:**
  amount of silt-clay size minerals in sand
  – usually washed out in processing

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1. What is frac sand?

Resin coated frac sand

- Resin-coated frac sand provides significantly higher production
- Strong, highly conductive proppant and provides sand control in fracking
- Increased resistance to crushing prevents loss of permeability in fractures

Resin coated 40/70

Source: Momentive

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1. What is frac sand?

US frac sand deposits

- Geologically older sandstones, supermature, ie. Cambrian-Ordovician 495Ma
- Sand grains endured extensive fluvial and eolian reworking cycles = high roundness
- Unconsolidated quartzose sands, and deformed, folded formations generally cannot meet API spec
- Young formations, grains not sufficiently reworked
- Cloudy, crusted grains indicate internal fractures = brittleness
- Limited success relating size distribution to depositional environment
- Difficult to predict grain size changes in a deposit

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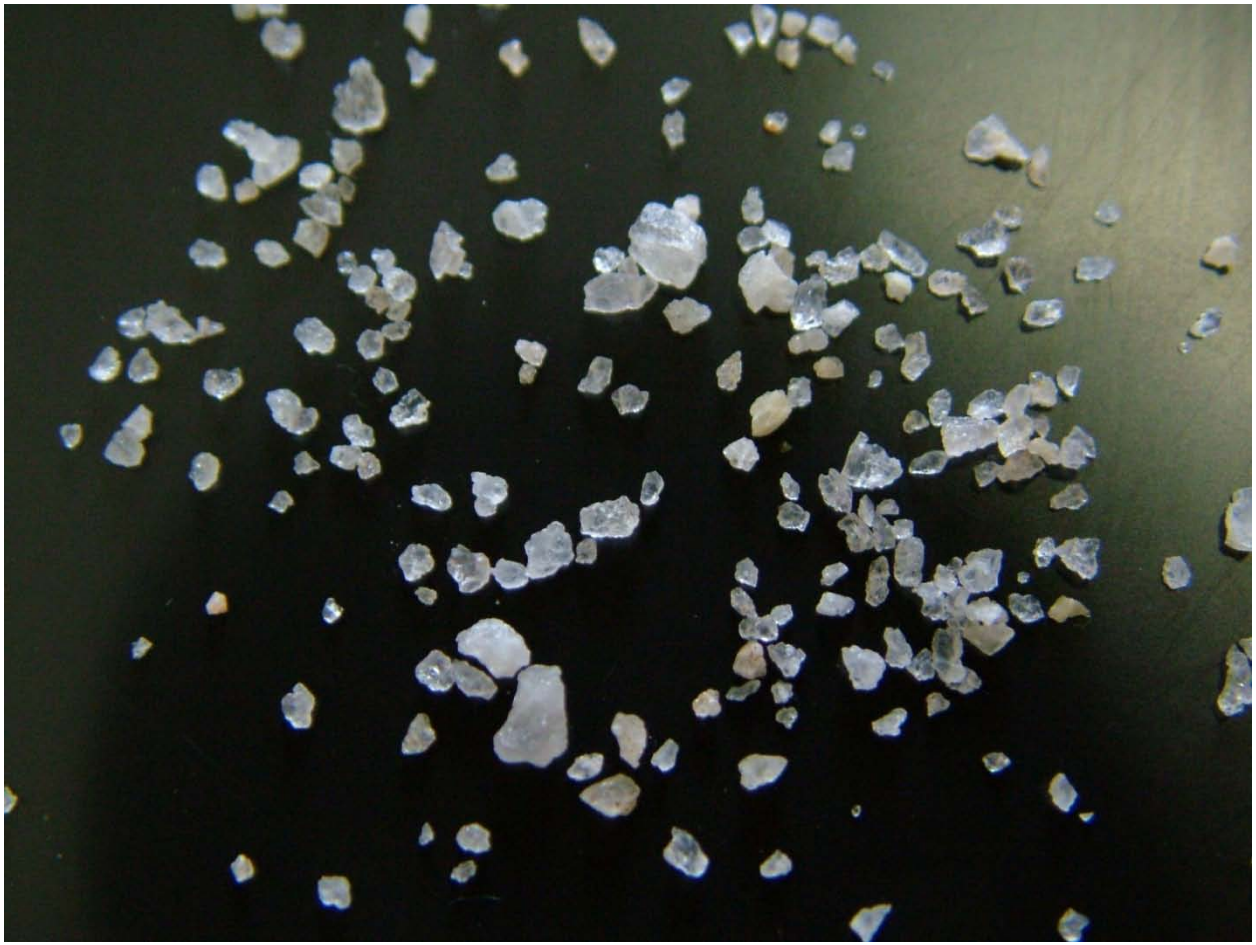

Showing typical angular grains of Cretaceous-Miocene, east coast USA - will not meet spec.

Source: Mark Zdunczyk

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1. What is frac sand?

Showing typical rounded grain quartzose St Peter sand, meets API specifications for sphericity and roundness

Source: Mark Zdunczyk

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1. What is frac sand?

Key US frac sand deposits

Cambrian-Ordovician sandstone formations

- **St Peter (Ottawa): MN, MS, IL, NE, SD, WI**
- **Hickory (Brady): TX**

- Jordan: MN, WI
- Wonowoc: WI
- Mt Simon: IL, MN, OH, WI
- Riley: TX
- Old Creek: OK
- Bidahochi: AZ

- river deposits
- inter-coastal plain deposits
- dune deposits

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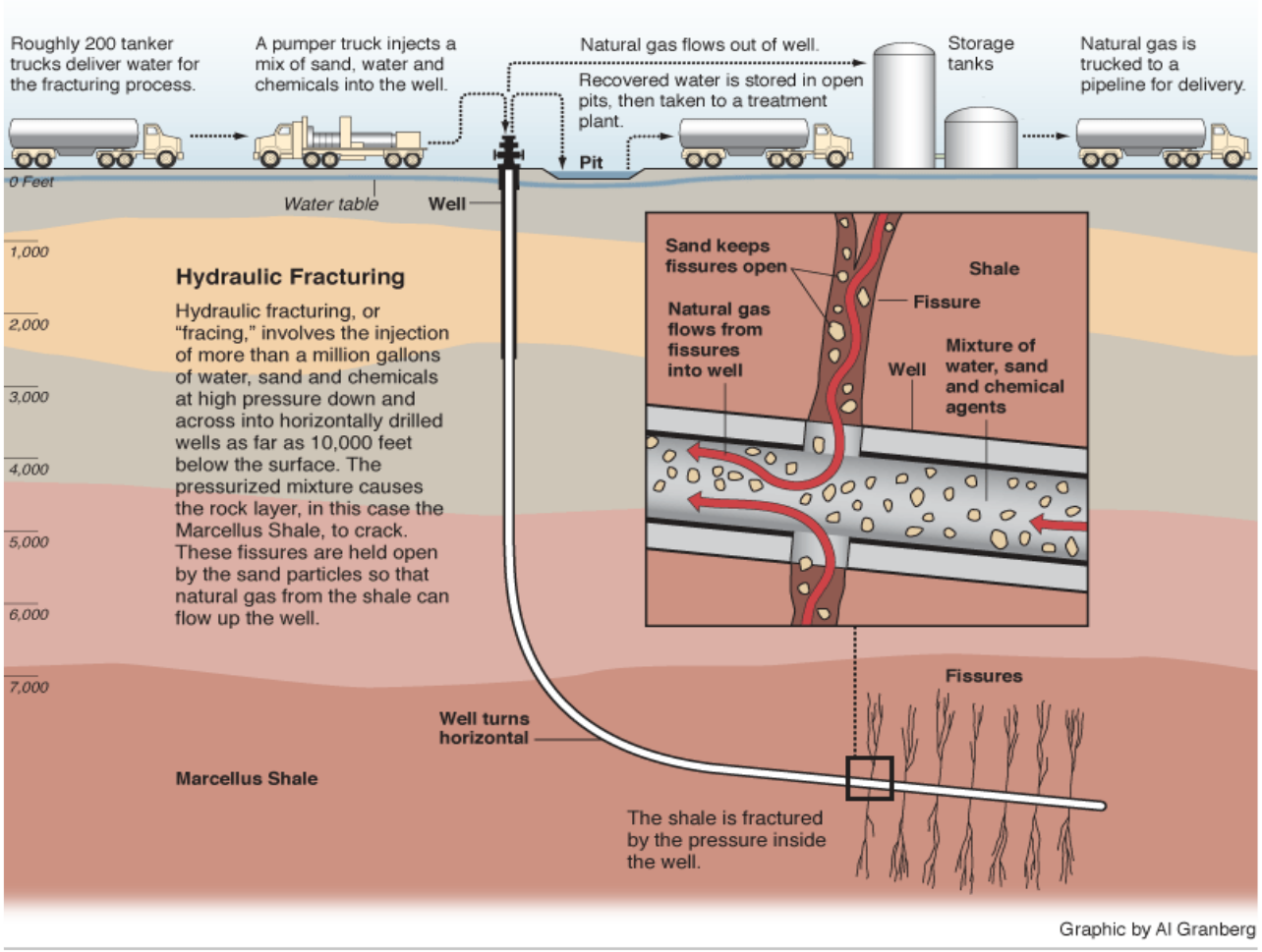
2. Consumption

Hydraulic fracturing



- **Plugs inserted to isolate well section**

<u>Avg. consumption</u>

- **1-2m lbs FS/well**
  2-3,000 s.tons
  1.8-2.7k tonnes
- **97-99% water**
- **3% sand/additives**
- **4-5m gal water**
  15-19m litres

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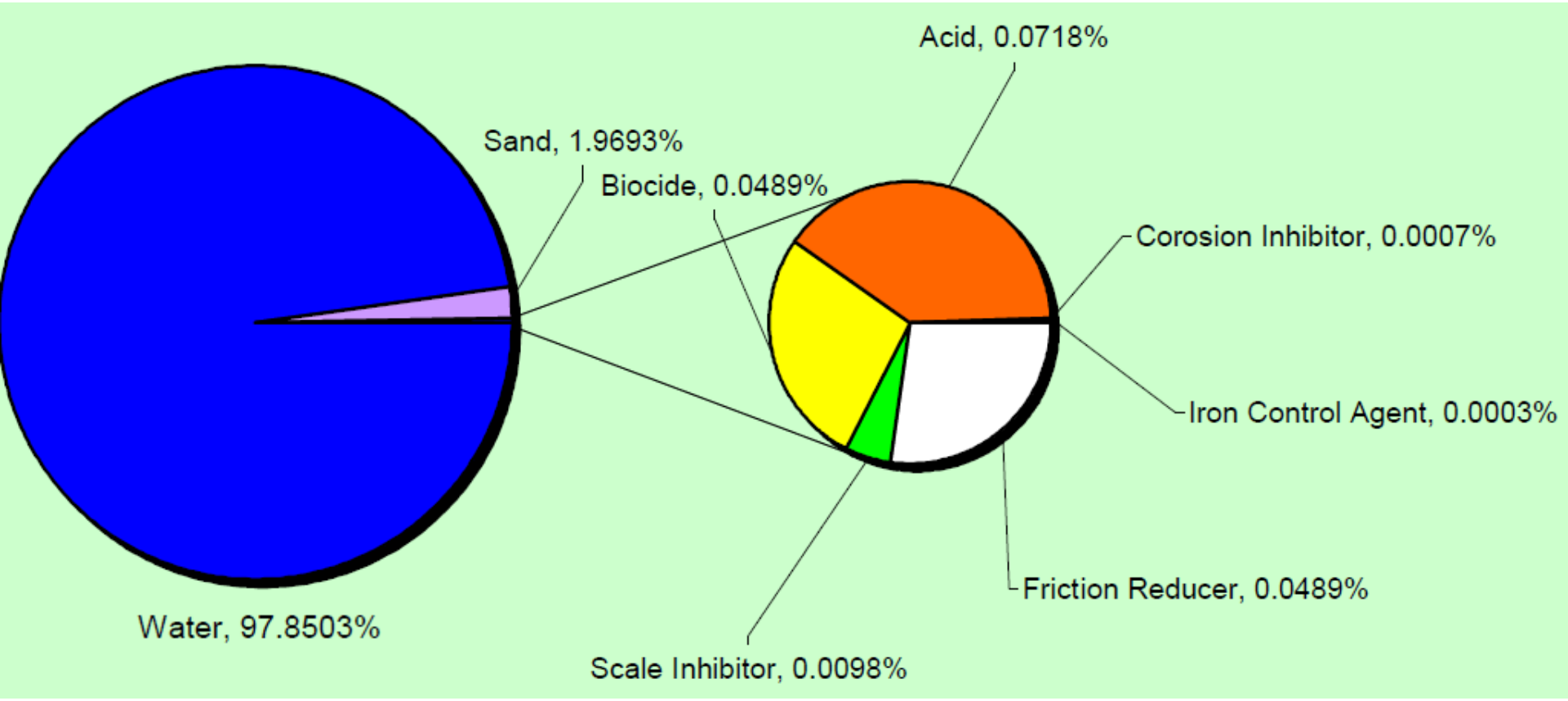

Source: Talisman Energy

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2. Consumption

Fracking fluids – key components

Typical Hydraulic Fractured Well

Product Type	Purpose	Approximate Concentration/Amount Used on a typical well	Typical Volume Per Well, liters	Overall %
Water	Creates a fracture network and carries sand to fractures	15,000 m^3	15,000,000	97.85%
Sand	When the pressure is released the sand placed will hold the fracture open	800 tonnes	301,887	1.97%
Friction Reducer	Reduces friction between the fluid and the pipe	1 liter of Friction Reducer per 2000 liters of water pumped	7,500	0.05%
Scale Inhibitor	Mitigates scale formation on tubulars and perforations	1 liter of Scale Inhibitor per 10000 liters of water pumped	1,500	0.01%
Biocide	Eliminates bacteria in carrier fluid	1 liter of Biocide per 2000 liters of water pumped	7,500	0.05%
Acid	Dissolves cement and material near the wellbore to provide pumping pressure relief	11 m^3 at 7.5% concentration	11,000	0.07%
Iron Control Agent	Prevents precipitation of metal oxides	40 liters	40	0.00%
Corosion Inhibitor	Prevents the corrosion of the pipe	110 liters	110	0.00%

Source: Talisman Energy

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2. Consumption

Fracking fluids – typical components

Water (Includes Mix Water Supplied by Client)	-	-	89.60915%
Crystalline silica	14808-60-7	94.59684%	9.82941%
Hydrochloric Acid	7647-01-0	0.60824%	0.06320%
Distillates (petroleum), hydrotreated lig	64742-47-8	0.41782%	0.04341%
Alcohol ethoxylate C-10/16 with 6.5 EO	68002-97-1	0.05223%	0.00543%
Methanol	67-56-1	0.03300%	0.00343%
Ethane-1,2-diol	107-21-1	0.02846%	0.00296%
Organic Phosphonate	Proprietary	0.02212%	0.00230%
Sodium salt of aliphatic amine acid	Proprietary	0.02156%	0.00224%
Diatomaceous earth, calcined	91053-39-3	0.02050%	0.00213%
Fatty acid amidoalkyl betaine	Proprietary	0.01766%	0.00184%
Propan-2-ol	67-63-0	0.00897%	0.00093%
Aliphatic acids	Proprietary	0.00617%	0.00064%
Aliphatic alcohols, ethoxylated #1	Proprietary	0.00617%	0.00064%
Calcium chloride	10043-52-4	0.00474%	0.00049%
Sodium chloride	7647-14-5	0.00474%	0.00049%
5-chloro-2-methyl-4-isothiazolin-3-one	26172-55-4	0.00342%	0.00035%
Magnesium nitrate	10377-60-3	0.00342%	0.00035%
Prop-2-yn-1-ol	107-19-7	0.00206%	0.00021%
Calcium carbonate	471-34-1	0.00205%	0.00021%
Ethoxylated alcohols	Proprietary	0.00199%	0.00021%
Ethoxylated alcohols #2	Proprietary	0.00199%	0.00021%
Synthetic organic polymer	Proprietary	0.00193%	0.00020%
Sodium hydroxide (impurity)	1310-73-2	0.00180%	0.00019%
2-Methyl-4-isothiazolin-3-one	2682-20-4	0.00171%	0.00018%
Magnesium chloride	7786-30-3	0.00171%	0.00018%
Sulfonated polystyrene	Proprietary	0.00051%	0.00005%
Trisodium nitrilotriacetate (impurity)	5064-31-3	0.00036%	0.00004%
Crystalline silica: cristobalite	14464-46-1	0.00034%	0.00004%

Talisman Energy drill hole Altares, BC

total water vol.
89%
37,201m³
37.2m litres
9.82m gallons

Sand
9.8%

Source: Talisman Energy

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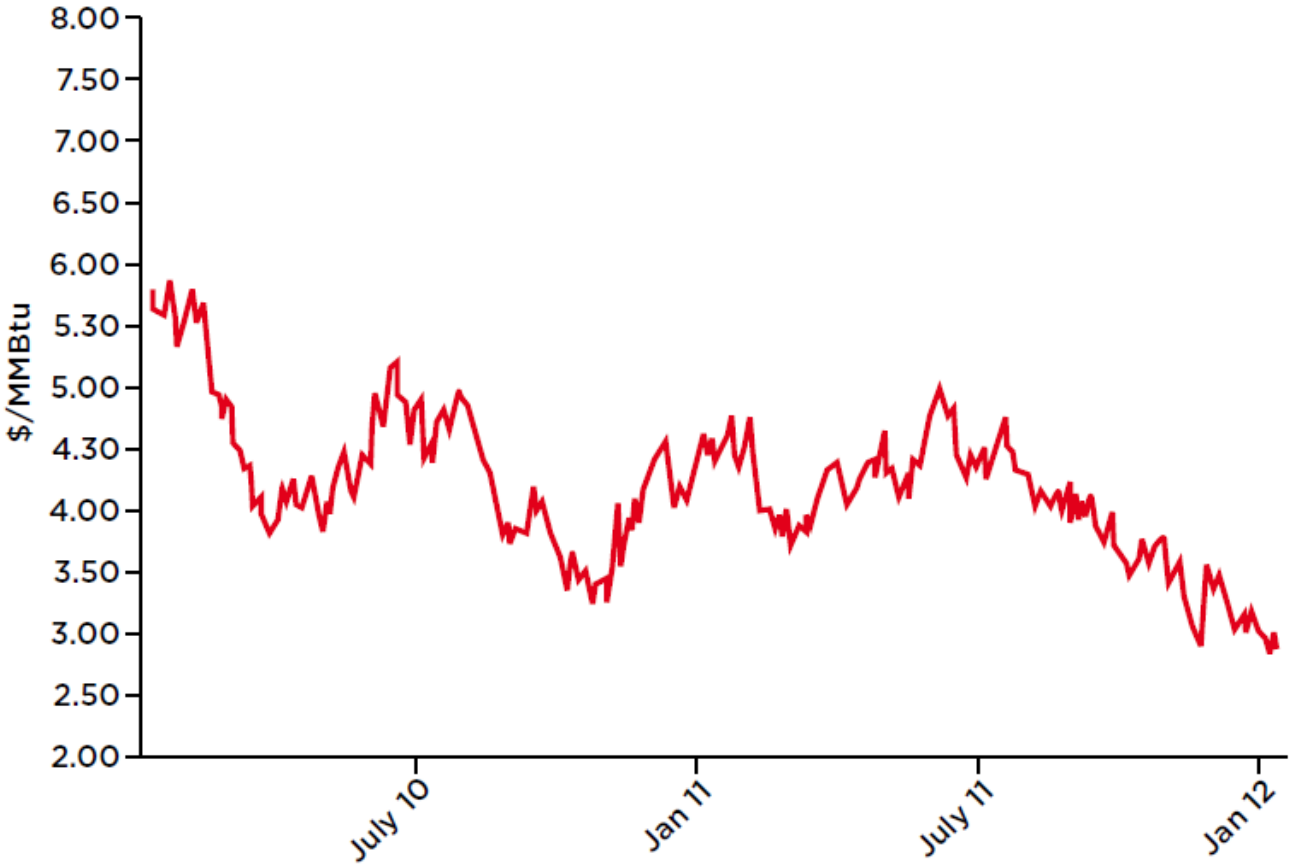
3. Demand & developments

N. American natural gas demand boom

Rising oil prices + US drive for increasing consumption of cheaper natural gas

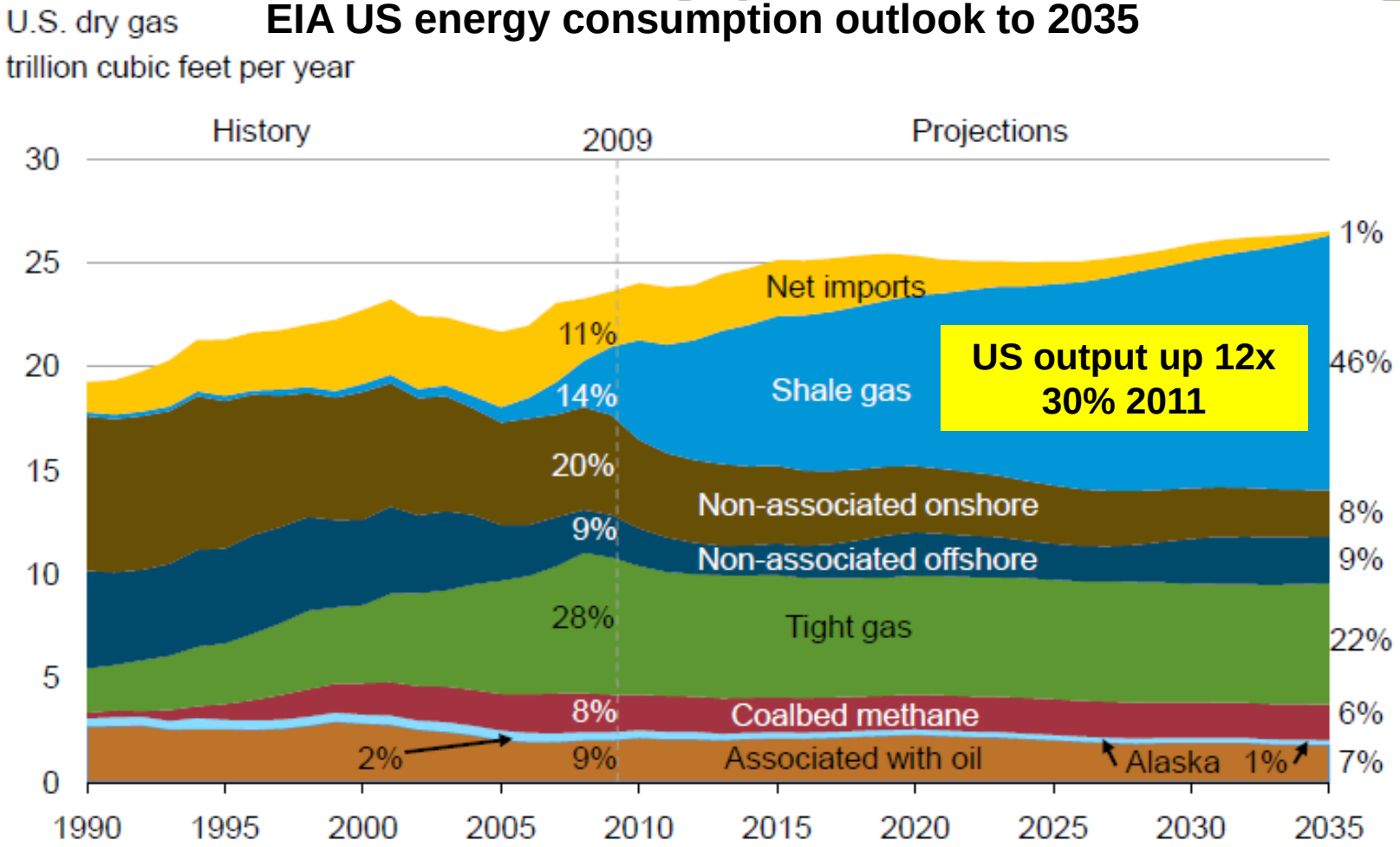


Source: National Gas Intelligence

3. Demand & developments

N. American natural gas demand boom

EIA US energy consumption outlook to 2035



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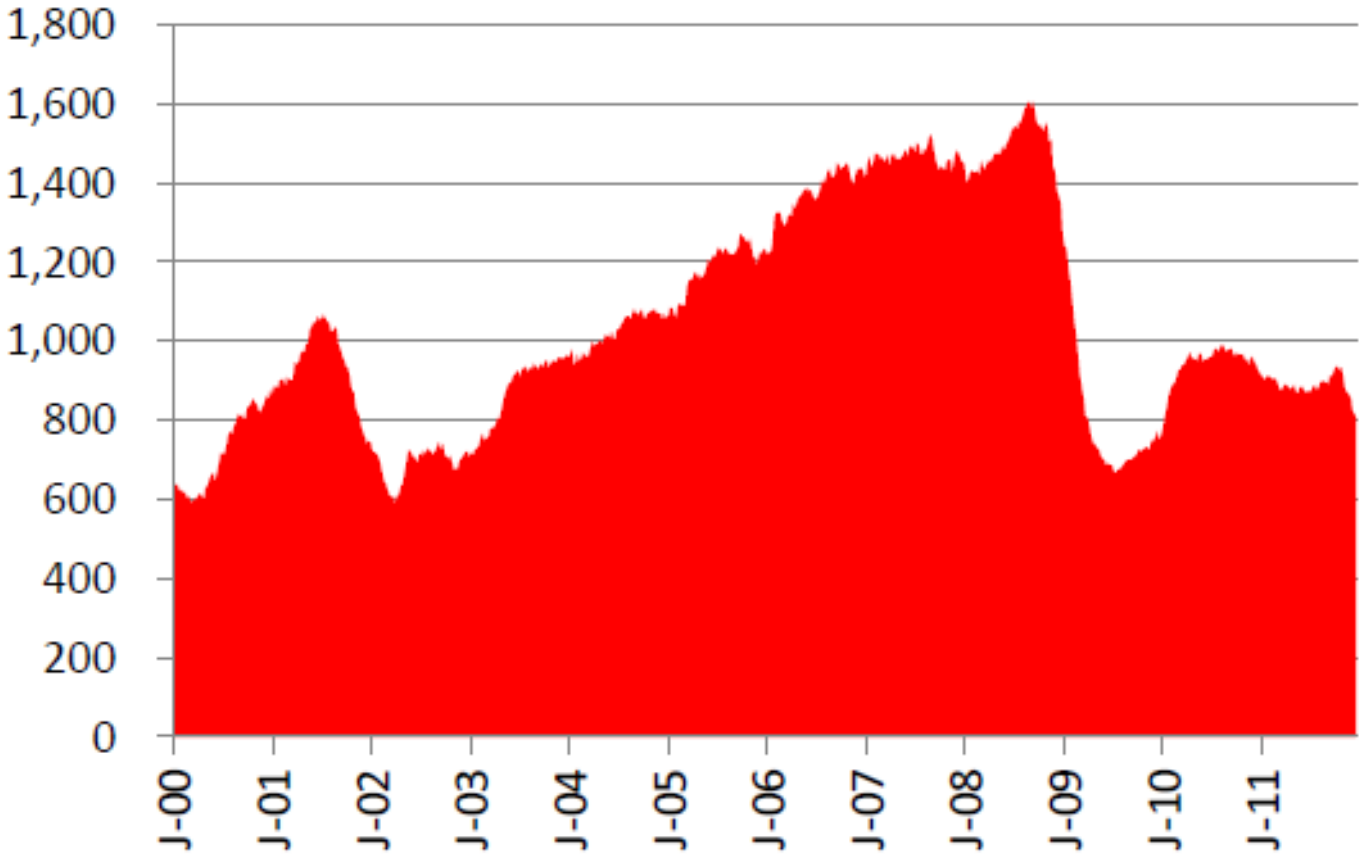
3. Demand & developments

N. American natural gas exploration boom

US gas drilling rigs 2000-2012



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Source: Baker Hughes

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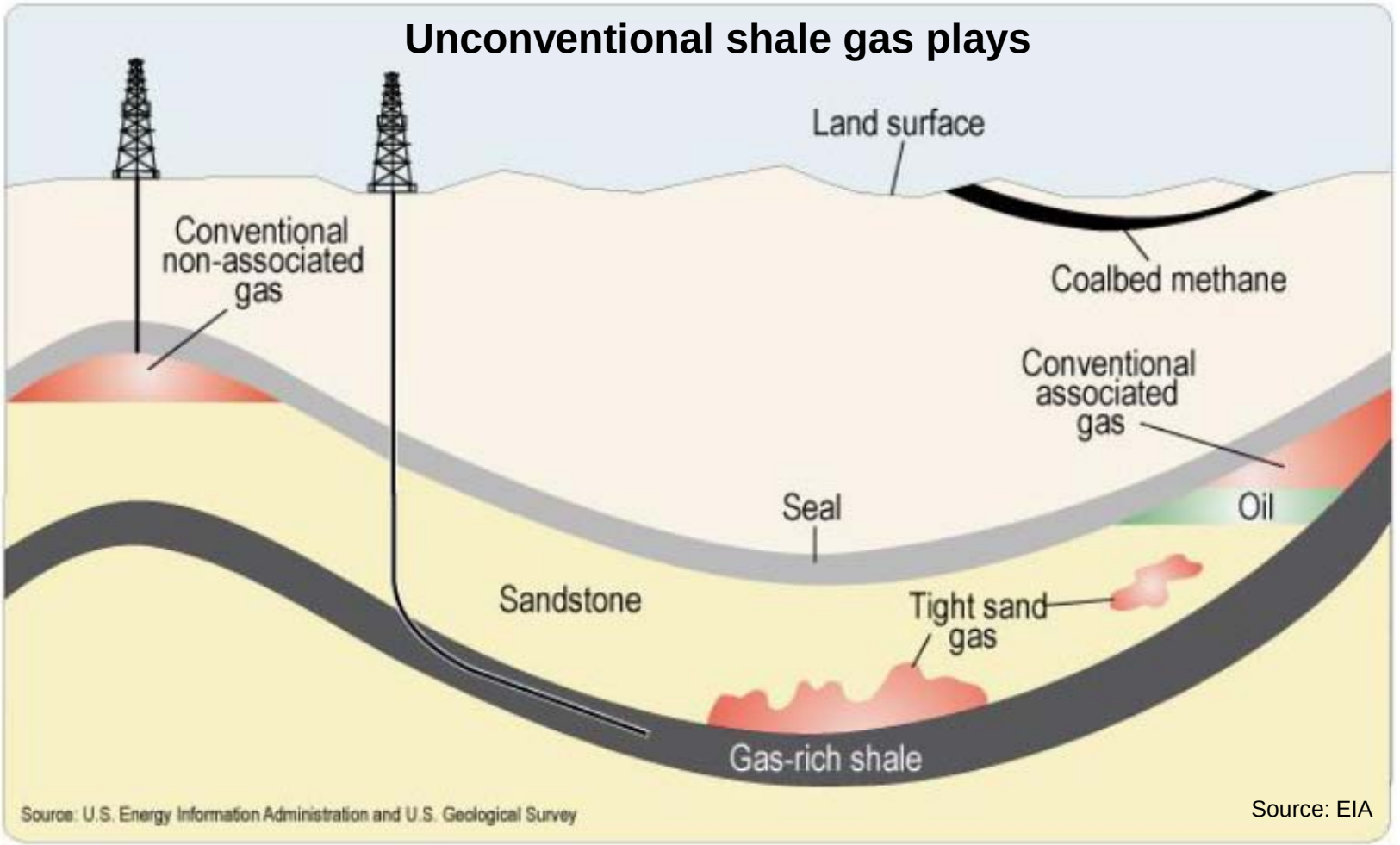
3. Demand & developments

N. American natural gas exploration boom



Source: EIA

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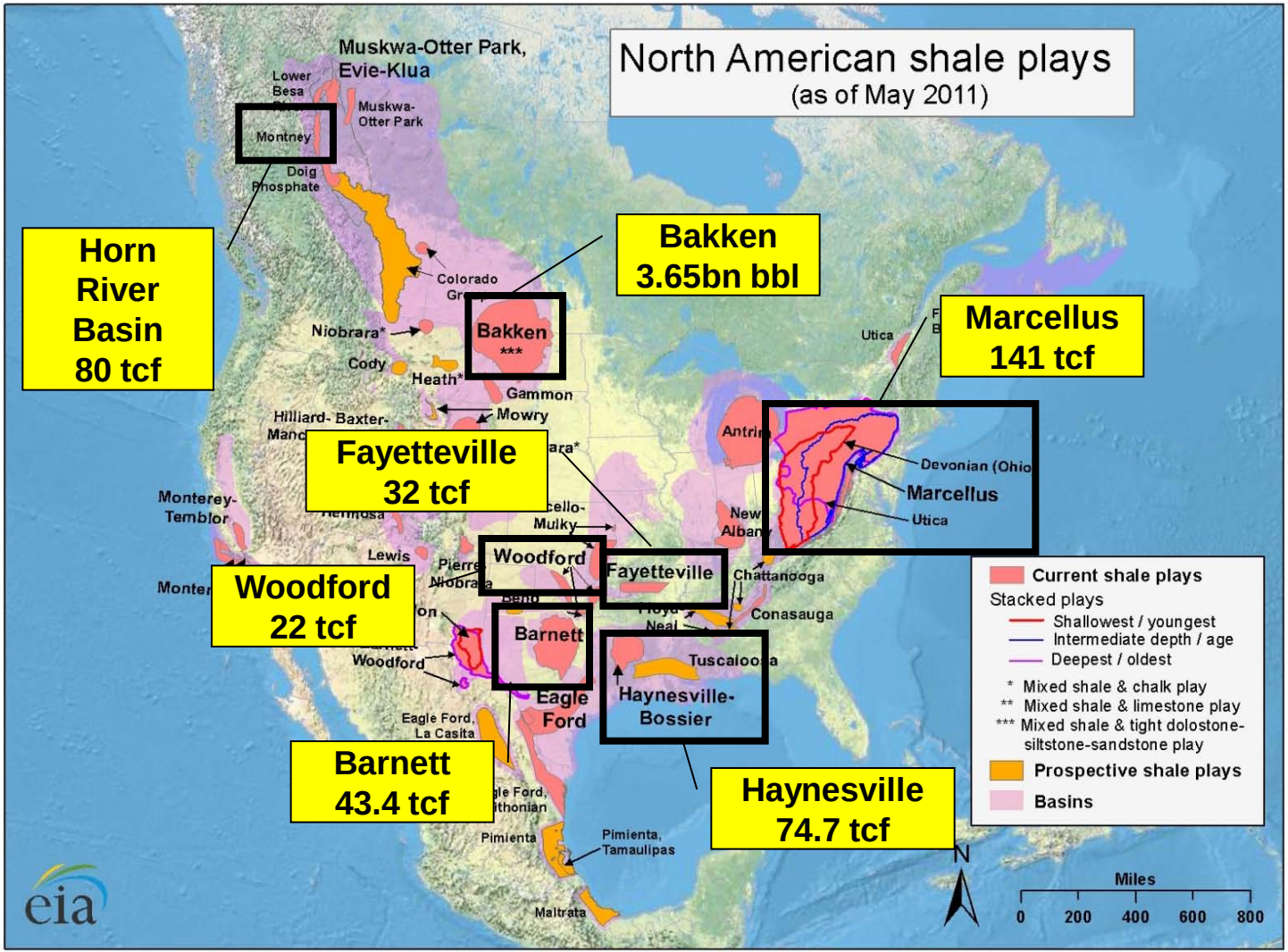

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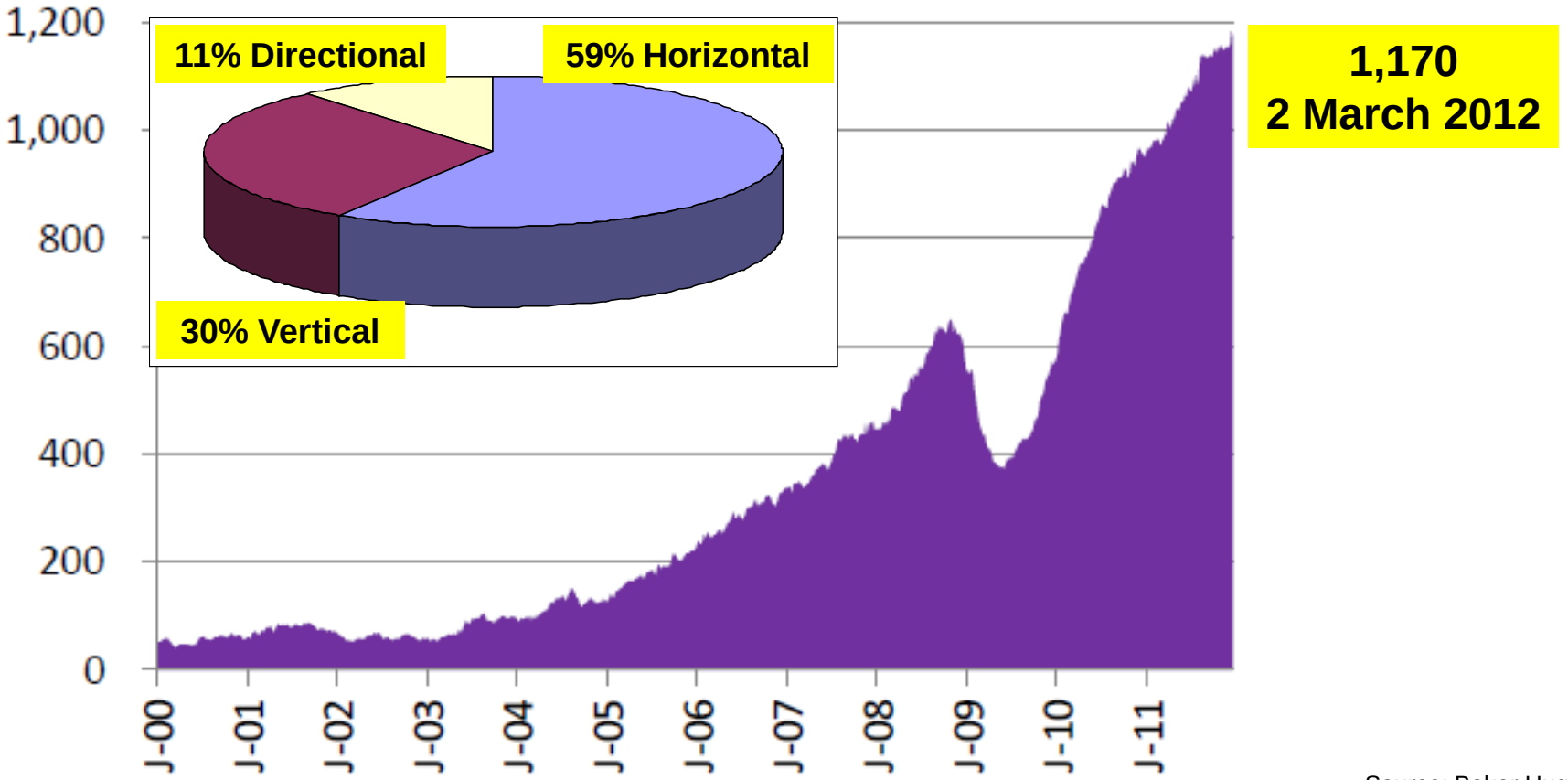
3. Demand & developments

N. American natural gas exploration boom

US horizontal drilling rigs 2000-2012

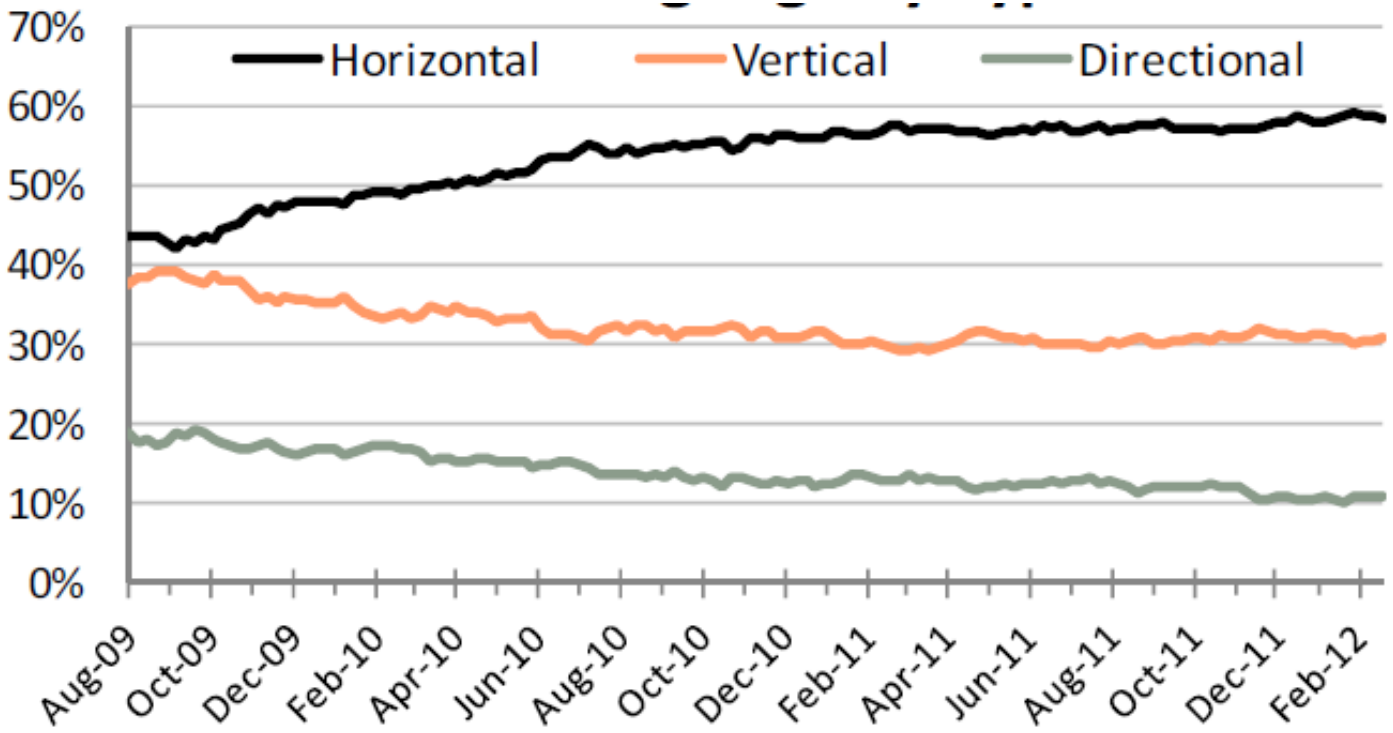


Source: Baker Hughes

3. Demand & developments

N. American natural gas exploration boom

US drilling rigs by type



Source: Baker Hughes

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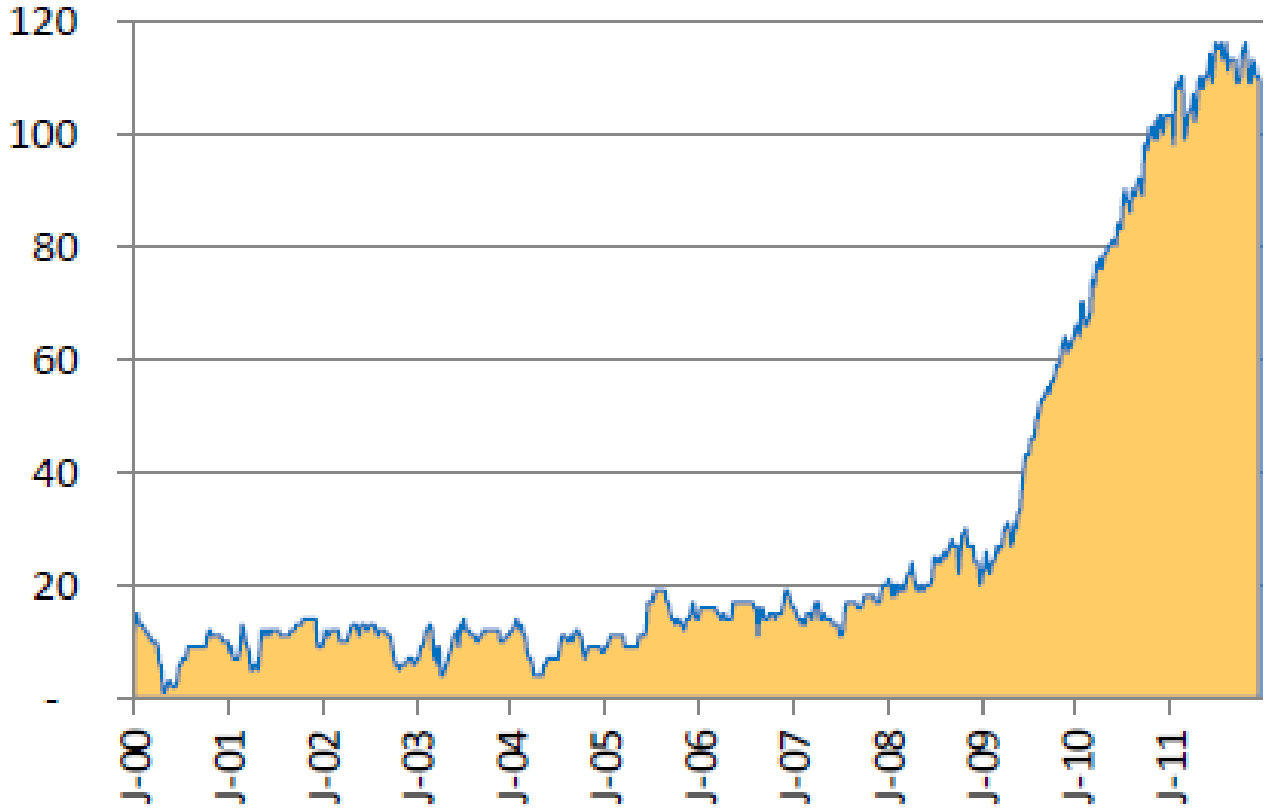
N. American natural gas exploration boom

Pennsylvania drilling rigs 2000-2012 (Marcellus shale)



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Source: Baker Hughes

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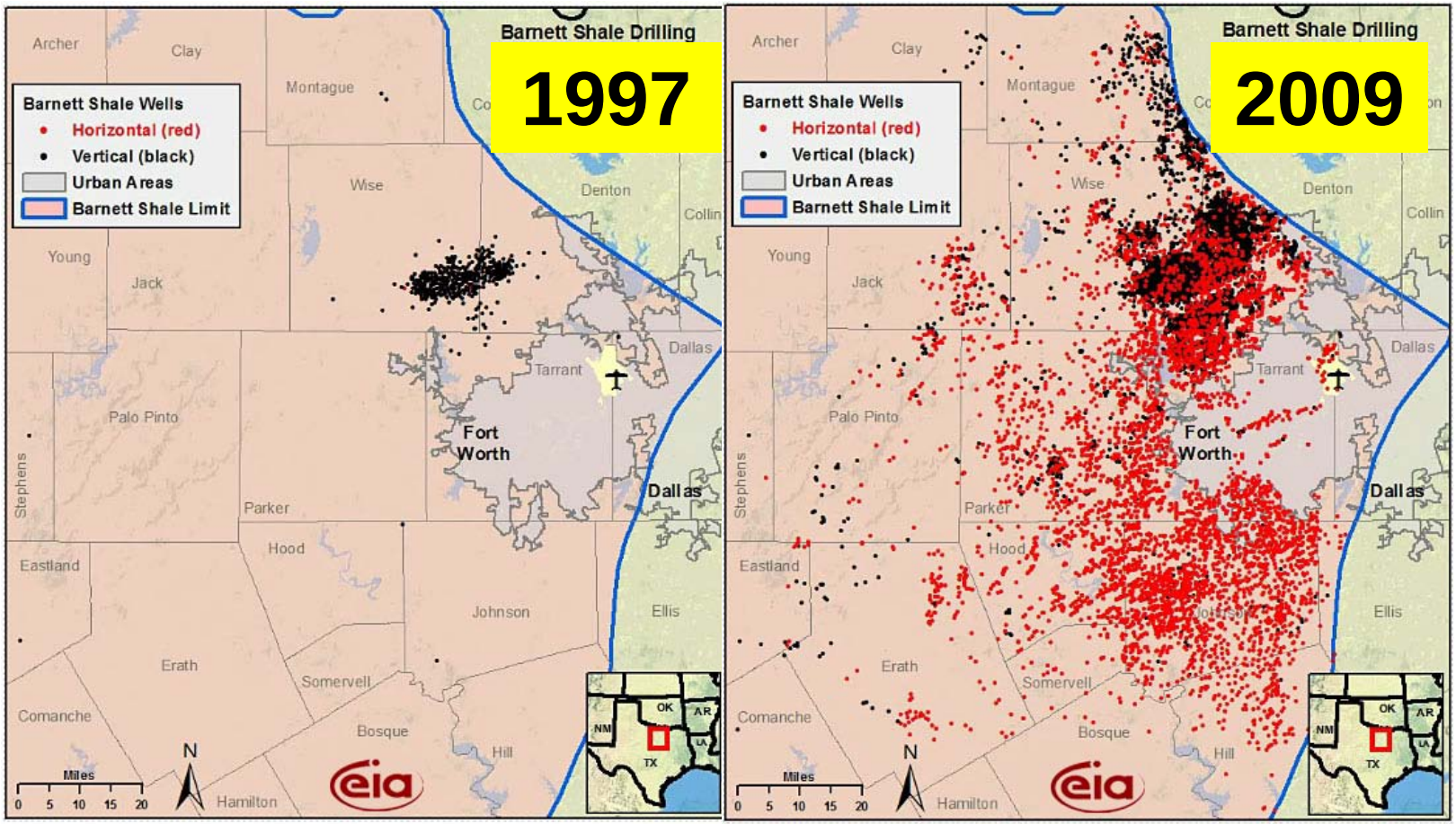
N. American natural gas exploration boom

Barnett, Texas shale gas boom 1997 compared to 2009



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3. Demand & developments

Fracking operations

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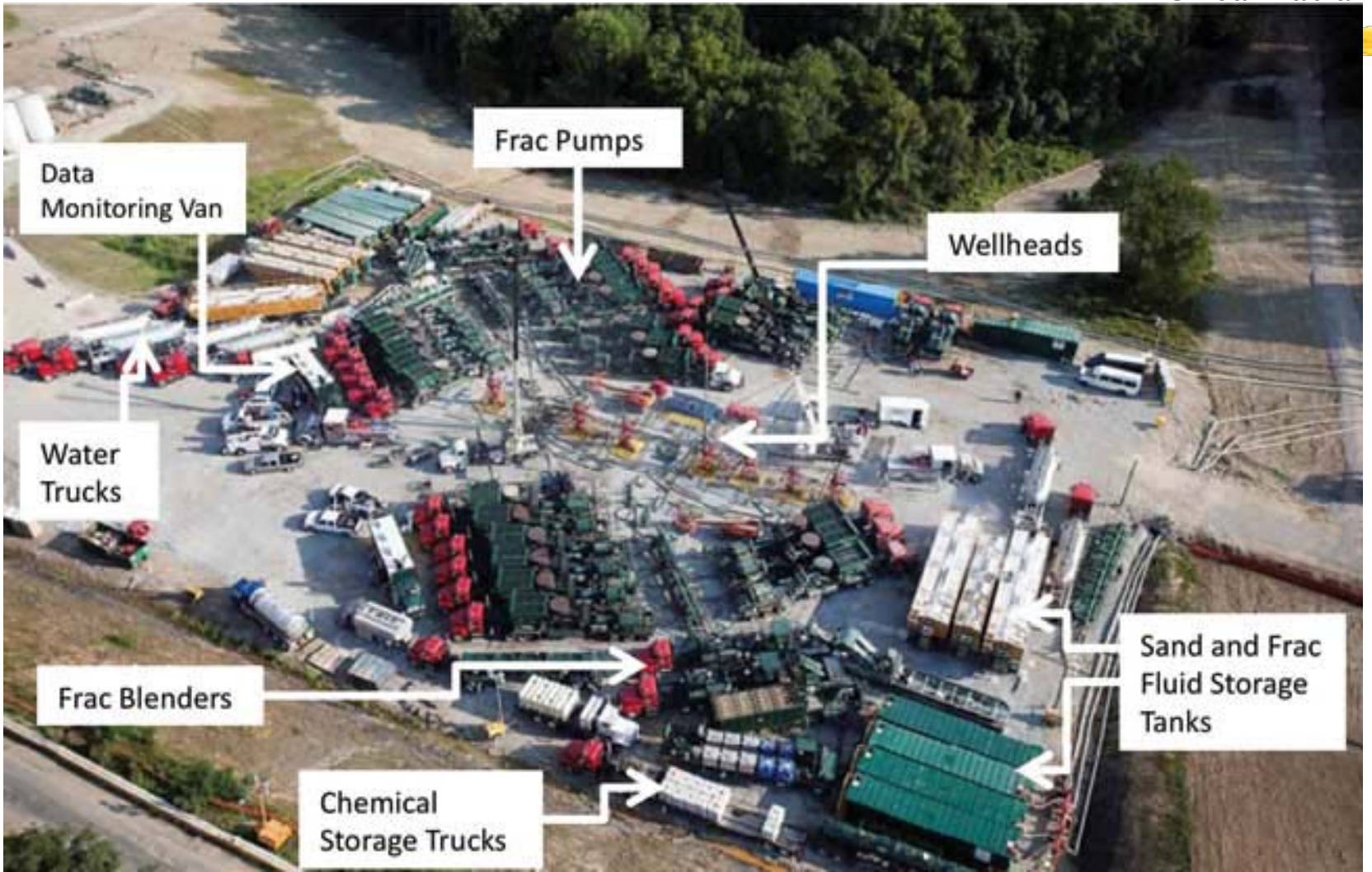

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3. Demand & developments

FS exploration/development boom

- **Unprecedented demand for frac sand**

  eg. typical Barnett Shale well

  2000: 300,000 lbs proppant
  2011: 3-5m lbs/well
  – longer horizontal wells in 20+ stages

- **Majors' expansion & development**

- **New producers emerging & growing**

- **New developers emerging & growing**

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3. Demand & developments

FS exploration/development boom

7 March 2012: Cadre Proppants sold 1,000,000,000th lb of frac sand

After just 6 months

Voca, TX plant started April 2011;

20,000 trucks to Eagle Ford shale & Permian Basin

3. Demand & developments

FS exploration/development boom

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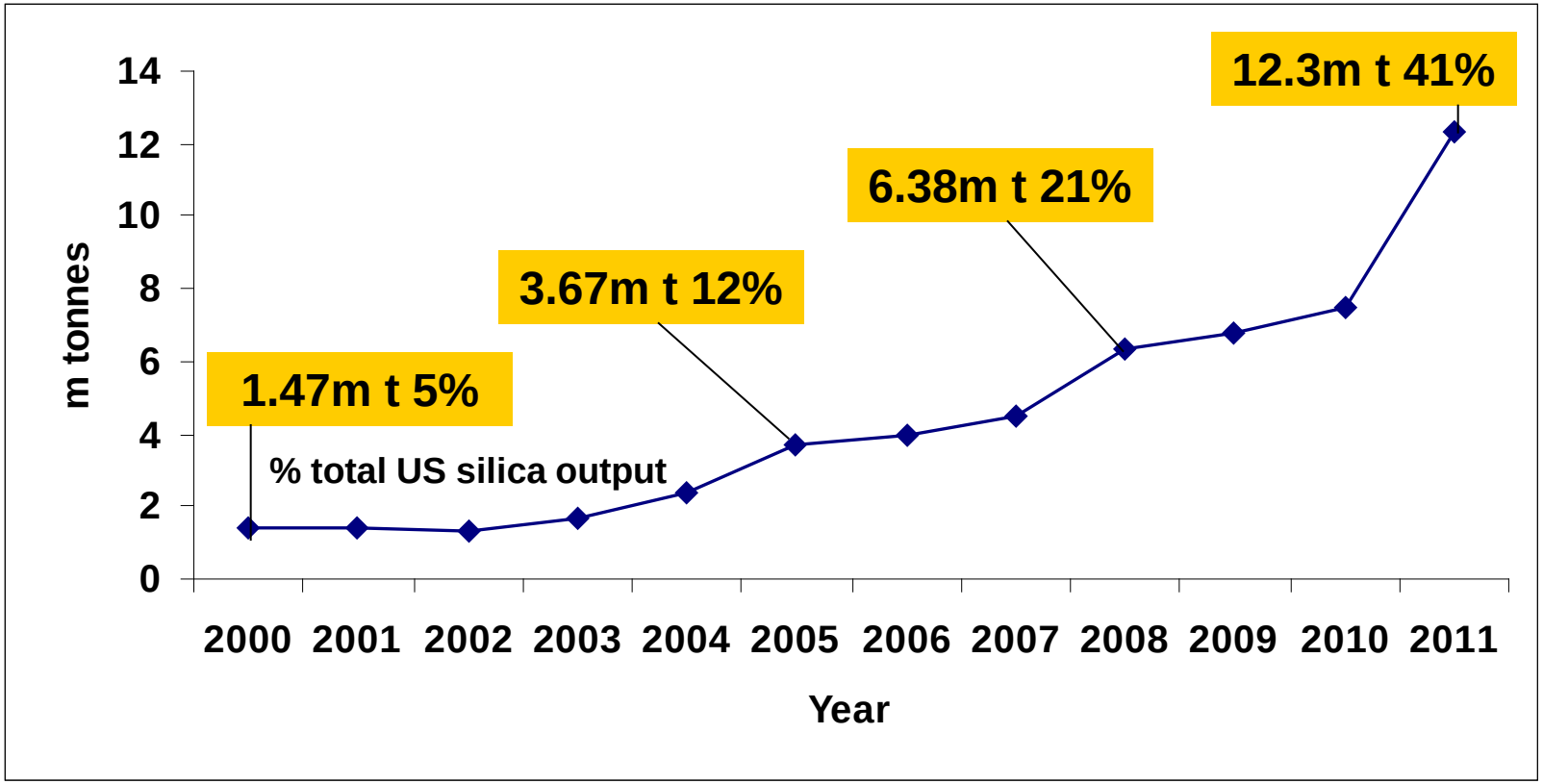
Rise of US silica sand used for fracking, well cements 2000-2011



Source: USGS data

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FS exploration/development boom

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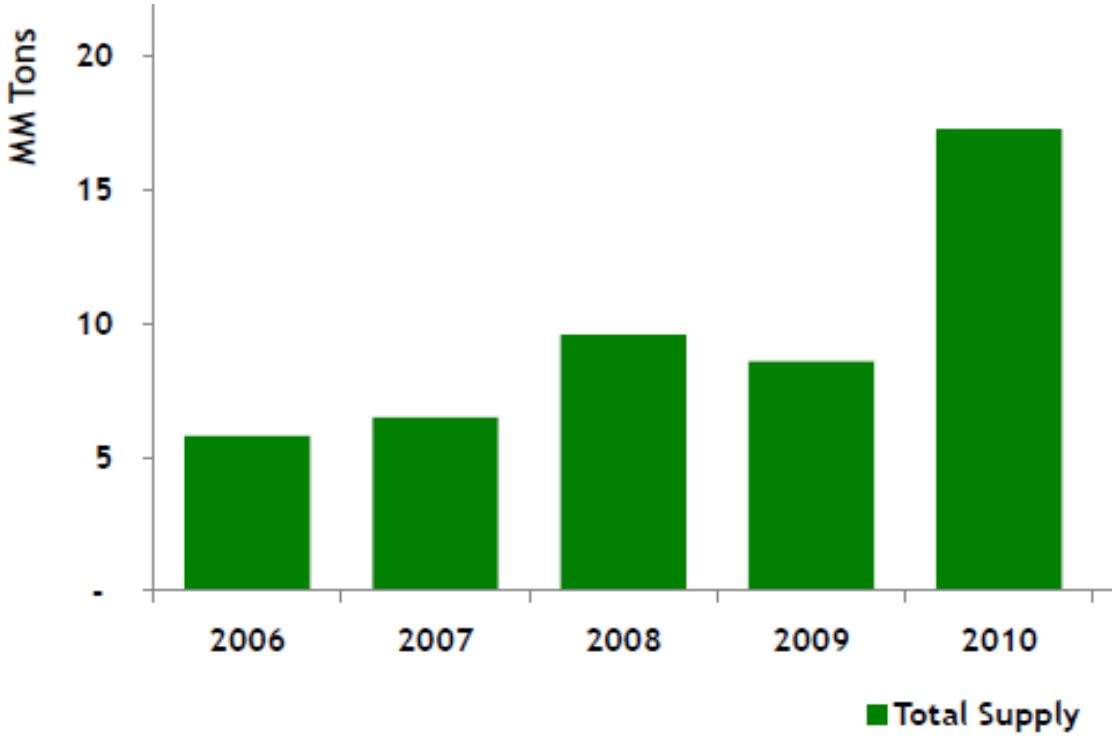
USGS data too conservative

Industry experts estimate US FS market nearer 21-22m t in 2011



Jan. 2011 FS study by Proptester Inc.

3. Demand & developments

FS exploration/development boom

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Established producers expanding & developing

Majors

Badger Mining
Carmeuse Ind. Sands div.
(just sold to Pioneer)
Carbo Ceramics (ceramic)
Fairmount
Saint-Gobain (ceramic)
Unimin
US Silica

Minors

Chieftain Sand & Proppants
Heemskirk Canada
Progressive Railroad
Northern Frac
Smart Sand
Western Permian
St. Peter Sand
CCS Silica

3. Demand & developments

FS exploration/development boom

Recent/new N. American FS producers

Atlas Resins & Proppants
Cadre Proppants
Canadian Proppants
CanFrac Sands
Cardinal
C-E Minerals (ceramic)
Completion Sand
EOG (captive)
Erna Frac Sand
Hi Crush
J5Global
Manley Bros
Mississippi Sand LLC
Natural Resource Partners
Ozark
Pattison Sand
Preferred Sands
Premium Bluebird Sand
Proppant Specialists (Frac Tech)
ProSands
Sargent Sand
Superior Silica

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3. Demand & developments

FS exploration/development boom

N. American FS developers

Hunt Global
Gossan Resources
Interstate Energy
Jayhawk Frontier
Ottawa Sand
Silica North
Stikine Energy
Taylor Frac
Victory Nickel
Winn Bay Sand

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FS exploration/development boom

Source: Robert Johnson, Business Insider

Attractive for overseas exporters of proppants

Chinese 20/40 ceramic proppants stored at railhead in Williston, North Dakota

2011: China Gengsheng Minerals signed $5.4m deal for 1,500 tpm to US; expanding Gongyi, Henan plant to 90,000 tpa

2012: CMP, Tianjin started proppants production

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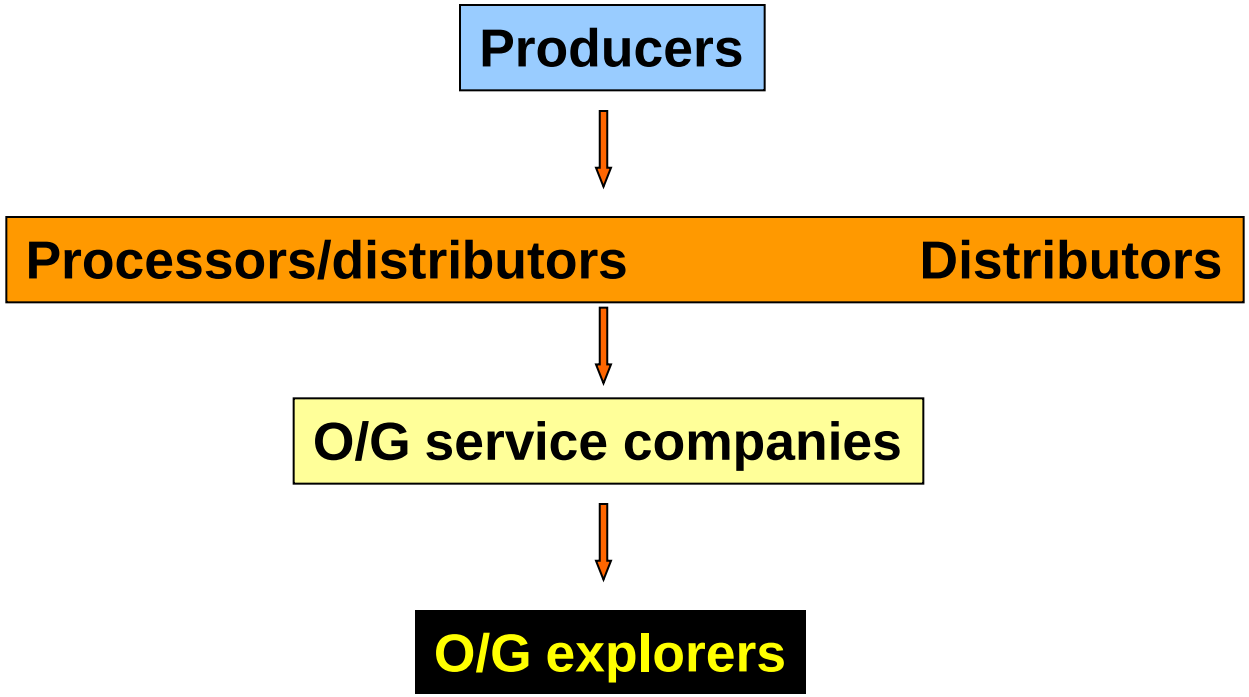
FS exploration/development boom

Created enlarged FS related industry



3. Demand & developments

Seeking new sources/marginal deposits

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- 2005: St Peter/Hickory = 90% of US frac sand used
- 2011/12: c.70-80% from St Peters/Brady
- Remainder from alternative and API-marginal sources
- Producing from Jordan formation since 2005
- Recent/new production from Mt Simon/weathered Mt Simon, other unconsolidated river and dune deposits
- Expect more from Wonowoc on line this year
- Increasing volumes of below API spec. material consumed

"There's been a sand shortage in the US. Those who have sand, or access to sand, can pretty much charge what they want for that sand." Mark Papa, CEO, EOG Resources

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3. Demand & developments

Vertical integration

- Trend of O/G explorers securing captive FS supply
- EOG: developed own mine 2011
- Pioneer Natural Resources: acquired Carmeuse Ind. Sands 2012
  - PNR FS demand to increase from 1.2m t 2012 to 1.6m t 2015
  - brown FS demand tight and prices rising
  - CIS no.1 producer of Brady sand (Hickory), TX supplies PNR
  - Secures captive supply for 30+yrs below market prices, saving $65-70m
  - Potential to double CIS mine from 1m tpa to 2m tpa and develop 1m tpa white FS mine in WI

3. Demand & developments

Vertical integration

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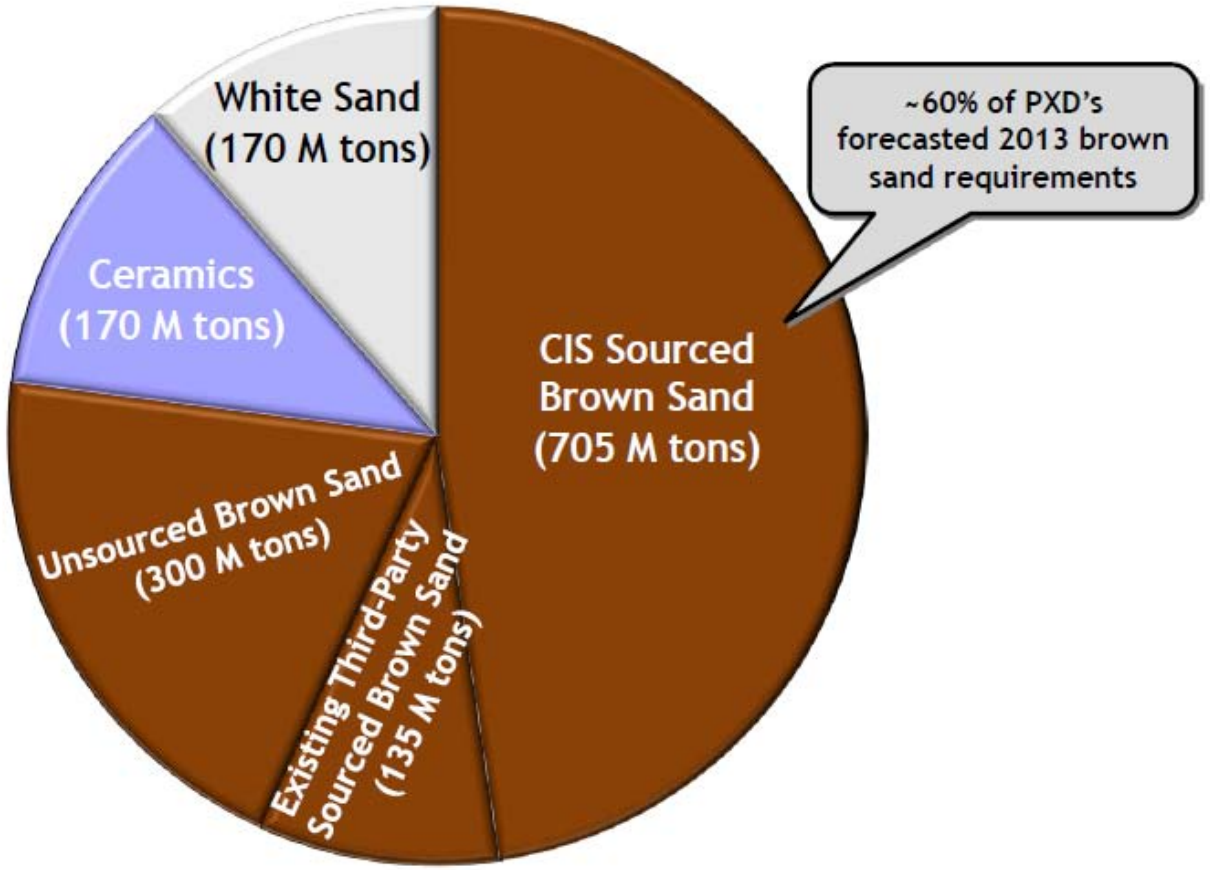
PNR's estimated 2013 proppant requirements pre-CIS buy



Source: PNR

3. Demand & developments

Logistics vital to FS distribution

- 1 well = 4m lbs proppant = 20 rail cars

Truck mine to railhead

↓

Rail freight

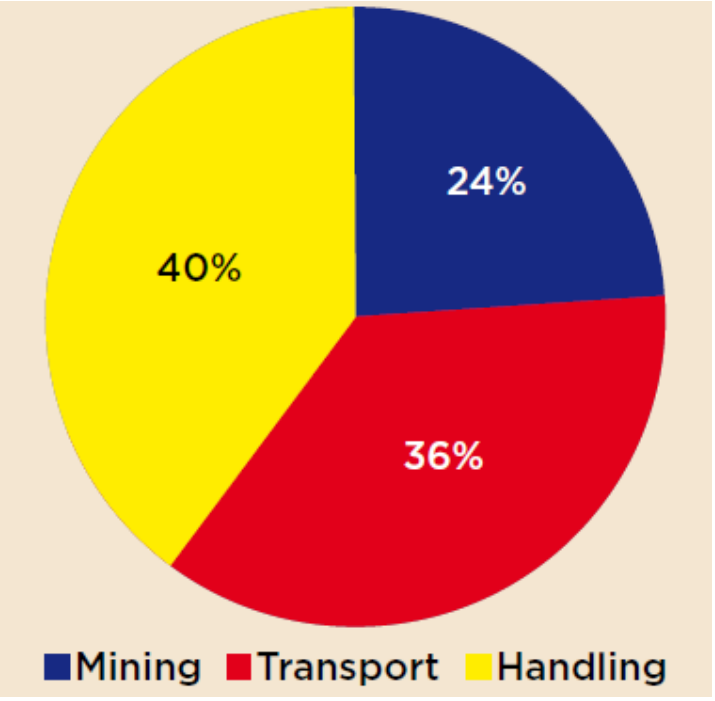
↓

Transloading rail to silos/trucks

↓

Truck to rig site

Breakdown of delivered FS price USA



- Logistics can add 8x to ex-works $ price

Source: Thomas Dolley, USGS

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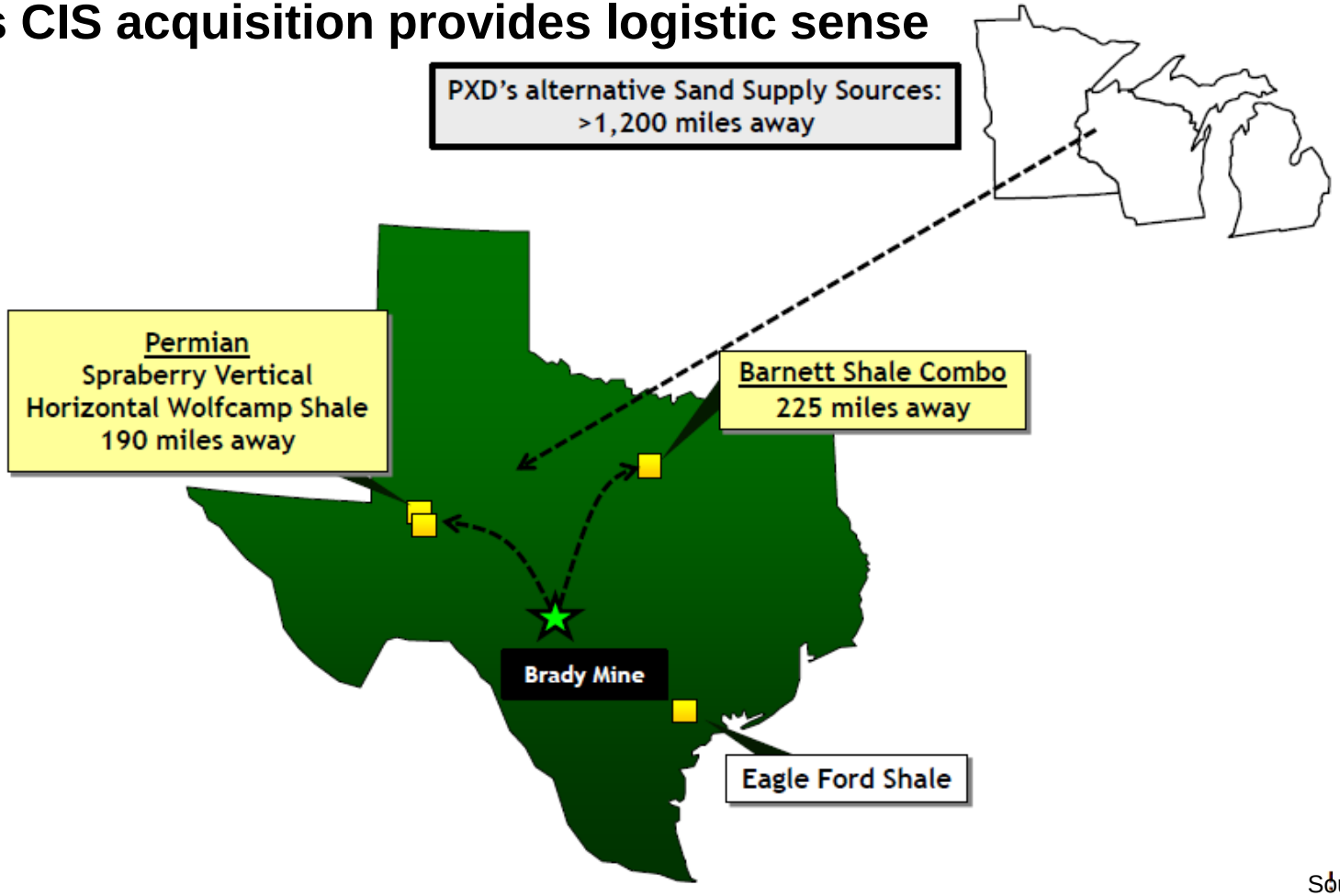
Logistics vital to FS distribution

PNR's CIS acquisition provides logistic sense



Source: PNR

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3. Demand & developments

Logistics vital to FS distribution

- **2012: Halliburton to build $20m, 54 acre frac sand storage terminal at Windsor, CO – supplying Niobrara shale in the Denver-Julesburg Basin**

Photo courtesy Preferred Sands

- **2011: Preferred Sands runs 90+-car unit train service between its Genoa silica sand mine in Nebraska and a 14,000 t storage facility in McKees Rocks, Pennsylvania**

2012

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3. Demand & developments

Frac sand grades & prices

- **Coarse, 20/40, seen as optimal for conductivity, deeper wells**
- **Fine, 40/70, 70/140, for horizontal shale gas**

Table 1: North American frac sand prices (FOB)

Location	Grade	Price ($/tonne)
South-east Arkansas	Mid quality 40/70	60
Eastern Ohio	Mid quality 40/70	85
North-west Wisconsin	High quality 20/40	110
Shreveport, Louisiana	High quality 20/40	145
San Antonio, Texas	High quality 20/40	195
North Dakota	High quality 20/40	200

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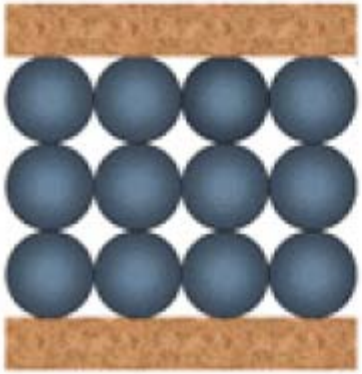
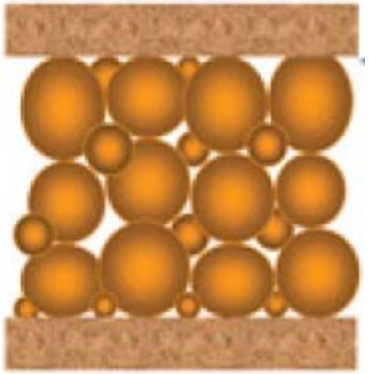
Natural v Synthetic proppants

- **Natural FS appropriate for reservoirs with 6,000 psi closure stress ie., depth of about 6,500 ft in shale gas reservoir**
- **Synthetic proppants used in higher closure stress environments, invariably deeper reservoirs, can increase well stimulation by up to 30%**

Ceramic



Uniform size/shape enhances conductivity of proppant pack



Natural sand

Broadly sized, irregular shaped, tightly packed grains reduce conductivity

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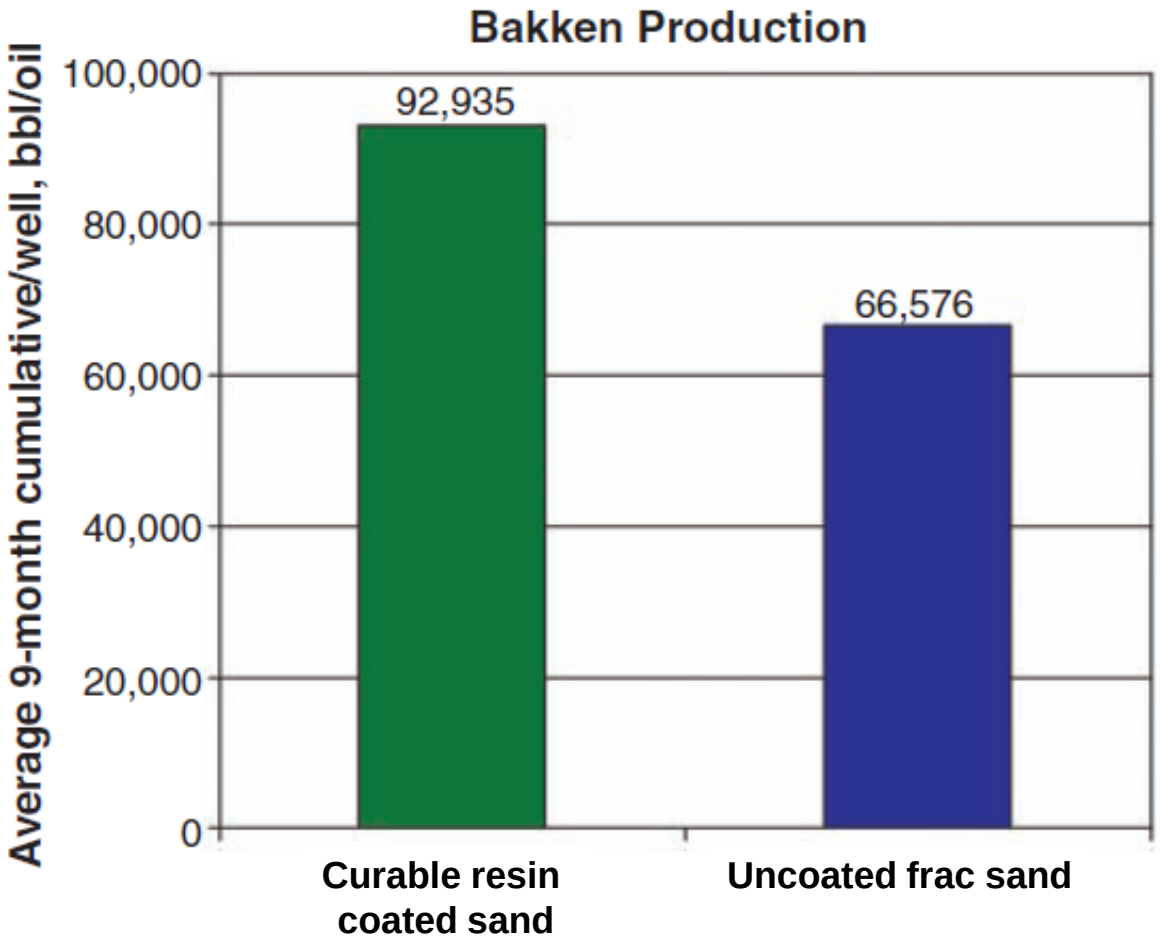
Resin coated proppants



Source: Momentive

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Natural v Synthetic proppants

Mei Yang, Lead Research Engineer, Cadre Poppants Inc.
Feb 2012

"For tight gas reservoirs, we correct the prejudice that natural sand proppants cannot be applied to deeper reservoirs by showing results that are superior to those of manmade proppants.

Natural sands proppants have a much larger range of applicability than previously thought."

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3. Demand & developments

Environmental issues

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Environmental issues

- **Protests worldwide; moratoria in USA**
  1. **Against fracking practice**
  2. **Against frac sand mine development**
- **Pollution concern**
  1. **Fractures might extend into shallow rock used for drinking water supplies**
  2. **Well casing might fail and allow fluids to escape into above**
  3. **Accidental spills of fracking fluids or fluids expelled during fracking**

- **US & Polish studies allay contamination concerns**

- **Potential earth tremor/ground disturbance trigger**

Ohio, USA

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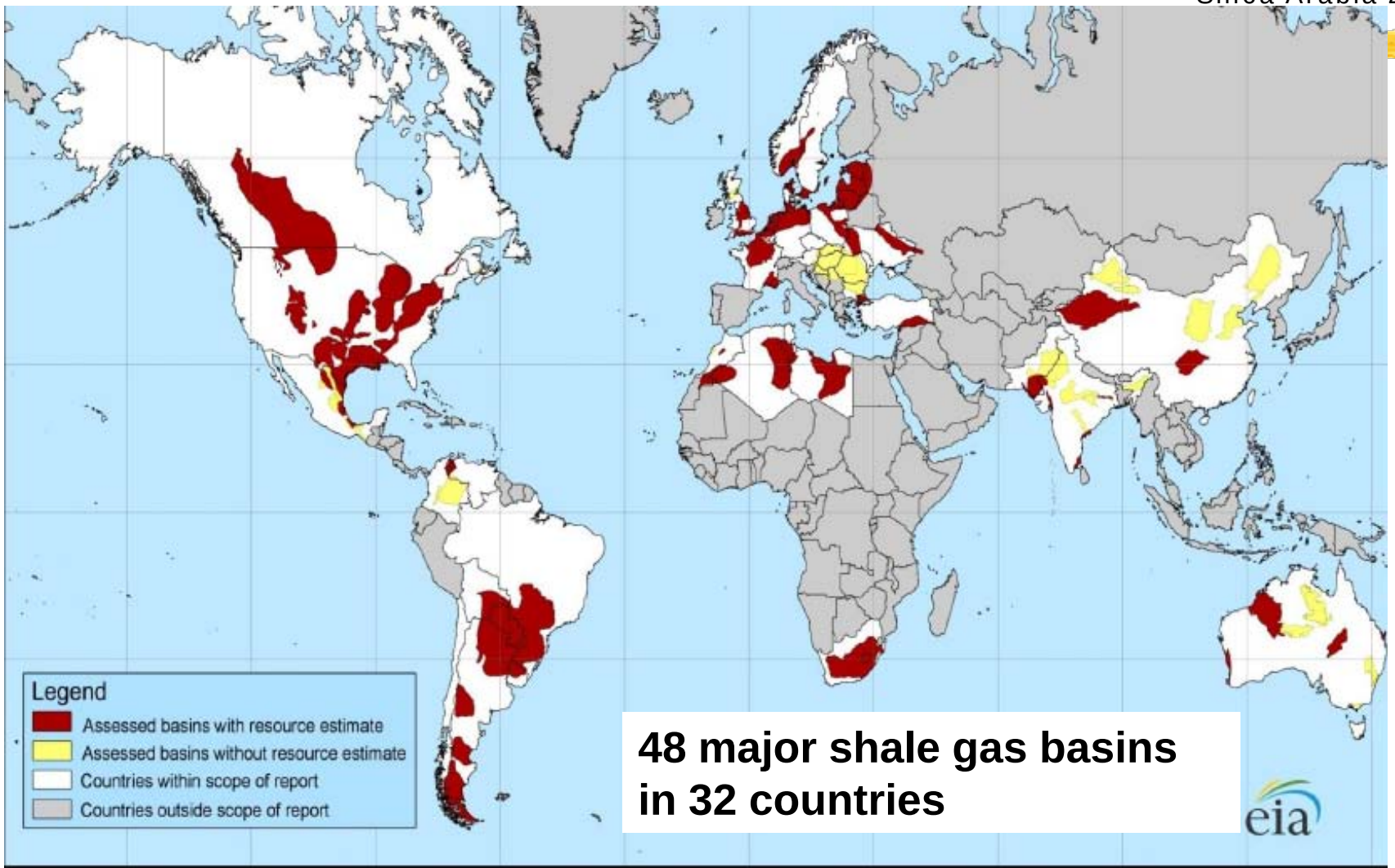
Shale gas development goes global



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Shale gas development goes global

EIA estimates of technically recoverable resources of shale gas

Continent		Technically Recoverable (Tcf)
North America (non U.S.)	Canada, Mexico	1,069
	U.S.	862
Total North America		1931
Africa	Morocco, Algeria, Tunisia, Libya, Mauritania, Western Sahara, South Africa	1,042
Asia	China, India, Pakistan	1,404
Australia		396
Europe	France, Germany, Netherlands, Sweden, Norway, Denmark, U.K., Poland, Lithuania, Ukraine, Turkey	624
South America	Colombia, Venezuela, Argentina, Bolivia, Brazil, Chile, Uruguay, Paraguay	1,225
Total		6,622
Total without U.S.		5,760

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Shale gas development goes global

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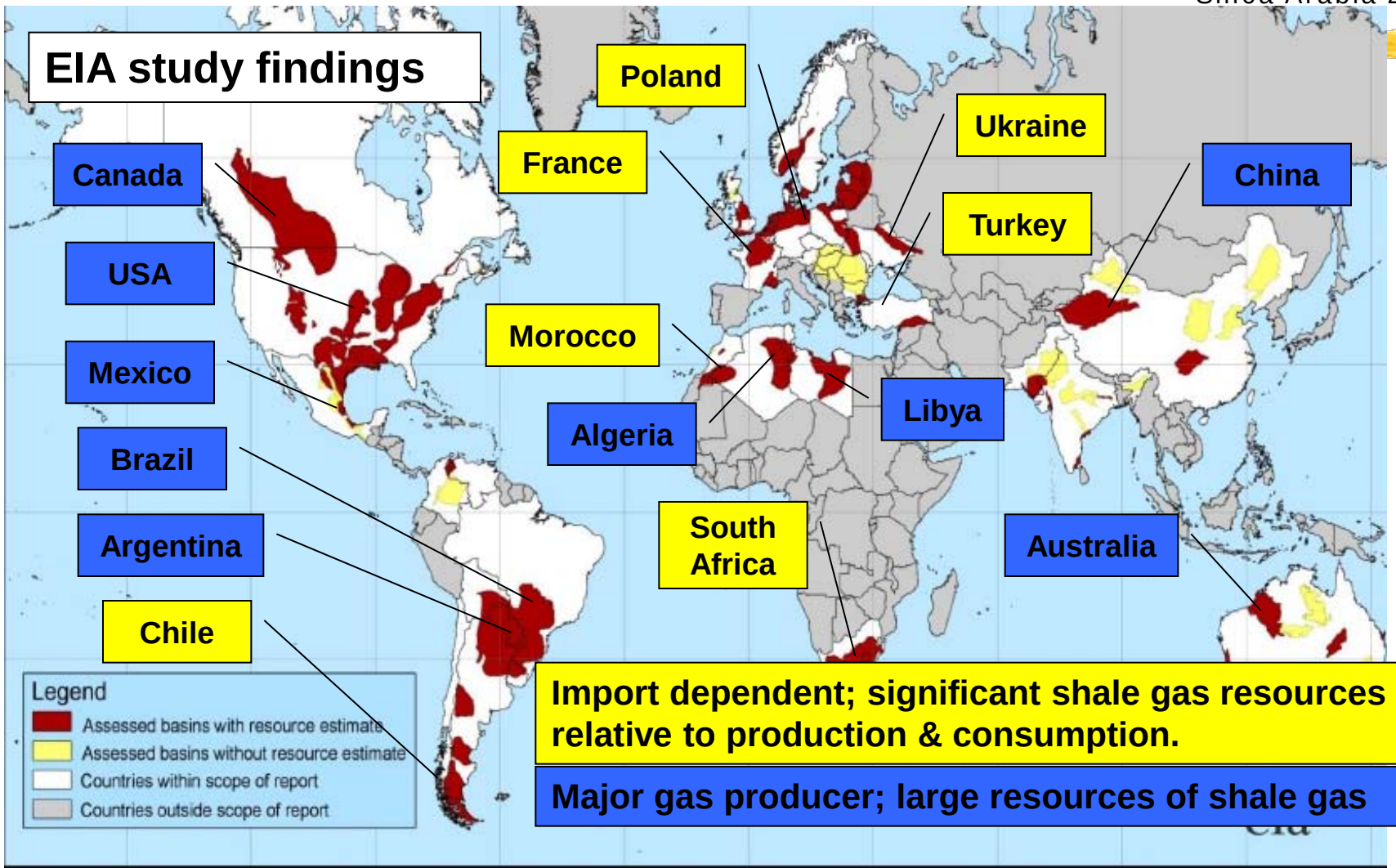

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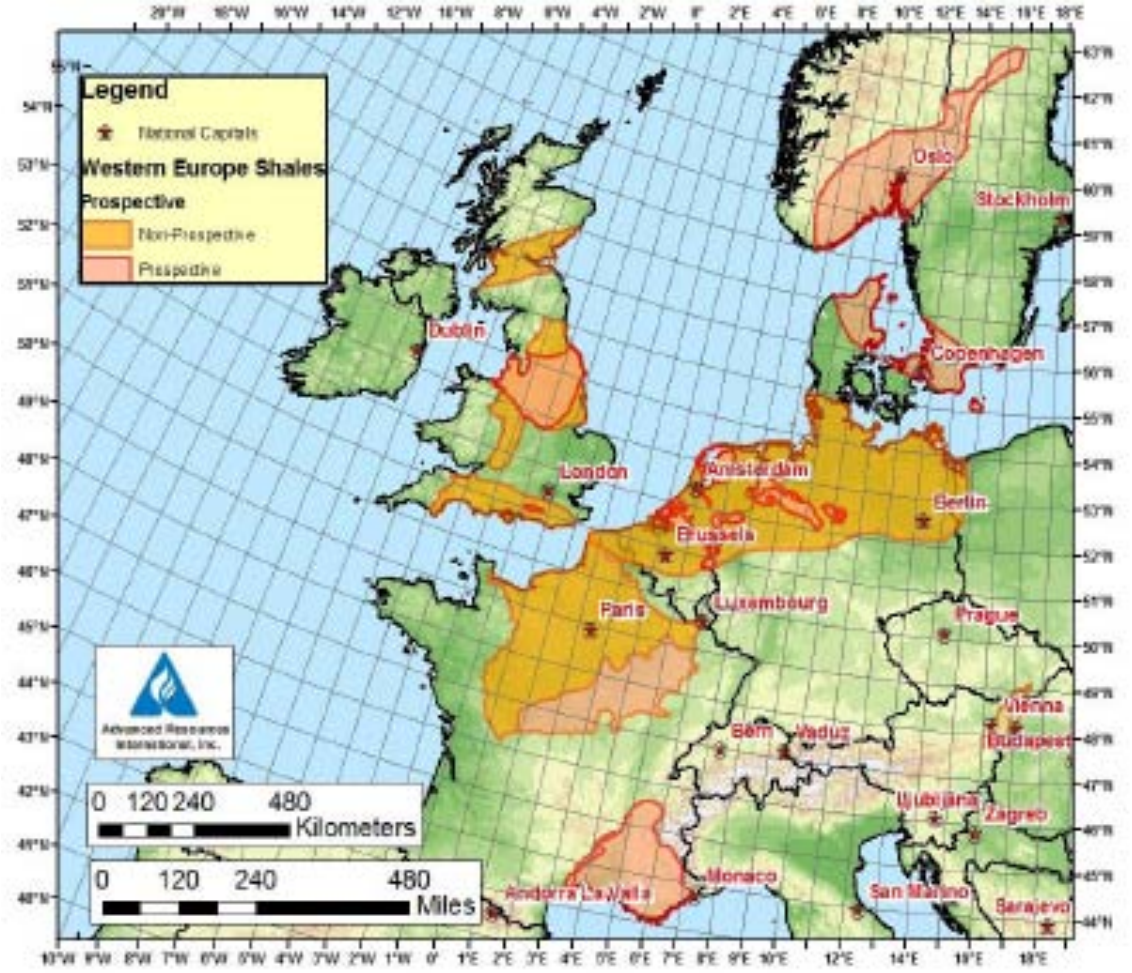

EIA: W. Europe

- **Major shale resource 372 Tcf**

- Ordovician Alum, Scandinavia
- Permian/Carboneriferous, Paris
- Jurassic, numerous

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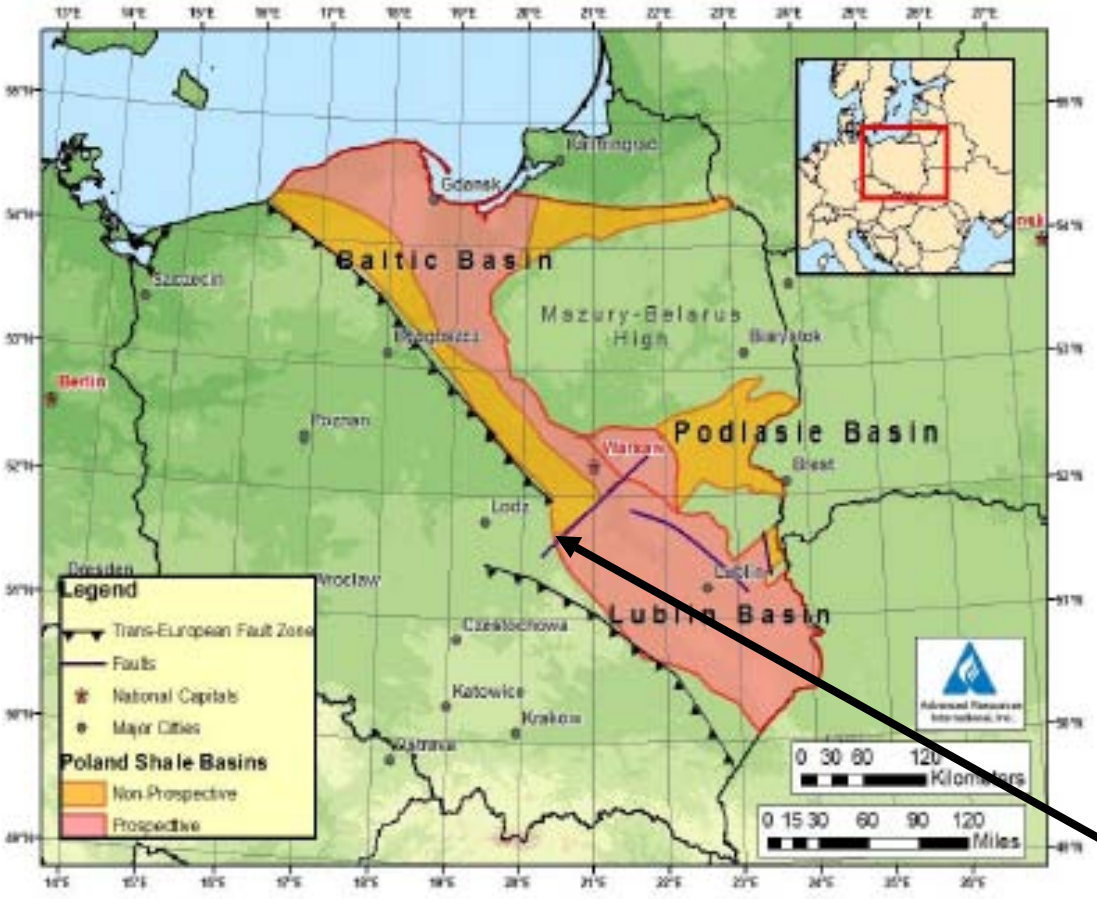

Poland

- **Major shale resource 187 Tcf**
- **Chevron, Exxon Mobil, Conoco, Marathon**

Badger Mining Poland Sp zoo Tomaszow Mazowiecki

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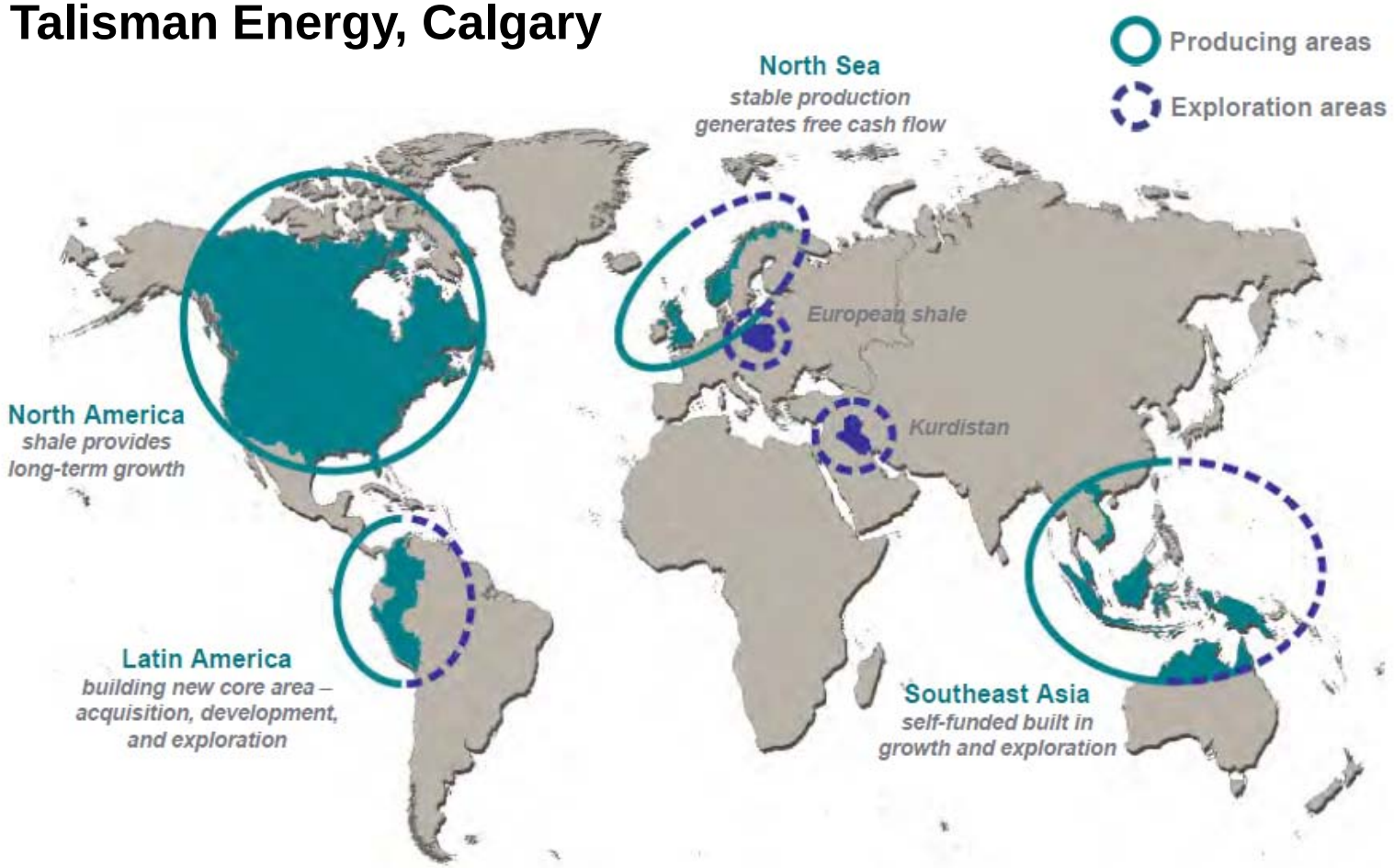
Shale gas development goes global

eg. Talisman Energy, Calgary



3. Demand & developments

Shale gas development goes global

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Recent news headlines from *World Oil*

"Algerian shale gas potential equal to that of US"

"Chevron to explore for shale gas in China, Argentina, Romania"

"USGS releases first shale oil-gas resource assessment for Alaska North Slope"

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4. Conclusions

- Drive for cheaper natural gas consumption worldwide to continue
- Assured future demand for proppants, esp. frac sand
- Enhanced by more shale gas plays and horizontal drilling
- O/G explorers looking to replicate shale gas boom worldwide
- Not all silica sands will make API spec, older deposits more likely
- SiO_2%, roundness, sphericity, crush resistance very important
- But "off-spec" material will be consumed until new sources on line
- Prices still firming, but expect to level off 2012-2013 as new sources come on line – logistics continue to play major role
- Expect to see more activity from Chinese ceramic proppant suppliers
- Expect to see more vertical integration from end users
- Look out for impact on glass/foundry sand demand as producers switch or "favour" supplying frac sand market

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SAUDI GEOLOGICAL SURVEY

Industrial Minerals Research

Silica Arabia 2012

FRAC SAND REPORT

Coming August 2012

Contact: Mike O'Driscoll, Editor, IM

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Anglo Pacific minerals 英美太平洋矿物 www.angpacmin.com

Alfred H Knight

Hilton Houston Post Oak, Houston 20-21 June 2012

Oilfield Minerals Outlook

Frac sand • Barytes • Bentonite • Drilling fluids • Logistics • Processing

The future's bright
The future's frac sand*

Thank you

* with acknowledgements