“Natural Gas and the Impact on Pulverized Coal Injection in Blast Furnace Operations”

Dr. Joseph J. Poveromo

Raw Materials & Ironmaking Global Consulting

Bethlehem, PA

Joe.poveromo@rawmaterialsiron.com

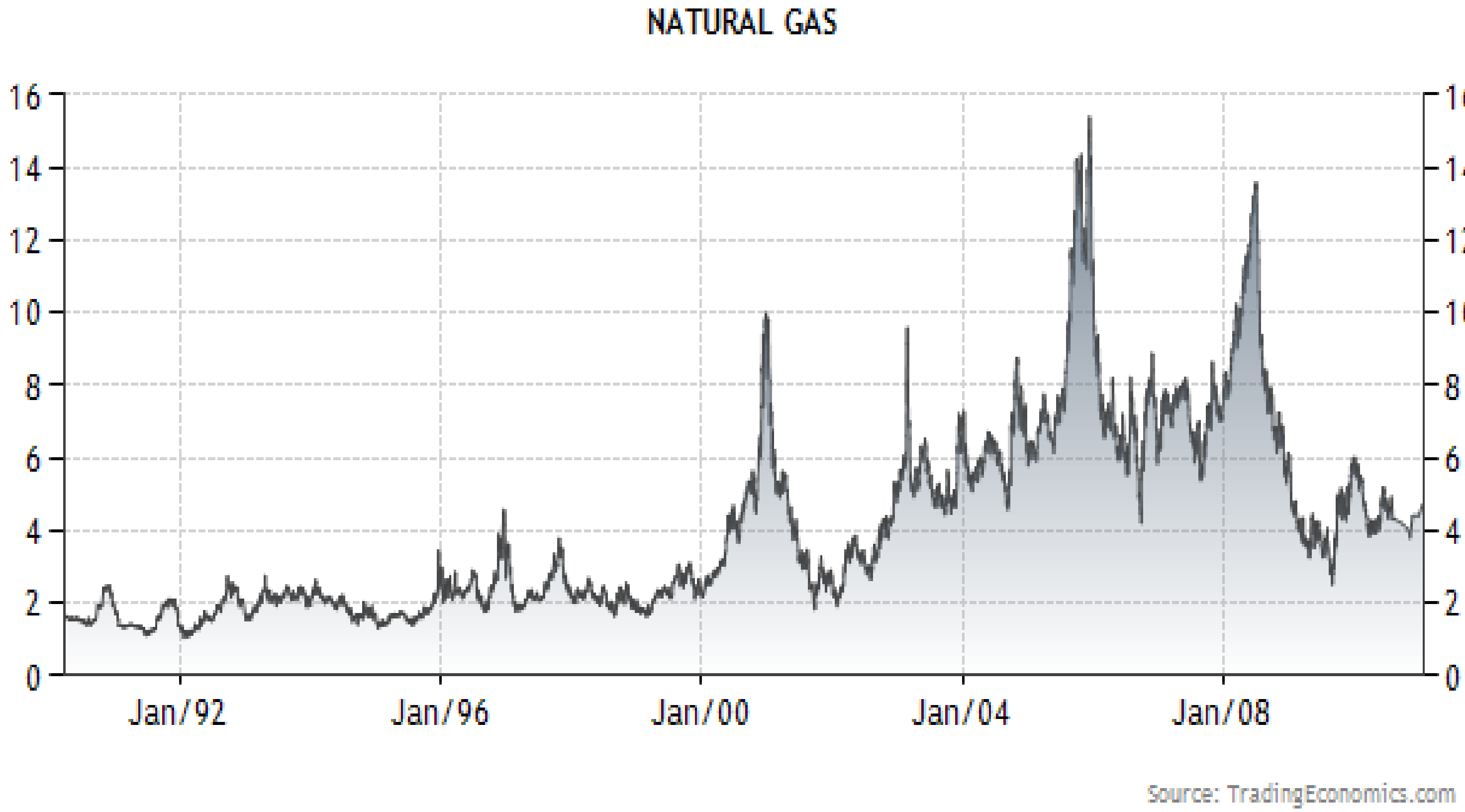
610-974-9553

Topics

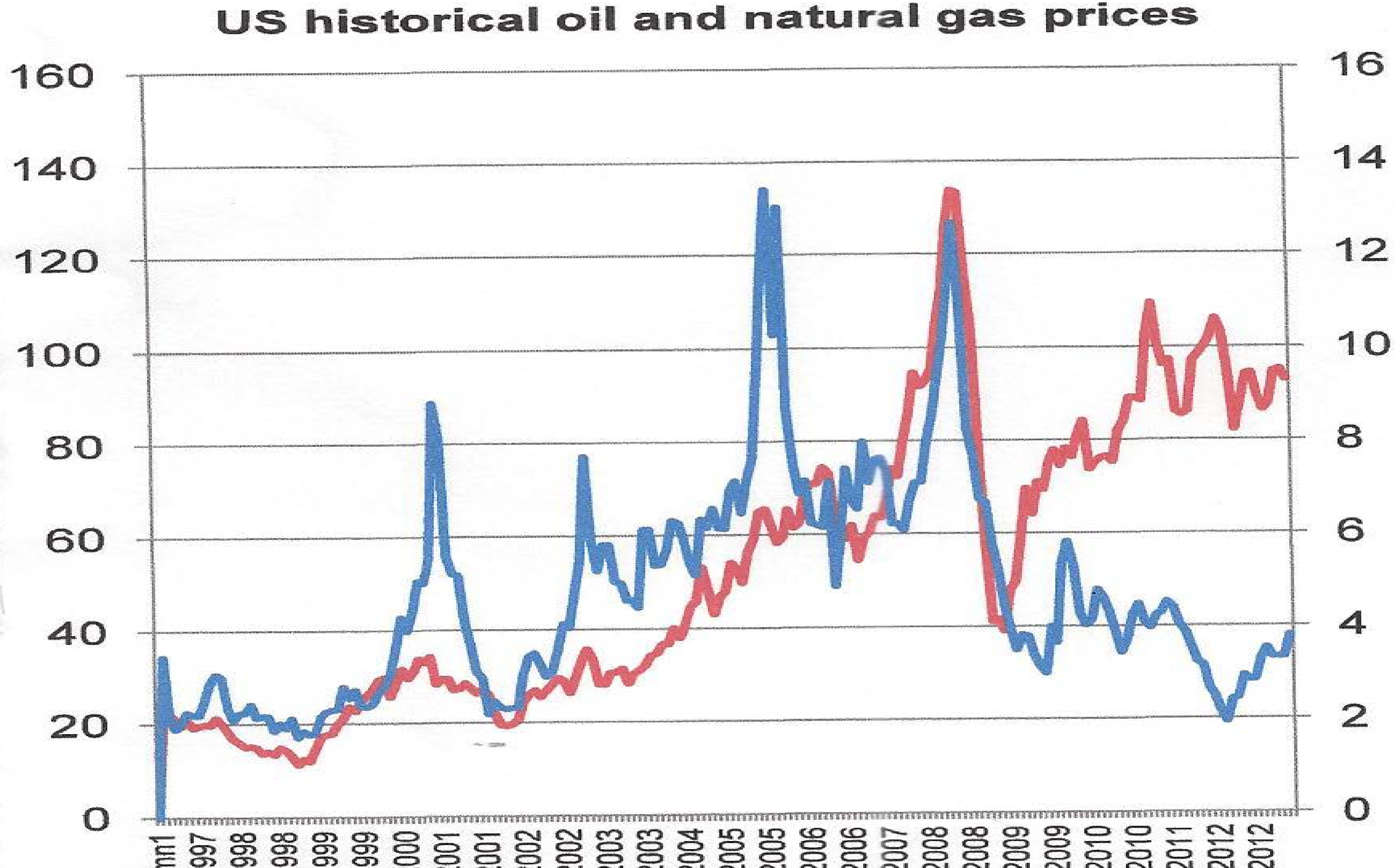
- Latest results on use of natural gas in NAFTA blast furnace operations,
- Progress with “co-injection” of natural gas and coal injection in NAFTA BF operations,
- Limits of coke replacement with injectants in BF operation,
- Global prospects for increased use of natural gas

Decreasing Natural gas Prices Promote Increased Use of Blast Furnace Natural Gas Injection

- Mainly a USA phenomena:



In the US, gas prices have decoupled from oil prices.



Blast Furnace Natural Gas Injection

- Lower natural gas prices lead to increased injection of natural gas in blast furnaces,

- In 2013, all but 1 of 29 of NAFTA blast furnaces are injecting gas while 45 % are co injecting with gas and PCI, while one coal injection system (to serve 2 BF's) remains idle

- Natural gas is cheaper than coal at many but not all BF sites; continued use of coal maximizes total coke replacement

NAFTA Blast Furnace Reductant Rates

- **Weighted (by Production Rate) Averages of Reductants by AISI BF's**

	Hot Metal Production, M tonnes	# of Operating BF's	Coke			Reductant Usage, kg/tHM				
			Lump	Nut	Total	Coal	Oil	Gas	Tar	COG
1990	55.55	60	454	1	455	1	12	23	3	0
1995	61.00	51	402	8	410	34	13	38	1	1
2001	51.92	45	395	24	419	59	9	17	3	2
2004	52.75	38	366	26	392	58	10	35	4	2
2007	47.85	35	377	28	405	65	9	27	2	2
2008	44.80	35	379	29	408	62	9	32	0	2
2010	41.80	33	376	32	409	73	2	39	0	1
2011	43.70	32	364	36	400	69	1	50	0	1
2012	44.10	32	364	34	398	52	0	65	0	0
2013	33.10	29	362	31	394	57	0	62	0	1

- * 9 months

Limits of BF Natural Gas Injection:

- Replacement ratios of BF injectants:
- (Kg of coke replaced per kg of injectant)
- Natural gas 1.3 – 1.4
- Fuel oil 1.1 – 1.2
- Coal 0.9 - 1.0

- Natural gas suppresses raceway (combustion zone) flame temperature more than oil or coal

Limits of BF Natural Gas Injection

- Typical BF Raceway Flame Temperatures Range from 3400 F to 4000 F,
- Research by Gas Research Institute/Charles Rivers Associates showed that smaller BF's could operate at 3100 – 3400 F range,
- Increased oxygen enrichment can restore flame temperature but upper limit of oxygen enrichment set by BF top temperature as well as practical limits: cost of O_2, excess hot metal production,
- Typical NG injection limit: 100 to 125 kg/ton of hot metal

Examples of NAFTA BF Gas Injection Only Practices

BF	A	B	C	D	E
Hearth Dia. (m)	9.2	10.7	10.7	10.9	9.0
Production,					
(tons/day)	5844	6612	6428	6364	4461
(tons/day/M3)	3.9	2.7	2.4	2.4	2.9
Coke Rate, kg/T	370	409	365	349	397
Gas Rate. Kg/T	115	91	99	107	95
Coal Rate kg/T	0	0	0	0	0
Oxygen, % of Blast	33.1	30.0	25.6	25.9	27.4
Flame Temp, C	1852	2027	1827	1819	1804
F	3366	3681	3321	3306	3279

Examples of NAFTA BF Gas Coal Co -Injection Practices

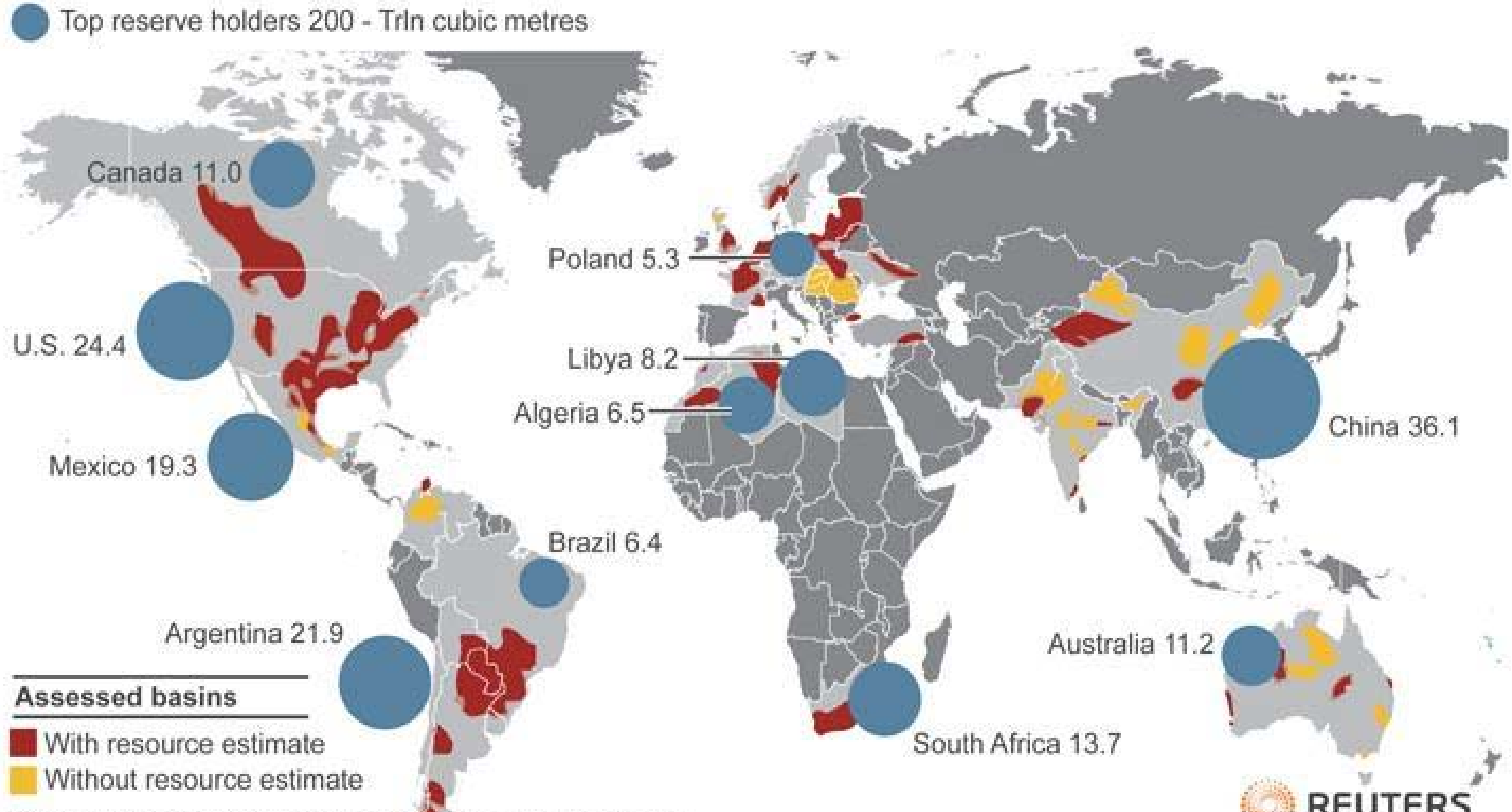
BF	F	G	H	I	J	K
Hearth Dia. (m)	10.2	8.5	13.7	9.2	9.7	11.7
Production,						
(tons/day)	4585	3446	8234	5764	5831	7332
(tons/day/M3)	2.2	2.2	2.0	3.2	2.5	2.3
Coke Rate, kg/T	428	376	336	357	422	345
Gas Rate. Kg/T	37	23	30	70	71	34
Coal Rate kg/T	71	111	151	83	5	144
Oxygen, % of Blast	25.7	24.3	26.3	30.9	25.7	26.6
Flame Temp, C	2096	2092	2133	2091	1932	2160
F	3805	3798	3871	3796	3279	3920

Global prospects for increased use of natural gas

Global shale gas reserves for 2012 (trillion cubic meters)

- 36.1 China;
- 24.4 U.S;
- 21.9 Argentina;
- 19.3 Mexico;
- 13.7 South Africa;
- 11.6 Australia;
- 11.0 Canada;
- 8.2 Libya;
- 6.5 Algeria
- 6.4 Brazil;
- 5.3 Poland.

Global shale gas basins, top reserve holders



Source: EIA based on Advanced Resources International Inc data, BP

Reuters graphic/Catherine Trevethan

Challenges to global shale gas production

- **Major environment risks :**
- **o Water consumption during the hydraulic fracturing process**
- **□Effects on bio diversity**
- **□Channeling away from agriculture uses**
- **o Treatment and disposal of Waste Water**
- **□Proper secure storage on site**
- **□Infrastructure to recycle or treatment for discharge or reuse**
- **o Groundwater Contamination from fracturing fluid**
- **□Accidentals spills**
- **□Leakages**
- **□Higher scale leading to higher risks**

- **Some wells at least in China could be more complex and deeper. Economics for drilling these wells have not been clearly established**

Challenges to global shale gas production

- **Gas prices have fallen in US but in ROW it remain linked to oil indexed prices. It does not appear that it will follow the US path very soon,**
- **In the US, gas prices have decoupled from oil prices... .. . but what about other regions?**
- **In Europe, it is a mix of oil indexed gas prices (from Statoil and Gazprom) and some hub prices from Qatar mirroring current spot prices. But the average gas prices remain very high. In the medium term, this is unlikely to change.**

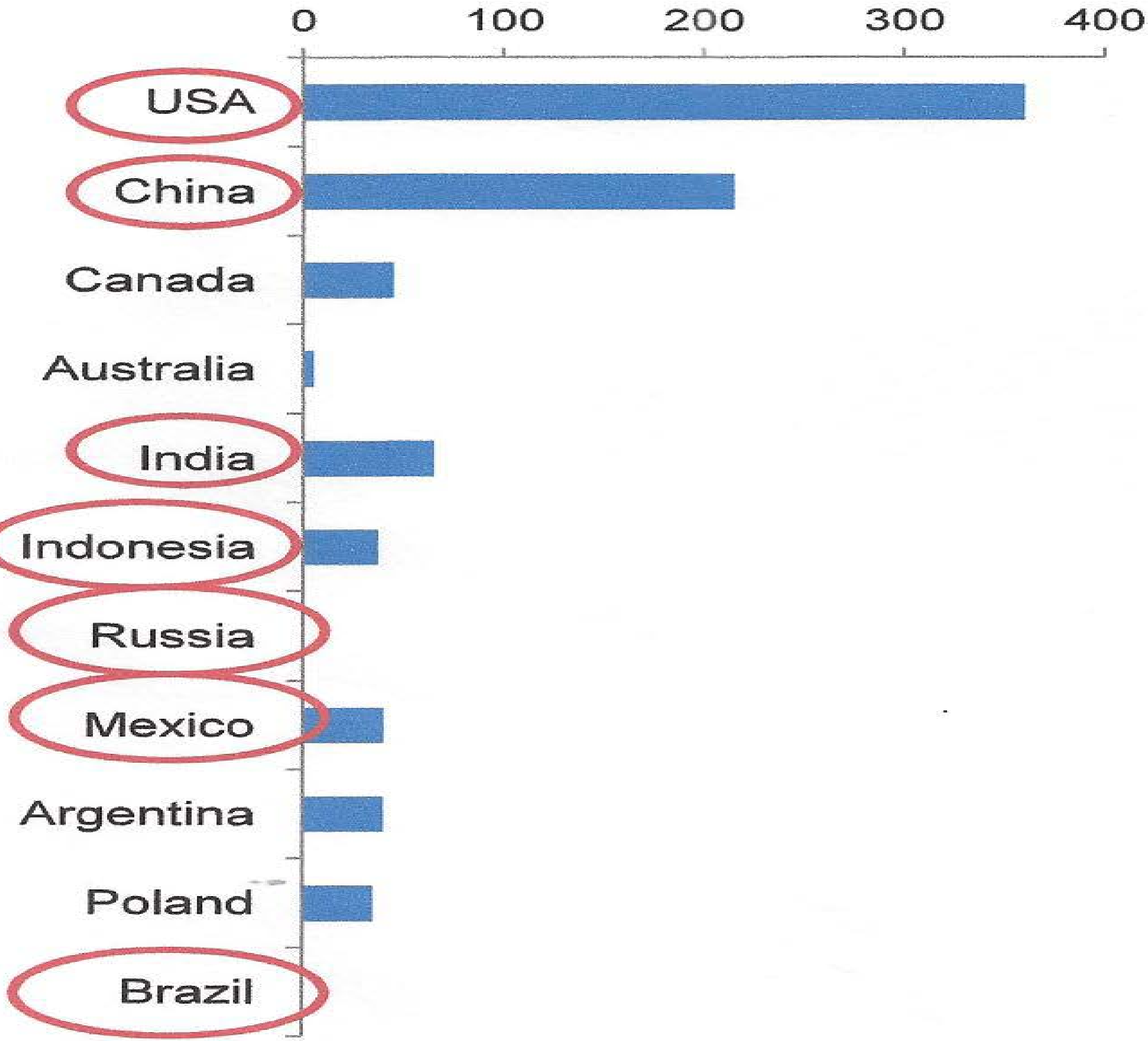
Challenges to global shale gas production

- In China gas prices remain stubbornly linked to oil indexed prices despite pressure from buyers. There is talk about reforming these to reflect the current spot prices but it could take a number of years before shale gas imports and local shale gas production to start before prices align to market levels in the US.
- • In Brazil, the situation is no different from Europe and China.
- Key Point – In USA landowners control mineral and gas ownership; elsewhere globally the State controls mineral and energy resources

Challenges to global shale gas production

- In the US at least, the ready gas pipeline and distribution infrastructure was available. Therefore it has been possible to increase gas supplies relatively easily.
- • In other regions like India, Brazil, Indonesia, Mexico the pipeline infrastructure is underdeveloped. Meeting the large growing production would require building new pipeline infrastructure which is inherently very capital intensive and potentially slow with burdens of permitting process

Forecast of shale gas production up to 2035 (cu mt)*



* Golden Rules Scenario

Thank You for Your Attention!

Special Acknowledgement to Hatch for use of material in slides 4, 13-18

Appendix - slides from 2012 presentation

Impact of Blast Furnace Process Improvements on Met Coke Demand

Global Trends in BF Operations That Reduce Met Coke Demand:

- Concentrate Production in Largest , Most Efficient Furnaces,
- Incremental Increases in Injection of Coal, Gas, Plastics, other reductants,
- Improvements in Sinter, Pellet Properties

- Declining iron ore grades will increase BF slag volumes and coke rates

Overall: expect 3-5 % decrease in specific coke consumption over 5 year period

Gas Based Shaft Furnace Direct Reduction

- **Now economically feasible in USA,**
- **Nucor building 2.5 MTPY DRI plant in Louisiana to ship DRI to existing EAF plants; planning second plant;**
- **SeverstalNA has been planning DRI plant,**
- **Other EAF flat rolled mini mills studying gas based DRI projects**

Gas Based Shaft Furnace Direct Reduction

- **Major initial impact:**

  elimination of imported merchant pig iron (Brazil, Russia, Ukraine)

  No further expansion of coal based DRI, hot metal or pig iron nugget projects in USA,

  IDI, Mesabi Nugget plants will continue but further plants less likely

Alternate Steelmaking Production Route: EAF Steelmaking based on Ore Based Metallics

- Gas Based Shaft Furnace Direct Reduction - **Longer range impact:**
- **Shift towards DRI/EAF steel production route:**
  - o **Continued expansion by current EAF flat rolled steel companies: e. g. expansion at Severstal Columbus helped Severstal divest BF/BOF plants**
  - o **Switch to DRI/EAF steel production by current BF/BOF producers: less likely due to capital constraints**

Prospect for Large Scale Smelting Reduction to Replace Blast Furnace Ironmaking,

- Objectives: eliminate coke, sinter, pellet facilities with hot metal process to feed existing BOF steel plants

HOT METAL

======================

coke	**coal-based -------------------------→**			
Blast Furnace	**Smelting-Reduction**		**RHF/ SAF**	**RHF**
Pellets/lump sinter	**fines**	**pellets/ lump**	**fines**	**fines**
Mini-Blast Furnace	**large scale**	**Corex**	**IDI**	ITmk3
	Finex		Fastmelt	
			Redsmelt	
Low CO2 Blast Furnace	HIsmelt			
	CCF/HIsmelt		**Primus (multiple hearth)**	
Cupola	AISI			
- scrap	DIOS			
- waste oxides	**small scale - EAF feed, waste oxides**			
OxyCup	Romelt, AusIron, Tecnored			

Prospect for Large Scale Smelting Reduction to Replace Blast Furnace Ironmaking,

- **Corex, Finex processes only ones to reach commercial status:**

  global production < 10 MTPY

Corex, Finex processes have very high capital costs; high operating costs; adopted in niche situations only

Conclusions

- **NAFTA met coke demand decreasing due to:**

  - increased BF natural gas injection

  - expansion of EAF flat rolled minimills, now being fed by gas based DRI plants

Globally, BF/BOF steelmaking will remain dominant but specific coke consumption will decrease with increased scale, injection rates and burden property improvements.

Smelting reduction processes will have limited impact globally in next 5 years